A SYSTEM DYNAMICS MODEL FOR PLANNING AND EVALUATING SHIFTS IN HEALTH SERVICES: THE CASE OF CARDIAC CATHETERISATION PROCEDURES IN THE NHS

VOLUME I

(Text and References)

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ABSTRACT

The shift in the balance between the primary, secondary and tertiary levels of the National Health Service is an established trend in health care. This has been motivated by various factors, including the desire to improve access to services. However, service shifts can stimulate further demand and thus undermine efforts to improve services overall. There is a need for "joined-up thinking" in respect of service shifts since existing analyses have been limited to isolated parts of the system, and little attention has been given to the actual mechanisms of the feedback or knock-on effects. The model-based methodology of system dynamics could be useful as it is designed for the study of the connections between different parts of systems and feedback effects.

This thesis assesses the usefulness of system dynamics as a planning and evaluation tool for service shifts. A case study approach is followed, based upon a shift in cardiac catheterisation services from the established tertiary level to the secondary level involving three hospitals in England.

The factors involved in service shifts are described, and the processes and causative forces at play across the different health service boundaries are captured by means of the system dynamics-based model procedure. The study reveals several interacting feedback mechanisms underlying changes in demand. It also demonstrates that by understanding the feedback structure, "joined-up solutions to joined-up problems" may be designed. For example, a more effective policy would be the service shift (to improve access) combined with the use of clinical guidelines (to suppress demand) and with changes to the forces that drive activity rates (to ensure that both the average waiting time and the waiting list length are controlled). In feedback terms, using clinical guidelines weakens existing feedback mechanisms whilst changing the forces that drive activity rates creates new feedback mechanisms.

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CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

The shift in the balance between the primary, secondary and tertiary levels of the National Health Service (NHS), is an established trend in health care that is bringing services closer to home. It has been driven by various factors, including the desire to improve access to services and reduce costs. However, improving access can stimulate further demand and thus undermine efforts to improve services overall. There is a need for "joined-up thinking" in respect of service shifts since existing analyses have been limited to isolated parts of the system, and little attention has been given to the actual mechanisms of the feedback or knock-on effects. The model-based methodology of system dynamics (SD) could be useful as it is designed for the study of the connections between different parts of systems and feedback effects.

1.2 PURPOSE AND APPROACH

This thesis aims to assess the usefulness of SD as a planning and evaluation tool for service shifts in health care. Usefulness is considered in terms of the ability to contribute to the policy making process. This probes beyond the ability to provide policy insights, to also consider the value of these insights, and the ease of use of SD.

A case study approach was followed, based upon a shift in cardiac catheterisation (CC) services in the NHS from the established tertiary level to the secondary level. The study involved three hospitals in England: one tertiary centre and two of its referral centres. The analysis focused on explaining how the shifts in CC services helped and hindered the provision of NHS cardiac services over time and, how NHS purchasers and providers could have effectively intervened to alleviate pressure on the system.

1.3 THESIS OVERVIEW

Chapter 2 sets the context to the research. This chapter concentrates on the NHS as this formed the context to the case studies. However, other health systems are also considered since the key features that contribute to the stimulation of demand, the phenomenon of interest, are also present in these systems. An overview is provided of the NHS in terms of the people, processes and pressures involved. The primary, secondary and tertiary service levels are described, and the motivation underlying the shift in the balance of care is discussed. This chapter also highlights the increasing scrutiny that is being placed upon health care and the associated calls for greater evaluation, which forms a recurrent theme in this thesis.

The shift in the balance of care is explored further in Chapter 3. Its diversity is discussed by describing the various service reconfigurations and changing roles which have occurred. The evaluation theme continues by considering calls made for service innovations to be evaluated. The established approach to evaluation, economic appraisal is reviewed. It is argued that relying upon economic appraisal alone is incomplete and can lead to misleading assessments, as this approach cannot fully consider the potential ramifications of shifts in the balance of care. In particular, it cannot explore the mechanisms underlying the stimulation of latent demand for services in response to increases in access. SD is introduced as a way of addressing this limitation.

The purpose of Chapter 4 is to describe SD and clarify its role in health care. This is achieved via a comparative review of the health care simulation modelling literature, which follows from SD adopting a particular approach to simulation modelling. The SD approach is compared and contrasted with the more traditional approach to simulation modelling. The latter approach is more aligned with the emphasis in health care on individual patient detail, and subsequently has a higher profile in health care. To clarify the differences between the two approaches, and thus emphasise the potential benefits of SD, a 3-dimensional classification of complexity is defined. This chapter concludes by addressing a number of potential obstacles to the use of SD.

Having offered some insight into how SD might be used to evaluate shifts in health services, Chapter 5 expands upon §1.2 to clarify the research design that was followed in order to probe further. The shift in CC services, from the established tertiary level to the district (secondary) level, was selected to form the basis of a case study. In this chapter, the CC procedure and its use are described to explain the issues involved in deciding who should undergo this procedure and where it might be safely undertaken. The collaborative centres are introduced and the research methods are briefly described.

The literature on the shift in CC services is reviewed in Chapter 6. The issues regarding the general trend of the shift in the balance of care, discussed in Chapters 2 and 3, are considered with specific reference to the case of CC services. This involves a discussion of the motivation for, and provision of, district services, and concerns about stimulated demand and the appropriateness of the use of these services. Evidence of the shift in CC services generating further demand is highlighted, thus supporting a call for an SD analysis.

Chapter 7 describes the experiences of the shift in CC services at the case study centres in detail. The tertiary perspective is first considered before examining its two referral centres in turn. For each, the extent of the service shift and the impact on CC activity are described. The existence of corroborative evidence of the shift in CC services generating demand is highlighted. Also addressed are issues relating to the costs of, and the different attitudes to, the shift in services.

Chapter 8 presents the first phase of the SD study of the shift in CC services, a process known as conceptualisation. As part of this process, the effects of the service shift were defined using a series of graphs. A conceptual model was constructed to portray the key processes that were understood to generate these effects. The purpose of the model was also clarified.

In Chapter 9, the description of the study progresses from the informal conceptual model to the formal simulation model. An overview of this model is presented before describing it in further detail. This chapter also describes the procedures that were applied to gain confidence in the model. This involved a series of tests that targeted both the model's structure and its behaviour.

Chapter 10 presents how the model was used to perform base case analyses for the two case studies. These experiments sought insight into how the shifts in CC services helped and hindered the provision of NHS cardiac services over time, thus addressing the first question stated in §1.2. For each case, the problematic behaviour was explained with reference to the underlying feedback structure. This led to some suggestions into how more desirable behaviour could have been achieved. Further suggestions for improvement arose from the sensitivity analyses that were carried out to probe further into the base case behaviour.

The suggestions for improvement were followed up with a series of policy experiments, as explained in Chapter 11. These experiments sought insight into how purchasers and providers could have effectively intervened to alleviate pressure on the system, thus addressing the second question stated in §1.2. Note that this chapter concentrates upon the causes and effects of these experiments, whilst the policy implications are discussed in the next chapter.

Chapter 12 forms the final chapter of the thesis. The base case analyses and policy analyses are first summarised in lay man terms, in contrast to Chapters 10 and 11 which are quite technical in nature. The policy implications of the results of the experiments are then derived. The issue of the usefulness of SD is addressed in the context of the case studies. The validity of the research hypothesis is considered thus producing a revised statement regarding the causal mechanisms and the usefulness of SD. Moving on from the case studies, the findings of the research are generalised. To conclude the thesis, the research contributions are highlighted and a number of directions for future research are suggested.

The references are followed by a set of appendices. The abbreviations used within this document are listed in Appendix A. Abbreviations have been made selectively to restrict their number. Appendix B provides glossaries of the health care and modelling terms used. Efforts have been made to keep the health-related jargon to the minimum, and technical terms are explained as they arise. The health care glossary is intended to consolidate these definitions and descriptions. The inclusion of the modelling glossary is intended for the reader who is unfamiliar with modelling in general, and/or SD modelling in particular. Appendix C provides further details about the collaborative work, including the dates of site visits and meetings, brief notes about the purposes of the meetings, and the sources of numerical data. For confidentiality reasons, all parties involved are referred to by the use of pseudonyms. Appendix D contains several diagrams and notes regarding the conceptual model. Appendix E refers to the simulation model. It includes full documented listings of the model and detailed tabular output of the simulation runs.

CHAPTER 2

THE NATIONAL HEALTH SERVICE AND OTHER HEALTH CARE SYSTEMS

2.1 INTRODUCTION

The purpose of this chapter is to set the context to the research. The different types of health care systems are briefly introduced (§2.2) before focusing on the NHS, the UK health care system. The structure of the NHS is outlined (§2.3) in three different ways in order to highlight the existence of several different types of linkages (§2.3.1-§2.3.3). This is followed by a description of the broad aims of the NHS (§2.4), in preparation for a discussion of a number of challenges that arise in attempting to achieve these aims (§2.5). The funding constraints in the NHS are addressed (§2.5.1) and the subsequent challenge of balancing the competing demands on the limited resources (§2.5.2). The changing health care environment is examined with respect to two trends. Firstly, the service reconfigurations and changing roles, that are producing a shift in the balance of care closer to home (§2.5.3). Secondly, the increasing scrutiny placed upon health care (§2.5.4). The subsequent need for greater evaluation leads to a discussion of several difficulties associated with evaluation (§2.5.5). The chapter is summarised in the final section (§2.6).

2.2 HEALTH CARE SYSTEMS

Three types of health care models appear in western economies: national health service models, public subsidies to private insurance funds, and national insurance schemes, which are supported by compulsory levies. In a national health service, the state assumes direct powers to provide health for the entire population. It owns the institutions where services are provided and it is responsible for the employment of staff. In the past, this arrangement has been referred to as 'socialized medicine'. Italy, Spain and New Zealand also possess national health systems but the UK system, the NHS, remains closest to the ideal and, thus, is of particular global interest (Webster 1998).

The focus of this research is on the NHS as this is the context for the case studies but, actually, the key features that contribute to the phenomenon of interest apply to other health care systems. Later chapters will describe the phenomenon of interest as the stimulation of demand in response to increased access. This is a common response in the NHS and it is a consequence of services being, primarily, free at the point of delivery. However, it could also be argued that services in other health care systems, whether insurance-based or private, are all free in one sense or another.

2.3 STRUCTURE OF THE NHS

The structure of the NHS is undergoing constant changes and the period that was studied (April 1995 to April 2001) was no exception. To set the context, it is necessary to consider a longer period, dating back to significant policy changes in the late 1980s/early 1990s. These changes will be described over several sections in this chapter.

For the purposes of this thesis, it is useful to present the structure of the NHS in three different ways: from an organisational perspective, from a health provision perspective and from a patient needs perspective. This highlights the management, contractual, administrative and patient referral links.

2.3.1 An Organisational Perspective

The structure of the NHS is typically presented using a diagram that shows the key individuals and groups and their inter-relationships. Figure 2.1 is one such example, which depicts the managerial, contractual and administrative linkages that were in place in 1998.

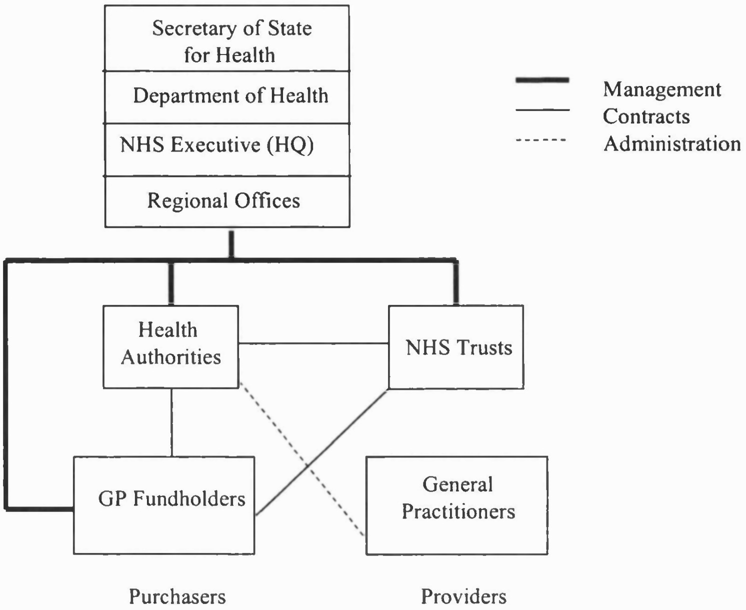


Figure 2.1 The National Health Service in England, 1998

Referring to Figure 2.1, the Secretary of State in the Department of Health is answerable to Parliament for the provision of health services. The Department of Health is responsible for: setting the policy framework for the NHS; negotiating the overall level of funding with the Treasury and allocating funding; and, monitoring the performance of the NHS health authorities and the NHS Trusts and holding them to account (carried out by the regional offices of the NHS Executive). The policy board within the Department of Health sets the broad strategic direction for the NHS whilst operational matters are dealt with by the NHS Executive. The health authorities have several functions including assessing their populations' needs for health care and purchasing health care for their population.

The figure includes the term 'purchasers', although the term 'purchasing' was gradually replaced by 'commissioning' in order to play down the market and competitive connotations (Webster 1998). GP fundholding practices, which were later abolished, were general medical practices that had been allocated a budget for the purchase of certain hospital services - elective (non-emergency) surgery, outpatient (OP) attendances, pathology and community care. NHS Trusts are independent self-governing units. They consist of hospitals and other units providing patient care. They are accountable to the NHS Executive (Ham 1998).

Associated with the evolution of the NHS since the late 1980s/early 1990s are a series of White Papers, other documents and Acts of Parliament. These have led to a simplification of the structure of the NHS. Examples are the White Papers, *Working for Patients* (NHS 1989a), *Managing the New NHS* (NHS 1993a), *Making London Better* (NHS 1993b), *The New NHS* (NHS 1997b) and the Tomlinson Report into the future of London's services (NHS 1992). Acts of Parliament include the National Health Service and Community Care Act in 1990, Health Authorities Act in 1995, Primary Care Act of 1997 and the Health Act of 1999. All the above provided details, recommendations and legislation for: the creation of the policy board and regional offices; the introduction of the 'internal market'; the introduction of the concepts of GP fundholding and NHS Trusts; creation of the health authorities; rationalisation of London's hospital services; development of various forms of locality commissioning involving GPs and health authorities; replacement of the 'internal market' with a system based upon co-operation and partnership; abolition of GP fundholding; creation of Primary Care Groups; and, implementation of Primary Care Trusts.

The above description provides a useful basis upon which to establish the context for the research and to introduce the distinction between the purchasing/commissioning and the provision of health services. This research focuses upon the purchase and provision of a particular health service at the local level. This does not directly concern policy makers at the national level such as the Secretary of State for Health or those at the Department of Health (NHS 1997a). Furthermore, the issue of interest for this research concerns developments in the provision of services involving service reconfigurations and changing responsibilities. Therefore, a more detailed representation of the provision of services is required.

2.3.2 A Health Care Provision Perspective

An alternative representation is shown in Figure 2.2. This concentrates on the provision of health services and the referral of patients (including self-referrals) between the three levels of health care: primary, secondary (or district) and tertiary levels. NHS services only are considered, although this diagram also applies to the provision of services in the private sector.

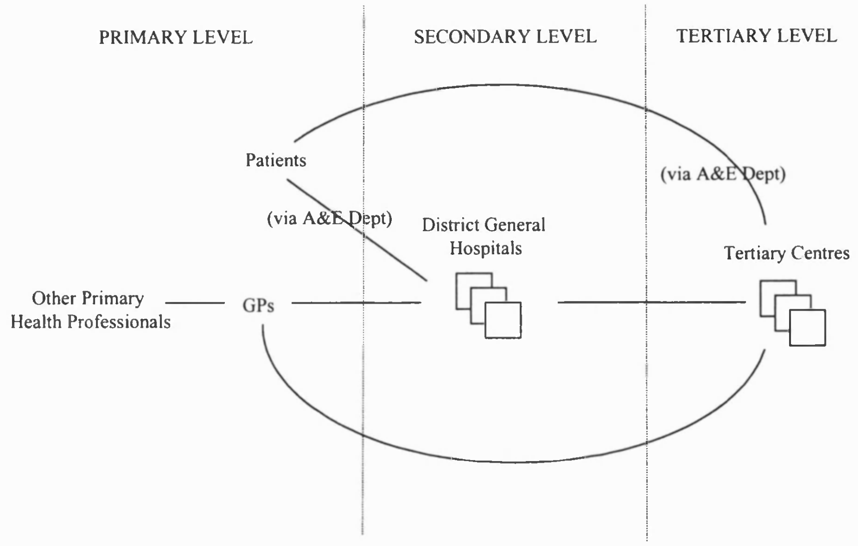


Figure 2.2 The Patient Referral Chain Across the Primary, Secondary and Tertiary Levels

A common description of the primary, secondary and tertiary divisions refers to the location of services and the key inputs in terms of the professionals involved. Based upon this viewpoint, primary care is that which takes place in the community and is provided by GPs and practice nurses, and a host of community health professionals. These include district nurses, speech therapists and chiropodists. The secondary and tertiary levels comprise hospital care. The secondary level refers to district general hospitals (DGHs). These can offer patients more sophisticated investigations and treatments and 24-hour supervision which cannot be provided in the community. The tertiary level refers to the most advanced hospital care. This is delivered in highly specialised units. They provide services to patients that have been referred from the primary and secondary levels for specialised investigation and treatment.

GPs may receive referrals from another primary care health professional, such as a district nurse or pharmacist. The usual route to hospital care is via a GP referral for an OP appointment. Patients may be referred directly to a tertiary centre or via a DGH, but the latter forms the usual route. Patients may also obtain direct access to hospital services by self-referring to a hospital accident and emergency (A&E) department or one of a few other specialist services, such as genito-urinary clinics. Therefore, doctors primarily, filter patients along the referral chain, which spans across the three levels of health care. The degree and method of filtering will depend on a variety of factors, including the patients' symptoms, medical history and preferences, the doctors' expertise and the facilities available to them. Patients flow in both directions along the referral chain. Referrals backwards involve patients who have successfully undergone the necessary investigations, treatments and follow-up procedures.

Some services are not easily classified using a description based upon the service location or professionals involved (NHS 1994c). For example, in practice, some primary care is provided to patients in a hospital A&E department (Dale *et al* 1995). An alternative description of the different service levels focuses upon service attributes. For example, the attributes of primary care include: direct access (WHO 1978a); service delivery in the community as opposed to in a hospital (Hughes and Gordon 1992); ambulatory care (Peckham 1992); and, "first-contact, continuous, comprehensive and co-ordinated care, provided to populations undifferentiated by gender, disease or organ system", as described by Starfield (1994). However, Godber *et al* (1997) emphasise the lack of robustness in these definitions. Again, A&E care is cited as an example where conflicts occur. A&E departments offer patients direct access, which is an attribute of primary care. However, care is condition-specific and is delivered in a hospital rather than the community. Godber *et al* offer a robust definition of primary care based upon a concise, comprehensive and exclusive set of attributes: direct access, generalist and longitudinal care, and delivery in a community setting.

Godber *et al* only provide an attribute-based definition for primary care but the basis of this thesis involves all three levels of care. The primary care attribute set of Godber *et al* may help in attempting to derive a suitable set of attributes to describe secondary and tertiary care. Indirect access could be considered as a suitable attribute for hospital care as it is clearly the opposite of direct access. Specialist care is the opposite of generalist care. Godber *et al* appear to use the term longitudinal to encapsulate Starfield's attributes, "continuous" and "co-ordinated". Occasional care may be used to capture the essence of non-longitudinal care. Finally, delivery in a non-community setting implies delivery in a hospital. This produces the following set of attributes: indirect access, specialist and occasional care, and delivery in a hospital-based setting.

Providing a robust definition which will differentiate between the secondary and tertiary levels is difficult. Secondary care and tertiary care differ by the degree of specialisation with the latter involving the use of highly specialised staff and facilities, concentrated at regional centres. A robust definition cannot be derived from the mode of access as with primary care, since although tertiary care is usually accessed by a referral from a secondary specialist, this is not always the case (NHS 1994c). For cardiac services, secondary care is traditionally characterised by the exclusive use of *non-invasive* methods of diagnosis and treatment where invasive methods are defined as involving penetration of the skin (LIG, 1993; BCS/RCP 1993). Due to their geographical location, a patient could be referred directly to a tertiary centre for investigation. It is possible that this patient may subsequently undergo investigation by non-invasive methods alone. Therefore their care could be defined as either secondary or tertiary. The distinction between secondary and tertiary levels is thus blurred. However, the distinction is clear when considering the need for a method of investigation or treatment of high complexity, such as *invasive* methods, which are traditionally conducted at the tertiary level.

2.3.3 A Patient Needs Perspective

The primary/secondary/tertiary split is a useful basis upon which to introduce and discuss the shift in the balance of care. However, for the purpose of this research, the referral chain is also conceptualised in different terms, focusing upon the patient pathways through the processes of care. Figure 2.3 shows a simple example. This is not restricted by the location of services, professional boundaries or service boundaries. Instead, this view is built around the needs of the patient (Harrison 2001).

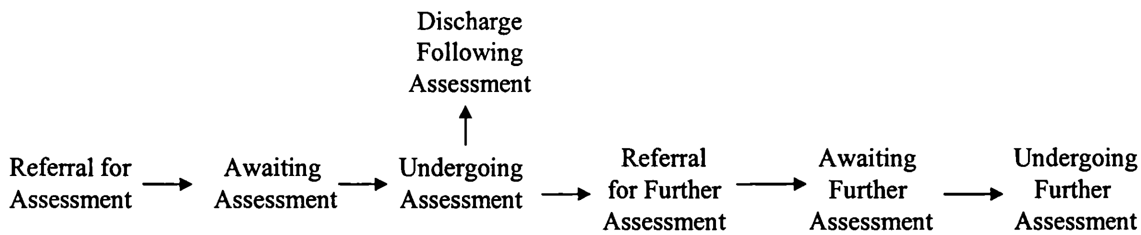


Figure 2.3 A Patient Needs View of the Patient Referral Chain

2.4 AIMS OF THE NHS

The underlying principles of the NHS are to provide a universal, comprehensive, first-class health service, which is free at the point of delivery, except for a few items, and is largely financed from general taxation (NHS 1946). The inception of the NHS, in 1948, was announced in a leaflet, *The New National Health Service,* which was distributed to all homes. This leaflet contained the following:

> It will provide you with all medical, dental, and nursing care. Everyone - rich or poor, man, woman or child - can use it or any part of it. There are no charges, except for a few special items. There are no insurance qualifications. But it is not a charity. You are all paying for it, mainly as taxpayers, and it will relieve your money worries in time of illness.
> (Webster 1998, p.24)

The basic principle remains unchanged (Webster 1998): to provide a service according to need and for this service to be financed by the community according to their means (NHS 1974).

The broad objectives of NHS policy makers are to maintain and improve the quality of the health service. Different aspects of service quality encompass the structure of the health service, process issues and resulting outcomes (Maxwell, 1984; Hopkins 1990; Calman 1992). Structural aspects of quality involve the *skill base* in terms of the knowledge, skill and competence of the staff, and the *scope of services* provided regarding the nature and capability of facilities available. Process issues involve *equity* or fairness in terms of the provision of services and health status, *efficiency* or resource use, *cost-effectiveness*, *relevance* of service availability with respect to the population's needs and utilisation of services, and *responsiveness* to patient needs including the respect, dignity and humanity shown. Further quality issues relate to the *accessibility* of services. This involves the distribution and location of services (geographical access), the numbers and time spent waiting for services (access times) and also the ability to fund services (financial access). Service outcomes involve the *effectiveness* of care in reducing mortality and morbidity and, *patient satisfaction* with the services provided.

The broad objectives of NHS policy makers are connected to the World Health Organisation's goals (WHO 1985), which are associated with the broad concept of 'health gain': to reduce disease, disability and avoidable deaths, and to improve the quality of life and equity (Rathwell 1994).

The objectives of the NHS translate into a number of targets. These include those outlined in the *Health of the Nation* health strategy document (NHS 1991b), the service delivery standards encapsulated in the *Patient's Charter* (NHS 1991a, 1996a), and clinical guidelines (e.g. RCP/RCS 1992; ESC 1997). Further targets arise from national directives filtering down to the local level and combining with other targets and goals. These include the activity and waiting time targets which are stipulated in health care purchasing contracts.

Policy makers, throughout the tiers of the NHS, face a number of challenges in attempting to meet these broad objectives and the specific targets which arise from them. Difficulties are presented in both identifying ways in which the quality of services may be improved, and in implementing the necessary changes to obtain improvements (Curnow 1972; Rosenhead 1978; Lee and Mills 1982).

In formulating new policies, NHS policy makers have to balance competing demands for resources, whilst operating within funding constraints. They also have to deal with a number of other difficulties relating to the changing health care environment and the evaluation of health care policies. These challenges are discussed in the next section.

2.5 CHALLENGES TO NHS POLICY MAKERS

2.5.1 Funding Constraints and Funding Crises

The NHS has often been described as being in a continual state of crisis of under-funding (Webster 1998; Rivett 1998). This leads to various problems. In addition to having to make sacrifices, difficulties arise in funding improvements to services. Often presented as evidence of this funding crisis are the budget deficits that apply to many purchasing authorities and providers, and the existence of rationing.

Increasing pressure is being imposed on NHS budgets by the rise in demand for health services. This rise is associated with medical advances, rising public expectations, demographic changes and other factors. Medical advances have provided new and sophisticated treatments and improved prospects for survival. Advances in technology have led to increasing technological sophistication, which is expensive and requires highly trained personnel for its operation and maintenance. Improvements in the skills of doctors and medical technicians have led to demands for higher wages. As medical technology has advanced, so have public expectations and there are some instances where the public have imposed greater demand on health services even when all hope of recovery is lost (Cohen, 1993). Disappointment can lead to litigation when treatment or practitioners fail to deliver.

Demographic changes are illustrated by an aging population, arising from the post-war 'baby boomers' reaching retirement age and increases in the average life expectancy. In 1991 the population in the UK over 60 years of age was 11.9 million (21%) and the estimate for 2011 is approximately 13.3 million (22%) (OPCS, 1991). In the developed world, the average life expectancy in 1950 was 66, rising to 72 in 1985, with the United Nations forecasting 78 years by the year 2025 (NERA, 1993). Corresponding to the increase in life expectancy is the need for treatments for longer periods. Unlike the simple, quick therapy which is appropriate to infectious disease, complicated and prolonged care is required for the results of degenerative changes associated with aging. The elderly are the major consumers of health care but there are relatively fewer people in employment to pay for the associated costs.

Increasing demand on health care is also associated with other factors, including the emergence of new illnesses such as acquired immune deficiency syndrome (AIDS), and the development of new drugs by the pharmaceutical industry.

As in other industrialised economies, health care expenditure in the NHS has increased significantly. For example, in 1949, the NHS expenditure was £444 million (Ham 1990) but by 1999 it had risen to nearly £52 billion (OHE 2000). The proportion of gross domestic product (GDP) devoted to the NHS has also risen. The mechanisms underlying the rise of health care expenditure are very complex and are not confined to demand factors. The costs incurred are also understood to be influenced by supply factors in terms of the availability of funds. This is reflected in the proportion of GDP devoted to health care and the method of payment for health services. The incentives associated with the method of payment may be to either economise or overuse health care (NERA 1993). Compared with other health systems in developed economies, the NHS does have a number of cost-saving features (Sweeney 1994; Abel-Smith *et al* 1995). These include the referral system in which GPs play the role of 'gatekeepers' to hospital services. Another important feature is the global budget which is determined by the state of the UK economy and the competitive status of health care among the Government spending departments. The use of a global budget ensures that in the UK, a lower proportion of its GDP is spent on health care, compared with other OECD countries. However, this coupled with the fact that demand continues to outstrip the supply is often presented as an argument for the NHS being under-funded (Dixon 1997).

2.5.2 Balancing Competing Demands

Given the limited resources available, trade-offs have to be made when setting priorities between the various demands (New and Le Grand 1996; Lenaghan 1996). Balances have to be made between different treatments, and between emergency needs and elective care. Priorities also have to be set between the immediate health care needs and the other determinants of health which produce long-term benefits such as diet and education (Heginbotham *et al* 1992; Langham *et al* 1993; Abel-Smith 1994; Evans *et al* 1994). Stakeholder conflict often arises in decisions about health care especially about priority setting which is often regarded as a euphemism for rationing (Reinke 1988; Abel-Smith 1994) - a term which politicians are reluctant to use (Smith 1995). Rationing is manifested in the inability to obtain certain treatments on the NHS, cancellations of operations, closures of hospital facilities and long waiting lists for elective hospital services (Dixon 1997).

The NHS inherited a significant waiting list for hospital treatment (Yates 1987). Excessive waiting lists and waiting times have persisted in spite of a series of policy interventions which have been applied over the years to tackle them (Harrison and New 2000). It was only fairly recently in 1994 that the Government acknowledged that the delay for an OP appointment should also be considered as part of the total delay for treatment although a Royal Commission (1979) had argued this 15 years earlier.

Efforts to reduce the waiting list by funding activity increases have been criticised for failing to address the increases in referrals that occur as a response, thus undermining the impact of the activity increases (Hamblin *et al* 1998a, 1998b). Furthermore, it has been argued that the waiting time should be the key concern, not the waiting list length (Royal Commission 1979; Hamblin *et al* 1998a, 1998b). Whilst this may be true from the perspective of the patient, for those funding and delivering services, the waiting list length is also important. It indicates the level of activity required to meet the desired waiting time; the longer the waiting list, the greater the activity rate required in order to maintain the desired waiting time.

Public opinion of the NHS has always been influenced by the presence of excessive treatment delays. Opinion is reinforced by the considerable media attention that long treatment delays attract. Some patients choose to supplement NHS care with private health insurance and thus overcome the limits imposed by rationing. However, many cannot afford this luxury. In 1996, 17% of the respondents of a British Social Attitudes Survey were covered by private health insurance with a significant differential across the different income groups (Mulligan 1998).

2.5.3 The Shift in the Balance of Care

The dynamic nature of the health care environment presents a host of further challenges to NHS policy makers. One important health care trend is the ongoing shift in emphasis away from the acute hospital sector towards primary and community care. This trend has arisen, to some extent, as a response to the pressures arising from funding constraints. This is because one of the many factors motivating this shift has been the perceived cost benefits. Also instrumental in the development of this trend were the 1991 NHS reforms, and the change in the focus of government policy towards primary care. This policy shift began in the 1980's (Hughes and Gordon 1993) and has led to the current goal of a primary care-led NHS (NHS 1983, 1991c, 1994b, 1998a, 2000b).

The 1991 NHS reforms arose from a radical review, which the Government carried out in 1988. This review had followed renewed pressure for additional funding for the NHS. The results of this review were published in 1989 in the White Paper, *Working for Patients* (NHS 1989a). The reforms were enacted as law in the NHS and Community Care Act in 1990, and were implemented in 1991. The broad aims were to improve efficiency and make services more responsive to patients' needs by delegating power down from Regions to Districts, and from Districts to hospitals. The reforms involved management changes and the introduction of competitive forces by the separation of the purchasing and provider roles in an arrangement known as the 'internal market'. Hospitals and community services were permitted to opt out of district control and assume independent status as NHS Trusts. Another change was that some GPs were eligible to become fundholders. Further reforms that focused on primary care included pilot schemes to extend the purchasing roles of GPs (Beecham 1994; TPET 1996, 1997; NHS 1994b), and later, the replacement of GP fundholding with Primary Care Groups and the conversion of these groups into Primary Care Trusts (NHS 1997b).

The implementation of the 1991 NHS reforms led to various pressures, including the need for health professionals to quickly develop new skills as they assumed new responsibilities for contracting (Ham and Shapiro 1995; Maynard and Bloor 1996). Furthermore, a number of structural changes followed. The Government formed a committee, chaired by Sir Bernard Tomlinson, to examine the future of London's health services (NHS 1992). In response to the Tomlinson report, the Government announced a number of changes. These were to scale down London's hospital services, with hospital mergers and bed closures, and to improve primary and community services (NHS 1993b). Additional funding was provided to support the shift in balance from the hospital sector to primary and community care.

The shift away from hospital care has been driven by financial pressures and promoted by financial incentives. Financial pressures were created by the internal market which encouraged trusts to reduce the length of stay in order to maintain or increase patient activity levels. Associated with both the 1990 GP contract (NHS 1989b) and GP fundholding were various incentives to GPs to provide an enhanced range of practice-based services such as minor surgery, chronic disease management for diabetes and asthma, and consultant outreach clinics (NHS 1989b, 1993c; Glennerster *et al* 1994).

The shift in the balance of care has also been motivated by consumer pressure, and it has been facilitated by technological advancements (Hensher *et al* 1999). Technological developments have led to shorter hospital stays and have enabled a greater number of procedures, which formerly required in-patient stays, to be conducted on an OP or day surgery basis (Newchurch 1993; Wickham 1994).

Other driving factors have involved the change in the supply and planning of the NHS medical workforce (Ham *et al* 1998). There have been several major policy developments in medical staffing, including the new deal on junior doctors' working hours (NHS 1993d) and the Calman report on specialist medical training (NHS 1993e). These have combined with and reinforced the shift in the balance of care by leading to a reconfiguration of clinical services within and between hospitals, centralising services and involving fewer hospitals. The assumption is that centralising services provide economies of scale and improve quality although the evidence is conflicting (Fergusen *et al* 1997; Posnett 1999).

Hospital facilities are being used more intensively with fewer beds and higher patient throughput (Vetter 1996). District general hospitals are expected to form linkages with regional tertiary centres and primary care-based services, and thus form health care networks. These arrangements are considered to offer a means to maintaining local access and ensuring high quality care. As the reconfiguration of hospital services develops, further mergers of NHS Trusts are expected (Ham *et al* 1998). These changes will impose great pressure on DGHs. It is expected that they will be squeezed between pressures to regionalise some services and decentralise others as services are shifted to primary care and closer to home (Warner and Riley 1994; Vetter 1996). Some DGH's may close or reduce services whilst for others, their path to survival will involve forming alliances with GPs and other agencies and networks with other hospitals (Pollard 1998; Ham *et al* 1998).

In addition to the reconfiguration of services, the shift in the balance of care has been reflected in the increasing emphasis on health promotion and the prevention of ill health. This formed an integral part of the reforms to general practice (NHS 1987) and the Government's *Health of the Nation* health strategy which acknowledged the various determinants of health, such as exercise and diet in addition to health care (NHS 1991b). The goals of the *Health of the Nation* strategy embraced an integral part of the World Health Organisation's *Health for All* targets (WHO 1985). The Government's strategy was mapped out further in the recent White Paper, *Saving Lives: Our Healthier Nation* (NHS 1999).

The shift in the balance of care in the NHS will be explored further in the next chapter.

2.5.4 Health Care Coming Under Increased Scrutiny

In addition to the shift in the balance of care, another important trend that is altering the health care environment is the increasing scrutiny placed upon health care and the gradual erosion of clinical autonomy. This trend is also, to some extent, a response to funding pressures, given the increased emphasis placed on the costs and cost-effectiveness of services.

Doctors' actions are being scrutinised by their peers and those outside the medical profession, including hospital managers, purchasers and patients. The 1991 NHS reforms formalised audit procedures conferring the responsibilities for financial and medical audits on the Audit Commission and the medical profession respectively. Medical audit involves the systematic examination and review of medical performance and outcome. It is not a new concept, nor is the need to assess evidence rather than succumb to personal bias (West 1992). However, the collection, analysis and social context of the use of medical evidence has changed over time. There has been an increasing appreciation of probabilistic reasoning and population-based studies over anecdotal evidence and clinical case studies, and the benefits of meta-analysis which combines evidence from different sources (Mulrow 1994; Davidoff *et al* 1995). These changes are reflected in the focus of the evidence-based medicine (EBM) movement (EBM 1992; Davidoff *et al* 1995; Sackett *et al* 1996). EBM emerged in recognition of the fact that certain differences exist between research evidence and clinical practice. Randomised controlled trials (RCTs) form the central focus of EBM. A RCT is commonly acknowledged as the 'gold standard' method of formal evaluation of treatments. EBM involves the systematic review of RCTs by the Cochrane Collaboration, a worldwide collaborative group that embraces the concerted efforts of doctors, scientists and epidemiologists. These reviews are basically designed to identify treatments whose efficacy has been proved by individual RCTs and overviews of RCTs. EBM is not restricted to RCTs. Where RCT data is not available, the practice of EBM considers reviews of other evidence. EBM also considers the use of diagnostic procedures with established and documented high sensitivity and specificity.

The 1990s brought the assessment of medical technologies under greater scrutiny (Warner 1994). In 1985, it was estimated that only one fifth of medical interventions at most had been evaluated by an RCT (Brook and Lohr 1985). The situation will have improved since then. However, a large proportion of patients are unable to enter a RCT. For example, of all the patients screened for entry into a major trial which compared two treatments for coronary heart disease, only 3% were eligible for randomisation (RITA 1993). A further problem is that when the results of clinical trials are known, they are often out of date, because treatments are constantly being updated. Observational studies can overcome some of the limitations of RCTs (Black 1996), but considerable uncertainty remains.

The increased emphasis on evidence was also reflected in government policy. EBM was expressed in the Government's expectations of primary care in its expanded role (NHS 1996b). The government also embarked upon an ambitious NHS R&D health technology assessment programme. The term, health technology, extended beyond treatments alone to any method used by health professionals to promote health, treat disease and organise services. The aim was to create a "knowledge-based health service" where all clinical, managerial and policy decisions are based upon sound evidence. Assessments would consider the issues of costs, effectiveness, outcomes and acceptability (Smith 1994; Stein and Milne 1998; NHS 1998a).

It is understood that the general lack of evaluation of the majority of medical interventions, coupled with clinical uncertainty, are the primary causes of the wide variations which exist in all areas of medical practice (Anderson and Money 1990). Attempts have been made to standardise medical practice by the development of protocols and guidelines. These may incorporate recommendations for treatments that have been evaluated by RCTs. Further challenges are presented in disseminating new evidence effectively (Smith 1994) and in ensuring that changes in behaviour are made as a result. The absence of a hierarchy of authority in health care can impede the necessary changes in behaviour (Curnow 1972).

Medical practice is also coming under further scrutiny in the wake of various scandals, involving gross incompetence, cases of murder and sexual abuse of patients by their GPs and the illegal retention of human organs (Carvel 2001). Health professionals are under pressure to improve the quality of services. Moreover, increasing pressure is being placed upon hospital doctors to justify their use of resources, as both purchasers and hospital managers are demanding cost-effective care. These aims are encapsulated in the concept of managed care (Fairfield *et al* 1997), which is gaining increasing popularity in the NHS (Dixon *et al* 1998). Some doctors have found it difficult to adapt to the market culture and, in addition, perceive satisfying managerial demands as a threat to clinical freedom (Frostick *et al* 1993).

Meanwhile, patients are insisting on a greater role in decision making. Patient's expectations have been fuelled by the Government initiative, *The Patient's Charter* (NHS 1991a, 1996a), which specifies service delivery standards for patients, and patients' increasing knowledge. These service delivery standards include waiting time targets for surgery and OP appointments, and other issues, such as complaint procedures and standards of hospital food. The gain in patients' knowledge has been facilitated by the plethora of medical information that is available via the media. Patients are also increasingly accessing information via the internet. Furthermore, the rising incidence of medical litigation suggests that patients are not afraid to question the doctors' authority. In fact the costs of medical negligence in the NHS has been reported as doubling in three years to almost £150 million in 1995 (Warden 1995). Formerly these claims were met by an NHS Trust's revenue or by borrowing. However, in response to this increasing problem, an insurance scheme was set up to help trusts spread the costs of settlements.

The two broad trends, which are associated with the changing health care environment - the shift in the balance of care and the increasing scrutiny placed upon health care - are connected. Like any other health care technological innovation, the shift in the balance of care is going to be subjected to close scrutiny by its various stakeholders.

2.5.5 Evaluation Difficulties

Calls are made to evaluate the technologies, innovations and other aspects of the health service. However, this leads to several difficulties that present a further set of challenges to policy makers as evaluation may not be straightforward. As discussed in §2.5.4, it may not be feasible to employ the ideal evaluation approach such as an RCT, or the results of a RCT may be out of date. There are various other evaluation problems including trade-offs, stakeholder conflict, measurement difficulties and the unexpected consequences of policy changes.

In theory, the quality of the health service may be evaluated with reference to the objectives described in §2.4. However, in practice, difficulties arise in the operationalisation of these objectives and the inevitable trade-offs involved. Trade-offs are often made between efficiency and effectiveness, and between efficiency and equity

(Reinke 1988). The increased emphasis in the UK on efficiency and cost-effectiveness (NHS 1989a) is often in conflict with considerations of equity (Lees and Mills 1982; Abel-Smith 1994). Challenges are presented by the prevailing inequalities in health status, use and provision of health services (Wilkin 1992; McPherson 1994; Benzeval *et al* 1995; Webster 1998). Further problems arise in accommodating the different stakeholders involved, and in addressing potential conflicts between their respective objectives (Kitson 1992; Benton 1996). In health care, stakeholders may comprise politicians, purchasers, providers, patients and other interested parties. Each party will be influenced by their particular values and beliefs. Kitson (1992) provide an example where nurses and doctors held opposing views on what constitutes a quality issue. Whilst nurses were concerned about the dignity of elderly men who had undergone prostrate operations, doctors focused on the incidence of post-operative infection rates.

Some aspects of quality are difficult to quantify. For example, measuring infection rates requires a quantitative approach which is more straightforward compared to the measurement of patient dignity which involves a more qualitative approach. Equity is another aspect of quality that is notoriously difficult to quantify (Reinke 1988). Measurement difficulties can lead to a tendency to focus on factors that are easily measured, to the neglect of others (Nutley and Smith 1998). Kitson highlighted that in 1992 considerably more resources (eight times more) were devoted to medical audit compared to nursing audit. In evaluating the performance of a health service, it might be considered desirable to measure the outcomes but difficulties in measurement can shift the balance towards the health service process (Davies and Crombie 1995).

It is important to have a broad set of evaluation measures which fully address an organisation's activities. Otherwise, the activity of an organisation may be skewed towards dysfunctional behaviour. For example, some health care policy changes can have unintended and undesirable consequences. If the evaluation is too narrow and these unintended effects are ignored, they may be reinforced or misleading conclusions may be drawn. Unintended and undesirable consequences of policy changes include counter-productive effects and the creation of new problems (Forrester 1961; Rittel and Webber 1973).

Consequences of policy changes are often difficult to anticipate in view of the multiple factors involved, which combine to produce many different effects. An example of a policy change which has led to counter-productive effects concerns NHS waiting lists. Resource increases may only offer temporary relief to excessive waiting lists as referral rates may rise in response to the increased access, thus causing waiting lists to 'bounce back' (e.g. Buttery and Snaith 1979, 1980; Roland and Morris 1988; Worthington 1991; Pope 1992; Newton *et al* 1995; Hamblin *et al* 1997; The Economist 1998; Goddard and Tavakoli 1998; Hamblin *et al* 1998a; Earwicker and Whynes 1998; van Ackere and Smith 1999). In fact, given that patients' expectations are so high, any policy change which increases access to services can potentially stimulate further demand and thus impose pressure on the system. However, although this phenomenon is well-known, this policy is frequently employed in order to reap short-term benefits.

The introduction of GP fundholding is an example of a policy change that created a new problem of a two-tiered service in the provision of hospital care. This caused great public concern. The two-tiered system arose because GP fundholders were in control of their budgets and so were able to secure privileges that were denied to non-fundholding GPs. In addition, they could finance operations for their patients when access for others was withdrawn because block contracts had been filled and the health authorities' funds had been exhausted (Honigsbaum, 1993). Reductions in NHS hospital beds provides another example of a policy change which may lead to the creation of a new problem. It might be assumed that efficiency levels will rise to ensure that emergency admissions are not compromised by this policy change. However, if the scope for efficiency savings is limited, what occurs in practice is that elective care acts as a safety valve creating a new problem of excessive levels of elective cancellations (Lane *et al* 2000).

In recent years, increasing emphasis has been placed on the interactions between different elements of the NHS with the use of the terms like "joined-up thinking" or a "whole systems" approach (Harrison 2001; Spurgeon 2001). For example, on the long-term planning of hospitals (NHS 2000b; Smith 1999) and national priorities on improving access to services (NHS 1998b). To fully understand the consequences of policy changes, it is necessary to consider an overview of the system and the system interactions. In other words, "joined-up thinking" is required.

2.6 SUMMARY

In this chapter, health care systems were introduced in general before focusing on the UK system, the NHS, which formed the context to the case studies for this research. The structure of the NHS was presented in three different ways considering: its organisation; its provision of health care across the primary, secondary and tertiary levels; and, patient pathways with respect to patient needs. The broad aims of the NHS were outlined before discussing a number of challenges that arise in attempting to achieve these aims. Several key obstacles associated with the policy formulation were highlighted. Amongst these is the need to balance competing demands whilst operating within resource constraints. Other challenges are associated with the changing health care environment involving two important inter-related trends. The first trend is the gradual shift in balance away from the acute hospital sector towards primary and community care. The second trend is the increased scrutiny placed upon health care.

The shift in the balance of care, like any other health technology innovation, is being subjected to further scrutiny. However, several problems with the evaluation of health technologies were highlighted including the trade-offs that occur between different performance measures and stakeholder conflict. Several further problems that were considered were the difficulties in measuring the quality of services and how these difficulties can skew measurement towards what it easily measurable, to the neglect of certain aspects of service quality. In evaluating policy changes, the importance of addressing the possible unintended and undesirable consequences of these changes was also discussed. These issues form the focus of later chapters.

The shift in the balance of care and its evaluation are explored in the next chapter.

CHAPTER 3

THE SHIFT IN THE BALANCE OF CARE

3.1 INTRODUCTION

The previous chapter set the context to the research by presenting an overview of the UK health system, the NHS. The changing health care environment was discussed, with particular reference to service shifts (or reconfigurations) and changing roles (shifts in responsibility) that are collectively referred to as the shift in the balance of care. The motivation underlying this trend was reviewed. Several driving forces were identified including the need to reduce costs and improve access. The increasing scrutiny placed upon health care was also discussed.

The purpose of this chapter is to explore further the shift in the balance of care and its evaluation. Note that changes in individual services associated with this trend will be referred to as service shifts.

This chapter considers the diversity of service shifts (§3.2). The broad range of patient groups that have been affected is described (§3.2.1), and the varying degree to which shifts in health services have occurred (§3.2.2 and §3.2.3) is reviewed. The reservations that have been expressed about this trend developing without being properly evaluated are discussed (§3.3). An established approach to the evaluation of shifts in health services, economic appraisal, is described (§3.4), briefly reviewing its principles (§3.4.1) and the assessments of service shifts (§3.4.2). Opportunities are highlighted for the application of SD, which forms another evaluation approach (§3.5). The chapter is summarised in the final section (§3.6).

3.2 THE DIVERSITY OF HEALTH SERVICE SHIFTS

The development of the shift in the balance of care, both within and outside the UK, has led to extreme diversity. This is reflected in two ways. Firstly, in terms of the broad range of patient groups which have been affected. Secondly, in the different types of service shifts which have occurred, both across different service levels and within the same service levels (Warner and Riley 1994; Coulter 1995; Godber *et al* 1997).

3.2.1 Scope of Health Service Shifts

The scope of service shifts which have occurred extends across a vast range of specialties. These include opthalmology (Gillam *et al* 1995), physiotherapy (Hackett *et al* 1993), orthopaedics (Hollingworth *et al* 1993; O'Cathain 1994), dermatology (Black *et al* 1997), rheumatology (Helliwell 1996), paediatrics (Atwell and Gow 1985; Strayer *et al* 1980) and surgery (O'Cathlain *et al* 1992) amongst others. This trend has not been prioritised towards any particular patient group. It has affected both services for high profile diseases such as cancer (NHS 1995; Selby *et al* 1996) and heart disease (BCS 1997; de Bono 1998), and the 'cinderella' specialties such as mental health (Shah 1995; Knapp *et al* 1994; Muijen *et al* 1992). Moreover, it has affected both established specialties such as maternity care (Brooten *et al* 1994; Scott 1994) and services for new illnesses such as HIV/AIDS (Tramarin *et al* 1992).

The shift in the balance of care is primarily represented by shifts in services from the secondary level to the primary level. Subsequently, commentators have tended to focus on these, but in fact, shifts have occurred across the primary, secondary and tertiary levels. Furthermore, shifts to primary care do not exclusively originate from the secondary level. For example, the tertiary level is the established place for CC services. This procedure is increasingly being carried out on a day case basis with early discharge and community follow-up, as opposed to on an inpatient basis. Therefore, this constitutes a shift across the primary/tertiary interface.

3.2.2 Shifts Between Service Levels

In §2.3.2, differences between the primary, secondary and tertiary levels of health care were discussed in terms of their respective inputs, locations and service attributes. Godber *et al* (1997) have argued that an attribute-based definition provides the most robust basis upon which to discuss service shifts. They recommend that the set of attributes, direct access, generalist and longitudinal care, and delivery in a community setting serve as suitable descriptors of primary care. Based upon this definition, a shift towards primary care is said to occur when the new service acquires additional primary attributes. In §2.3.2, Godber *et al*'s classification was extended by proposing attribute sets for secondary and tertiary care. The attribute set of indirect access, occasional and specialised care, and delivery in a hospital-based setting, was proposed, with the degree of specialisation differing between tertiary and the less specialised, secondary care.

A full shift to the primary level is said to involve the gain of all four service attributes of primary care when previously there were none (Godber *et al*, 1997). Full shifts to primary care include substitutions for hospital-based services. Associated with this are GPs undertaking minor surgery (O'Cathlain *et al* 1992; Lowy *et al* 1993) and the substitution of hospital A&E services in a community setting (Roberts and Mays 1998). Other examples are 'near patient testing' which involves standard diagnostic tests being carried out at the GP surgery rather than in a hospital (Rink *et al* 1993; Grieve *et al* 1999) and GP practices employing physiotherapists (Hackett *et al* 1993). Further examples are early discharge schemes with community follow-up (Brooten *et al* 1994; Hollingworth *et al* 1993; Atwell and Gow 1985; Scott 1994; Beech *et al* 1999).

Partial shifts to primary care involve shifts to a lesser degree. They comprise shared (or integrated) care (Strayer *et al* 1980; Muijen *et al* 1992; Tramarin *et al* 1992; DICE 1994; GRASSIC 1994) and hospital-at-home schemes (Knowelden *et al* 1991; Hensher *et al* 1999). They also include the provision of specialist services in outreach clinics in the community (Bailey *et al* 1994; Shah 1995; Gillam *et al* 1995; Helliwell 1996; Russell-Jones 1996; Black *et al* 1997; Bowling *et al* 1997). Another example is early discharge with secondary sector community follow-up as opposed to the case of a full shift where the follow-up is by primary sector staff (Burns *et al* 1993). Partial shifts to primary care also include radiological telemedicine to remote communities (Halvorsen and Kristiansen

1996), and direct bookings onto surgical waiting lists that dispense with the usual specialist OP consultation (Coulter 1995). Further examples are open access clinics, which provide direct access to certain diagnostic services by eliminating the need for a referral by a specialist. This has involved gastroscopy, endoscopy, echocardiography and radiological services, (Tybulewicz *et al* 1996; Chawda *et al* 1997; BMA 1997; de Bono 1998).

Although service shifts have tended to be away from acute hospital care, some shifts across the secondary/tertiary interface have occurred in the opposite direction. This has been intended to concentrate complex work in order to maintain a critical volume and skill base. Specialities effected have been obstetrics, radiology, trauma and surgery (HSM 1996).

Shifts from the tertiary level to the secondary level, have been designed to improve local access and enable tertiary centres to concentrate on more complex work, whilst less complex cases, which nevertheless require specialised hospital care, are delegated to secondary centres. This arrangement has been referred to as a "hub and spoke" model (Ham *et al* 1998) or "network of expertise" (NHS 1995). It has involved cancer services (NHS 1995; Selby *et al* 1996) and cardiac services (BCS 1994a, 1997).

The Calman-Hine cancer report on the organisation and delivery of cancer services (NHS 1995) called for a new structure composed of a network extending from cancer centres out to cancer units and beyond to primary care. Cancer units would only treat common cancers, whilst only the more specialised cancer centres would treat the rarer cancers. *The New NHS* document (NHS 1997b) proposed that the Calman-Hine proposals should be used as a model for national service frameworks covering other major services.

Regarding cardiac services, facilities have been developed at DGHs to provide low risk diagnostic CC. This service development has been intended to improve local services and to enable the tertiary centres to concentrate on emergency care, high risk diagnostic and treatment procedures. Further connections within the hub and spoke model involve the primary level, which plays an important complementary role in prevention and rehabilitation in the management of heart disease.

As these shifts in cancer and cardiac services involve substitutions for tertiary services, they represent full shifts to the secondary level. The shift affecting cancer care is poorly defined, from irregular service provision, delivered on an *ad hoc* basis with gaps in provision. Therefore, the shifts from the tertiary level to the secondary level will be accompanied by the expansion of tertiary services.

3.2.3 Shifts Within Service Levels

Further service shifts occur within a particular service level rather than across the interface between different service levels. These include the use of telephone consultations in general practice, which provide an alternative to consultations in the surgery and home visits (Brown and Armstrong 1995; Salisbury 1997). They also improve the degree of direct access within primary care, in terms of reducing the access time, by offering out-of-hours services. Other examples of shifts within primary care, based upon telephone-based services, also involve the delegation of responsibility from doctors to nurses. This includes the NHS Direct helpline which is a 24-hour telephone-consultation service delivered by nurses, and practice nurses conducting telephone-based triage (or prioritisation) in GP surgeries (Gallagher *et al* 1998; Shekelle and Roland 1999). In these cases, access to primary care is improved but access to GP services becomes indirect. Another example involves the NHS 'walk-in' centres which are nurse led although the skill mix may involve GPs (Walker 1999; Merry 2001). These offer free consultations without an appointment at convenient times. They may substitute for hospital usage as some patients who find access to their GPs difficult seek health care at an A&E department.

Shifts within the secondary level include the replacement of long-term beds with acute beds (Stevens *et al* 1990) and the switch from inpatient care to day surgery (Warner and Riley 1994). Another example is the transfer of patients from DGHs to community hospitals which represent an intermediate institutional setting (Hine *et al* 1996).

Further service shifts are expected in the future, both across and within the primary, secondary and tertiary levels, reducing the need for hospital services and gradually bringing care closer to home (Warner and Riley 1994; NHS 2000b). This will involve internet access to NHS services, an increase in the use of home-based diagnostic kits, genetic engineering and, eventually, the use of vaccines for conditions that are currently incurable, such as HIV/AIDS.

3.3 CALLS FOR FORMAL EVALUATION

As discussed in §2.5.4, there has been an increasing call for all health technologies and technological innovations to be properly evaluated. Following these calls, many have expressed concern about the lack of evaluation of the shift in the balance of care (Scott and Maynard 1991; Harris 1994; Coulter 1995; Haines and Iliffe 1995; Scott 1996; Godber *et al* 1997; Pedersen and Leese 1997; BMA 1997; Scott and Wordsworth 1998; Hensher *et al* 1999). This lack of evaluation is, perhaps, surprising given that the shift to primary care has been high on the agenda of government policy.

The evaluation of service shifts could focus on the effects on the quality of services. Different aspects of service quality were outlined in §2.4 including the access to services, patient satisfaction and cost-effectiveness. Service shifts could also be evaluated on the basis of other factors such as changes in the workload of the staff involved.

Service developments may involve shifting a workload away from the established service to alleviate pressure on that service. However, this may create a new problem by imposing additional workload pressures on the health professionals who are responsible for the new service. This is of particular concern for the service developments in primary care where the intensity of the GP workload is already high and there is a recruitment crisis (BMA 1996, 1997; Scott and Vale 1998). Furthermore, shifting services may lead to unintended financial pressures. Shifting a workload to a new service may be cost-effective. However, if the new service facility is used to augment rather than substitute for the established service, or both, as illustrated in Figure 3.1, then demands on staff are increased and pressure is imposed by calls for further funding (Lowy *et al* 1993; Rink *et al* 1993; Scott and Wordsworth 1998).

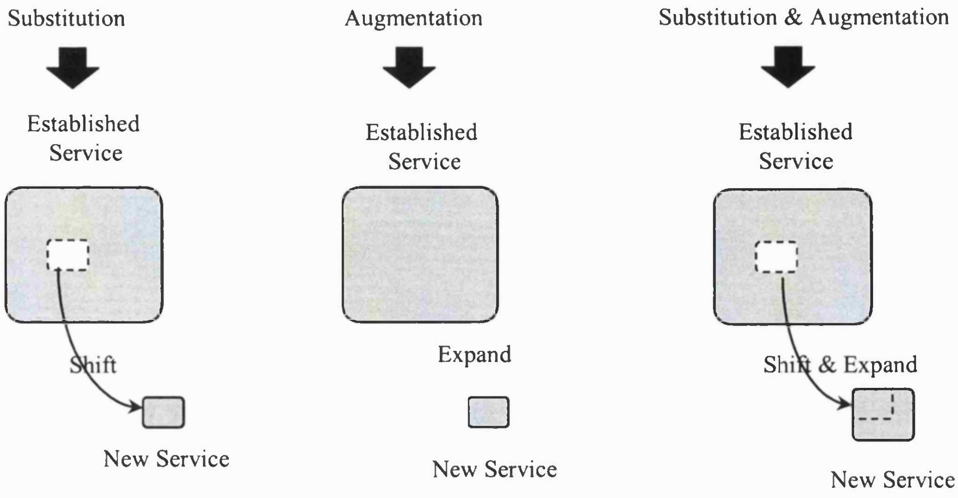


Figure 3.1 Changes in Workload Associated with Service Shifts

Increases in the overall workload may be driven by increases in demand, which have been stimulated by the improved access associated with the service development. As described in §2.5.4, patients have high expectations for the NHS to deliver and these expectations will be fuelled by service developments. Demand may also be stimulated by the reduction in waiting times derived from increased capacity. This well known phenomenon was highlighted in §2.5.5. Hamblin *et al* (1998b) describe another mechanism whereby demand may be stimulated. When GPs gain new skills, as a result of taking on new duties, they identify more patients in need of treatment.

Allowing demand to be met may cancel out any cost benefits associated with a service development that is deemed to be cost-effective (Harris 1994). Coulter (1995) suggests that cultural change is required to ensure that the cost benefits are not cancelled-out by increases in inappropriate demand. Attempts to stem the levels of inappropriate demand have been made by the use of clinical guidelines (Coulter 1995; Edwards and Hensher 1998).

A further issue to consider in evaluation, which is associated with changes in workload, is the remuneration for services delivered. This is a cause of concern for GPs, as they are not remunerated for all new tasks that they have adopted within the service innovations in primary care. In cases where GPs have not been remunerated, further investment is required. For shifts in NHS services between the hospital sectors, remuneration concerns do not arise because hospital doctors are salaried. This difference between GPs and hospital doctors may change in the future. A government white paper signalled a number of proposals for certain changes to primary care, including the option of GPs being salaried by practices or NHS trusts (NHS 1996c).

Therefore, there are various issues, which need to be considered in evaluating the shift in services, considering both the direct effects of the service shift and its ramifications. These issues include the access to services, patient satisfaction, cost-effectiveness, financial and workload pressures, appropriateness of service use and remuneration.

There are various approaches to evaluating shifts in services. For example, a survey may be carried out to sample patient preferences and patients' attitudes to service developments, or to evaluate changes in GP workload (e.g. Bailey *et al* 1994; Gillam *et al* 1995; Scott and Wordsworth 1998). An expert panel could convene to evaluate the appropriateness of service use. An established approach to the evaluation of the shift in the balance of care is economic appraisal.

3.4 AN ESTABLISHED EVALUATION APPROACH

3.4.1 Economic Appraisal

Economic appraisal represents a well recognised and established health care evaluation approach although it has yet to reach full acceptance in health care (Hutton 1994; Rutten and Drummond 1994). Since the 1960s, the growth in health economic appraisal has been exponential. It has been the subject of a number of texts (Drummond 1980; Warner and Luce 1982; Drummond *et al* 1987; Luce and Elixhauser 1990) and the focus of numerous other publications in the medical and health care literature. These include overviews of its basic principles (Weinsten and Stason 1977; Detsky and Naglie 1990; Robinson 1993a, 1993b, 1993c, 1993d, 1993e; Petrou and Renton 1993; Mason *et al* 1993), bibliographies and reviews (Adams *et al* 1992; Backhouse *et al* 1992; Udvarhelyi *et al* 1992; Coyle and Drummond 1993; Elixhauser *et al* 1993; Rutten and Drummond 1994).

There are a number of different variants of economic appraisal. They are often collectively referred to by the term cost-effectiveness analysis. This can be misleading, given that cost-effectiveness analysis is the specific name given to one such variant. The other variants, which are mainly applied to health care, are cost-minimisation analysis (also known as cost-analysis), cost-benefit analysis and cost-utility analysis. The basic principle underlying each is to assist in the choice between several different procedures or programmes by compiling a 'balance sheet' of the expected costs and benefits associated with each option. More formally, costs and benefits are referred to as, inputs and outputs (or outcomes) respectively (Figure 3.2).

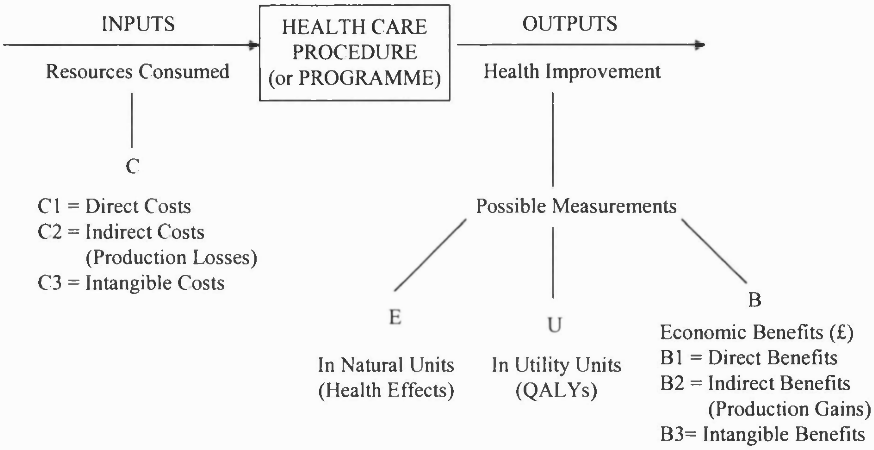


Figure 3.2 Components of Economic Evaluation
(Source: Rutten and Drummond 1994)

Inputs may comprise direct, indirect and intangible costs. Direct costs of health care are primarily the responsibility of the health service but they may also fall upon patients and their families. Indirect costs are productivity losses that arise when patients are withdrawn from the workforce to undergo care. Intangible costs refer to the pain or discomfort associated with treatment. Outputs (or outcomes) may encompass direct, indirect and intangible benefits. Direct benefits are the savings in other direct medical care, which are achieved as a result of the medical intervention. Results of the medical intervention might also include productivity gains associated with an earlier return to work. These are referred to as indirect benefits. Intangible benefits include the value of improved health from the patient's perspective. Although economic evaluations rely upon comparisons between different health care procedures or programmes, doing nothing can constitute a viable alternative.

Costs are measured in monetary terms. The four types of economic appraisals differ in their analysis of the outputs (or outcomes) of the different options considered. The application of cost-minimisation analysis is appropriate when the outcomes of the different options are assumed to be similar. In this case, only the costs are considered. Cost-benefit, cost-effectiveness and cost-utility analyses also measure outcomes but different units are used.

Cost-benefit analysis imposes monetary values on all outcomes. Given that intangibles are difficult to measure in these terms, they are often ignored and this has led to severe criticism against cost-benefit analysis. Criticism has also been directed against the measurement of benefits by productivity gains in cost-benefit analysis. More recent approaches consider individuals' observed or stated preferences.

Cost-effectiveness analysis measures outcomes in natural units (health effects), such as life-years gained or positive cases diagnosed. This approach has two key limitations. Firstly, it cannot be used to compare programmes with different natural units of outcomes. Secondly, it cannot combine improvements in mortality with improvements with morbidity.

Cost-utility analysis, which is the most sophisticated form of health economic appraisal, aims to overcome these two limitations by producing a combined index of utility. Several indices have been developed including the quality adjusted life year (QALY) which provides a common universal unit for cost-utility analysis – cost per QALY gained. Although the QALY has been criticised on various levels, it is the index most commonly used (Robinson 1993d; Petrou and Renton 1993). However, in considering service shifts, the QALY is not appropriate, as the use of this measure assumes that the length and quality of life are the key benefits. Scott (1996) argues that the appropriate measures, for service shifts, relate to the health care process, such as the waiting time and convenience of the service.

The standard approaches to economic evaluation produce a single index score to compare different options, such as cost per QALY gained or cost per positive case diagnosed. By contrast, an alternative, non-standard approach, which has been applied to evaluate the cost-effectiveness of service shifts, has been to produce costs accompanied by a range of outcome measures. These may include clinical variables and process variables such as waiting times, convenience of the service and patient satisfaction with the service (Godber *et al* 1997). Drummond (1994) refers to this approach as cost-consequence analysis. Whilst this approach has the advantage of making the various outcome measures explicit, it has been argued that multiple process measures can be considered within standard approaches to economic evaluation using techniques such as willingness-to-pay and conjoint analysis (Scott 1996; Godber *et al* 1997).

Most decisions in health care are concerned with how much a service should be provided, not whether or not it should be provided at all. Therefore, in presenting results of economic appraisals, incremental analysis is generally shown. Focusing on average costs may produce misleading results because there is often a significant difference between the average costs and marginal costs. Discounting and conducting sensitivity analysis are also regarded as constituting good practice. Adjustments should be made for costs and benefits occurring at different time points by discounting to present values, because it is assumed that costs incurred now are more important than those incurred in the future. Sensitivity analysis should be conducted to address any uncertainties.

Whilst there is a high level of agreement among health economists on some issues, such as the importance of sensitivity analysis and the use of discounting, various debates exist about other issues. Examples of issues of contention are the inclusion of indirect costs and benefits, and the actual choice of discount rate for health benefits (Drummond *et al* 1993). The Department of Health and UK Treasury support the view that health benefits should not be discounted (Cairns 1992). The rationale for using a zero discount rate for health benefits is that health has no monetary value, it cannot be invested, and there exists no evidence to suggest that people consider that future health states are less important than present health states (Parsonage and Neuberger 1992).

The shift in the balance of care may be supported by economic appraisal in several different ways. For example, economic analysis may be applied to determine the appropriate number and location of health service facilities. To promote the appropriate use of facilities, economic evidence may be incorporated into clinical guidelines and medical audit procedures. Furthermore, when operating within a limited budget, cost-effectiveness data may be used to make decisions about whether or not a service shift is appropriate. Purchasers/commissioners may not support a service shift if it is not deemed to be cost-effective.

3.4.2 Economic Assessments of Service Shifts

Several reviews and discussions have reported poor evidence of the cost-effectiveness of some service shifts and methodological shortcomings in the assessments of service shifts (Maynard 1994; Haines and Illife 1995; Sowden *et al* 1995; Scott 1996; Godber *et al* 1997; Roberts and Mays 1998; Miller *et al* 1999; NHS 2000b).

The extent of evidence in favour of service shifts varies considerably (Haines and Illife 1995). For example, specialist outreach clinics (Harris 1994; Black *et al* 1997) and services substituting for hospital A&E services (Roberts and Mays 1998) present little evidence, and the cost-effectiveness of integrated care for asthma and diabetes has been found to be inconclusive (GRASSIC 1994; DICET 1994). There is sound evidence of cost-effectiveness, based upon a RCT, for the provision of care attendants for elderly patients discharged from hospital (Townsend *et al* 1988) and the early discharge of stroke patients into the community (Beech *et al* 1999). As discussed in §2.5.4, the RCT is the acknowledged gold standard method for collecting evidence. However, conducting RCTs of the organisation and delivery of services is not always feasible. Furthermore, it is quite different to conducting RCTs of medical interventions, for which the potential volume of evidence is so much greater, as evidence can be derived from large multi-centre trials and meta-analyses. Therefore, for service delivery innovations, it is necessary to consider other study designs such as observational studies and comparative trials. The evaluation of hospital-at-home schemes is one such example where modest evidence of cost-effectiveness has been provided, based upon a non-RCT approach (Marks 1991).

Methodological shortcomings have included: ambiguity of definitions; incomplete data; failing to justify why outcomes have not been evaluated; the absence of sensitivity analysis; and, failing to control for differences between the study and control groups. Godber *et al* (1997) have expressed concern that inappropriate comparisons may be made. For example, if a new service is substituting for the established service, then the appropriate comparison is between the new service and the established service. However, this is not the appropriate comparison to make if the new service is augmenting, rather than substituting for, the established service (as illustrated in Figure 3.1). In this case, the new service should be compared with either no service or, with appropriate discounting, delayed treatment from the established service.

The strength of evidence of the cost-effectiveness of a service development may also be weakened by the inability to draw generalisations from a study. Sometimes, important information about the study setting such as staffing levels and skill mix is not reported. On other occasions, the reported outcomes of a service development may only be specific to a particular setting. For example, the evaluation of an early hospital discharge programme based in urban location may not easily translate to the same service in a rural setting where domiciliary care may not be feasible (Casiro *et al* 1993). Evaluations may rely upon restrictive assumptions about the resources available. For example, GPs conducting minor surgery may be considered to be cost-effective (O'Cathain *et al* 1993), but the additional workload requirements may be so high that only a limited number of GPs may be able to adopt this new role. Another example relates to early discharge policies with community follow-up. Although they may be deemed to be cost-effective, if there is insufficient capacity, these policies may lead to unacceptable delays for community services. Generalisations may also be difficult to make across international boundaries. For example, assumptions about changes in demand in response to primary care innovations in the US, where availability varies, will differ from that in the UK, where there is universal access (Roberts and Mays 1998).

In summary, the evidence on the cost-effectiveness of service shifts is fragmented and of poor quality. Moreover, whilst economic appraisal forms an established evaluation approach in health care, the emphasis has tended to be on the assessment of new treatments rather than other health technology innovations, such as service shifts. Over the course of time, the situation will improve as more service innovations are subjected to the scrutiny of economic evaluation. In its evaluation of health care technologies, the NHS Executive gave a high priority to the evaluation of several service shifts (NHS 1994c). These include diagnostic facilities, specialist outreach clinics and shared (or integrated) care schemes. With greater awareness of the methodological shortcomings, these should also be reduced over the course of time.

3.5 A POTENTIAL ROLE FOR SD MODELLING

However, the scope of evaluation will be restricted for as long as the emphasis is on the need to evaluate the cost-effectiveness of health service innovations without seeking to fully understand their ramifications. An important ramification of improved access is the stimulation of latent demand. In other words, "joined-up thinking" is required.

As discussed in §3.3, in calling for the service shifts to be evaluated, commentators have recommended that cost-effectiveness analyses should be carried out. However, implicit in a simple cost-effectiveness analysis of a service shift is the assumption that demand will remain constant. Service developments are conceptualised as simple service shifts and substitutions, in isolation of the potential secondary or knock-on effects, most notably the stimulation of latent demand for services. Given that secondary effects can impact upon both service costs and benefits, a simple cost-effectiveness analysis can be misleading.

Commentators have acknowledged that service shifts may stimulate demand and their response has been to call for the use of clinical guidelines to stem the inappropriate demand. Cost-effectiveness data about the appropriate use of medical procedures may be incorporated into clinical guidelines. However, the stimulation of demand cannot be fully addressed by the use of a clinical guideline because it is an inherently complex process, involving a series of decisions. By contrast, the focus of a guideline is on a single decision.

It is possible to deal with increases in demand associated with a service shift with economic appraisal via a cost-benefit analysis; considering both expansions in demand along the existing demand curve and shifts in the demand curve. However, economic appraisals of the cost-benefit type cannot explain the feedback mechanisms underlying increases in demand.

It would therefore be useful to present a coherent framework in which to seek an understanding of the mechanisms and consequences of the stimulation of latent demand. With this understanding, guidelines and other policy interventions may be applied effectively to alleviate pressure on the system. Such a framework may be provided by the application of SD.

SD has a considerably lower profile in health care and there are no documented cases of SD studies of service shifts. Therefore, it is not surprising that, whilst calls have been made for cost-effectiveness analyses to be carried out on service shifts and service use, no such calls have been made for these to be accompanied by SD analyses. Unlike the emphasis of economic appraisal on fine detail, the analysis of SD is based upon an overview of the system. An SD model could elucidate the key mechanisms underlying both existing and potential primary and secondary effects of policy changes (i.e. support "joined-up thinking").

As an evaluation tool, SD could be applied in cases where service shifts have occurred and produced undesirable effects. Insights could be provided on how to intervene to produce a better future without triggering further side effects. Alternatively, SD could be used as a planning tool when planning a service shift to indicate what effects to anticipate and thus prepare for a better future. Mass (1981) refers to SD models constructed within the 'evaluation mode' and 'planning mode' as "type 1" and "type 2" models respectively. SD will be explored further in the next chapter.

3.6 SUMMARY

In this chapter, the diversity of service shifts was reviewed. It was considered how they have applied across a host of different specialties and to varying degrees, both within and across service levels. Following concerns expressed about the need for this trend to be rigorously evaluated, the available evidence was reviewed. Economic appraisal was presented as an established health care evaluation approach. Economic evaluations of the costs and benefits of service shifts, based on cost-effectiveness analyses, were reviewed. The inability to consider ramifications of service shifts, in particular the stimulation of latent demand, was highlighted as a key problem arising with simple cost-effectiveness analyses. It is possible to study shifts in the demand curve by applying another variant of economic appraisal, cost-benefit analysis, which is used less frequently in health care. However, various questions remain about the mechanisms underlying changes in demand. It was argued that SD could be applied to explicate the mechanisms underlying existing and potential cases of the stimulation of demand and other dynamic ramifications of service shifts. SD, which has a considerably lower profile in health care, will form the subject of the next chapter.

CHAPTER 4

THE SYSTEM DYNAMICS APPROACH

4.1 INTRODUCTION

The previous chapter considered the evaluation of service shifts in the NHS and economic appraisal which forms an established approach to evaluation. It was argued that an SD analysis could complement economic appraisal by explaining both existing and potential secondary effects of health service shifts, most notably the stimulation of latent demand. SD has a considerably lower profile in health care.

The purpose of this chapter is to describe the SD approach and clarify its role in health care. This is achieved via a comparative review of the health care simulation modelling literature which follows on from SD adopting a particular approach to simulation.

Simulation modelling is first introduced (§4.2). Complexity, which forms the focus of simulation, is described with the aid of a 3-dimensional classification to differentiate between the different types of complexity (§4.2.1). A brief overview of the processes of simulation modelling is offered (§4.2.2). The next section considers the different variants of simulation modelling (§4.3). Using the 3-dimensional classification of complexity introduced in §4.2.1, SD is compared and contrasted with the more traditional approach to simulation modelling, which has a higher profile in health care. Discrete event simulation (DES) exemplifies the traditional approach. For the purposes of this research, DES serves as a suitable vehicle to illustrate the relative advantages of SD over the traditional approach to simulation modelling and the potential benefits obtainable by the use of the SD approach. The comparison is conducted by first introducing the DES approach (§4.3.1 and §4.3.2), and then the SD approach (§4.3.3 and §4.3.4). The differences between the two are illustrated with a specific health care example (§4.4) and then summarised (§4.5). The low profile of SD is addressed (§4.6) before concluding the chapter (§4.7).

4.2 SIMULATION MODELLING

4.2.1 The Focus of Simulation: Complexity

Health care policy problems are inherently complicated and a powerful feature of simulation is its ability to explore complexity over time (Davies and Davies 1986). Complexity, broadly defined, may be classified into three dimensions: detail, dynamic and organisational complexity. The general distinction between detail and dynamic complexity has been alluded to in the SD literature and articulated by Senge (1990). This categorisation is extended by identifying a third dimension, organisational complexity.

Detail complexity originates from the existence of multiple variables which potentially can produce an enormous number of possible connections and effects. It is prevalent in health care, and presents great difficulties to planners and policy makers. It generally focuses on the system's physical processes and tangible elements, and often involves the interaction between patients and resources. Examples are the multiple characteristics of patients and resources. Resource constraints may determine when and if patients receive care. Further examples are the inherent uncertainty and variability about demand, clinical events, length of stay, survival times, emergency arrival times, and the various patient pathways through the processes of care. Associated with detail complexity are difficulties in scheduling and the associated trade-offs between patients queuing and resource inefficiency and various other trade-offs (Lee and Mills 1982; Reinke 1988; Abel-Smith 1994).

Dynamic complexity arises in situations where the consequences, over time, of the cause and effect relationships are not obvious. It might include counter-intuitive secondary or knock-on effects of policy changes, variations between short-term and long-term responses and complications arising from the global consequences of policy changes (Forrester 1961; Rittel and Webber 1973). Delays are important determinants of dynamic behaviour, and a distinction may be made between delays in physical flows and the lags in the transmission of information, such as cognitive and perception delays. Non-linearities are also important in determining the behaviour of social systems (Forrester 1961, 1987).

An example of a non-linearity is presented by hospital admission rates not being simply proportional to the number of available beds, as admission policies may be modified to account for periods when vacant bed numbers are low. Another source of non-linearity exists when decisions about hospital admissions are not independently responsive to several factors, such as available beds and demand; 100% bed occupancy renders the level of demand irrelevant in determining admission rates.

The mechanisms of dynamic complexity may be illustrated by the discussions in the literature about the dynamics of NHS waiting lists and waiting times (e.g. Buttery and Snaith 1979, 1980; Roland and Morris 1988; Worthington 1991; Pope 1992; Newton *et al* 1995; Hamblin *et al* 1997; The Economist 1998; Goddard and Tavakoli 1998; Hamblin *et al* 1998a; Earwicker and Whynes 1998; van Ackere and Smith 1999). A policy of injecting more resources into the system may be intended to reduce waiting lists and waiting times. Whilst this policy may be effective locally, in the short-term, by increasing throughput and therefore reducing waiting lists and waiting times, the long-term effect might be an increase in these variables. This may arise because, once doctors have perceived a reduction in waiting times, they may respond by increasing their referral rates, thus stimulating demand. Therefore, although increasing the level of available resources may seem to be a reasonable reaction to concern about excessive waiting lists and waiting times, the benefits may eventually be cancelled out due to counter-intuitive, compensatory system behaviour. As non-linearities are responsible for shifts in the dominant feedback structure in a system, the significance of this phenomenon may vary according to the circumstances.

The third dimension, organisational complexity, may be crudely defined as a collection of social factors which influence the operation of the system. It includes elements that are difficult to quantify including the quality and value of outcomes (Pierskalla and Brailer 1994) and intangibles. Intangibles can have significant effects on the dynamics of the system. Examples of intangibles and affected variables are: frustration about contractual constraints and treatment decisions (Mullen 1994; Black *et al* 1996); incentives or disincentives and the costs generated (Beech and Morgan 1992); waiting times and treatment decisions (Starkley 1993; RCS/ RCP 1993); patient expectations and emergency admission rates (Edwards 1996); and, various pressures and purchasing behaviour (Shaw 1995). Organisational complexities also include uncertainties that cannot be assigned probabilities relating to the lack of knowledge about present and future dimensions such as system responses to unprecedented actions and the preferences of individuals (Rosenhead 1989). Other examples of organisational complexity are the poor quality of information due to biases, distortion or incompleteness as frequently encountered in NHS waiting times data (Mullen 1994; Black *et al* 1996), and the nature of organisational decision making which evolves typically out of tradition rather than being based on rationality (Simon 1979). Further examples are the predominantly non-quantitative and non-planning culture within health care (Clayden 1995) and its pluralistic context. This involves the powerful force of the medical professions and the long tradition of clinical freedom (Lee and Mills 1982; Jones and Hirst 1986; Ham 1995) which has repeatedly led to conflict during government attempts to reform the NHS (Webster 1998).

Health care problems and other issues may span all three dimensions of complexity. These problem situations often share many characteristics with "wicked" (Rittel and Webber 1973) or "squishy" problems (Strauch 1975) and "messes" (Ackoff 1979), as described in the social sciences literature. For a certain class of policy problems for which time is an important factor, the application of simulation modelling can assist policy makers in learning how to "tame" or unravel the "mess" to some extent. The shift in the balance of care spans all three dimensions of complexity and involves significant consequences that propagate over time. Therefore, simulation modelling may be effectively employed to explore the shift in the balance of care.

Fundamentally, a computer simulation model can offer a *powerful, experimental policy analysis tool* with logical, flexible, explicit, comprehensive and rigorous dynamic analyses. It provides a cheap, risk-free environment in which to seek insight into the effects of current policies. In addition, without making a commitment to change, it provides an opportunity to test out ideas, explore the likely effects of alternative policies and *design more robust policies* (Meadows and Robinson 1985; Davies and Davies 1986; Vennix 1990; Davies and Davies 1994; Pierskalla and Brailer 1994). A computer simulation model can also offer a relatively painless way to study controversial or emotive issues. Holmes *et al* (1994) provide such an example, where a computer simulation model was used to address the emotive issue of treatment withdrawal in an intensive care unit. This model was used to implement an algorithm, which estimated the number of bed-days that could be released if treatment were withdrawn from the patients who were expected to die before hospital discharge.

Compared with other stochastic models and optimisation approaches, a powerful feature of simulation is its ability to address and explore different aspects of complexity. It can effectively be applied to study many problems that are intractable by analytical means, such as markov, semi-markov and mathematical programming methods (Boldy 1976; Lambo 1983; Davies and Davies 1994). Simulation, as opposed to optimisation, also avoids certain criticisms made against the quest for optimal solutions in social systems, including oversimplifying assumptions and a lack of appreciation of the transiency of optimal conditions (Rittel and Webber 1973; Ackoff 1979; Rosenhead 1978, 1989; Lane 1992).

4.2.2 Basic Processes of Simulation

Various definitions of the term, 'simulation', exist (Kleijnen 1974; Pritsker 1979) and sometimes, the definition is extended to include optimisation methods (e.g. WHO 1978b). For the purposes of this research, simulation is defined as a pragmatic, non-optimising approach which involves the construction and dynamic analysis of a model. This model represents the salient features of a system, and is constructed for a specific purpose (Banks and Carson 1984). Figure 4.1, which was adapted from Clark and Cole (1974), provides a schematic representation of the processes of simulation modelling which are both sequential and iterative.

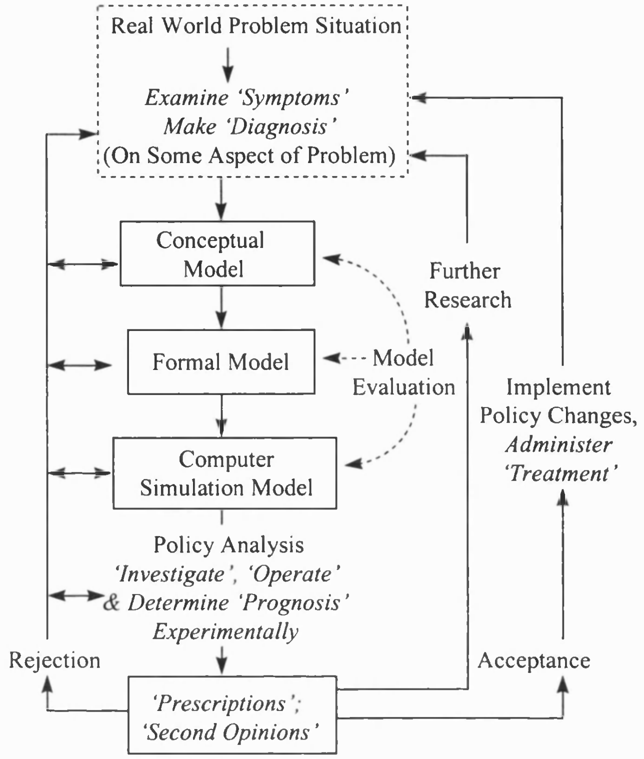


Figure 4.1 Processes of Simulation Modelling
(Source: Taylor and Lane 1998)

Simulation modelling is based on the premise that a problem has been identified as the focus for the study (Shannon 1975; Randers 1980). An unambiguous definition of the central problem is first derived. This is achieved by examining its characteristics or 'symptoms', consulting experts, considering related studies and analysing various data, including historical time series. A preliminary conceptual model or 'diagnosis' is produced, comprising the key factors and interactions, which are understood to represent the basic mechanisms underlying the central problem. The conceptual model is then formalised into mathematical terms and converted into an executable computer program so that dynamic analyses may be performed in order to investigate existing policies and develop more effective policies. Embedded within the different modelling phases is a process whereby the model is subjected to considerable scrutiny and evaluation in order to amend conceptual and computational errors. Sensitivity analysis plays an important role in this process in testing the robustness of model-based insights. The experimental phase forms the predominant, though not exclusive, source of policy insight. Dynamic effects may be monitored using both graphical and tabular output.

In Figure 4.1, a broader context is illustrated than that given by many traditional simulation authors as it also depicts the stages beyond the delivery of policy insights and recommendations. These 'prescriptions' are evaluated and may contribute to policy debate within a broader political context. They may be accepted or rejected and may contribute to further research endeavours.

In simulation studies, many complexities can be explicitly modelled, such as assumptions about patient and resource characteristics, delays, non-linearities and system interactions. Patient pathways may be traced at various levels of detail, with the purpose of the study determining what is appropriate (Davies and Davies 1994). Uncertainties associated with risk may be represented using constant probabilities or values sampled from a probability distribution. Organisational complexity presents some difficulties; if it is ignored, acceptance of the study's conclusions is unlikely. It may be considered implicitly by: acknowledging the organisational context and adopting a facilitative, rather than expert role; making simulation modelling more accessible to the client by using powerful visual interactive computer facilities; constructing transparent models and analyses to facilitate communication and debate; and, promoting a high degree of client participation to ensure a sense of 'ownership' over the model and the policy recommendations which thus emerge (Rosenhead 1978; Jones and Hirst 1986; Clayden 1995).

It is important to be aware that whilst great benefits may be obtainable from the use of simulation modelling, as with all modelling methodologies, it is not without certain problems and potential pitfalls. These include applying a particular model inappropriately; seeking academic rather than policy goals; failing to keep the model comprehensible and relevant to the policy problem; and, ignoring the by-products of modelling (Quade 1980; Law and Kelton 1991). One such by-product is the model acting as a communication facilitator and learning tool. Simulation can also have certain drawbacks. For example, stochastic simulation is time consuming, because various values have to be repeatedly sampled to construct a realistic representation of the system. Further difficulties relate to problems with data acquisition (Davies 1994) and model validation. Validation, in the sense of confirmation, can never be absolute (Popper, 1959). However, in simulation modelling, a pragmatic approach is adopted to establish confidence in whether the model is sufficiently accurate for its intended purpose (Forrester 1961; Richardson and Pugh 1981; Neelamkavil 1987; Pidd 1998).

There are several different varieties of simulation modelling. The SD method differs from the traditional approach to simulation modelling. Therefore, it is important to clarify this distinction.

4.3 VARIANTS OF SIMULATION MODELLING

4.3.1 A Traditional Approach: DES

Traditionally, health care simulation modelling has focused on the analysis of localised decisions and problems orientated towards individual patient detail. The scope of the traditional approach may be illustrated by considering DES, which represents the most sophisticated variant. For non-DES examples, see Bensley *et al* (1995) and Mather (2000). The 3-dimensional framework of complexity, introduced in §4.2.1, is used as a basis for this discussion. For the purposes of this research, the principles of DES are not described in detail. Further details may be found in standard simulation texts (e.g Banks and Carson 1984; Law and Kelton 1991; Paul and Balmer 1993; Pidd 1998).

DES models focus on individual activities - discrete events - which proceed according to the logic of the system under study. In the context of the health services, a discrete event may represent an arrival or death of an individual patient. Distinctive features of DES studies often include the analysis of heterogeneous patient flows, queues for hospital personnel and facilities, and resource utilisation. Individual patient detail is fundamental in issues addressed by DES studies, as it determines the interactions between resources and patients as they progress through the system. This detail may reflect the patients' initial needs, the risk of subsequent clinical events and an estimate of the time they spend in hospital.

Referring to the 3-dimensional framework of complexity, DES modelling primarily concentrates on detail complexity. It is therefore considered the most appropriate methodology for modelling health care problems dominated by detail complexity (Davies 1985; Davies and Davies 1994). Dynamic complexity is also considered to some extent in DES modelling. However, the consequences of policy changes are restricted to the local level, as the emphasis tends to be on isolated or closely interlinked decisions. Whilst queuing and the subsequent physical delays are central themes of DES modelling, information delays are not considered explicitly. Intangible elements tend to be ignored but attempts are made to implicitly consider other organisational complexities, as described in §4.2.1. In constructing DES models, generic computer packages are often inadequate to address the subtleties of the system, such as patient prioritisation and the flexibility of resource scheduling and sharing (Davies and Davies 1994). Subsequently, modellers often resort to writing their own programs using a high-level general purpose computing language (Dumas 1985; Jones and Hirst 1986; Davies 1994).

4.3.2 Health Care Applications of DES

The literature on DES in healthcare is vast, extending back over many years with DES applied to numerous issues. These studies involve problems relating to patient scheduling, admissions, routing and flow schemes (e.g. 'fast track' schemes); staff sizing, scheduling and planning; bed planning; facility sizing and planning; and, budgeting. Studies have occurred within a variety of settings, both within and outside the UK.

Examples of different settings include casualty (Badri and Hollingsworth 1993; Huang *et al* 1995; Blake and Carter 1996), outpatients (Wilt and Goddin 1989; Babes and Sarma 1991; Lehaney and Paul 1994), radiology (O'Kane 1981), surgery (Kwak *et al* 1975; Wright 1987; Jones and Hirst 1986; Fitzpatrick *et al* 1993), intensive care (Williams 1983; Romanin-Jacur and Facchin 1987) pharmacy (Vemuri 1984; Mukherjee 1991) and ambulance services (Savas 1969). DES has also been applied to issues associated with treatment for renal disease (Davies 1979; Roberts *et al* 1980; Bolger and Davies 1992; Davies and Flowers 1995; Davies and Roderick 1998) and coronary heart disease (Davies 1994). By modelling changes to demand, supply and utilisation variables, studies have sought improvements in efficiency and other aspects of health care.

Bed planning simulation studies have focused on improving the efficiency of the configuration of hospital beds and patient placement policies. For these studies, important outputs have included bed occupancy rates and patient misplacement rates, which occur when bed shortages lead to placements in an inappropriate department or patients being sent to another hospital. Examples are studies by Dumas (1985) and Butler *et al* (1992).

Further DES health care examples include the analysis of a diagnostic radiology department (O'Kane 1981) which, as a support service, has important implications for the overall hospital efficiency, and studies of surgical units (Jones and Hirst 1986; Wright 1987). Wright's (1987) study of inpatient care for the general surgery and urology specialities in a health district evaluated ways in which efficiency might be improved in the context of proposed reductions in the number of beds. Another example involved an investigation of the number of personnel required to achieve minimum performance standards in a hospital OP pharmacy (Johnson *et al* 1972). OP studies, such as those by Wilt and Goddin (1989), Babes and Sarma (1991) and Lehaney and Paul (1994) considered efficiency by addressing the common problem of trade-offs between patients waiting and doctors being idle. DES has also been used to assist hospital managers in assessing the potential impact of a merger between two different clinics (Mahacheck and Knabe 1984).

In hospital casualty DES studies, assistance has been given in preparing for a range of scenarios including unforeseen events such as serious road traffic accidents. Hospital casualty models were constructed by Badri and Hollingsworth (1993) and Huang *et al* (1995). DES has also been applied to the ambulance service. A simulation model by Savas (1969) evaluated different allocations of ambulances and assist in balancing an effective service against cost considerations.

Although resource limitations are generally included to examine bottlenecks in the system, unconstrained DES models have considered other health care issues, such as the cost-effectiveness of different treatment strategies for end-stage renal disease (Roberts at al 1980), the dynamics of the HIV infection and AIDS (Brailsford *et al* 1992), and the development, in an African village, of trachoma which is a contagious eye condition (Hawkins 1989). The trachoma study provided predictions of the long-term effects of different preventative strategies, including vaccination and antibiotic treatment. Other DES studies which have predicted the effects of changes in treatment strategies, are the renal study by Bolger and Davies (1992) and the coronary heart disease study by Davies (1994). These studies considered the effects on future demand and costs, and thus assisted in purchasing, planning and budgeting. Further unconstrained DES models were used to evaluate screening services for the loss of vision associated with diabetes (Davies *et al* 1996, 2000).

Further examples and descriptions of DES applications to health care problems are given by Davies and Davies (1994), Lehaney and Hlupic (1995), and Jun *et al* (1999).

As the pressure on scarce health care resources continues, further calls will be made to reduce costs and improve efficiency. This will provide opportunities for new applications of DES. This will be facilitated by technological developments providing more powerful and user-friendly software. These developments are discussed by Jun *et al* (1999).

4.3.3 SD Simulation

Although the DES approach is extremely powerful, some problems are beyond its scope such as those dominated by dynamic or organisational complexity. There is, therefore, scope for the application of an alternative methodology. SD is proposed as one such alternative. Detailed accounts of this methodology are provided in SD texts (e.g. Forrester 1961; Richardson and Pugh 1981, Wolstenholme 1990; Sterman 2000). SD is often referred to as systems thinking, with some authors referring to SD in general and others referring to qualitative SD only (Senge 1990; Wolstenholme 1999b) but, it should not be confused with other schools of system thinking (see Richardson *et al* 1994; Checkland 1981).

As with the description of DES, the discussion of SD is based on the 3-dimensional complexity framework that was introduced in §4.2.1.

Practitioners of SD probe beyond individual detail and isolated events and, adopting a more holistic perspective, study the relationship between the underlying structure of a system and its behaviour over time. Structure refers to the integrated network of information which links the different flows in the system, such as flows of people, resources and money. Information feedback loops are traced out. An information feedback loop arises from a decision, based upon information about some property of the system, resulting in an action, which is intended to influence the value of that property. The action changes the property of the system and thus leads to new information about that property. This may lead to further actions. A closed causal relationship thus propagates through the system as time unfolds. The policies continuously transform information into decisions. Isolated feedback loops can have a balancing, goal-seeking effect or a reinforcing effect.

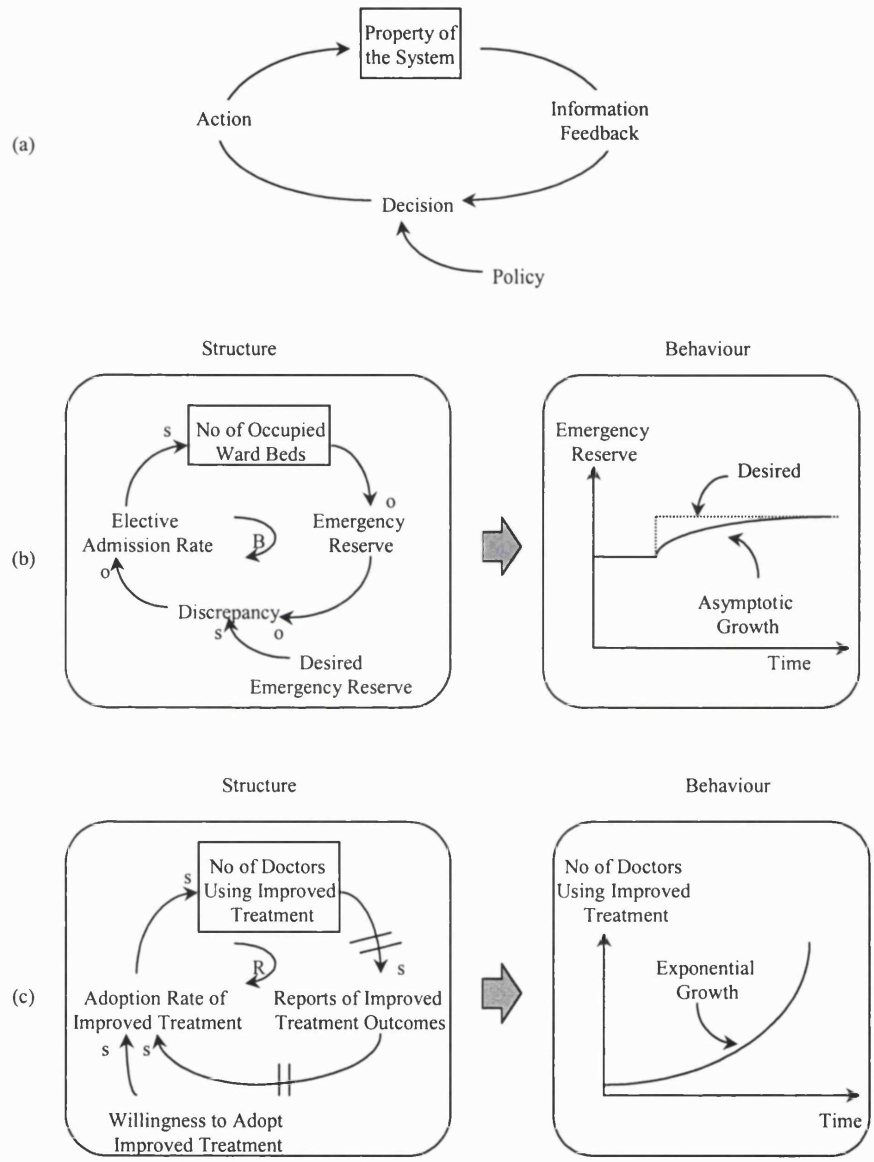


Figure 4.2 Examples of Information Feedback Loops

(2 lines - Delay; B - Balancing loop; R - Reinforcing loop; Polarities of causal links: s/o - Variables change in the same/opposite direction, *ceteris paribus*)

Figure 4.2 shows the basic structure of an information feedback loop (Figure 4.2(a)), and simple examples of the structure-behaviour linkage for a balancing loop with no delay (Figure 4.2(b)) and a reinforcing loop (Figure 4.2(c)). Figure 4.2(b) depicts how, if the desired level of emergency reserve in a hospital is increased, then the elective admission rate has to be reduced to achieve this goal. The polarity of the causal link between "Elective Admission Rate" to "No of Occupied Ward Beds" is such that when the elective admission rate increases, this causes an increase in the number of occupied ward beds. The change occurs in the same direction *ceteris paribus* and is indicated by an 's'. By contrast, when the number of occupied ward beds increases, this leads to a decrease in the level of emergency reserve. The change occurs in the opposite direction *ceteris paribus* and is indicated by an 'o'. Figure 4.2(c) shows the initial growth pattern of a new successful treatment. It illustrates how, if there is an increase in the willingness to adopt the new treatment, perhaps due to the release of a report of its benefits, the number of doctors using the treatment will rise. This will generate more information about the treatment's benefits and thus encourage the adoption of the new treatment. This will lead to an exponential growth in the number of doctors using the new treatment.

The relative significance of different information feedback loops is determined by non-linearities which alter their strength (or, more technically, their gain). In doing so, non-linearities establish which loops are dominant and are responsible for shifts in loop dominance.

The SD focus is on the feedback effects, or repercussions, of policy changes, including reactions to exogenous events. Using SD, endogenous-based insights into dynamic policy problems are sought. The feedback structure may not necessarily be immediately apparent as a correct 'conceptual distance' (Forrester 1961; Richardson 1991), or perspective, is necessary so that:

> "..events and decisions are *deliberately blurred* into patterns of behavior and policy structure" (Richardson 1991, p. 346, italics added).

SD insights are most relevant to those who require an overview of the system, such as a hospital chief executive or a clinical director, but perhaps not the junior doctor who is preoccupied with the detail complexities of isolated decisions and individual patient events. In SD, these events are viewed as:

> "..*riding on the surface* of an underlying tide of policy, pressures and, dynamic pattern" (Richardson 1991, p. 323, italics added).

Computer models are employed in SD to explore the dynamic implications of structure as erroneous inferences can be made from static analyses (Richardson 1986). Practitioners of

SD recognise that the mental database of expert knowledge, based on observation and experience, is by far the greatest source of information, compared to the formal, written and numerical databases (Forrester 1961, 1975). Knowledge about non-linearities resides primarily within the mental database.

SD modelling concentrates primarily on dynamic complexity and may encompass all the elements outlined in §4.2.1. Detail complexities are considered but considerably fewer compared to DES modelling, so software with extensive in-built functionality very often suffices for SD analyses such as STELLA (High Performance Systems 1997) or VENSIM (Ventana Systems 1996). Unlike in DES, the formation of a queue by the arrival of individual patients is not usually represented in an SD model. However, the reaction to a queue might be included in an SD model, such as the effect of NHS waiting times on the decision to switch to a more easily accessible treatment or to private care (Starkley 1993; BCS/RCP 1993).

Organisational complexity is an important feature in SD and this is reflected in several ways. Intangibles and the distinction between perceived and actual values are explicitly represented in SD models (Richardson and Pugh 1981, Sterman 2000). The organisational context is frequently discussed in the SD literature where authors have exploited the knowledge about group processes thus probing further than discrete event simulators. (Morecroft 1983; Lane 1992; Sterman 1994; Vennix 1990, 1996). The development of qualitative SD (see Wolstenholme 1999b) in its own right also reflects connections between SD and organisational complexity. Qualitative SD is presented as an approach to map out and achieve a shared understanding about the interactions between different parts of systems amongst the different stakeholders.

4.3.4 Health Care Applications of SD

The application of SD to health care policy problems is not as well established as DES and involves considerably fewer studies. Nevertheless, the principles of SD have been applied to a number of health care issues involving a high degree of dynamic complexity. These include: the evolution of the effects of changes to community care (Wolstenholme 1993, 1999a); diffusion of new medical technologies (Finkelstein *et al* 1984; Homer 1983, 1987); transmission of HIV and AIDS (work by Roberts and Dangerfield 1990, 1996, 1999a); evolution of waiting lists (van Ackere and Smith 1997, 1999; González-Busho and García 1999); escalation of health care costs (Vennix and Gubbels 1992); and, formation of kidney stones (Mojtahedzadeh *et al* 1992).

In order to address important group process issues, some authors have reported their findings before proceeding to the quantitative, simulation phase. For example, Vennix and Gubbels (1992) studied the counter-intuitive effects of a policy designed to reduce the escalation of health care costs. Their aim was to illustrate an effective method of knowledge elicitation for SD models. Coyle (1984), Cavana *et al* (1999) and Wolstenholme (1993) demonstrated how SD could contribute to the policy debate with qualitative SD models to share worldviews amongst stakeholders. Wolstenholme later provided a dynamic analysis (1999a).

Whilst the boundaries of DES studies are often confined to an individual hospital department, many SD health studies cross organisational boundaries. Bernard *et al* (1977) offer one example. They constructed an SD model to study the social impact of changes to services which aimed to integrate children with disabilities into the community. Other work was that by Finkelstein *et al* (1984) and Homer (1983, 1987). They considered the emergence and evolution of medical technologies with case studies focusing on two interventions for heart disease, coronary angioplasty and the cardiac pacemaker, and the antibiotic clindamycin. These studies crossed the boundaries between clinical practice, manufacturing of medical technology and government. In these studies, the interactions between practitioners' perceptions of clinical effectiveness, technological substitution, market penetration and innovation diffusion were brought into a coherent simulation framework. Homer's work was interesting in that he illustrated how the same model could explain the different diffusion dynamics of successful and unsuccessful technologies. Another study which crossed organisational boundaries was that by Wolstenholme (1993, 1999a). He considered the consequences of proposed changes in responsibility for community care services. By examining the dynamic and organisational complexities between the health services, social services and community, he illustrated how SD could contribute to a strategic debate.

SD has been applied to epidemiological issues. Roberts and Dangerfield (1990, 1996, 1999a) used SD to contribute to the HIV and AIDS debate, by providing an endogenous theory of the dynamics of transmission, and a tool to explore the efficacy of different intervention strategies. Richie-Dunham and Méndez Galván (1999) used to SD evaluate interventions to manage dengue (a mosquito-transmitted virus) fever in Mexico. The authors emphasised how SD provided an effective forum to address multiple viewpoints on this contentious issue. Homer *et al* (2000) presented a preliminary study of the dynamics of antibiotic resistance.

SD has been used in the Department of Health to model a range of issues of varying degrees of complexity (Royston *et al* 1999). Three examples were presented based upon screening for cervical cancer, the sexually transmitted disease, chlamydia, and emergency health and social care. Beech (1995) highlighted the potential for SD to be used to evaluate health screening strategies for another disease, cystic fibrosis, in terms of the evolution of costs and outcomes over time. Another example of SD applied to emergency services was provided by Lane *et al* (2000). They illustrated how erroneous conclusions may be drawn about the success of policy changes if they are evaluated too narrowly. They considered that although reducing hospital bed capacity does not adversely affect emergency admissions, this is at the expense of elective care, as cancellations of elective admissions sharply rise to compensate. Elective services were also considered by van Ackere and Smith (1997, 1999). They used an SD model to simulate the variation of NHS hospital waiting times which results from the interaction between supply and demand variables including hospital capacity, efficiency levels and referral rates. They demonstrated how injecting further resources to reduce waiting times may only be effective in the short-term, as waiting time reductions could lead to the release of latent demand.

Mojtahedzadeh *et al* (1992) provide an example where SD has been applied to tackle a clinical rather than policy issue. They used SD to examine the dynamics of renal stone formation and thus sought insight into responses to different treatments.

Further health-related applications of SD include a study of the dynamics of heroin addiction involving the complex interconnections between the rate of drug abuse, police action and drug-related crime (Levin *et al* 1975).

4.4 AN ILLUSTRATIVE EXAMPLE

4.4.1 Use of DES

To illustrate the differences between the DES and SD approaches, let us consider the problem of reducing NHS waiting times for coronary heart disease treatment within certain budgetary constraints. Difficulties arise from the expected increases in demand due to improved survival prospects, the introduction of new technologies and rising public expectations. Treatment for coronary heart disease includes coronary bypass surgery, coronary angioplasty and medical therapy. A DES model could be used to investigate the effects of changes to treatment strategies, and other localised decisions, on the development of both hospital waiting lists and patient queues within a hospital. A DES model would be very detailed (Figure 4.3), describing how arrivals of different types of patients 'compete' for staff and facilities. Various patient attributes would be highlighted to model the heterogeneity of patient flows, which result from the variations in patient needs, risk of clinical events, probability of transfers between different treatments and the estimated length of stay.

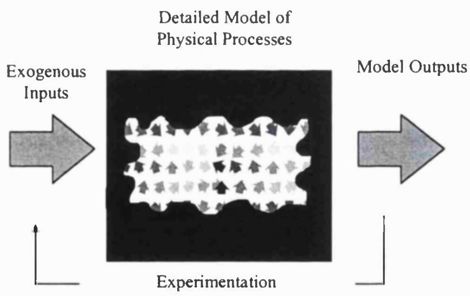


Figure 4.3 Policy Analysis Using Discrete Event Simulation
(Source: Taylor and Lane 1998)

The study could examine the quantitative effects of adjustments to treatment strategies under different assumptions regarding demand levels by altering the relevant exogenous inputs to the model. Alternative interventions might involve changes to bed-borrowing strategies, staff or resource schedules, or length of stay distributions. Different interventions might be compared using the model outputs. Outputs would include detailed DES predictions over time of various outcome measures for each treatment group. For example, financial costs, average waiting times, average numbers waiting, incidence of various clinical events and treatment cancellations and resource utilisation measures. In this way, a DES study might indicate to purchasers and providers where the priority for resource expenditure lay, and may estimate the cost of reductions in waiting times.

4.4.2 Use of SD

Now, let us consider how an SD analysis might help to reduce waiting times for coronary heart disease treatment. The emphasis and focus of enquiry of an SD policy analysis would be considerably different from a DES analysis. The SD model (the causal hypothesis) would be more transparent (Figure 4.4), only focusing on the information feedback mechanisms underlying a well-defined dynamic problem over a specific time frame. This last point is important; in a single SD model it would be inappropriate to combine the day-to-day dynamics of hospital queues and the long-term dynamics of hospital waiting lists. Instead, an SD study could focus on the inability of a specific policy to reduce NHS bypass surgery treatment delays in the long-term.

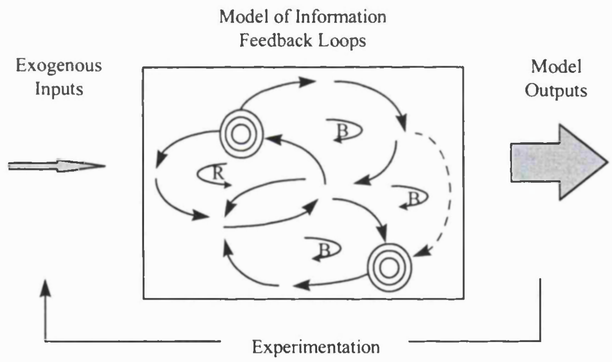


Figure 4.4 Policy Analysis Using System Dynamics
(B = Balancing loop; R = Reinforcing loop; Dashed arrow = New link;
Concentric circles = Policy intervention point. Source: Taylor and Lane 1998)

One such policy might be the promotion of angioplasty as an alternative treatment for certain patients. However, this policy may be a 'fix that fails' (Senge 1990). The underlying structure for this dynamic pattern is two feedback processes. Angioplasty has several advantages over bypass surgery, including its shorter NHS waiting times and lower initial costs. A *balancing process* arises as some bypass patients may be reallocated to angioplasty to avoid long treatment delays (Starkley 1993; BCS/RCP 1993), and thus counterbalance bypass surgery undersupply. However a higher proportion of post-angioplasty patients subsequently require early re-intervention (RITA 1993), and thus contribute to further demand on purchasing budgets for bypass surgery. This contributes to a *reinforcing process:* whilst effective in the short-term in dealing with waiting list problems, the long-term consequences require yet greater use of the angioplasty 'fix'. This simple model (or this model extended to a more complex model) could be used as a basis upon which to investigate the use of coronary stents which are designed to improve angioplasty re-intervention rates (Bittl 1996).

The focus of SD models requires fewer exogenous inputs than those of DES. Furthermore, an SD model would not focus on the detail complexity concerning the formation of waiting lists, but instead would concentrate on the feedback processes underlying changes to waiting lists and waiting times. This would concern how treatment delays are perceived, the associated perception delays, reactions to these delays (including corrective actions taken) and their consequences over time. Reductions to hospital waiting times might trigger various responses (e.g. increases in referral rates) which may produce further dynamic complexity.

In SD policy analyses, both parameter and structural changes are made to intensify or diminish the intensity of existing feedback loops, or create further loops to reinforce or control the effects of the dominant loops. Parameter changes which might diminish the intensity of reinforcing process might include an increase in the number of bypass surgery procedures purchased, or the introduction or promotion of certain treatment guidelines. These might alter the tendency of clinicians to reallocate patients to angioplasty according to the current average waiting times for bypass surgery. A structural policy change might involve the prioritisation of patients by need, and thus control demand responses to some extent. Structurally, this would involve the introduction of a new link. This would represent the use of information about the levels of patients who are returning for re-intervention and who therefore might be assumed to have the more advanced disease. This information would be used to prioritise other patients.

SD practitioners evaluate both quantitative and qualitative effects of policy changes. They do not provide point predictions as in DES. Instead, they seek insight into the underlying processes which are responsible for the endogenous mode of behaviour (or dynamic pattern) of the system. The angioplasty 'fix that fails' exemplifies a 'better before worse' mode for NHS waiting times. Modes of behaviour corresponding to other policies might include periods of exponential decay or oscillation.

4.5 OFFERING COMPLEMENTARY INSIGHTS

The differences between the DES and SD approach to simulation are summarised in Table 4.1. Note that whilst this discussion follows an applied agenda, a more technical comparison is provided by Mak (1992).

Table 4.1 Two Contrasting Approaches to Policy Analysis

	Discrete Event Simulation	**System Dynamics**
Aims	Complex behaviour output resulting from exogenous factors. Point predictions (e.g. demand forecasting)	Understanding basic mechanisms of modes of endogenous behaviour. Behavioural insights including reactions to exogenous events.
Perspective	Details Emphasis on detail complexity	Holistic Emphasis on dynamic complexity
Clients	Operational level Clinical (individual patient) level	Strategic level Policy (aggregate patient) level
Resolution	Individual patients Primarily stochastic	Aggregated and systemic Primarily deterministic
Models		
Flows	Physical	Physical and information
Delays	Physical	Physical and information
Feedback Loops	Physical	Physical and information
Elements	Tangible	Tangible and intangible
Data Sources	Emphasis on numerical and written databases	Extending beyond the numerical and written databases to the mental database

(Source: Taylor and Lane 1998)

As simulation-based methods, both DES and SD address complexity but they focus on different aspects of complexity. DES concentrates on problems associated with detail complexity whilst SD concentrates on those associated with dynamic complexity. Their respective aims and models reflect these different emphases. Whilst discrete event simulators construct models to generate detailed output to produce point predictions, system dynamicists consider the underlying trends and probe beyond to identify the structure which is responsible for those trends. DES-based policy insights generally appeal to decision makers at the operational level whilst SD-based policy insights are designed for those at the strategic level. The passage of an individual patient through the physical processes of care would be represented in a DES model. In contrast, an SD model would reflect an aggregated view of patient flows. Moreover, in an SD model, the flow of patients and other physical flows would be secondary to the information network linking these different flows. Finally, whilst data about physical processes and other elements in DES models may be derived from numerical and written sources, mental data is the richest source of information about information feedback.

In §3.5, it was argued that an SD analysis could complement an economic appraisal in evaluating shifts in health services by explaining increases in demand. With SD, insight may be sought into the basic mechanisms underlying the primary and secondary feedback effects and also demonstrate how these effects may vary under different conditions. By conducting an SD-based policy analysis, an understanding may be sought into how the behaviour of the system could have been altered by changes in referral responses, waiting list management policies and funding policies.

In fact, a DES study could also be employed to complement an economic appraisal. A DES model may be used to consider how to improve the implementation of a service innovation, which is deemed cost-effective. Policy insight may be obtained into how to improve the utilisation of the available capacity by reducing potential bottlenecks in the system which may arise as a result of the shift in services. In §3.4.2, it was mentioned that capacity constraints might hinder the generalisations of a cost-effectiveness analysis to other settings. By helping to release further capacity, a DES study may enhance the ability to generalise from a cost-effectiveness analysis. Moreover, if the cost-effectiveness is evaluated on the basis of process variables, such as waiting times (as a cost-consequence analysis, which was mentioned in §3.4.1), a DES study may help to improve the cost-effectiveness of the service. However, this research does not concern these issues. Instead, the focus is on the potential secondary effects of shifts in services, which would not lie within the scope of DES modelling.

4.6 THE LOW PROFILE OF SD IN HEALTH CARE

Although DES and SD clearly have different roles in health care, and both roles are important, the profile for SD has been low. DES has dominated the agenda whilst SD has been conspicuous by its absence. The culture of the NHS traditionally leads to a preoccupation with isolated events and individual patient detail. Meanwhile, shocking headlines about individuals and isolated cases, which are perpetuated by the media, fuel the public perception of the NHS. Therefore, it is perhaps not surprising that DES is frequently advocated as the most appropriate simulation modelling approach (Davies 1985; Davies and Davies 1994). However, no single modelling approach can offer a panacea to policy problems. The ability to explore different aspects of policy problems can be greatly enhanced by an improved appreciation of different methods.

One can speculate about the reasons for the historically low status of SD in health care. The volume of DES health care studies is vastly greater than that of SD, so DES might be expected to dominate the agenda. For the same reason, the modelling and health care research communities might be expected to be unfamiliar with SD. It is also possible that the profile of SD health care case studies is too low. Efforts have been made to raise the profile of SD both within the health care and modelling communities (Taylor and Lane 1998; Dangerfield and Roberts 1999b; Coyle and Morecroft 1999).

In common with other modelling methodologies, SD is not without its critics within the modelling community. Obviously, it is important to acknowledge the limitations of a method and to understand its scope, which will develop over time as limitations are addressed. Furthermore, in SD, as with all modelling approaches, there are examples of bad modelling and these misrepresent SD.

Critiques and discussions have frequently misrepresented SD. For example, one description of SD demonstrated a lack of awareness of the dangers of carrying out a static analysis without proceeding to a dynamic analysis with a computer simulation model (Keys 1990). The dangers of static analyses have been emphasised in the SD literature (Richardson 1976, 1986; Wolstenholme 1999b, Homer and Oliva 2001). However, the publication of static SD analyses may mislead those who are unfamiliar with SD into believing that accurate policy insights may be derived without a dynamic analysis. Another example is that erroneous assertions have been made that SD is about seeking optimal behaviour and high quality predictions (Flood and Jackson 1991). Further examples are suggestions that SD modelling neglects the importance of client participation and implementation (Keys 1990; Flood and Jackson 1991).

SD has also been described as incapable of engaging in complex, pluralistic contexts (Flood and Jackson 1991). It would be incorrect to adhere to this view, as there are several cases where SD has been used to engage in complex, pluralistic contexts (see §4.3.4). There are also examples of SD practitioners connecting with other work relating to the organisational context and complexity of human decision making (e.g Morecroft 1983; Lane 1992).

Critics have failed to acknowledge the richness of the SD approach that arises from the distinction between the model and the modelling process (Forrester 1985). SD was first perceived as merely another simulation technique (Forrester 1968) and this misperception seems to have continued as comparisons with DES (e.g. Mak 1992; Pidd 1998) have only focused on technical differences. The seminal text of SD (Forrester 1961) has been described as over ambitious (Ansoff and Slevin 1968; Pidd 1998) and SD considered as merely a simplified approach to modelling feedback, following the sophisticated design and analyses of servomechanisms by engineers. A narrow view of SD is that it only addresses the stability of dynamic systems and responses to external shocks and is therefore only concerned with reducing oscillatory behaviour (e.g. Flood and Jackson 1991; Pidd 1998). However, this ignores the extensive analyses of other modes of system behaviour that are more widely employed in the field.

Undue emphasis appears to have been placed on the physical elements of systems. Furthermore, if the issue of conceptual distance is ignored, then the appreciation of information feedback loops becomes merely superficial. Whilst efforts have been successful in raising the awareness of the feedback perspective and SD in the US (Meadows 1989 1991; Sterman *et al* 1997), it would appear that the profile of SD amongst modellers in the UK is only beginning to gather momentum (Lane 1994).

A number of health care policy problems have been successfully conceptualised and explored using SD, and there exist many opportunities for further applications of this methodology. This is particularly true given the increased appreciation of the importance of system interactions in determining the consequences of policy changes and the associated need for "joined-up thinking". This has been acknowledged in the Department of Health in the NHS (Royston *et al* 1999). However, the use of SD within the health care domain is still in its infancy. Consequently, in exploring the applicability of SD in health care, many issues remain unresolved.

For example, little has been documented about the practical issues involved in conceptualising problems and working with professionals in the health service. Related work includes the guidelines by Randers (1980), Richardson and Pugh (1981), Sterman (2000) and the research of Vennix (1990, 1996) on how to elicit information from experts. Another issue concerns the identification of an effective way to accommodate the pluralist nature of the NHS and the inherent conflicts. Conflict may arise during the process of constructing a model and in evaluating policy changes as disagreements arise about what factors should be included and excluded and their relative importance. Gardiner and Ford (1980) and Reagan-Ciricione *et al* (1991) have proposed that decision analytic methods may be useful for addressing these issues. However, as SD and decision analysis emerge from different decision making schools, a number of questions arise about the appropriateness and limitations of such a merger. A further issue concerns the limitations of SD in health care, given that it tackles issues at the aggregate level, which is in contrast with the emphasis in the NHS on individual patient detail. The question arises as to how this restricts the phenomena that may be investigated and the insights that may be generated.

These are interesting issues associated with the practicality of applying SD. Some of these issues will be considered, to some extent, as part of the research.

4.7 SUMMARY

In this chapter, the SD approach to simulation modelling was described and its role in health care was clarified. In doing so, some insight was provided into how it might be used to offer policy insight into shifts in the balance of care.

Following an applied health care agenda, simulation modelling was first introduced. A 3-dimensional framework of complexity was developed - detail complexity, dynamic complexity and organisational complexity - to differentiate between the different types of complexity. The stimulation of demand was presented as an illustration of dynamic complexity. The 3-dimensional framework was used to discuss the focus of simulation and its different variants, and an overview of the processes of simulation was presented. The SD approach to simulation was compared and contrasted with the traditional approach to simulation. The latter is characterised by an emphasis on individual patient detail and has a considerably higher profile in health care. Some reasons were suggested why the traditional approach to simulation modelling has dominated the agenda of health care simulation modelling, and several criticisms and limitations of SD were addressed.

So far, the discussion of the potential usefulness of SD, in studying shifts in the balance of care, has been relatively abstract. To investigate further, it is necessary to adopt a 'hands-on' approach and conduct an SD study of a specific service shift. The next chapter will describe how this was achieved.

CHAPTER 5

EXPLORING THE CASE OF CARDIAC CATHETERISATION SERVICES

5.1 INTRODUCTION

In the previous chapter, the SD approach was described and its role in health care was clarified. In doing so, some insight was provided into how SD might be used to evaluate service shifts in the NHS. The purpose of this chapter is to clarify the research design that was applied to probe further into the ability of SD to contribute to the policy making process.

The research design (§5.2) involved a case study-based research strategy (§5.2.1). The selected case of the shift in CC services (§5.2.2) and the case study centres (§5.2.3) are introduced. The CC procedure and its use are described (§5.3). This serves to provide background and insight into the issues involved in deciding who should undergo this procedure and where it might be safely undertaken. The different types of CC procedures are summarised, from the most basic procedure to the most complex (§5.3.1). The description of the use of CC focuses on the patients who undergo this procedure (§5.3.2), and the role for CC in context with other medical procedures (§5.3.3). An outline is given of the research methods that were employed (§5.4) to collect data (§5.4.1), apply SD (§5.4.2), evaluate the model-based policy experiments (§5.4.3), and those that will be applied to draw insights from the SD study of the shift in CC services (§5.4.4). The chapter is summarised in the final section (§5.5).

5.2 RESEARCH DESIGN

5.2.1 The Basic Approach

There exists two broad philosophical approaches to research. Empiricism (or positivism) represents the first approach, and this encompasses quantitative research methods. The second approach is interpretism which supports qualitative methods of enquiry (Rein 1976; Bryman 1984; Little 1993). Although some feel that these philosophical beliefs are irreconcilable, others advocate the use of both quantitative and qualitative methods (Bryman 1984; Yin 1994a). This exploits the advantages of both, and thus implies a pragmatic approach to research. The intention for this study was to pursue such an approach in addressing the following research question:

> How useful is SD, in planning for and evaluating service shifts in the NHS, in terms of its ability to contribute to the policy making process?

The ability to contribute to the policy making process will first involve the issue of *modelling power*, more specifically, the ability to both explain the effects of service shifts and inform purchasers and providers about how they could improve the situation. The extent of modelling power will be assessed on the basis of the *quality* of the analysis, its *significance* and *completeness*. The assessment of usefulness will then probe further to address important questions about the *value* of the policy insights in terms of whether the recommended interventions are *feasible* and whether purchasers and providers are being given any *new information*. Finally, the process of applying SD will be considered by assessing issues associated with the *ease of use* of SD. This will refer to the *skill, time* and *client involvement requirements* and the *need to modify* the basic SD paradigm.

The actual use or implementation of the policy recommendations in the real world will not be considered. This is ruled out because using something does not imply that it is useful; it could in fact be useless but in use because there is a reluctance to change from what is familiar - the 'better the devil you know' attitude.

The usefulness of SD in planning for and evaluating shifts in the balance of care was explored via a case study. Yin (1994b) describes case study research as an empirical inquiry, which investigates a contemporary phenomenon within its real-life context in cases where the boundaries between the phenomenon and its context, are not clearly evident. Case study research is also characterised by the use of multiple sources of evidence. Case studies are based upon certain research questions and stated propositions (or theories) that both reflect important theoretical issues and suggest where to look for evidence to address the key questions. Generalisations are made to theory, as with experiments. This is referred to as analytical generalisation. In selecting a suitable case (or cases), the emphasis is not on finding a typical or representative case (or cases) but on having a suitable basis upon which to explore broad theoretical issues. Making generalisations from a sample to a population is referred to as statistical generalisation. This is appropriate for survey-based research but not case study research (Yin 1984).

To probe towards the potential primary and secondary effects of shifts in the balance of care the following questions were posed:

How do shifts in services help and hinder the provision of NHS services over time?
How can NHS purchasers and providers effectively intervene to alleviate pressure on the system?

These questions prescribed an explanatory case study research strategy as the appropriate research approach.

5.2.2 The Research Hypothesis

The hypothesis that drove the research was as follows:

> Health service shifts, intended to improve access to services, may actually reduce access by stimulating further demand. By improving access to services, patients become more demanding. Those who refer patients on for services, from the number of requests for assessment, may stimulate demand in response to increased patient pressure and reduced waiting times. Service shifts may also stimulate demand if they produce increases in the skill of identifying patients in need. The increased patient pressure may also lead to higher demand for assessment. The stimulation of demand will impose increasing calls for further funding. A new referral guideline may be

introduced in an attempt to suppress the inappropriate use of services. However, this may only have a limited impact in reducing pressure because the mechanisms underlying secondary effects are so complex. By applying SD, it is possible to explain the primary and secondary effects of policy changes, and provide policy makers with valuable information about how to intervene more effectively in the system. Therefore, SD can present a useful planning and evaluation tool for exploring health service shifts.

This research hypothesis encapsulated theories about the effects of the shift in health services and the value of SD. This hypothesis arose from evidence presented in the literature (see §3.3) combined with assumptions about the effectiveness of clinical guidelines and the value of SD. In order to follow good practice in case study research, rival theories were posed. Doing so provided a sound basis upon which to challenge the assumptions presented within the research hypothesis. The rival theory regarding the value of SD was that SD is useless because it cannot contribute to the policy making process. For example, this would apply if it were shown that there was no dynamic complexity involved, where increases in demand were simply explained by exogenous factors rather than endogenous, feedback mechanisms. Based upon this view, SD would be irrelevant and the costs and benefits of the shift in the balance of care could be adequately evaluated with a simple cost-effectiveness analysis. The inability to contribute to the policy making process would also apply if there were insurmountable practical problems in applying SD, if the analysis could only offer infeasible policy recommendations or if it offered nothing new to the debate about service shifts.

The assessment of the value of SD was not confined to the dichotomy SD is useful verses SD is useless as the degree of usefulness of SD was considered. However, it was not deemed appropriate to pose several theories based upon the degree of usefulness of SD, such as SD is very useful, SD is moderately useful, SD has limited use and SD is useless, as these distinctions would be arbitrary.

A rival theory about the effects of service shifts would already be represented in the rival theory about the value of SD i.e. the theory that the changes in demand were simply explained by exogenous factors. The causal theory (or dynamic hypothesis) represented in the research hypothesis was based upon the existing literature about the stimulation of latent demand for health services. The evidence from the literature was limited in that it involved anecdotal or unsubstantiated assertions that service shifts could stimulate demand. The research sought to verify and revise these assertions, thus producing some hard empirical evidence.

5.2.3 Case Study Selection and Access

The case of the shift in CC services, from the established tertiary level to the district (secondary) level for low risk patients, was selected for the study. This choice was based on pragmatic considerations. The study of a single health service was limited by the research design, which involved time-consuming activities to be undertaken by a single individual. The consideration of a shift relating to cardiac services was restricted by the conditions of the funding for the research. The study of this single service was regarded as providing a legitimate basis upon which to form theoretical generalisations.

The shift of CC services could be considered at both the national and local levels, but it is easier to discern problem 'owners' at the latter. It is very important to have a problem owner, or client, to provide a purpose for the study. The owners of health care delivery problems who hold a national perspective include those located in the Department of Health and the medical professional bodies and societies. Although the Department of Health policy makers, who are responsible for the NHS in England, are interested in the shift in the balance of care, they do not become involved with individual clinical initiatives, such as the evolution of district CC services (Phillips 1997). The Royal Colleges and the British Cardiac Society are interested in individual clinical initiatives, and frequently publish clinical practice guidelines. However, their policy recommendations need to account for variations in local access to CC services and other issues. Therefore, it was decided to study the shift in CC services at the local level.

The research used a multiple case study design in that shifts in CC services to two centres were considered. In multiple case studies, the replication logic is quite different to sampling logic, where the emphasis is on the frequency of a particular phenomenon. In case study research, each case must be selected to either predict similar results or different results for predictable reasons. The former is referred to as literal replication and the latter is called theoretical replication (Yin 1984). The case study centres were chosen for pragmatic reasons, given the convenience of their location. They were composed of two DGHs and one tertiary centre. The DGHs presented histories of two different variants of the basic district policy: a temporary district service which temporarily alleviated capacity shortages and a permanent district service which created capacity shortages. The inclusion of the tertiary centre provided an opportunity to study the evolution of district services from the tertiary perspective as well as the district perspective. Again, the number of centres was limited by the research design, which involved time-consuming activities to be undertaken by a single individual. The study of two district hospitals was considered to be a realistic number, and they were regarded as providing a legitimate basis upon which to form theoretical generalisations.

Access was granted on the condition that all parties concerned would remain anonymous. Therefore, pseudonyms are used. The tertiary centre, which is a major cardiac tertiary centre in South East England, is referred to as 'Heartwick Hospital'. The DGHs are referred to as 'Veinbridge General Hospital' and 'Ribsley General Hospital'. Heartwick Hospital is the main tertiary referral centre for both these DGHs. Figure 5.1 illustrates the relationships between these three collaborative centres.

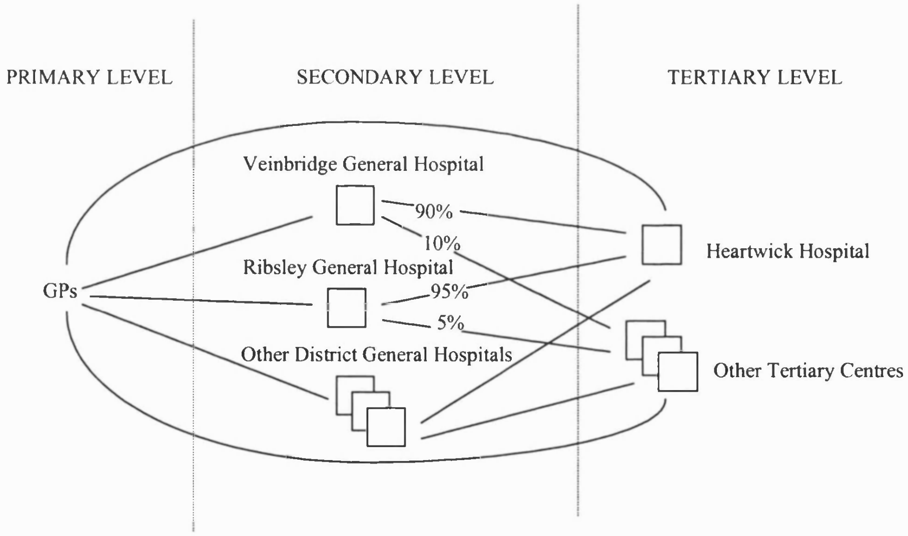


Figure 5.1 The Collaborative Centres and Referral Links
(The percentages relate to referrals which are sent from the secondary centres to the tertiary centres in the absence of a district service.)

Prior to the introduction of district CC services, cardiologists from Ribsley General and Veinbridge General carried out CC procedures at Heartwick Hospital. District services were originally introduced to compensate for the temporary closure of one of Heartwick's catheter laboratories. The laboratory was closed, for repairs, from May 1996 to March

1997. District services for CC investigations on low risk patients opened at Veinbridge General in May 1996, and one month later at Ribsley General. After Heartwick's laboratory re-opened, the service at Veinbridge General continued and was developed into a permanent service. In contrast, the CC service was withdrawn from Ribsley General. A further temporary service was offered at Ribsley General between February 1998 and May 1998. Sessions for the first two months were supported by Waiting List Initiative funding. Heartwick Hospital funded the district service for a further two months to compensate for a second period of construction work at Heartwick's laboratories.

For the case of Ribsley General, numerical data were collected for the period April 1995 to the end of May 1998 (38 months). By that time, a permanent service had not been introduced to Ribsley General, and there were no plans to do so. Mental and written data were collected until August 1999 and the analysis extended to the end of September 1999 (54 months). For the case of Veinbridge General, numerical, written and mental data were collected between April 1995 and the end of August 1999 (53 months), and the analysis considered the period April 1995 to the end of March 2001 (72 months). The certainty about the continuation of district services at Veinbridge General justified the longer time scale compared to the Ribsley General case.

By studying both Veinbridge General and Ribsley General, the usefulness of SD as both an evaluation and planning tool was considered. SD in the 'evaluation mode' was examined as both hospitals had a history of a shift in CC services. SD in the 'planning mode' was also considered to some extent by modelling the hypothetical case of a planned reintroduction of services to Ribsley General. Further consideration will be given to SD in the 'planning mode' when the results of the case studies are generalised to other DGHs and health services.

From an initial contact with a consultant cardiologist at Heartwick Hospital, a series of meetings were arranged with various health professionals. This led to the development of a collaborative network of health professionals associated with Heartwick, Veinbridge General and Ribsley General Hospitals. The health professionals comprised: consultant cardiologists; medical and nursing support staff; information technology staff; hospital managers; senior members of health authorities; and, managers of the company which supplied CC facilities and consumables to Ribsley General and Veinbridge General. This company is referred to as 'Cardiocare'. The main collaborators were: three consultant cardiologists, one from each of the three hospitals; one hospital manager from each of the three hospitals; four purchasers/commissioners, two from the host district of Ribsley General, and two from the host district of Veinbridge General; and, the business manager at Cardiocare. During the course of the research, contacts were also made with two consultant cardiologists and a hospital manager based at hospitals outside the collaborative centres.

In order to appreciate the arguments of the research, it is important that the subject of the shift in CC services is clearly understood. It is explained over two chapters. The next section describes the CC procedure and its use. The shift in CC services is addressed in Chapter 6.

5.3 CASE STUDY FOCUS

5.3.1 CC Procedures

CC is an invasive clinical procedure which uses long, narrow, flexible tubes called catheters to carry out investigations of, and treatments to, the heart. A catheter is inserted into a major artery or vein, either in the arm or groin. Under X-ray guidance, the catheter is manoeuvred along the arterial passageways until the tip reaches the heart. There are several different types of cardiac catheters as they are manufactured to different specifications for special purposes. A CC procedure may only be used for diagnostic purposes, where information is obtained about the coronary anatomy and the function of the heart's pumping chambers and valves. Measurements may be taken of the blood pressure and oxygen saturation levels inside the heart. The coronary anatomy may be studied by using contrast agents, which produce images called coronary angiograms. The distribution of the dye is followed by a series of high speed X-rays. These images can highlight sections of the coronary arteries, which supply blood to the myocardium (heart muscle), which have been narrowed, and are thus restricting the blood flow. CC is preferably undertaken under local anaesthetic for several reasons. For example, the patient may be required to assist in the procedure by coughing at certain points. Information derived from investigational CC may be used to confirm a diagnosis, stratify risk or to plan therapy (Charles and Marshall 1989; Grace *et al* 1993; Swanton 1998).

Throughout the CC procedure, the patient's blood pressure and heart rhythm are monitored. If the procedure is completed successfully, the patient will be discharged onto the ward to recuperate. However, during this procedure, there is a small risk of mortality and other complications, some of which result in the need for emergency surgery. These risks depend on various factors including the expertise of the operator, the severity of the patient's medical condition and the complexity of the procedure (Stewart *et al* 1990). A confidential multi-centre enquiry into complications for diagnostic CC procedures reported 0.8% complications overall of which 0.12% involved mortality and 0.08% emergency surgery (de Bono 1993).

The Coronary Angioplasty Procedure

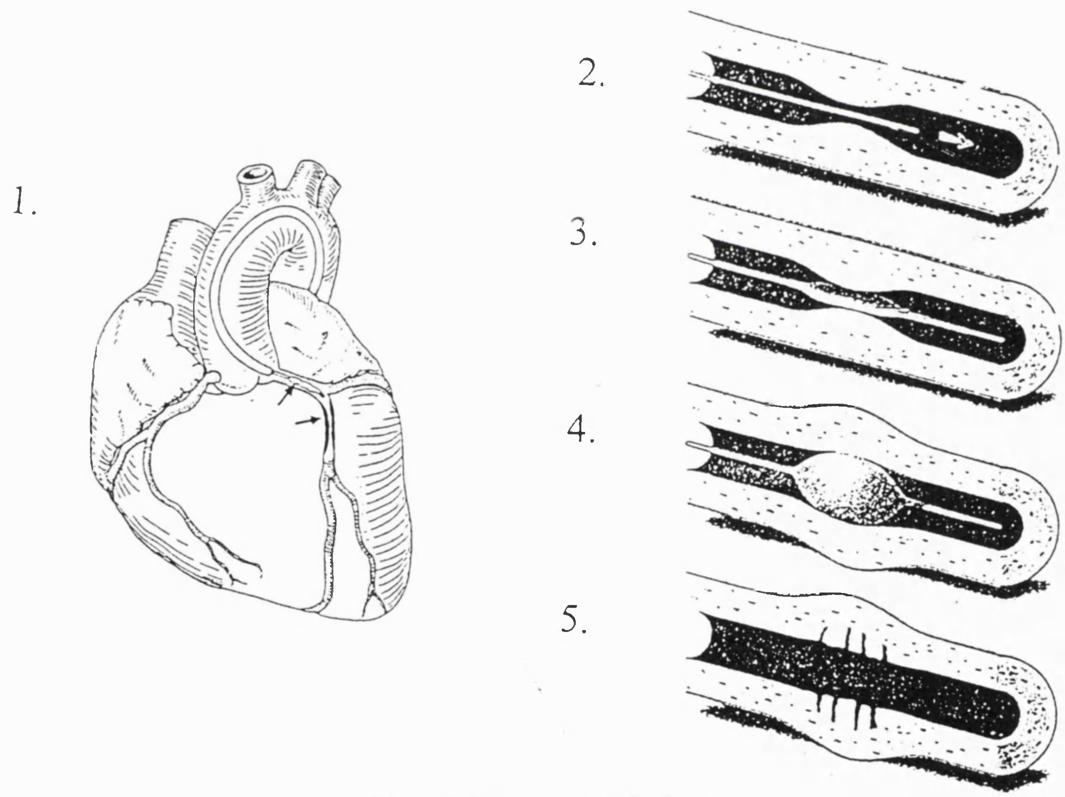


Figure 5.2 Coronary Angioplasty

(1. Insertion of balloon catheter into the heart; 2. Insertion of catheter guide wire; 3. Balloon in place; 4. Balloon expanded; 5. Balloon withdrawn and improved blood flow. Sources: BHF 1996; Bonner 1994)

More complex CC procedures involve interventions (treatments), in particular, the coronary angioplasty procedure (Grüntzig 1978, Grüntzig *et al* 1979), as shown in Figure 5.2. This is carried out by passing a fine guide wire through a catheter and down the coronary artery past an area which has been narrowed. A special catheter with a deflated balloon at its tip is passed over the guide wire. The balloon is then inflated to give a controlled stretch of the narrowed section of the artery and to split and compress the material blocking it and thus improve the flow of blood.

The coronary angioplasty procedure has associated risks and other problems. These have led to the development of more sophisticated catheter systems. A serious complication with the coronary angioplasty procedure is that the balloon inflation may cause the vessel wall to dissect. This is the most common cause of abrupt vessel closure, which in turn accounts for the majority of the serious complications of coronary angioplasty - death, myocardial infarction ('heart attack') and the need for emergency surgery. Various factors, including improvements in catheter design, have led to an increased success rate of coronary angioplasty over time. This is despite an increasing average age of patients who undergo this procedure, and the more frequent occurrence of patients with more complex disease. A multi-centre study recently reported the complication rates for death, myocardial infarction and emergency surgery at 0.9%, 5.2% and 2.7% respectively (Ellis *et al* 1995).

Another significant problem with coronary angioplasty relates to the healing process which may cause the artery to return to its narrowed state - a process known as restenosis. This process is understood to occur because the angioplasty procedure damages the inner lining of the blood vessel wall, so that splits form in its inner layer and muscle cells migrate into the centre. It can occur in 25-50% of patients (Serruys *et al* 1993) but little is known about why it occurs in some patients and not others.

Improving Coronary Angioplasty

Various attempts have been made to overcome the limitations of coronary angioplasty (Sigwart 1990; Corr 1994; Bittl 1996). These attempts have included the use of powerful drugs and various mechanical approaches. Some mechanical approaches have been to extend the duration and magnitude of the inflation of the angioplasty balloon. Other approaches have involved the development of complex catheter systems (Waller 1989). These have ingenious devices such as fluid jets, drills, shavers and lasers which remove the blockage in the artery by cutting away the obstructing material and collecting the debris or pulverising the obstruction. Devices that are widely used are mesh tubes called coronary stents which are inserted to support the vessel wall after the angioplasty balloon has been withdrawn.

Whilst stenting is still undergoing formal evaluation, it is understood to be the most successful technique currently available in overcoming the limitations of coronary angioplasty. Stents can be used to hold back and seal dissections in the artery and thus reduce the need for emergency surgery - 'bail out' stenting. They also reduce the need for reintervention by helping to keep the arteries open (Serruys 1996; Meads et al 2000). The use of stenting is escalating, and its practice is rapidly developing. Advancements include the refinement of post-stenting drug regimens to reduce complication rates (Schomig *et al* 1996), and the design of more sophisticated stents (Serruys 1996). Examples of refinements to the early stents include the use of special markers, so that the location of the stent can be monitored on a coronary angiogram, and special coatings to reduce the risk of clotting. Stents of varying sizes are becoming available so that a greater number of sections of the arteries can be targeted (Meads *et al* 2000).

5.3.2 CC Patients

Coronary heart disease (CHD), also referred to as coronary artery disease or ischaemic heart disease, accounts for the vast majority of patients who undergo CC. The second largest group of patients are those with heart valve disease, and those with congenital heart disease form the third largest group (Charles and Marshall 1989). Congenital heart disease relates to problems during fetal development and causes the malformation of the heart or major blood vessels. It affects approximately 0.8% of live births (Swanton 1998). Heart valve diseases prevent the valves of the heart from opening or closing properly. There are a number of underlying causes of valve defects including congenital abnormalities and scarring from rheumatic fever.

CHD refers to the presence of degenerative changes in the walls of the coronary arteries with deposits of hard, fatty substances called atherosclerotic plaques. These deposits lead to narrowings in the coronary arteries, and thus lead to an inadequate blood supply (ischaemia) to the myocardium. Further complications arise as the arterial wall may crack, causing clotting, or it may weaken, which will eventually lead to haemorrhaging. The process of CHD has yet to be completely understood but this slow, progressive disease is recognised to begin in childhood. Research has also identified certain risk factors which might predict its development including smoking, family history of heart disease, hypertension (high blood pressure) and elevated levels of blood cholesterol (Mann 1993; Patterson and Treasure 1993).

Clinical Manifestations of CHD

Some people with significant CHD experience no symptoms. Others may experience angina, a myocardial infarction or sudden cardiac death. Angina is a choking sensation in the chest, which results from insufficient blood reaching the myocardium. It typically occurs during exercise or excitement, when the myocardial demand for oxygen increases. Normally, the blood flow in the coronary arteries will increase to meet this demand. However, the potential to increase demand is limited by a coronary artery which is narrowed by the presence of CHD. Myocardial infarction is caused by the complete blockage of a coronary artery. This leads to the death of the surrounding cells in the myocardium and the formation of an area known as an infarct. Sudden cardiac death is believed to be associated with a fatal disorder of the heart rhythm. CHD may also eventually lead to heart failure where the pumping ability of the heart muscle is diminished. CHD is chronic and unpredictable. Its complexity is such that over a patient's lifetime, their symptoms may vary, various clinical events may occur and their course of treatment may alter several times (Patterson and Treasure 1993; Jackson 1993).

Morbidity and Mortality of CHD

CHD is often misperceived as simply an inevitable consequence of old age, but in fact, it claims the lives of a considerable number of people in their prime, especially from certain ethnic groups which have a predisposition to CHD (McKeigue 1992). This disease is a major cause of mortality and morbidity in the UK, and its management is expensive. Although since the early 1970's the death rate from CHD has slowly declined, it remains one of the highest death rates in the world (Beaglehole 1990; Sans *et al* 1997). In 1997, CHD accounted for about 123,000 deaths in the UK, representing 22% of the annual mortality from all causes (NHS 1997c).

The Health Survey for England reported a prevalence of CHD of 7.1% for men and 4.6% for women overall which increased with age to 23.4% in men and 18.4% in women over 75 years. These figures referred to those who had confirmed diagnoses of angina or a heart attack (Erens and Primatesta 1999). However, there is a substantial reservoir of undiagnosed heart disease, including an estimated 75% of people with mild angina who fail to seek medical advice. Although they incur no immediate medical costs, the risk of a future myocardial infarction is increased to 3-4 times the average. There is no national data on the incidence of CHD. General practice statistics provide estimates, but they underestimate the true extent, as they do not account for sudden deaths, deaths before discharge of patients admitted directly to hospital and cases, which are unrecognised (Langham *et al* 1993).

Although there has been a decline in the prevalence of CHD, demand for invasive treatment continues to rise (Weintraub *et al* 1990; Hubner *et al* 1990). Furthermore, the incidence of myocardial infarction has dropped but demand for prescriptions for CHD has increased (NHS 1994a). If these trends persist, calls for treatment for CHD will impose an ever increasing demand on purchasing budgets. Gunnel and Smith (1994) estimate that, in a typical district of about 500,000 people, there will be at least 1,275 acute myocardial infarctions and 5,700 patients clinically presenting with angina per annum. Of these, 8-13% will be referred to a cardiologist by their GP, and between 600-900 will be considered as potentially suitable for invasive treatment.

It has been estimated that in 1991 at least £917 million was attributable to the costs of NHS treatment for CHD. This consisted of costs for inpatient activity, GP consultations, drugs and dispensing (OHE 1992). CHD also impinges on purchasing budgets for prevention, and it is estimated that £10 million per annum has been attributed to this aspect of health care (Langham *et al* 1993). CHD accounts for high social costs, which are difficult to quantify. These relate to quality of life impairment, unemployment, premature retirement, the costs associated with absence from work due to sickness. In 1990/1991, 53 million working days were lost in Britain due to CHD amounting to 10.5% of all the days lost to sickness. The government provided £463 million in invalidity benefit for 47.3 million of these lost working days. Furthermore, it was estimated that the working days lost to CHD cost over £3 billion in lost production (Rayner 1993; HEA 1993).

Given the scale of CHD, it has consistently formed one of the key priority areas targeted by the Government's long term strategy to improve the nation's health (NHS 1991b, 1994a, 1999).

5.3.3 Role of CC

CC plays a vital role in the management of heart disease but, in a broader context, it is only one of a number of diagnostic tests, investigations and treatments used in mainstream clinical practice.

As a Diagnostic Tool

Patients may present clinically complaining about chest pain which may or may not be angina. Furthermore, if angina is confirmed, CHD may not necessarily be the underlying cause. In forming a diagnosis, it is important to consider other causes of chest pain which resemble angina. Differential diagnoses include heart-burn or hyperventilation. A clinician seeks to define anginal pain by enquiring about its location, duration, intensity and the factors which precipitate and relieve it. There are different types of angina, and the most characteristic symptom of stable angina is retrosternal chest pain, which is precipitated by exertion and relieved by rest (de Bono and Hopkins 1993). However, pain may instead be experienced in other parts of the body such as the face (Swanton 1998).

Preliminary tests for patients with suspected angina include checks of their blood pressure, blood cholesterol levels and medical history (Jackson 1991). Clinical investigations are more specialised. They have two primary roles: to confirm a diagnosis and to stratify risk. Various techniques can be used to examine the structure and performance of a living heart, but no single diagnostic method can produce a complete picture. The standard chest X-ray only shows the basic size, shape and orientation of the heart. For further detail, more sophisticated methods are required to enhance the clarity of the images and obtain detailed information about the function of the heart. In addition to the CC procedure, the methods used in mainstream clinical practice comprise electrocardiogram (ECG) recordings, echocardiograms and radionuclide tests.

An ECG is a recording of the voltage changes produced by the action of the heart muscle. It may show evidence of previous myocardial infarctions. The ECG is an important and widely used diagnostic tool, with the advantage of being non-invasive. However, it can give false positive results, especially in women (de Bono and Hopkins 1993), so further tests may be necessary.

The echocardiogram scan uses sound wave echoes reflected from different parts of the heart, to provide images of the heart structure and its movement. It has the advantages of being non-invasive and the equipment is relatively inexpensive. Although the image quality is relatively poor, with technological developments, it is improving. Its principal use is for assessment of the performance of the heart valves and the function of the left ventricle, the main pumping chamber of the heart. Left ventricular function is an important risk stratification variable when invasive treatment is being considered.

Radionuclide tests involve the injection of a small, harmless quantity of radioactive substance into the blood. A gamma camera is used to view the size and pumping function of the heart, and to identify areas of the myocardium which are short of blood. Radionuclide scans have the benefits of being non-invasive and are more reliable than ECG monitoring (de Bono 1999).

As a Treatment Procedure

CC also has a role in the treatment of heart disease. Heart disease is currently incurable, but there are various strategies for its clinical management and the prevention of further cardiac events. These include changes in lifestyle to control risk factors, and various drugs which may increase the blood supply to the heart, reduce the amount of work the heart has to do or unblock an occluded coronary artery. §5.3.1 described how CC is used to carry out angioplasty procedures. In addition to coronary angioplasty procedures, clinically invasive strategies for heart disease include catheter procedures for congenital heart disease and valve disease, surgical replacement of defective valves, surgical correction of congenital defects and coronary bypass surgery. Coronary bypass surgery involves the construction of a bypass channel around a narrowing in a coronary artery, using a section of a vein or artery.

Its Future Role in the Management of Heart Disease

CC has played and continues to play an essential role in both the investigation and treatment of heart disease. Although its use is primarily for patients with suspected heart disease, some normal results will be expected, as some CC investigations are only intended to resolve diagnostic uncertainty (King and Talley 1989). Coronary angiography remains the 'gold standard' for cardiac investigation and has thus assisted in the development of non-invasive methods such as echocardiography and radionuclide tests. As a consequence, many patients can be successfully diagnosed and treated without invasive investigation, which is both risky and expensive.

For some conditions, the advent of new and refined technologies, such as more sophisticated echocardiograms or magnetic resonance imaging may reduce the need for coronary angiography in the future (Manning *et al* 1993). Currently, in the treatment of CHD, diagnostic CC is essential when planning invasive treatment, that is, coronary angioplasty or coronary bypass surgery (de Bono and Hopkins 1993; Swanton 1998; Patterson and Treasure 1993). The image of the coronary anatomy, given by the coronary angiogram, indicates which section of the artery should be targeted. It is also used to evaluate the success of the intervention in restoring the blood flow. In the future, it is expected that the development of interventional CC will impact upon the use of cardiac surgery, as the design of sophisticated catheter-based treatments will enable some patient groups to avoid the need for surgery.

5.4 RESEARCH METHODS

5.4.1 Data Collection

Collaborative work was conducted between late June 1997 and August 1999. See Appendix C for details about site visits, meetings and data acquired from the collaborative centres.

Observation work was conducted at the catheter laboratories at the three hospitals. This occurred in June and August 1997 at Heartwick and Veinbridge Hospitals, after Heartwick's laboratory had reopened after closing for repairs. Observation work was carried out at Ribsley General, during the second period that district services were in place, in March 1998. These site visits provided an insight into the complexities associated with the delivery of CC services and opportunities to elicit data during informal discussions with both the medical and support staff. Observation work also took place at another hospital.

Interviews provided opportunities to build a rapport with the collaborators, collect data, obtain further insight into the problem and obtain feedback on analysis. Guidance was also given on background reading for the research. The form of the interviews varied. Patton (1980) differentiates between four types of interview, based upon the degree of structure, as determined by the interviewer. The interviews for this project were a combination of two of these types: the interview guide approach and the more structured, standardised, open-ended interview. In the former, the topics are determined in advance, but flexibility is given to the interviewer to decide upon the sequence of the topics and wording of the questions. In the latter, both the sequence and wording of the questions are fixed, but the questions are phrased in an open-ended format. To facilitate the process of recording these meetings, some of the interviews were tape-recorded with the permission of the interviewees. These interviews were transcribed within 24 hours of the interview. A considerable amount of informal communication also took place via the telephone.

Although replies were sought to a series of predetermined questions, the discussion was not constrained by these questions. A question would often lead to a useful new line of enquiry, and further questions would emerge. Sometimes, especially in the early stages, feedback was also sought on a preliminary hypothesis about the causal mechanisms underlying the effects of the service shift. This hypothesis, which was based upon insights from the literature, was presented as text to the interviewee to read. At a later stage, questions were based upon graphs of data supplied by the collaborative centres and an informal conceptual model. These were also presented on paper. Presenting the graphs proved very fruitful, as this enabled the collaborators to reflect upon, and sometimes revise, their assumptions about the trends represented in the graphs. A learning process thus emerged. A conceptual model was presented as a summary of the insights obtained from the literature, the various interviews, data analysis and observational work. The conceptual model was presented to the consultant cardiologists at the three collaborative centres and the behavioural implications of the structure were described. Their views on this model were sought. All three found the model acceptable subject to certain amendments, which were incorporated into the model.

In seeking the cardiologists' views of the conceptual model, the aim was to form a consensus about the general mechanisms underlying the effects of the shift in the balance of care, using a Delphi-like process (Linstone and Turoff 1975). Whilst the effects at Ribsley General and Veinbridge General differed, the underlying mechanisms should be the same (the different effects would arise from the different relative strengths of these mechanisms). It was not considered necessary to check the conceptual model with the other collaborators because the associated sections of model structure, such as cost constraints, were relatively easy to represent. Although GP referral behaviour is represented in the conceptual model, due to time constraints, the research design could not extend to include interviews with GPs. Insights about how to represent GP referral behaviour, in the structure of the model, were thus derived from the literature and the experiences of the collaborators.

Numerical data was derived from various databases. Written sources of data comprised hospital reports, annual reports of purchasing authorities, and brochures and other documentation of suppliers of CC services, in addition to the literature.

The use of several data sources follows classic research design and is known as triangulation. Triangulation is based on the assumption that a single source alone may produce undetected errors, which may lead to erroneous conclusions. The background to the shift in CC services is first presented in Chapter 6. The case studies findings are then reported, with the triangulation of evidence in Chapter 7. The case study evidence demonstrates a potential role for SD to investigate further.

5.4.2 Use of SD

A retrospective analysis of the shift in CC services was carried out by considering how improvements could have been made. The two policy questions that were stated in §5.2 were thus recast as follows:

How did shifts in CC services help and hinder the provision of NHS cardiac services over time?

How could NHS purchasers and providers have effectively intervened to alleviate pressure on the system?

In investigating the primary and secondary effects of the shift in CC services, we can speculate about the dynamic implications of the underlying mechanisms. However, our cognitive limitations prevent us from fully understanding the inherent complexity involved. These limitations may be overcome with the aid of an SD simulation model.

The Modelling Processes

In §4.2.2, the basic processes of simulation modelling were described in general terms. More specifically, the first phase of an SD simulation study is referred to as the process of conceptualisation. The problem or issue of interest is defined. Its context and characteristics are described, and the central questions to be addressed are clarified. For problems and issues that have a history, historical reference modes are constructed to produce an unambiguous descriptions of the problematic behaviour in graphical terms. Further reference modes may reflect more desirable behaviour and observed policy behaviour if different policies have been tried in the past. Ideally, these graphs are produced from numerical data, and hypothetical graphs, based upon verbal descriptions of the system, may be used when numerical data is unavailable. Both real and hypothetical reference modes were employed in this study with the emphasis on the latter for the Veinbridge General case.

SD can also be applied to problems and issues that do not have a historical precedent. For example, in planning for a particular service shift for which there is no previous history, SD can provide a useful planning tool in helping to anticipate the effect of this policy change. However, in the absence of historical reference modes, it is essential to have clear *a priori* expectations about the possible dynamic effects of interventions (Mass, 1991). Based upon these expectations, reference modes may be derived.

Also as part of the conceptualisation process, an informal conceptual model is constructed to present the basic mechanisms that are understood to generate the system behaviour. A causal hypothesis is presented and the purpose of the model is stated. The former is a verbal statement describing the relationship between the behaviour and feedback structure. The latter concerns: the intended audience for this study; the policy levers of interest that need to be represented in the model; and, the desired level of implementation or use of the model. The level of implementation of the model could range from raising awareness to a one-time adoption of a set of policy recommendations, and to the adoption of the model as an ongoing policy analysis tool.

The second phase of an SD simulation study involves the conversion of the informal conceptual model into a formal simulation model. This is referred to as the formulation phase. It is followed by an experimental phase, which aims to provide insight into the base case behaviour and, by conducting policy analyses, obtain insight into how more desirable behaviour may be achieved. In practice, the different modelling phases are iterative. As stated in Chapter 4 and illustrated in Figure 4.1, a process of model testing and refinement is embedded within the SD approach. This produces iterations as models are constructed gradually and undergo a series of revisions. The model output is analysed for sources of insight into the relationship between behaviour and structure and the existence of model errors. The model structure is refined and analyses are rerun on the revised model.

In describing the model of the shift in CC services and its use, it is necessary to organise the chapters sequentially. Unfortunately, this will inevitably obscure the underlying iterative nature of the SD approach. The simulation model and its use is presented over three chapters (Chapters 9, 10 and 11). In the first of these chapters, the final version of the simulation model is described and the procedures that were applied to validate/gain confidence in this model are described. This was based on a series of established tests. The second chapter presents the simulations which were carried out on the model in order to understand the existing use of district services at the case study centres - the base case analyses. The third chapter describes the simulations that provided insight into the effects of alternative policies - the policy analyses.

Use of Data

To calibrate the simulation model, parameters were derived from both numerical data, provided by the collaborative centres, and expert estimates in cases where numerical data was unavailable. For Veinbridge General, the little numerical data that was available had a number of omissions and inconsistencies and some of the expert estimates proved to be unreliable as they led to further inconsistencies. However, most of the descriptions of the system seemed reliable. There was no reason to believe that Veinbridge General was atypical and these descriptions were consistent with those found elsewhere.

In spite of the data problems, for several reasons, it was important to consider Veinbridge General in addition to Ribsley General. Studying Veinbridge General provided an opportunity to develop a model that accommodated uses and experiences of district services beyond those that applied to Ribsley General e.g. involving phase 2 development and a permanent rather than temporary service. It also enabled an examination of the effects of more 'aggressive' referral behaviour; considering more aggressive referral behaviour at Ribsley General would not have constituted a plausible departure from the base case assumptions. Finally, Veinbridge General would be the more interesting case to system dynamicists as the mechanisms underlying the system behaviour had a greater emphasis on endogenous factors.

It would have been infeasible to overcome the data problems with the Veinbridge General case study by collecting more reliable data directly from the patient records, even if patient confidentiality problems could have been overcome, due to the time constraints. Instead, by making some reasonable assumptions, the useful data was employed as an aid to the estimation of other parameters that produced behaviour that was consistent with the descriptions of the Veinbridge General experience. This approach was also successfully adopted with the Ribsley General case to estimate several OP parameters.

Use of the Simulation Model

Sensitivity analysis was applied to test the effects of uncertainties in parameter values, such as GP referral parameters. Sensitivity analysis was also used to generate insight into the structure-behaviour linkages in both the base case and policy analyses (Tank-Nielsen

1980). There are three different types of model sensitivity: numerical, behavioural and policy sensitivity (Richardson and Pugh 1980). All quantitative models will exhibit *numerical sensitivity* by their very nature so this is not a source of concern. This is in contrast to cases of *behavioural sensitivity*. It occurs when the basic pattern or trend of the model output changes in response to a model parameter or structural change.

The behaviour of SD models tends to be insensitive to parameter changes due to the effects of: loop dominance (the parameter change may not apply to the dominant loop); shifts in loop dominance (it may only apply to the dominant loop for a short period); and, system compensation (other loops may intensify or weaken to compensate). If the model behaviour is sensitive to a structural change, then the appropriate structure for the base case analysis is that which produces the behaviour exhibited by the real system. *Policy sensitivity* is the greatest potential concern as policy conclusions should be robust to reasonable changes in the model. If policy sensitivity is found to be due to a model artefact, the model must be reformulated. If policy sensitivity exists and the model structure is considered to be appropriate and consistent with the real system, efforts should be directed at improving the accuracy of the model's parameters. Given that the real system could exhibit the same sensitivity, it is also advisable to develop policy recommendations that rely on different parameters.

In addition to sensitivity analysis, partial-model testing was employed in the use of the simulation model. Partial-model testing is a SD technique that can be used for several purposes: to provide insight into how the model operates; improve the model structure; and, improve the parameter estimation (Homer 1983; Morecroft 1983, 1985). It involves disabling, or switching off, parts of the model so that the analysis can focus on an isolated sub-model.

The policy experiments reflected changes to the forces that drive activity, changes to demand patterns and capacity constraints, and the assumed effects of the use of new clinical guidelines to prioritise demand. In considering the issue of the appropriateness of demand, the possible impact of a clinical guideline was represented in the simulation model by considering a reduction in the assumed response to the increased access. For example, rather than assuming that demand could increase by as much as x% in response to a reduction in waiting times, it was assumed that the increase would be constrained to (x-y)%. Expert estimates were obtained for 'x' and 'y' from the consultant cardiologists and made various assumptions about the potential effects of the use of clinical guidelines by GPs. An audit was not carried out on the individual patient data in order to establish the appropriateness of decisions about individual patients. Such an analysis would have been extremely time consuming and would have required specialised skills. For the purposes of this study, the use of expert estimates and sensitivity analysis sufficed.

5.4.3 Evaluating the Model-Based Experiments

Chapter 2 described how there have been increasing calls made for greater evaluation within health care. In Chapter 3, this health care trend was discussed with specific reference to shifts in the balance of care. Several different aspects of service quality were introduced in §2.4. This section identifies the aspects that were considered and the key performance measures that were used in evaluating the results of the model-based experiments. It also describes how these measures were evaluated. In carrying out the experiments, an attempt was made to provide a balanced evaluation of the system. The aspects of service quality that were relevant were considered to varying degrees.

Selecting Appropriate Performance Measures

Equity was not evaluated, as this aspect of service quality was not relevant to this research. Only a single patient population was considered for each case study i.e. those referred for an elective CC investigation from a given DGH. Equity would have been relevant if the availability of district CC services for different patient populations had been considered.

Several service quality variables were considered implicitly but they were not measured. It was assumed that the local purchasers regarded a district CC service as *relevant* to the local population's needs, otherwise they would not have supported its introduction. Providing a local CC service obviously improved the *geographical accessibility* of CC services to the local population. Geographical accessibility could be measured by the average journey time spent by patients and/or district-based CC operators. Such a measure did not feature in the model as it was irrelevant to its purpose. However, considered in calculating the relative cost of a district-based CC investigation and tertiary-based CC investigation, was the need for a certain proportion of patients to require an inpatient stay at the tertiary centre which could be avoided if they underwent a district-based CC investigation. This proportion thus reflected the degree of geographical inaccessibility. It was assumed that the shift in CC services only occurred on the basis that it did not compromise clinical *effectiveness* and that it had proven to be *cost-effective*. This was confirmed by the interviews. The responses to patient questionnaires at the collaborative centres provided evidence of high *patient satisfaction* with the district service. It was assumed that this implied that the new service was *responsive* to patient needs. These questionnaires and their replies were not studied as part of the research. Instead, the model implicitly assumed that high patient satisfaction and patient responsiveness formed factors in the support for the shift in CC services. Introducing district CC services obviously increased the *scope of facilities* for clinical investigation at the district hospital. In the model, this was indicated by the number of patients undergoing district CC investigation.

Financial accessibility was represented in the model but did not form a key evaluation variable. The same applied to the *skill base*. It was assumed that the quality of the skill base was not compromised by the shift in CC services, otherwise the service shift would not have been permitted to take place. Instead, it was reported that improvements were made to the quality of the skill base; the rate at which junior CC operators gained skills during the presence of district CC services was increased as more patients were investigated (with the increased capacity). The model reflected the underlying mechanisms involved in the gain of CC skills.

One key evaluation variable for the experiments comprised the resource usage which connects with *efficiency*. Two further key variables were the *average waiting time* and the *waiting list length*. Each represents different aspects of pressure on the system associated with *access times*. The former represents the delay to undergo investigation (or treatment) and as stated in §2.5.2, this is a key performance indicator from the perspective of the patient. The latter represents the need for investigation (or treatment) and represents a further important performance indicator from the perspective of those responsible for funding and delivering services. A fourth key evaluation variable, the *referral rate,* was considered for two reasons. Firstly, because this variable represented a key determinant of the other three. Secondly, because it was the stimulation of referrals that provided the motivation for the investigation of the use of the SD method.

By concentrating on resource usage, waiting times, waiting lists and referral rates, both the supply and demand for CC investigations were addressed, in addition to the interplay between supply and demand variables. These four evaluation variables were considered across the cardiac referral chain with respect to both the cardiology OP services at the district hospital and delivery of elective CC investigations. By considering both OP and elective CC services, both the localised and broader consequences of the shift in CC services were addressed.

Introducing a Pressure Summary Index

SD models can generate both tabulated and graphical output for each evaluation variable. In SD modelling, to facilitate comparisons with the base case, base case graphs are often superimposed on the test (experiment) graphs so that changes in behaviour modes, amplitudes, phase changes and so on, can be viewed. In considering a single evaluation variable, sometimes it is clear whether or not the test conditions have produced an improvement to the system behaviour (see Figure 5.3(a) and (b)). However, on other occasions, it is not clearly apparent overall as there may be trade-offs involved between short-term and longer-term effects (see Figure 5.3(c)).

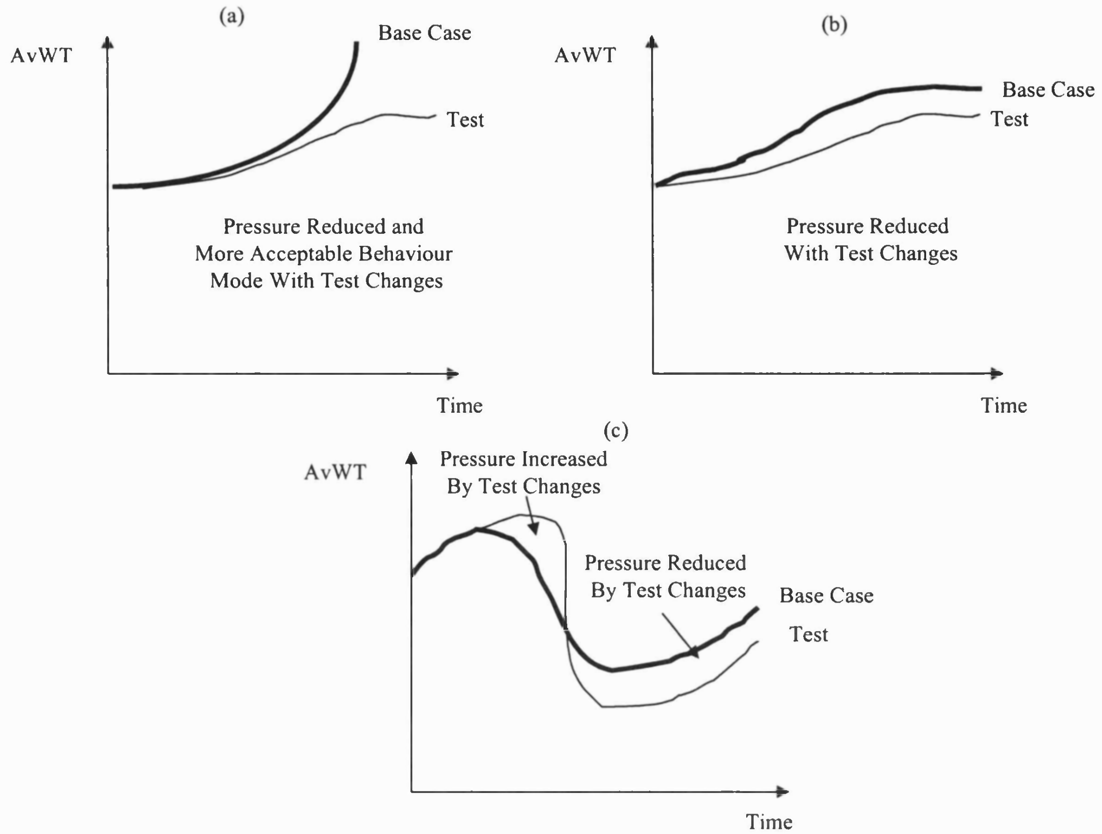
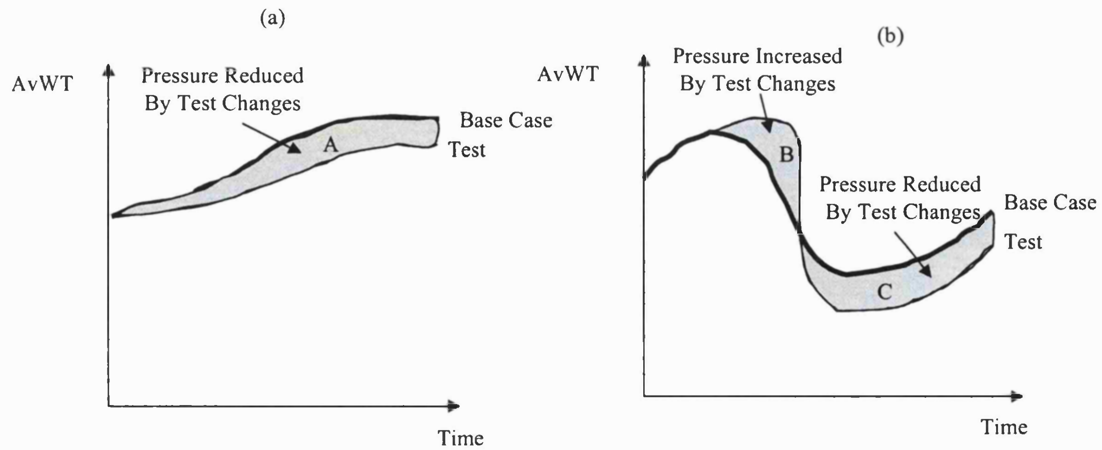


Figure 5.3. Comparing Base Case Graphs with Test Graphs
(AvWT is a generic pressure variable)

I propose that measuring the area between the two graphs could help to summarise the differences in graphical output. The area quantifies the degree to which improvements have been made and can help to summarise the overall impact of short-term and longer-term effects (Figure 5.4).



Improvement With Test Conditions = Area Under Base Case Graph - Area Under Test Graph = { Area A For (a); Area C - Area B For (b) }

Figure 5.4 Quantifying Differences Between the Base Case Graphs and Test Graphs

The areas under the graphs of the referral rate and activity rate represent the cumulative referrals and activity respectively. The areas under the waiting list and average waiting time graphs could be interpreted as proxy measures for the pressure imposed on the system over time. Note that this represents a summary of, over a given time period, the instances when pressure affected behaviour. It does not represent the effect of pressure on behaviour. The latter is represented in the model by various factors including the waiting time effect.

In this study, areas for the graphs of activity rates, average time spent on the waiting list, the waiting list length, and referral rate for both elective CC investigations and OP appointments were measured. For the waiting times and waiting lists, the measure was modified (Figure 5.5).

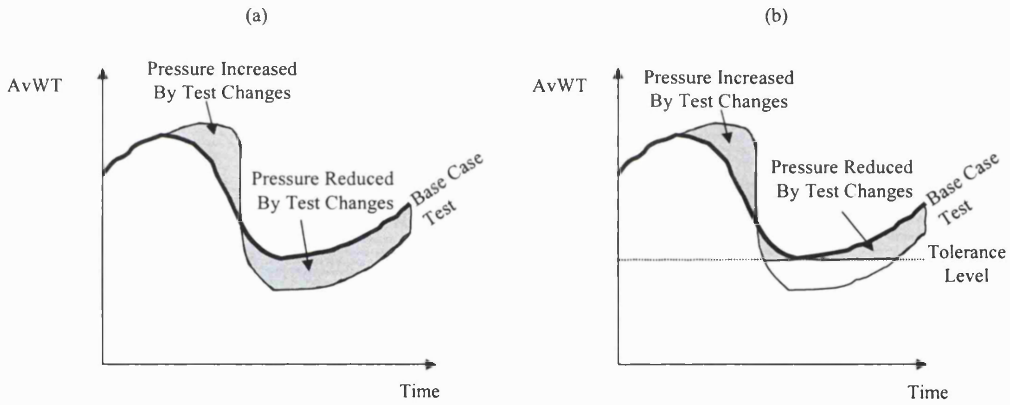
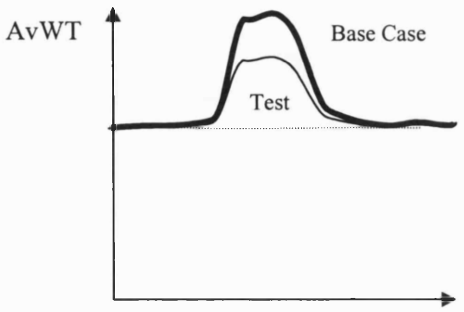
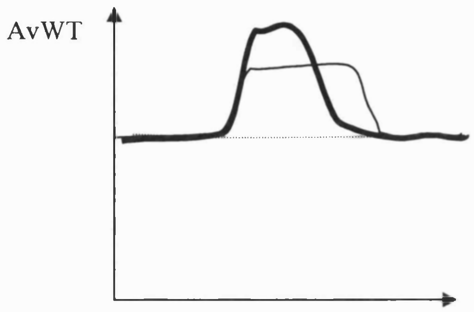


Figure 5.5 Adding a Tolerance Level

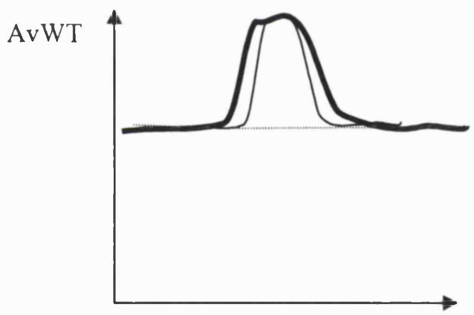
Measuring the area between the two graphs illustrated in Figure 5.5(a) reflects the implicit assumption that all levels of the waiting time (or waiting list) would be unacceptable. However, this is not necessarily true, as a certain level would be tolerated. Subsequently, a more refined measure would be based on areas under the graph and above a tolerance level, as illustrated in Figure 5.5(b). The tolerance levels were specified by the waiting time and waiting list goals.



Smaller area, same duration of excess and lower maximum value. Therefore, area is a good summary measure of the pressure imposed (pressure imposed is reduced)



Same area, longer duration of excess and lower maximum value. Therefore, area alone is misleading (pressure is reduced in one respect and increased in another)



Smaller area, shorter duration of excess and same maximum value. Therefore, area is a good summary measure of the pressure imposed (pressure imposed is reduced)

Figure 5.6 Pitfalls of Focusing on a Single Measure

I propose that this area-related measure can provide a good summary index to evaluate changes in pressure on a system. However, in some cases (see Figure 5.6), it can be misleading if used alone. Therefore, in this study, several measures were employed.

5.4.4 Drawing Insights from the SD Study

Insights will be drawn from the SD study by deriving policy implications from the results of the model-based experiments and assessing the usefulness of SD with reference to the CC study. The case study findings will then be used to challenge the research hypothesis. This will produce a revised statement about the causal mechanisms of the effects of the service shift and the usefulness of SD. Generalisations will then be drawn from the findings of the research. This will consider both the dynamics of service shifts and the conclusions regarding the usefulness of SD as a planning and evaluation tool for studying the dynamics of service shifts. Finally, reflecting upon the study, some recommendations for future research directions will be specified.

5.5 SUMMARY

The purpose of this chapter was to clarify the research design to probe further into the usefulness of the SD method.

A case study research strategy was presented, based upon the shift in CC services from the established tertiary level to the secondary (or district) level for investigations on low risk patients. Three case study centres were introduced. It was stated that access to data was provided on condition that all parties involved would not be publicly identified. For this reason, pseudonyms were assigned. The case study centres were composed of two DGHs ('Ribsley General' and 'Veinbridge General'), which offered contrasting histories of the shift in CC services, in addition to their main tertiary referral centre ('Heartwick Hospital'). An outline of the health professionals who acted as collaborators for this study was provided. The main collaborators were: consultant cardiologists; hospital managers; purchasers (commissioners) of health services; and, a manager from the company ('Cardiocare') that supplied CC facilities and consumables to the two DGHs.

The CC procedure was described and it was explained how it is used to diagnose and treat heart disease. This provided background and insight into the issues involved in deciding who should undergo this procedure and where it might be safely undertaken.

The research methods were outlined by describing how data was acquired and analysed, and how insights will be drawn from the SD study. Regarding the analysis of data, following on from the general description of simulation modelling in Chapter 4, the phases of SD simulation modelling were described in further detail. Four key performance measures which were used to evaluate the model-based experiments were identified: resource usage; average waiting times; length of the waiting lists; and, referral rates. A new index was proposed to summarise the pressure over time associated with an excessive waiting list and average waiting time.

The literature on the shift in CC services is reviewed in Chapter 6.

CHAPTER 6

THE SHIFT IN CARDIAC CATHETERISATION SERVICES

6.1 INTRODUCTION

In the previous chapter, the case of the shift in CC services in the NHS was introduced as a focus for further study. The purpose of this chapter is to present the review of the literature on the shift in CC services. This provided some background and motivation for the case studies. It included the evidence that was expected to arise from the case studies in support of the research hypothesis. This information also placed the shift in CC services to the case study centres in context with the general evolution of district CC services. The case study experiences of CC services will form the focus of the next chapter.

In this chapter, the traditional cardiac referral chain is introduced (§6.2). Following on from the general discussion about the motivation underlying the shift in the balance of care in the NHS in §2.5.3, four main factors motivating the development of district CC services are considered (§6.3). The provision of district services is then discussed (§6.4) in terms of the practicalities involved (§6.4.1) and the future prospects for this trend (§6.4.1). Again, following on from the general discussion, two key concerns about the possible consequences of the shift in CC services are highlighted. The first concern is that improving access will stimulate further demand (§6.5). Evidence of demand being stimulated is provided (§6.5.1), and the mechanisms by which this may occur are examined (§6.5.2). The second concern is that increasing access will lead to an increase in the rate of inappropriate use of CC (§6.6). The factors involved in defining the appropriateness of CC are considered (§6.6.1), before presenting the review of the available literature on appropriateness of CC (§6.6.2). The use of clinical guidelines to promote the appropriate use of CC is also discussed (§6.6.3). The final section provides a summary of the chapter (§6.7).

6.2 THE TRADITIONAL REFERRAL CHAIN

The referral chain was introduced in general terms in §2.3.2. Cardiac services are provided within both the community (primary level) and hospital sectors (secondary and tertiary levels). The health professionals located within the community include ambulance and first aid workers, but those who primarily deal with patients with heart disease are the GPs. They have important roles in disease prevention, diagnosis, treatment and rehabilitation. However, for some patients, their expertise and the facilities available to them are inadequate. These patients are subsequently referred to a hospital for an OP appointment so that they may be investigated further by a specialist, either a general physician or cardiologist. If surgery is necessary, the patient will be subsequently referred to a cardiac surgeon. Therefore, the GP acts both as a gatekeeper to elective hospital services and as an agent to patients. Patients may also enter the hospital sector via the A&E department as an emergency arrival. This arrival may have been arranged by their GP or the patient may be a self-referral.

Regarding hospital services for heart disease, the traditional role of the DGH is in the diagnosis and management of heart disease using non-invasive methods. Tertiary centres offer more specialised investigations and treatments such as coronary angioplasty and coronary bypass surgery. As CC is invasive, the established place for this service has been the tertiary level. Depending on their geographical location and other factors, patients may be referred directly to a tertiary centre or via a secondary centre. For example, in the Thames Regions, the majority of referrals to tertiary centres are by secondary centre cardiologists (LIG 1993).

6.3 MOTIVATION FOR DISTRICT SERVICES

In recent years, facilities have been developed to conduct low risk procedures outside the established tertiary level, at some DGHs. The complexity of different types of CC procedures were described in §5.3.1. The cases which have been shifted to the district level are CC investigations on low risk patients. Low risk patients comprise primarily uncomplicated elective referrals from outpatients and also inpatients whose condition has stabilised (BCS 1997). The latter group are derived from those who enter the system as emergency admissions. In practice, patients are only catheterised on an inpatient basis in DGHs with established CC facilities.

Although district services confer a range of benefits, the change in policy has been driven by four main factors (Stewart *et al* 1990; BCS 1994a 1994b 1997; Foale 1998). Firstly, the desire to address shortfalls in tertiary facilities. Secondly, the increased availability of district-based cardiologists who are trained CC operators. Thirdly, the increasing pressure to improve local services. Finally, the demonstrated cost-effectiveness and safety of conducting routine diagnostic CC without on-site surgical backup.

6.3.1 Addressing Shortfalls in Tertiary Facilities

There is a widespread concern about the inadequate provision of cardiac services and long waiting lists for both routine and urgent elective cases (Black *et al* 1996; BCS 1997). The limiting factor for elective CC activity is often an insufficient provision of beds for the post-procedural recovery period as beds are being 'blocked' by emergency admissions. Therefore, tertiary centres are under pressure to meet emergency and urgent needs without compromising routine elective care.

Tertiary centres are also called upon to carry out more interventional work including coronary angioplasty and coronary bypass surgery to support various targets including the standards set by the Government's National Service Framework on CHD (BCS 1994a, 1994c; Black *et al* 1996; Swanton 1999; NHS 2000a). These are driven by the national priority to reduce morbidity and mortality associated with heart disease and the desire to close the discrepancy between UK intervention rates and those of other industrialised countries. These treatments require capacity increases for the procedures themselves and also for diagnostic CC to plan these procedures. The ratio of investigations to interventions is 2:1 for patients with CHD and approximately 1:1 for patients with valve disorders and adult patients with congenital defects (BCS 1994a).

District CC facilities may be used to support a shift in activity away from the tertiary centre or to expand overall activity or both as was illustrated in Figure 3.1 in §3.3. These facilities may be provided temporarily or on a permanent or semi-permanent basis. Shifts in CC activity may be required to release tertiary capacity for more complex cases such as emergency care or treatment procedures. Alternatively they may be required to temporarily substitute for a tertiary catheter laboratory which has been closed due to repairs or contamination (BCS 1994d). Additional capacity may be provided to achieve a desired reduction in waiting times or to support a long-term expansion of services.

6.3.2 Availability of Necessary Skills

The evolution of district services has been supported and motivated by the emergence of a new generation of district consultant cardiologists who are fully trained CC operators and now have the responsibility of training junior staff (Hall *et al* 1995). In the absence of a district facility, district consultant cardiologists who administer CC (typically elective cases) have to conduct CC sessions at a tertiary centre to maintain their skills. Their junior staff will also rely upon sessions at the tertiary level to gain and maintain experience in CC.

6.3.3 Pressure to Improve Local Services

The development of district services has also been driven by the desire to improve local services. A local CC service has several advantages. It can reduce the undesirable fragmentation of specialist care between the tertiary and secondary levels, thus enabling some patients to be fully managed at their local district hospital. Low risk patients can undergo CC in familiar surroundings, close to home. The close proximity of services can also reduce the need for patients to remain in hospital overnight as CC is increasingly being carried out on a day-case basis (Christie *et al* 1985; Clark *et al* 1992; BCS 1994b; de Bono 1999; BCS/BCIS 2000). District services also present opportunities for support staff at DGHs to acquire new skills. In addition, by making DGHs more specialised, this facilitates the introduction of new technologies and thus reinforces the specialisation at the district level. This is appreciated by both the staff and their patients. Developing CC facilities at a DGH may also enable the host trust to generate income from further NHS purchasing contracts and private patients, and to offer sessions to visiting cardiologists from neighbouring districts (BCS 1997).

6.3.4 Cost-effectiveness and Safety Issues

Cost-effectiveness considerations have obviously been important factors in the debate about the appropriateness of having district CC services (Mills 1990; Gunnell *et al* 1995). In §3.4.1, it was mentioned that Scott (1996) recommended that, in a cost-effectiveness analysis of a service shift, the appropriate measures of the benefits should be process measures, such as waiting times and convenience, rather than mortality and morbidity measures. For the shift in CC services, both sets of measures should be considered. The latter set concern the key issue of the safety of shifting CC services to the district level.

The issue of cost-effectiveness has been frequently discussed with respect to the shift in CC services, but no economic evaluations have appeared in the literature. The debate has mainly focused on safety issues. The concern has been about removing CC services from the protective environment of the tertiary centre where surgery can be promptly given if necessary. The British Cardiac Society are satisfied that diagnostic CC can be safely undertaken at the district level on low risk patients. Consequently, they have endorsed the development of district services for these patients subject to the availability of adequate skills and facilities (BCS 1994a, 1997). Evidence continues to confirm the safety of district based services (e.g. Smith *et al* 1999; Papaconstantinou *et al* 1999).

There has been a similar debate about conducting interventional CC (coronary angioplasty) without surgical backup at DGHs. The current consensus is that this is not recommended although there are a few DGHs that have departed from this recommendation (BCIS 1992; de Bono and Hopkins 1993; BCS/BCIS 2000). As described in §5.3.1, interventional CC is more complicated than CC investigations and, therefore, carries more risk. A recent study has concluded that backup continues to be necessary in spite of the availability of stents that have reduced the need for urgent coronary bypass surgery (Shubrooks *et al* 2001).

6.4 PROVISION OF DISTRICT SERVICES

6.4.1 Practicalities Involved

There are a number of practicalities involved in the provision of district services. District services may be supplied by hiring a mobile catheter laboratory, which is shared with other district hospitals and is driven to the hospital only for prearranged visits. Alternatively, a hospital may hire a relocatable catheter laboratory, which remains on site or construct integrated CC facilities within the hospital. Mobile units may be used in cases where district services are only required on a short-term temporary basis, or temporarily as part of a long-term strategy during the period of construction of an integrated facility. Temporary district services may be necessary to provide additional capacity or to temporarily substitute for a laboratory which has closed.

Mobiles may also be used as a long-term arrangement in instances where the construction of an integrated facility would not be cost-effective. Integrated CC facilities have been reported to cost in the region of £1 million to install and further costs are incurred to staff, run and maintain the unit with regular upgrades. With both mobiles and integrated laboratories, the costs of overheads are absorbed into the procedural costs. With an integrated laboratory, the procedural cost declines as the patient volume increases whereas the procedural cost with mobiles may be fixed. Consequently, at low patient volumes, the mobiles offer lower procedural costs with the situation reversed at higher patient volumes. A DGH then has to process a large number of patients for an integrated catheter laboratory to become a viable option (Cardinal Medical 1995). This may be achieved by sharing the facilities with cardiologists from neighbouring DGHs.

The process of introducing mobile CC facilities to a DGH involves several steps and subsequently involves several delays (Cardiovision 1995). Although there may be significant clinical interest in developing a district service and an adequate provision of medical skills, a service cannot be developed without financial backing. A business case has to be presented to the local purchaser. To organise the hire of a mobile unit, depending on the desired level of activity and the regulations at the time, tender documents may also have to be drawn up. Arranging the contract to provide mobile services will have to go out to tender. At the time of the research, the two companies that held the UK market were Cardiovision and Cardinal Medical. A suitable site for the mobile has to be identified and prepared, if one does not already exist. Factors involved in site preparation include the development of a level base which can withstand the considerable weight of the mobile unit and an electricity panel which connects the mobile to the electricity supply of the host hospital. Staff scheduling and other arrangements also have to be made to ensure that staff are available and that day beds are provided for the post-procedural recovery period. The construction of an integrated facility will involve the use of a mobile to present a feasibility study and the submission of a further business case.

Mobiles are accompanied by fully trained support staff - a nurse, a radiographer and a cardiac technician. A relocatable catheter unit may be supported by staff from the host hospital or from the suppliers. Suppliers of mobile services also offer a range of support services including training for support staff at the host hospital. This is useful in preparing for the use of an integrated CC facility. In addition to the cardiology department, several other departments of the host hospital will be involved in the establishment and running of mobile services. These include the hospital management to co-ordinate the service, the estates department to prepare the site, security staff and hotel services to provide porters and cleaning. It is essential that a visiting mobile unit has exclusive use of a porter so that patients can be promptly transferred between the ward and mobile unit.

6.4.2 Future Prospects

In developing guidelines for a long-term strategy for the location of CC services, the British Cardiac Society Council considered the following four options (BCS 1994a):

> Option 1 - No district CC services and no district cardiologists undertaking CC.
>
> Option 2 - No district CC services but district cardiologists with appropriate skills to be offered sessions at tertiary centres to conduct (primarily elective) diagnostic CC.
>
> Option 3 - Some district hospitals, particularly those geographically remote from tertiary centres, to develop CC services in conjunction with neighbouring districts to ensure that facilities are used efficiently.
>
> Option 4 - Tertiary centres to concentrate on emergency cases, interventional work and investigations for their local population only, and for elective invasive investigations at the district level to become the norm.

An extensive range of factors formed the basis of their deliberations. These included various issues of safety, workload, access, efficiency, research and training. For each factor, the Council considered the case in favour of a regional tertiary provision, and the case in favour of a local district provision (Table 6.1).

Table 6.1 Tertiary Verses District Provision of CC

	For a Regional Tertiary Provision	**For a Local District Provision**
Safety Issues		
Patient Safety	Immediate surgical cover an advantage.	Increased safety through reduced delay.
Exposure to Radiation	May be higher if tertiary cardiologists undertake only interventional cases.	Radiation burden will be shared by more cardiologists.
Patient Activity		
Emergency Work	Centres must remain robust to cope with emergency referrals.	District hospitals without surgical cover should not investigate emergency patients.
Angioplasty Referrals	Ability to fast track patients and avoid second procedure.	Frees lab space at tertiary centre for more coronary angioplasty procedures.
Surgical Referrals	---	Rate may increase so that current unmet need is brought to light.
Waiting Time	Dependant on contracts	Probably reduced by providing more new facilities.
Efficiency & Costs		
Efficiency	Maximise use of expensive equipment.	Maximise use of expensive equipment.
Cost per Case	Reduced by increasing throughput	Lower capital charges and overheads
Research & Review		
Research	Reduced workload might hinder research.	Routine diagnostic work of limited value.
Audit	More easily organised if on one site. Tertiary centres provide a better forum for planning and discussing cases and protocols.	Would need to join national confidential enquiry on complications. District cardiologists should keep close links with the centre.

Training & Skills		
Training	Loss of cases for investigations may hinder training of registrars. Devolution to district may force all cardiologists inappropriately to develop invasive skills.	Some districts will have registrars rotating through higher cardiology training.
Skills	Sufficient activity to maintain skills.	Avoids wasting district hospital skills
Other Factors		
Travel Time	---	Reduced for patients and cardiologists. Most patients do not live near a tertiary centre.
Doctor Satisfaction	---	Increased through ability to see patients through whole course of illness.

(Source: BCS 1994a)

The Council rejected the first option on the basis that skills would be wasted but they supported the second and third options subject to certain criteria. These criteria are: the development of local services is within the context of a overall strategic plan for cardiology services agreed by providers and purchasers; staff are adequately trained; district activity is audited; the quality of medical images equals that of a tertiary centre; close links are maintained with the tertiary centres; and, that there is sufficient throughput to ensure cost efficiency and to maintain local skills. There is a strong positive correlation between outcome and throughput (Luft *et al* 1990; LIG 1993, McGrath *et al* 2000). A British Cardiac Society Working Group (BCS 1997) have recommended that there should be at least two operators in each district laboratory, carrying out a minimum of 500 cases per annum and that the throughput of each laboratory which is dedicated to cardiac work should be 1500-2000 cases per annum (minimum of 4 cases per session). The British Cardiac Society Council also accepted that over the course of time, district CC services would develop and converge towards the fourth option. The use of mobile catheter laboratories will play an important role in this process.

The development of district CC services has a number of important benefits to the delivery of specialist cardiac services. However, this initiative may prove to be counter-productive in the long-term as increasing access to CC may lead to the stimulation of further demand and thus impose increasing pressure on the system. Furthermore, increasing access could also lead to inappropriate use of CC services. However, demand may also be stimulated by reducing access to CC. The concerns of stimulated demand and inappropriate use are discussed in §6.5 and §6.6 respectively.

6.5 STIMULATION OF LATENT DEMAND

6.5.1 Evidence of Stimulated Demand

There is various evidence in the literature to suggest that shifts in CC services may stimulate demand. This supports the proposal that exploring this service innovation with SD could be useful.

Marked variations exist between the rates of CC and cardiac treatments, across different regions and within regions, despite apparent similarities in selection criteria (Gray *et al* 1990; Henderson *et al* 1995). However, a consistent finding is that where facilities are available, the preference of patients and doctors is for an increasingly interventionalist approach (de Bono and Hopkins 1993; Every *et al* 1993; BCS 1994a). The stimulation of demand by the introduction of CC facilities is also suggested in research in the US. This research has shown that the availability of CC services can influence the choice of hospital (Hodgkin 1996). Furthermore, there is the evidence that, for health services in general, referral rates rise in response to increasing access to services (e.g. Buttery and Snaith 1979, 1980; Roland and Morris 1988; Worthington 1991; Pope 1992; Newton *et al* 1995; Hamblin *et al* 1997; The Economist 1998; Goddard and Tavakoli 1998; Hamblin *et al* 1998a; Earwicker and Whynes 1998).

Stimulated demand is desirable if it constitutes the identification of new high risk patients. However, this latent demand may also include low priority or inappropriate cases. This will impose increasing pressure on purchasers and providers in their attempts to fund emergency care and to meet their waiting time targets. Eventually, these targets may become unsustainable.

6.5.2 Mechanisms of Demand Stimulation

The mechanisms underlying the stimulation of demand for health care are extremely complex, primarily involving dynamic complexity, but also elements of detail and organisational complexity (these different types of complexity were described in §4.2.1). Also associated with the stimulation of demand is the suppression of demand. It would be unrealistic for a single research project to attempt to consider all these issues. In this section, some insight is provided into the complexity involved, and the elements that were excluded from the analysis are identified.

Demand for a CC Investigation

Changing access to a CC investigation may result in changes in demand for this service: the stimulation of demand may arise from improvements in access and the suppression of demand may be associated with reductions in access. Referrals for a CC investigation are a fraction of the patients passing through inpatients (the source of emergency referrals for CC and a minor source of elective referrals) and outpatients (the main source of elective referrals). Therefore, changes in demand for a CC investigation will result from changes in the OP and inpatient activity rates or changes in the referral fraction.

Regarding increases in the inpatient and OP activity rates, it is important to distinguish between demand for these services (referral rates) and the delivery of these services (activity rates). Increases in demand will only translate to increases in activity if that demand is met. Given that demand for OP services is categorised as elective, it will not immediately result in demand for a CC investigation. The rate at which demand is met will be determined by forces that drive activity, typically the waiting time goal. By contrast, increases in demand for inpatient care (for admission as an emergency case) will be met immediately. This may subsequently contribute to further demand for an emergency CC investigation. Further demand for an elective CC investigation may be generated by emergency admissions who subsequently stabilise to become new referrals for a CC investigation i.e. those who were not already on the CC waiting list.

The CC investigation referral fraction is a sum of the elective and emergency referral fractions. If the development of district facilities leads to an increase in overall capacity, and therefore a reduction in waiting times, cardiologists may decrease their referral threshold (and thus increase their elective referral fraction) in response to this improvement in access. Cardiologists may also decrease their referral threshold in response to pressure by patients and GPs. An increase in the referral fraction could also arise from a change in the case mix of those undergoing assessment.

Access to a CC investigation does not only influence demand for this service. In fact, changing access to this service may cause demand to be stimulated, or suppressed, for several other services: OP appointments, inpatient services; private sector care and invasive treatments.

Demand for OP Appointments

Demand may be stimulated for OP appointments, where patients are screened for CC. Referrals for OP appointments are divided into new referrals and follow-up referrals. The former are referrals by GPs and the latter are referrals by cardiologists. Cardiologists use follow-up appointments to review patients' progress. In discussing the stimulation of demand for health care, the literature focuses on GP behaviour. It is, perhaps, assumed that the numbers of follow-up referrals are driven by clinical factors alone.

Patient expectations are rising and this is being fuelled by initiatives such as the *Patient's Charter* (NHS 1991a, 1996a). Developing district services results in both patients and the local GPs becoming more knowledgeable about CC and its benefits. The natural tendency for GPs lacking in knowledge of CC, typically for those in areas remote from CC facilities, is to focus on the risks associated with this procedure. The potential response to increases in knowledge about CC is an increase in referrals for OP appointments.

Demand for Inpatient Services and Private Care

Reductions in access to CC may affect demand for inpatient services as patients on the waiting list may deteriorate and thus stimulate the levels of emergency admissions. Reducing access to NHS CC services may also cause more patients to seek care privately. Demand for health care in the private sector lies beyond the scope of this research.

Demand for Invasive Treatments

The development of district CC services also imposes pressure by stimulating demand for invasive treatments. It has been reported that the development of district CC services has increased the need for coronary angioplasty and coronary bypass surgery procedures (LIG 1993; Black *et al* 1996).

The development of district services is considered to be the most powerful influence on the future need for coronary angioplasty and coronary bypass surgery:

> "Information from the focus groups and British Cardiac Society indicates that where [district cardiac catheterisation services have developed] the result is a twofold increase in the requirement for tertiary cardiac treatment" (LIG 1993, p.18).

A proportion of patients who undergo CC will be subsequently referred on for invasive treatments. The development of district services may increase the requirement for invasive treatments in two different ways: by increasing the referral rate for CC or by increasing the CC activity rate. Increasing CC referral rates will bring more patients into the part of the cardiac referral chain where invasive treatments might be considered (potential demand for invasive treatments). Increasing CC activity rates makes the existing patients within this part of the referral chain pass along more quickly (expressed demand for invasive treatments). The investigation of the stimulation of expressed demand for invasive treatments was restricted to that which arose from elective CC investigations only.

The 'Aggressiveness' of Referral Behaviour

The sensitivity to changes in waiting times and patient pressure will vary between the individual cardiologist and will depend upon their circumstances.

In general, patients screened for a medical procedure may be categorised as: those for which a referral is clearly inappropriate; those for which a referral is clinically indicated; or, those in the 'grey area' for which the appropriate course of action is uncertain. In the case of CC investigations, the 'grey area' arises from the fact that non-invasive tests are unreliable as described in §5.3.3. Therefore, unless it is clearly inappropriate to refer a particular patient or it is clearly indicated, they will fall in the 'grey area'. §6.6.2 provides examples of patients that fall into the first two groups.

'Aggressiveness' is a term that is often used to describe the degree of enthusiasm, confidence or interest in the use of a medical procedure. Where there is uncertainty about the appropriateness of a referral, an 'aggressive' clinician will be more inclined to refer, as illustrated in Figure 6.1. The most 'aggressive' clinician might typically refer all patients in the 'grey area', so the influence of the expected waiting time will be zero. For a less 'aggressive' clinician, there is more scope to alter their referral threshold according to factors such as the expected waiting time.

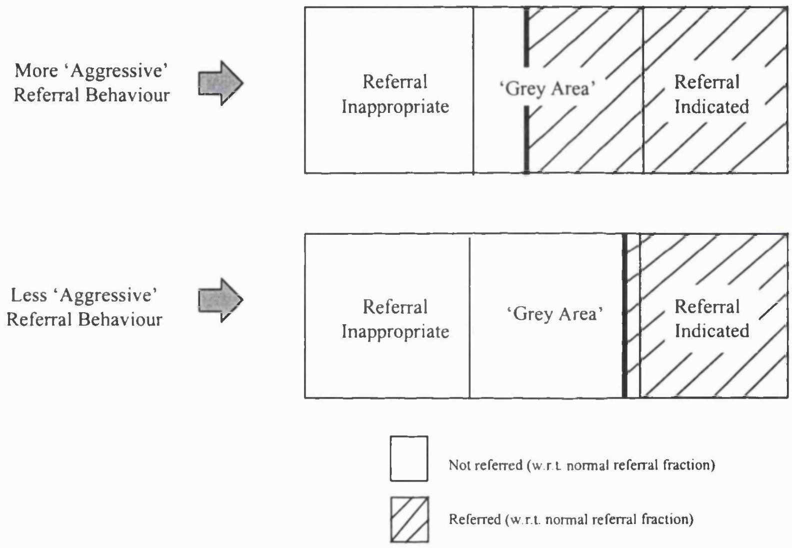


Figure 6.1 Variation in 'Aggressiveness' of Referral Behaviour
(The relative sizes of the three regions, which are shown to be of similar size, should not be regarded as descriptive as the purpose is merely to illustrate the contrasting referral behaviour)

Changes in Referrals

Figure 6.2 illustrates the possible changes in referral links, within the NHS, resulting from the increasing access to CC services at a DGH with CC services.

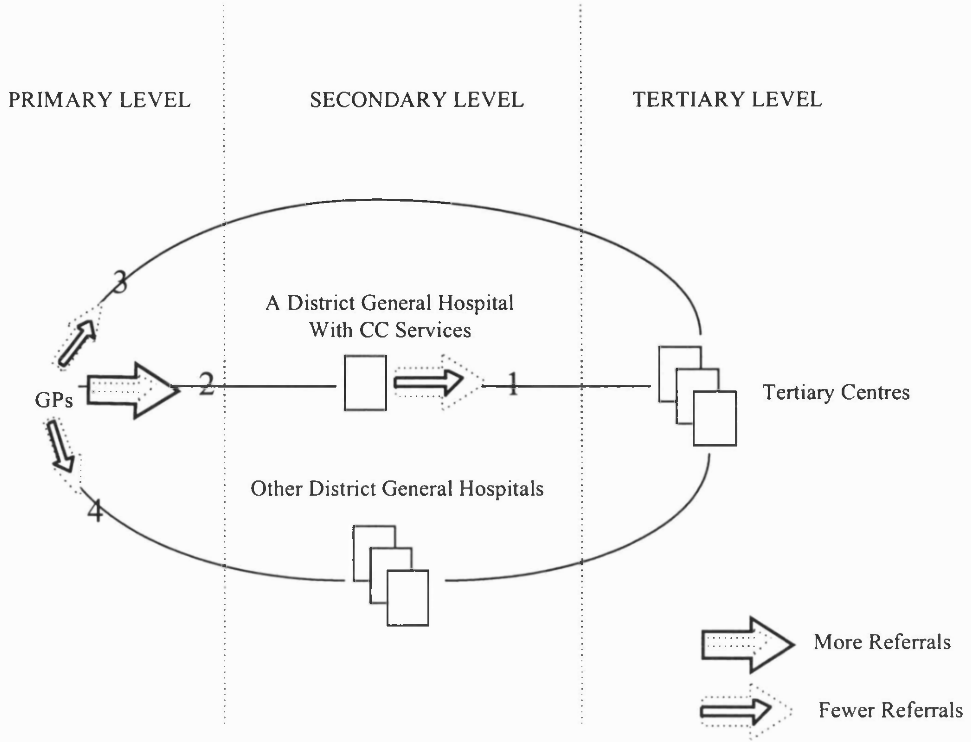


Figure 6.2 Potential Changes in Referrals

Developing CC services reduces the need to refer to the tertiary level (see referral link 1). Increases in demand for OP appointments at the given DGH may be within existing links with GPs (link 2). Alternatively, increases in demand may involve the creation of new links (demand switching from links 3 to 2, or from links 4 to 2) with GPs deciding to refer to the given DGH, rather than other hospitals. Therefore, demand could be shifted back from the tertiary level to the given DGH both directly (reductions in referrals along link 1) and indirectly via changes in GP referral links (reductions in referrals along links 3 and 4). The cardiologists at the given DGH will only have direct control over the former. The extent to which changes in referral links will occur will depend upon geographical factors and other factors, such as the price of services. As GP referral behaviour was not considered in detail, the issue of possible changes in GP referral links were not considered. However, this is a fruitful area for further research.

Therefore, changing access to CC can produce changes in demand for a CC investigation and other services along the referral chain. This creates several feedback effects and thus supports the research hypothesis about the potential usefulness of an SD analysis of the shift in CC services.

6.6 APPROPRIATENESS OF CC

Concern has been raised that stimulating demand may increase the levels of inappropriate demand (Gunnell and Harvey 1996). Therefore, the appropriateness of the use of CC is an important factor to consider in evaluating the development of district services.

How the appropriateness of a medical procedure is defined is considered, before assessing the available evidence about what is considered to constitute the appropriate use of CC. How clinical guidelines may be employed, to reduce the rate of inappropriate use, is also described.

6.6.1 Defining the Appropriateness of a Medical Procedure

Definitions of Appropriateness

One definition of a medical procedure being appropriate is that the benefit from undertaking the procedure is greater than the risks inherent in the procedure (Chassin *et al* 1986). A broader definition of the appropriateness of a procedure would consider its necessity, timing, effectiveness and cost-effectiveness (Coulter 1998). It is necessary to consider both the appropriateness of doing a procedure and the corresponding desire to reduce *overuse*, and the appropriateness of not doing a procedure and the corresponding desire to reduce *underuse*. Discussions of the appropriateness tend to focus on the former only. The implications of overuse of a procedure is that some patients are being subjected to an intervention which is potentially more harmful than it is beneficial, and resources are being wasted. However, underuse is as important because a patient's condition could deteriorate by not undergoing the treatment that they need.

Difficulties in Defining Appropriateness

Clearly defining the appropriateness of CC is difficult. In the case of diagnostic CC, for some patients the extent of coronary disease can only be confirmed by viewing the coronary angiogram. Therefore, the appropriateness cannot be fully established in advance of the patient actually undergoing CC.

Subsequent Variation in Clinical Practice

Due to the inherent clinical uncertainties involved, the appropriateness of CC can only be clearly established for selected patient groups or ideal conditions (Brook 1994). The available evidence is reviewed in §6.6.2. When making decisions about patients, for which evidence is not available, what is considered to be appropriate is determined by the judgement of the individual clinician. However clinical attitudes towards CC varies.

Variation in clinical attitudes is particularly apparent between clinicians in the US and those in the UK. It is well accepted that the former are the more 'aggressive' (Aaron and Schwartz 1984). Brook *et al* (1988) found significant differences between the attitudes of two panels of experts, one from the US and the other from the UK. In establishing appropriateness criteria for CC investigations, they found that the UK panel placed greater emphasis on the importance of symptoms and the degree of medical treatment, compared with the US panel. These differences were reflected in statistically significant differences in their appropriateness ratings of two groups of patients who had undergone CC investigations in the US. The disparity between US and UK attitudes is also reflected in the wide differences in utilisation rates in spite of similarities in prevalence (Brook *et al* 1988; Ham 1990; Black *et al* 1996).

Variation in attitudes about what is considered to constitute appropriate use has contributed to the considerable variation in utilisation rates which have been observed (Brook *et al* 1988; Gray *et al* 1990; Graboys *et al* 1992; Bernstein *et al* 1993; Henderson *et al* 1995; Gunnell and Harvey 1996; Selby *et al* 1996). Furthermore, studies which have measured the appropriateness of CC investigations have found significant levels of its inappropriate and equivocal use. Equivocal use refers to a procedure for which the potential benefit equals the potential harm. In a study of the Trent Region in the UK, of 320 patients over the age of 25 who underwent CC investigations for CHD, 21% were considered to be inappropriately investigated and 30% equivocal (Gray *et al* 1990). Murphy (1995) mentions several reasons for actual clinical use deviating from what might be considered to be appropriate. These include uncertainty, the fear of litigation, patient pressures and reimbursement issues.

6.6.2 Evidence Available to Define the Appropriate Use of CC

CC Investigations

Diagnostic methods are evaluated relative to a 'bench mark' diagnosis, which may be obtained via a biopsy, autopsy, surgical inspection or another method that marks the 'gold standard' (Altman 1993). Several basic statistical measures are used to focus on how sensitive and specific the method is in identifying abnormality and on its ability to predict abnormality. A diagnostic method's sensitivity is the proportion of abnormal cases which are correctly identified. Its specificity is the proportion of normal cases that are correctly identified by the method. The method's (positive) predictive value is the proportion of cases declared by the method as abnormal that are correctly diagnosed. Unlike the previous two measures, this measure provides an indication of the usefulness of the method in practice given that the true diagnosis will not be available.

CC investigations are presented as the 'gold standard' diagnostic method for CHD (Charles and Marshall 1989; Jackson 1991; Manning *et al* 1993; Swanton 1998). Subsequently, the appropriateness of CC investigations is reflected by diagnostic value of alternative methods. Weaknesses of alternative methods strengthen the argument for the appropriateness of CC investigations.

A CC investigation would never be conducted on all patients who presented with chest pain. Some referrals are made to hospitals simply to provide reassurance to the patient or advice to the GP on how to clinically manage the patient (Roland and Coulter 1992). With some patients who are investigated further, adequate and safer alternative means of diagnosis are available, as discussed in §5.3.3. One such example would be a patient who only experienced chronic stable angina upon moderate exertion, did not require maximum medical therapy and had produced a negative ECG stress test i.e. ECG test under exertion (Brook *et al* 1988).

At the other extreme, it is also universally acknowledged that all patients considered for coronary bypass surgery or coronary angioplasty should undergo a CC investigation first (de Bono and Hopkins 1993; Patterson and Treasure 1993; Swanton 1998). Another example of a patient for which a CC investigation is clearly indicated is one who has experienced chronic stable angina upon mild exertion, was on maximum medical therapy and had produced a positive ECG stress test (Brook *et al* 1988).

6.6.3 Promoting Appropriate Use With Clinical Guidelines

Clinical guidelines provide a means upon which to apply the best available evidence, reduce inappropriate referrals for, and use of, health care technologies and thus reduce the undesirable variations in medical practice. They can also present a basis upon which to maximise the potential benefits from the limited NHS resources available and thus are of interest to purchasers (Delamothe 1993). However, unless guidelines are developed, disseminated and implemented appropriately, they may fail to be effective. Guidance for purchasers has been produced so that they may verify the scientific validity and ensure the successful implementation of clinical guidelines (Grimshaw and Russell 1993a, 1993b, 1993c).

Appropriateness ratings are based upon the severity of symptoms, ECG test performance and the adequacy of medical treatment. They can provide a useful basis for clinical guidelines by producing a priority scoring system (Brook 1994; de Bono 1999). However, they possess certain limitations. For example, as stated in §6.6.1, in the case of diagnostic CC, for some patients the extent of coronary disease can only be confirmed by viewing the coronary angiogram. Therefore, the appropriateness cannot be fully established in advance of the patient actually undergoing CC. This was illustrated by the Trent audit of Gray *et al* (1990). 30% of patients in which diagnostic CC was deemed inappropriate (without using the information from the catheterisation investigation) did in fact require bypass surgery. However appropriateness ratings present the most reasonable method available upon which to develop clinical guidelines about who should be investigated first, especially in the context of pressures from resource constraints and excessive waiting lists.

Various guidelines have been issued on the appropriate timing and use of CC investigations (ACC/AHA 1991; BCS/RCP 1993; BCS 1994c; de Bono 1999).

6.7 SUMMARY

This chapter presented the review of the literature on the shift in diagnostic CC services from the established tertiary level to the district level for low risk patients. Four factors motivating the development of district services were discussed. The first factor is the need to address shortfalls in tertiary capacity. Given the availability of skilled CC operators at DGHs, the second factor is the desire to utilise these skills. Further factors are the pressure to improve local services and the demonstrated cost-effectiveness and safety of conducting district CC investigations without surgical backup facilities for low risk patients. The practicalities involved and the future prospects for the provision of district services were discussed in the context of either the shared use of mobile catheter laboratories or the shared use of integrated catheter laboratories. The stimulation of demand and inappropriate use were discussed as potential undesirable consequences of the shift in CC services. Clinical guidelines were considered as a useful means to reduce the rate of inappropriate referrals for, and use of, CC.

Having outlined background on the shift in CC services, and presented evidence from the literature of this demand being stimulated by this service innovation, the next chapter presents the evidence from the case study centres.

CHAPTER 7

THE CASE STUDY EXPERIENCES

7.1 INTRODUCTION

The previous chapter provided some background from the literature regarding the shift of CC services, from the established tertiary level to the district level. Evidence of this service shift generating further demand was presented, thus supporting the hypothesis that an SD analysis could potentially be useful.

The purpose of this chapter is to describe the experiences of district CC services at the case study centres and to highlight corroborative evidence of the service shift stimulating further demand. A tertiary perspective is first considered by describing the shift in CC services from Heartwick Hospital (§7.2). The shift in CC services to Ribsley General is then described (§7.3), thus providing a district perspective. The degree of use of district services (§7.3.1) is considered, before discussing the impact of the service on the delivery of CC investigations for Ribsley General patients (§7.3.2-§7.3.3). Evidence is presented of the district service stimulating latent demand for cardiac services (§7.3.4). The issues of the cost-effectiveness and efficiency of district services are discussed (§7.3.5), before reporting on the views, regarding district services, of different health professionals associated with Ribsley General (§7.3.6). The case of the shift in CC services to Veinbridge General is then considered (§7.4). Having presented evidence of the stimulation of demand, the appropriateness of demand is discussed (§7.5). The chapter is summarised in the final section (§7.6).

Numerical data supplied by the collaborative centres is used, albeit with some limitations, to illustrate the effects of the introduction of district services, including the existence of secondary effects. Appendix C contains further details about the collaborative work including the site visits, interviews, and data obtained.

7.2 SHIFT IN CC SERVICES FROM HEARTWICK HOSPITAL

Following the theme of Ham *et al*'s hub and spoke model (1998), a strategic view on the development of district CC is taken by first considering district services in relation to the tertiary centre, Heartwick Hospital (the main referral centre for both Ribsley General and Veinbridge General). This is consistent with the view of the Business Manager at Cardiocare, the company which supplied the mobile catheter laboratory to Ribsley General and Veinbridge General.

This section considers the CC activity conducted at Heartwick Hospital, and the CC workload which was shifted to its referring DGHs, Veinbridge General and Ribsley General. As explained in §5.2.3, the district services were initially introduced to compensate for the temporary closure of one of Heartwick's two catheter laboratories, for repairs, from May 1996 to March 1997. It was also understood from conversations with staff at Heartwick Hospital that they also partially compensated for the capacity loss by working overtime in their other catheter laboratory. After the CC service at Heartwick Hospital was restored to full capacity, the district service was withdrawn from Ribsley General but the service at Veinbridge General remained. The district service was temporarily reinstated to Ribsley General for several sessions between February 1998 to May 1998. The sessions in April and May compensated for further construction work to Heartwick Hospital's catheterisation facilities.

Heartwick Hospital was responsible for the district site preparation costs and also the running costs for the period in 1996/1997 when the district services were compensating for the loss of its capacity. Veinbridge General took over the responsibility for their district service in April 1997. Consequently, during their second period of construction work in 1998, Heartwick Hospital only paid for the running costs for the district service at Ribsley General.

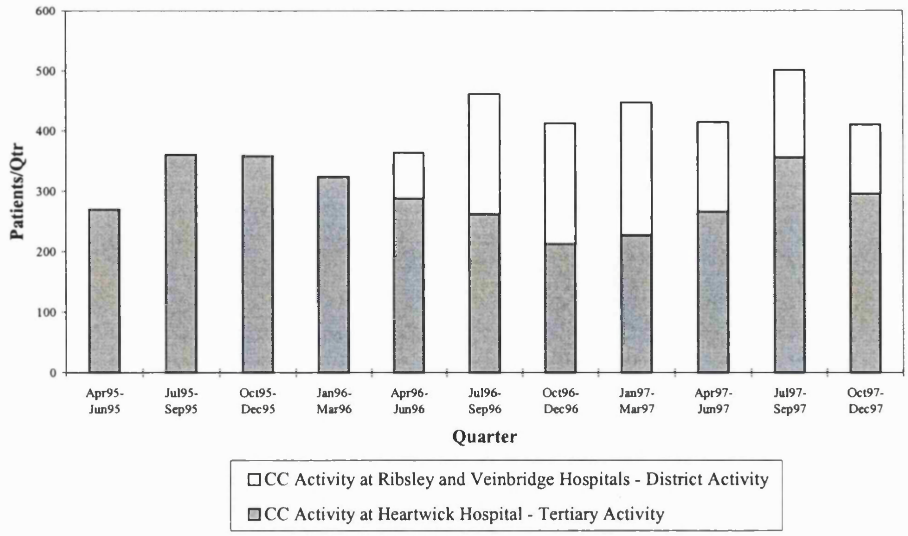


Figure 7.1 Impact of District Services on Overall CC Activity
(NHS only. Sources: Heartwick Hospital, Veinbridge General and Cardiocare)

Quarterly CC activity data was provided from April 1995 to Dec 1997 and is shown in Figure 7.1. This illustrates the temporary reduction in tertiary-based activity, and how district services both compensated for the loss of tertiary capacity at Heartwick Hospital and supported an increase in the overall CC activity levels. Tertiary activity refers to all the diagnostic CC procedures conducted, with or without treatment procedures, for both emergency and elective cases. These data derive from direct referrals by GPs and referrals from DGHs. District activity is elective and involves diagnostic procedures only, as was stated in §6.3.

Interviews and observation work began in June 1997. Information about the use and views of district services were obtained from various health professionals at Heartwick Hospital, including consultant cardiologists, support staff and the cardiac business manager. It was evident that the senior health care professionals at Heartwick Hospital were strong advocates of having district services. The use of the district facilities enabled Heartwick Hospital to carry out essential repairs on its catheter laboratories, without having to compromise on the quality of patient care in terms of safety and waiting times. Shifting low risk cases towards the district level also enabled Heartwick to direct its tertiary expertise towards more complex cases, that is, emergencies, high risk electives and treatment procedures.

Ideally, isolating the activity that relates to patients from Ribsley General and, Veinbridge General separately, would illustrate the changes in activity at these individual hospitals. It is these patients who could, if eligible, be directly held back at the district level and not GP referrals which are made directly to the tertiary centre. Unfortunately, these data could only be provided for Ribsley General. To derive comparable data for Veinbridge General, several approximations were made.

7.3 SHIFT IN CC SERVICES TO RIBSLEY GENERAL

In this section, different aspects of the shift in CC services to Ribsley General are explored based upon several data sources including a very useful database at Ribsley General. It contained various data on each patient on the CC waiting list, including their waiting list joining date and removal date, and the outcome of their CC investigation. A small proportion of patient records (just over 9%) were excluded because their data was incomplete. Using the remaining data, various time series were produced.

7.3.1 Degree of Use of District Services

Prior to the introduction of district services, and during the subsequent periods of the absence of district services at Ribsley General, cardiologists based at Ribsley General conducted CC sessions at Heartwick Hospital. They only conducted investigations, not treatments. In §6.4.2, four options (or degrees) of the use of district services were described. As a reminder, Option 2 involves no district services but skilled district cardiologists being offered sessions at tertiary centres to conduct CC. Option 3 represents the use of district services to a higher degree with some DGHs developing CC services in conjunction with neighbouring districts to ensure that facilities are used efficiently. Since June 1996, the cardiologists at Ribsley General have switched back and forth between Option 2 and the interface between Options 2 and 3 using a mobile catheter laboratory. The Ribsley CC service could not be described as reflecting Option 3, given the temporary nature of the district service.

7.3.2 *CC Activity Profiles*

For the period under study, all patients from Ribsley General who underwent elective CC, either did so either at Ribsley General or Heartwick Hospital. The 5% of referrals to other tertiary centres, as shown in Figure 5.1, related to non-CC procedures.

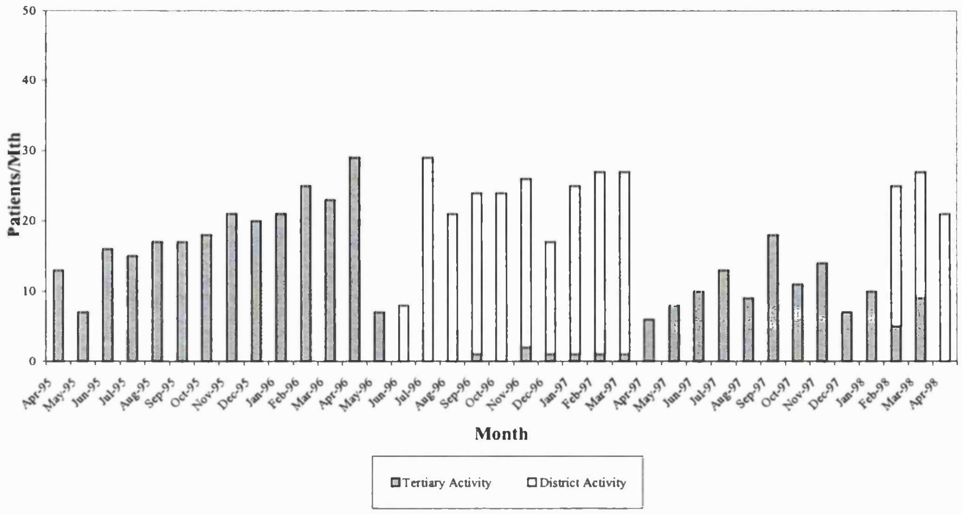


Figure 7.2 Temporary Expansion Followed by a Shift of Elective CC for Ribsley General Patients (NHS only. Source: Ribsley General)

Figure 7.2 illustrates the levels of CC investigations for Ribsley General patients. All activity is elective (unlike Figure 7.1). Tertiary activity refers to patients who were assigned for CC by Ribsley General cardiologists and underwent an elective CC investigation at the tertiary level. Some of these patients will also have undergone interventional catheterisation (coronary angioplasty) at the same time. District activity refers to low risk patients who were held back by the district cardiologists to undergo a CC investigation at Ribsley General.

Figure 7.2 shows that there was a temporary expansion followed by a shift of the elective workload of CC investigations. Prior to the closure of Heartwick Hospital's catheter laboratory in May 1996, there was an increase in tertiary activity. This activity increase, which was partially funded by a Waiting List Initiative, was intended to reduce the size of the waiting list and average waiting times and the for Ribsley General patients (the graphs for these two variables are shown in Figures 7.3 and 7.4, respectively). The sudden drop in activity in May 1996 and June 1996 was attributed to the combined effect of the loss of tertiary capacity and the delay in establishing the district service. Between July 1996 and March 1997, the district service sustained the increase in activity.

After the district service was withdrawn in March 1997, the level of activity dropped because the waiting times and waiting list had been reduced to a more manageable level. The district service at Ribsley General was reinstated in February 1998 following further reductions in access to elective CC services. Several sessions in February and March 1998 were provided using further Waiting List Initiative funding. Heartwick Hospital funded several additional CC sessions in April and May 1998, while Heartwick's second catheter laboratory was closed to undergo construction work.

It was stated earlier that the capacity for elective catheterisation on Ribsley General patients was first expanded at the tertiary level and when this workload was shifted to the district level, there was sufficient capacity at Ribsley General to sustain the increase in activity. In fact, the consultant cardiologist at Ribsley General explained that capacity constraints at the tertiary level did not necessary apply to the district level. For a patient to undergo catheterisation, they need to be allocated a slot in a catheter laboratory session, and a ward bed for the post-procedural recovery period. In practice, the availability of beds is the deciding factor. To expand capacity for Ribsley General elective patients at Heartwick Hospital, special arrangements had to be made because, during the regular sessions at Heartwick Hospital, only 4 elective Ribsley patients could be catheterised. In theory, Ribsley General patients had access to further beds but in practice, these were filled by emergency cases. By contrast, with a district CC service, emergency cases were transferred out to Heartwick Hospital, so Ribsley General could concentrate on elective care with more than double the capacity which was usually available at Heartwick Hospital.

Note that black blocks are used in subsequent figures to indicate the duration of district services.

7.3.3 Access to a CC Investigation

Figure 7.3 illustrates the size of the waiting list for Ribsley General patients. It illustrates how the increase in activity led to a dramatic reduction in the size of the waiting list. The graph also shows how the waiting list 'bounced back' after the additional capacity was withdrawn, requiring further increases in activity. This was not desired. Instead, the desire was for the waiting list to remain at a low level.

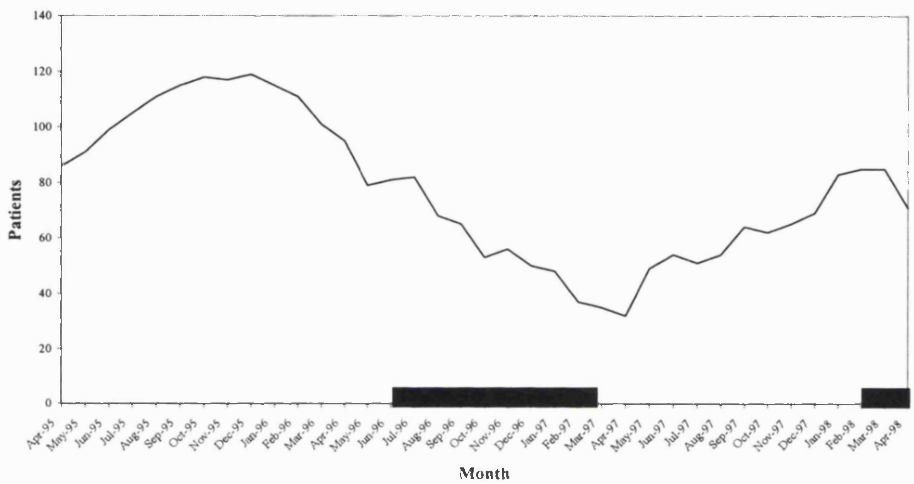


Figure 7.3 Waiting List for Ribsley General Patients for CC Investigation
(NHS only. Source: Ribsley General)

Figure 7.3 was constructed using an expert estimate. The consultant cardiologist at Ribsley General provided an estimate of the initial waiting list size, and using the individual patient data, the number of monthly waiting list additions and removals for the period April 1995 to April 1998 were calculated. Using the expert estimate, for the size of the waiting list in April 1995, the subsequent changes in the length of the waiting list were deduced.

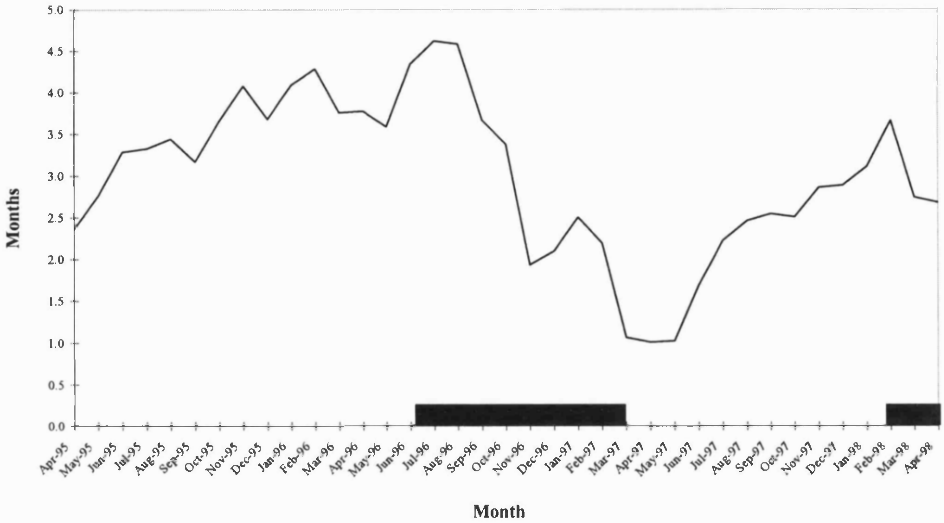


Figure 7.4 Average Time Spent on the CC Investigation Waiting List for Ribsley General Patients (NHS only. Source: Ribsley General)

The waiting time trend for CC for patients assigned for an elective CC investigation by Ribsley General cardiologists is shown in Figure 7.4. It illustrates the benefits of the capacity increases with a dramatic reduction in the average waiting time. To construct this figure, for each month, the average waiting time was calculated by averaging over all the patients on the waiting list. Note that average waiting time is calculated for patients on the waiting list rather than for patients leaving the waiting list, as the former measure provides a better representation of the pressure imposed on the system. If the waiting list removal rate were to become zero, assuming there were still patients on the waiting list, pressure on the system would rise. However, in these circumstances, the latter measure would not be calculated which would be a poor representation of the real world. The collaborators were happy with this choice of waiting time measure.

7.3.4 Evidence of Stimulated Demand

There was evidence of demand for cardiac services being stimulated by the introduction and use of CC services at Ribsley General. The issue of the appropriateness of demand is considered in §7.5.

§6.5.2 discussed how changes in access to CC could influence the levels of demand for various cardiac services. This study focused on changes in demand for OP appointments, elective CC services and invasive treatments. At Ribsley General, no evidence of demand being stimulated or suppressed for OP appointments was found. However, there was evidence of the stimulation and suppression of demand for elective CC services, and the stimulation of demand for invasive treatments.

Referrals for *OP appointments* are composed of new referrals (referrals by GPs) and follow-up referrals (referrals by cardiologists). It is clear from the numbers of new referrals, as displayed in Figure 7.5, that the district service at Ribsley General did not stimulate an increase in GP referral rates to Ribsley General. The variation appears to be random. Perhaps the knowledge that the district service was only temporary, and the subsequent lack of marketing of the service, served to stem the potential demand. Data on follow-up referrals was not available.

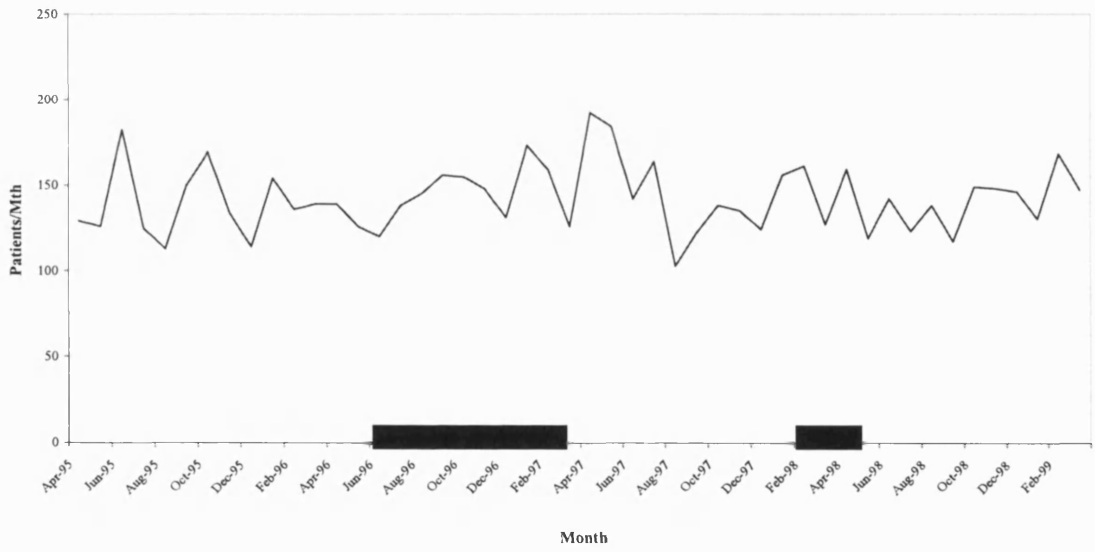


Figure 7.5 New Referrals for a Cardiology OP Appointment at Ribsley General
(NHS only. Source: Ribsley General)

Demand for an *elective CC investigation*, for Ribsley General patients, is shown in Figure 7.6 (see Additions). This figure shows changes in both the number of additions and removals to the CC NHS waiting list for Ribsley General patients. The removals are composed of elective activity only (as shown in Figure 7.2). Other waiting list removals, such as deaths, were removed from the data because the date of removal was not recorded. Although there is some random variation, there is also a trend in that the additions dropped when the system was under pressure and rose when this pressure was alleviated. The size of the waiting list and the average waiting time, as shown in Figure 7.3 and Figure 7.4 respectively, may be used as proxies for pressure on the system. Figure 7.6 thus indicates that demand for elective CC was both stimulated and suppressed at Ribsley General. The consultant cardiologist immediately saw the trend when shown Figure 7.6 and he then proceeded to provide explanations for this trend.

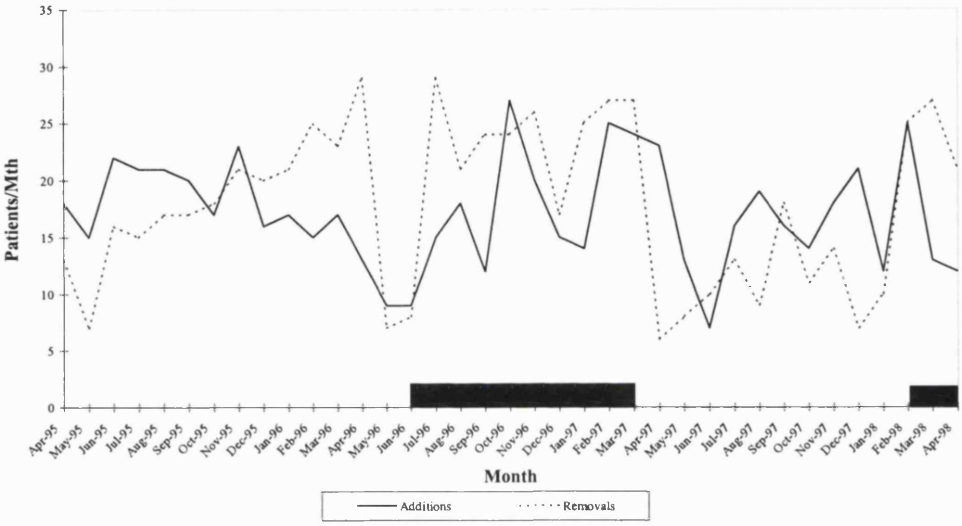


Figure 7.6 Additions and Removals onto the Ribsley General CC Investigation Waiting List (NHS only. Source: Ribsley General)

§6.5.2 stated that the referrals for an elective CC investigation are primarily composed of patients who have been referred onto the waiting list from an OP appointment, plus a few other new referrals of patients who were referred as inpatients. 'New' refers to the fact that they were not previously on the waiting list. The consultant at Ribsley General stated that the levels of cardiology OP activity were constant. It was not possible to illustrate this with data. Although access was given to OP activity data, due to the duplication of records and inconsistency in the way in which the data was recorded, it was impossible to extract any useful information for the purposes of this study. The numbers of new referrals from inpatients were negligible. Assuming that the case mix of the patients undergoing assessment as inpatients and outpatients remained constant, it can be concluded that the variation in the number of additions to the CC waiting list was solely due to changes in other factors that altered the OP to CC referral fraction.

The consultant cardiologist admitted to altering demand for CC by adjusting his referral threshold. He said that this was partially in response to changes in the average waiting time for CC. Whilst reductions in the average waiting time would stimulate his referral fraction, increases in the average waiting times would suppress some demand. However, an excessive waiting time would not induce him to suppress all his low priority demand. He believed that for some of these cases, it is better to place them on the waiting list sooner rather than later. In three month's time, he would review their condition and possibly remove them from the waiting list. However, if in three month's time he decided to keep them on the waiting list, they would have the advantage of being three months ahead in the 'queue'.

A second factor that was reported to increase the OP to CC referral fraction was increases in pressure by patients and GPs. The consultant at Ribsley General stated that pressure had risen because patients and GPs had become more knowledgeable about CC. They had learnt about CC through the new service at Ribsley General being reported in the local newspaper. In addition to this raised awareness, he believed that patients had gained knowledge about the service and its benefits through 'word of mouth' via family and friends.

He also believed that the OP to CC referral fraction was influenced by the level of skills of the doctors who selected patients for CC. He believed that highly skilled CC operators are able to identify a greater number of patients in need of CC than operators-in-training and non-operators. The operator-in-training at Ribsley General also agreed that his referral rate had increased as he gained experience and confidence in conducting CC procedures. The consultant cardiologist suggested that conceptualising the referral fraction as a simple monotonic increasing function of experience may not necessarily reflect the referral behaviour of all CC operators-in-training. It was possible that some junior operators might be over-confident and over-refer at first, and subsequently raise the referral threshold, as they became more experienced. Moreover, he believed that the pattern of referral behaviour might depend on the learning environment; some environments are more conservative than others. As junior operators at Ribsley General trained over a 12 month period, and were then replaced by a new trainee, the skills effect on demand varied periodically. The level of skills (and consequently the skills effect on demand) also depended upon the activity rate. Increases in activity increased the learning opportunities and thus accelerated the gain in skills.

This skills effect was also mentioned during an interview with a hospital manager from another hospital, outside the study centres. This was an interesting finding as it did not appear to be documented in the literature. As I highlighted in §3.3, Hamblin *et al* (1998a, 1998b) referred to a different skills effect on demand, more specifically, how GPs, by taking on new responsibilities associated with shifts in services across the secondary/primary interface could stimulate demand. Adopting the new responsibilities led them to gain "clinical intelligence" and thus identify more patients in need of treatment. This referred to a different skills effect on demand as it involved the development of new skills rather than the variation and acceleration of existing skills. It also referred to the effect of increased knowledge ("clinical intelligence") on demand associated with the gain in skills rather than the associated gain in confidence.

Demand was also stimulated for *invasive treatments*. Referrals for invasive treatments are a fraction of those undergoing CC investigations. Therefore, an increase in referrals for invasive treatments can arise from an increase in those undergoing CC, or result from an increase in the invasive treatment referral fraction. Increases in the elective CC investigation rate were shown in Figure 7.2. During this period, of the patients who had undergone an elective investigation, there was no trend in the invasive treatment referral fraction as shown in Figure 7.7.

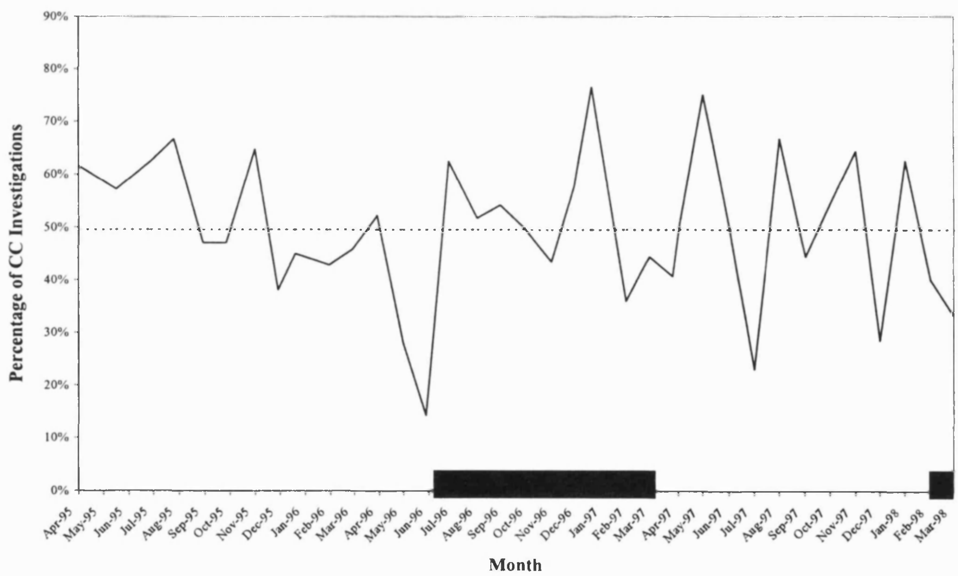


Figure 7.7 Invasive Treatment Referral Fraction for Ribsley General Patients

(NHS only. Following elective catheterisation only. Dotted line indicates the average of 50% which is 10% for coronary angioplasty and 40% for bypass surgery. Source: Ribsley General)

7.3.5 Cost-Effectiveness and Efficiency Issues

Although at Ribsley General the issues of the cost-effectiveness and efficiency were certainly considered with the introduction and withdrawal of district services, the data available for this study was of very poor quality.

It was reported that the introduction of the district service did not compromise patient outcomes. Therefore, safety should not be an issue in deciding whether to continue with a district service. In March 1997, when the district service was due to close, following the re-opening of Heartwick Hospital's catheter laboratory, a manager at Ribsley General wrote to the local purchaser to attempt to persuade them to support a continuation of the district service at Ribsley General. Whilst Heartwick Hospital would charge £450 per patient catheterised as a day case, and £675 per patient catheterised on an inpatient basis, it was stated that Ribsley General would charge a flat rate of £521 per patient. A breakdown of these figures was not provided. Given the close proximity of the district service to their homes, patients could avoid the need for an overnight stay which might be necessary after catheterisation at Heartwick Hospital which is located at an inconvenient distance from their homes. The consultant at Ribsley General estimated that at least 1 in 3 patients, who were eligible to undergo catheterisation at the district level, would require an inpatient stay after catheterisation at Heartwick. Therefore, the weighted average cost for a tertiary investigation was £525 per patient, assuming 1 in 3 patients required an inpatient day, compared with £521 per patient with a district service. Obviously, for assumptions about higher proportions requiring an inpatient stay, the cost differential would increase. For 1 in 2 patients, the weighted average cost for an investigation at the tertiary level would be £562.50 per patient, and for 2 in 3 patients the weighted cost would be £600 per patient.

However, it should be noted that, although, there might exist a procedural cost saving in undergoing CC investigation at the district level, this only applied to patients undergoing investigation only. If a patient investigated at the district level required an interventional CC, they would have to undergo a second procedure at the tertiary level. If that patient had been investigated at the tertiary level, they would have undergone treatment at the same time, and therefore only have incurred the costs, and been exposed to the risks, associated with one procedure. On average, about 10% of Ribsley patients were referred on for interventional CC, following an elective CC investigation. Given that this was a sizeable proportion, there seemed to be some appeal in having CC conducted solely at the tertiary level. Based upon the March 1997 figures, a tertiary-based service would be more efficient (on a cost/case basis) unless it required a large proportion of patients to undergo their investigation as an inpatient. See Appendix E, E4a for further details. However, what also needs to be considered that, assuming that there were no complications, 90% of patients did not need to be investigated at the tertiary level.

As was stated previously, those at Ribsley General failed to persuade the local purchaser to support a continuation of the district service.

7.3.6 Views of District Services

The consultant cardiologist and hospital manager at Ribsley General were in support of the district service and were keen to continue the service. They welcomed the ability to overcome capacity limitations associated with the tertiary service, and thus reduce the waiting list and waiting times for CC investigations. They also appreciated the opportunity to improve the local services and to provide continuity of care within the DGH, and the various other benefits as listed in Table 6.1. The local service saved the consultant cardiologist the inconvenience of having to travel to the tertiary centre to conduct CC sessions. However, he did admit to feeling rather isolated working at the DGH, given that he was the only consultant CC operator based at Ribsley General.

Although there was ongoing pressure to establish a long-term district service at Ribsley General, the local purchaser has maintained steady resistance. Both the contract manager and the public health consultant at the local health authority expressed the view that they were not keen on the district service. They were concerned about the costs and safety aspects. Whilst there had been no adverse incidents, they felt more comfortable, in principle, with CC investigations being conducted at the tertiary centre, where there were surgical backup facilities. They also emphasised the importance of concentrating patient activity at the tertiary level in order to maintain skills and to facilitate audit. The British Cardiac Society Council had taken all these factors into account when drawing up their positive recommendations for the development of district CC services (see §6.4.2). The Ribsley General service was certainly operating within the recommended practice.

However, it would seem that the development of long-term CC services would not have an easy passage into Ribsley General.

7.4 SHIFT IN CC SERVICES TO VEINBRIDGE GENERAL

This section explores different aspects of the shift in CC services to Veinbridge General. The experiences of district services at Veinbridge General provided an interesting contrast to those at Ribsley General.

7.4.1 Degree of Use of District Services

Prior to the introduction of district services at Veinbridge General, the cardiologists at Veinbridge General who performed CC procedures (CC operators), held sessions at Heartwick Hospital. The consultant cardiologist based at Veinbridge General also conducted interventional CC at Heartwick Hospital. Let us return to the four degrees of district services, which were introduced in §6.4.2. The operators based at Veinbridge General may be described as having operated within Option 2 prior to the introduction of district services, then on the interface between Options 2 and 3 from May 1996 until the opening of the integrated laboratory at Veinbridge General in February 1998, and thereafter, within Option 3. A mobile catheter laboratory was also used at Veinbridge General. The mobile was used during the eleven month period of the closure of the catheter laboratory at Heartwick Hospital and for ten months beyond this period until its integrated catheter laboratory opened. The opening of the integrated laboratory prompted a further shift in workload towards catheterising slightly higher risk patients at the district level.

7.4.2 CC Activity Profiles

It is understood that all Veinbridge General patients who underwent an elective CC investigation between April 1995 and December 1997, did so either at Veinbridge General or Heartwick Hospital. Although it was stated that 10% of referrals were made from Veinbridge General to other tertiary centres (see Figure 5.1), it is assumed that these referred to other patient referrals.

As stated in §5.2.3, district services were introduced to Veinbridge General in May 1996. Initially, district services were provided to compensate for the temporary loss of catheter laboratory capacity at Heartwick Hospital, from May 1996 to March 1997. This presented opportunities to provide local CC services at Veinbridge General and a feasibility study for the development of a permanent district service.

The use of the district service at Veinbridge General enabled work to be shifted out of the tertiary level and led to an overall increase in elective activity as shown in Figure 7.8. The district service at Veinbridge General thus illustrated a permanent shift and expansion of activity. By contrast, the district service at Ribsley General was involved in a temporary expansion followed by a shift. As data on elective CC investigations for Veinbridge General patients only was not available, this graph was derived by making some estimates.

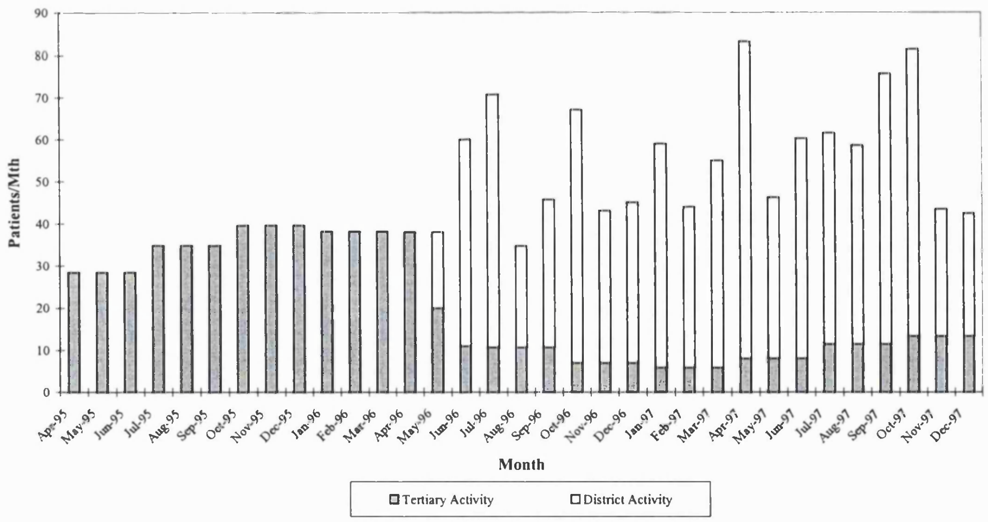


Figure 7.8 Shift and Expansion of Elective CC for Veinbridge General Patients (NHS only. Sources: Heartwick Hospital, Veinbridge General and Cardiocare)

The number of elective CC procedures, of patients referred from Veinbridge General, which were carried out at Heartwick General were estimated. From Heartwick Hospital's database, quarterly data was extracted for patients registered with GPs in the district where Veinbridge General is located (the host district) and the surrounding districts. Of these patients, those from the host district form the majority. They will primarily comprise referrals from Veinbridge General, but may also include a few referrals from other district hospitals and direct referrals by GPs. Simple average monthly rates were calculated in order to present these tertiary data on the same graph as the monthly district data (as with the Ribsley General case).

It can be seen from Figure 7.8 that, unlike the Ribsley General case, the increase in overall activity was sustained by an increase in demand for CC.

Data were not available for delays experienced by Veinbridge General patients, for a CC investigation. The consultant cardiologist at Veinbridge General reported that the average waiting time for a CC investigation was under control as sufficient funding had been available to expand the capacity, as illustrated in Figure 7.8. He prioritised his patients on his CC waiting list into three categories, routine, soon and urgent. His target waiting times were: more than 12 weeks for routine cases; 6 to 12 weeks for those classified as requiring catheterisation soon; and, 4 to 6 weeks for urgent cases.

7.4.3 Evidence of Stimulated Demand

As with Ribsley General, there was evidence of the district service stimulating demand at Veinbridge General. Changes in demand for OP appointments, elective CC services and invasive treatments were investigated. At Veinbridge General, evidence was found of demand being stimulated for OP appointments, elective CC services and invasive treatments. The issue of the appropriateness of demand is considered in §7.5.

Unlike the case of Ribsley General, the view of the consultant cardiologist at Veinbridge General was that the district CC service had stimulated demand for *OP appointments*. This was demonstrated by an increase in the number of new cardiology OP referrals to Veinbridge General, as shown in Figure 7.9. This increase may be due to either increases in the GP consultation rate or increases in the GP referral fraction. The interviews suggested that either of these factors could have increased but that the case mix of the patient population had not altered.

The consultant at Veinbridge General stated that the increase in referrals for new OP appointments had presented a new problem of increased waiting times for patients on the OP waiting list. This was an unintended and undesirable side effect of the introduction of district services. He had subsequently attempted to alleviate pressure on the system by reducing the number of follow-up appointments.

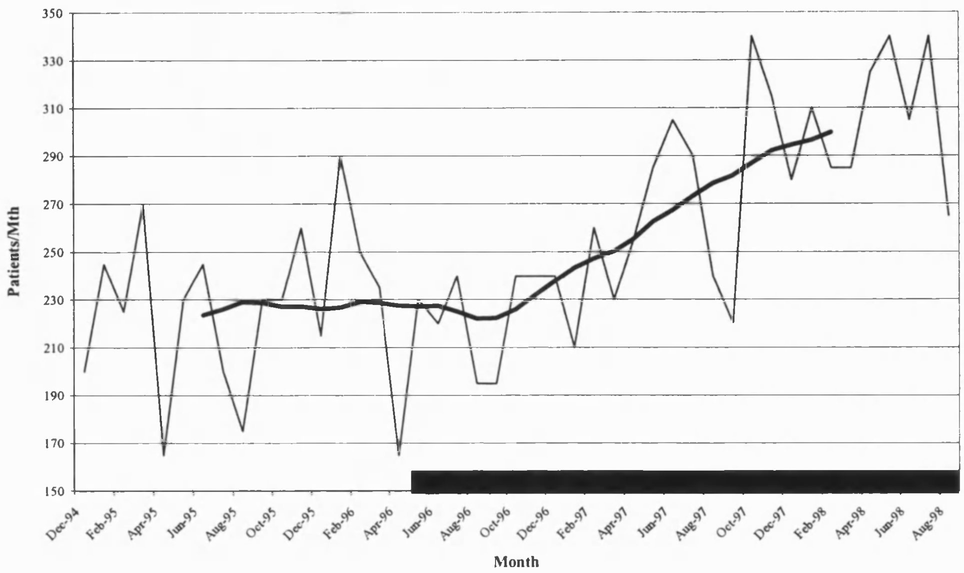


Figure 7.9 New Referrals for a Cardiology OP Appointment at Veinbridge General
(NHS only. The black block indicates the duration of district services. The change in the trend is highlighted by a 12-point centred moving average through the series. Source: Veinbridge General)

It was reported by the consultant cardiologist and the hospital manager at Veinbridge General that the OP rate had increased in response to the increase in demand. Given the comments of the consultant cardiologist at Veinbridge General, the increase in the OP rate was obviously insufficient to meet demand. The OP waiting list and average waiting time was rising because the number of referrals for OP appointments had exceeded the activity rates. OP activity data was provided and although they reflected a steady rise, they were rejected as unreliable due to the presence of a number of inconsistencies.

Given that a permanent CC service had been introduced to Veinbridge General, involving a large financial investment, it was necessary to have sufficient demand to sustain the service. The main source of demand for an elective CC investigation is patients assessed as OP services. Emphasis had been placed on marketing the district service. Marketing the district service was explicitly discussed in the business case which presented the argument for the construction of the integrated catheter laboratory at Veinbridge General. This was in contrast with the relatively low marketing strategy at Ribsley General. Demand for the Veinbridge service was also generated from within the private sector. Therefore, stimulating an increase in OP referrals was intentional, but the large extent to which demand was stimulated was unexpected and undesirable.

Data on the number of referrals for *an elective CC investigation* was not available. However, the reports that the OP rate rose suggested that these referrals had increased. As was stated in §6.5.2, the referral rate for an elective CC investigation is a fraction of the OP rate plus the referral rate of new electives from inpatients. The numbers of new referrals from inpatients were negligible. Therefore, the stimulation of demand for OP appointments had produced further demand for an elective CC investigation.

There was also evidence that there was an increase in the OP to CC referral fraction (a reduction in the referral threshold) from the interview with the consultant cardiologist. He stated that the fraction of patients seen at an OP appointment who were referred on for a CC investigation increased following pressure from patients and GPs. However, he declared that waiting times did not influence his referral decisions. The consultant cardiologist at Heartwick Hospital also stated that waiting times did not influence his referral decisions. These statements are, perhaps, unsurprising given that both cardiologists are enthusiastic CC operators in conducting both investigations and interventions, and adopting the latest techniques, such as coronary stenting. They could be described as 'aggressive' operators as discussed in §6.5.2. Given the 'aggressive' referral environment at Veinbridge General, the skills effect on demand could potentially lead to periods of over-referrals by juniors. The consultant cardiologist agreed with this but he also stated that the skills effect on demand would not play a role as he reviewed all referral decisions and thus corrected any tendency by juniors to over-refer or under-refer.

Demand was also stimulated for *invasive treatments*. The increase in the elective CC rate resulted in an increase in the referral rate for invasive treatments. The variation in the fraction of Veinbridge General patients who were selected for invasive treatments following elective investigation, is shown in Figure 7.10. Decisions for some patients were subject to review and, as the final decisions were not recorded, the actual referral fractions are not known. As with the case of Ribsley General, there did not appear to be any discernible trend. However, this conclusion can only be tentative, given the lack of data.

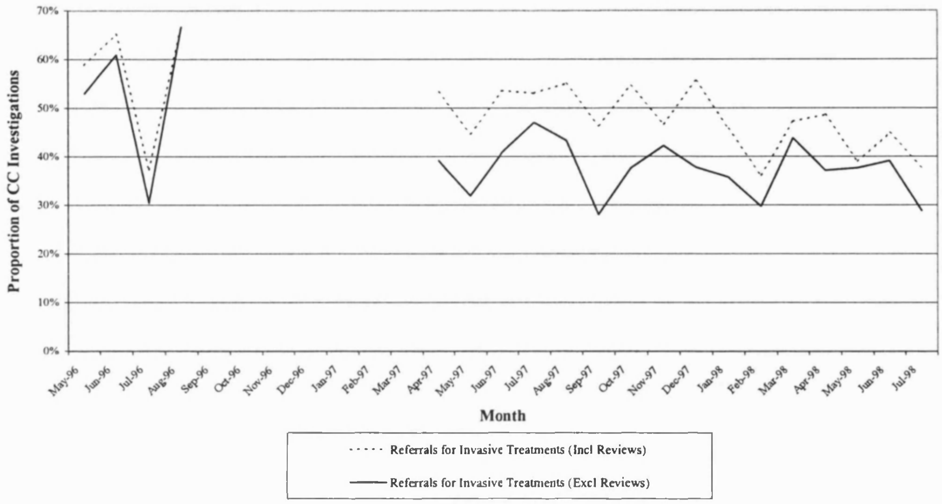


Figure 7.10 Invasive Treatment Referral Fraction for Veinbridge General Patients
(NHS only. Following elective investigation only. Data for the period September 1996 to March 1997 was lost. On average, between 11% and 17% of referrals were for coronary angioplasty and between 29% and 32% were referred for bypass surgery. Source: Veinbridge General)

7.4.4 Cost-Effectiveness and Efficiency Issues

The consultant cardiologist stated that the service would not have continued had it not been possible to demonstrate that the service was cost-effective. However, it was very difficult to qualify this with data.

As with the case of Ribsley General, the district service at Veinbridge General demonstrated that CC investigations could be safely carried out at the district level. In fact, the consultant cardiologist was so confident in its safety that, following the opening of the integrated catheter laboratory, he lowered the threshold for district investigation to include slightly more complex cases.

There was very little cost data available. Veinbridge General assumed responsibility for the contract for CC investigations in March 1997 when Heartwick's catheter laboratory re-opened. Charges to purchasers were made on a cost per case basis. The consultant cardiologist at Veinbridge General stated that his hospital matched Heartwick Hospital's prices for CC investigations and the service 'broke even'. As for patients referred from

Ribsley General, Heartwick Hospital charged £450 per patient catheterised as a day case and £675 per patient catheterised on an inpatient basis.

The points that were raised about costs in §7.3.5 with regard to the Ribsley General district service, also apply to the service at Veinbridge General. With a district service at Veinbridge General, costs were reduced due to the ability to catheterise more patients on a day case basis. Also mentioned in §7.3.5, were the costs incurred by a certain proportion of patients investigated at the district level who, requiring an interventional CC, have to undergo a second procedure at the tertiary level. If that patient had been investigated at the tertiary level, they would have undergone treatment at the same time, and therefore only have incurred the costs, and been exposed to the risks, associated with one procedure. On average, somewhere between 11% to 17% of Veinbridge patients are referred on for interventional CC, following an elective CC investigation. As with the Ribsley General case, given that this is a sizeable proportion, there seems to be some appeal in having CC conducted solely at the tertiary level. Based upon these assumptions and the March 1997 figures, a district service would be more efficient (on a cost/case basis) if it avoided a high proportion of patients undergoing their investigation as an inpatient. Increasing the interventional CC proportion cancelled out this potential advantage. See Appendix E, E4b for further details. However, it is also necessary to consider that, assuming there were no complications, over 80% of patients did not need to be investigated at the tertiary level.

The situation altered in favour of the district service when the integrated laboratory opened. With the mobile-based service (which was in place in March 1997), the cost/case was fixed but, as stated in §6.4.1, with an integrated laboratory, the cost/case declined as the volume of activity increased. Therefore, at sufficiently high volumes of activity, the district service would be more efficient. Allowing cardiologists from neighbouring districts to use the laboratory would boost the volume of activity. When drawing up the business case for an integrated laboratory at Veinbridge General, the intention to ensure that the service was efficient was clearly stated.

7.4.5 Views of District Services

The consultant cardiologist at Veinbridge General was a strong advocate of district CC services. He grasped the opportunity presented by the temporary closure of the catheter laboratory at Heartwick Hospital to promote the development of CC services at Veinbridge General. He appreciated all the benefits of district services, described in Table 6.1, and mentioned further benefits, including the ability to provide a more comprehensive service to the local GPs.

In the previous section, it was mentioned that the consultant cardiologist believed that the district service had stimulated further demand from GPs and that this is indicated by the higher referrals for new OP appointments. However, the hospital manager at Veinbridge suggested that the increase in GP referral rates could not be totally attributed to the introduction of the district service because an increase in referral rates had been observed across various specialities.

The local health authority, in the Veinbridge General area, believed that the district CC service was highly regarded by the local GPs, and that this was reflected in their referral rates. The purchasers appreciated the benefits of having a district CC service, but they also expressed concerns about the increased pressure imposed by the expansion of CC services. Moreover, they stated that their public health officials were concerned about safety issues, even though patient safety had not been compromised and that the district service at Veinbridge General was operating within the recommended practice of the British Cardiac Society Council.

7.5 APPROPRIATENESS OF DEMAND

§6.5 discussed how the development of district services could stimulate further demand for cardiac services, and §6.6 addressed the issue of the appropriateness of this stimulated demand. In both the Ribsley General and Veinbridge General cases, evidence of the stimulation of demand was found. In this section, the issue of the appropriateness of demand is considered, in particular the appropriateness of the stimulated demand. Definitions of appropriateness were provided in §6.6.1.

As was stated in §5.4.2, it was not possible to audit individual patient records to establish the degree to which referrals for cardiac services were appropriate. Instead, the related issue of changes in the referral thresholds were considered to some extent. §7.3.4 reported upon increases and reductions in the referral threshold for an elective CC investigation for Ribsley General patients. §7.4.3, reported upon reductions in the referral thresholds for an OP appointment and an elective CC investigation for Veinbridge General patients. However, the implications for appropriateness are difficult to establish. If the tendency is to over-refer, then a reduction in the referral threshold will result in a higher number of inappropriate decisions (in terms of over-use). However, if tendency is to under-refer, then a reduction in referral threshold will result in a lower number of inappropriate decisions (in terms of under-use). In this study, it is only possible to make relative, not absolute, assessments.

In defining the appropriateness of a procedure in §6.6.1, I considered the requirement for a medical procedure to be timely and according to need. Delays are inevitable, given the scarcity of resources. In fact, some level of delay to CC is desirable; a patient's condition can improve and they can thus avoid the risks of undergoing catheterisation. However, delays are considered inappropriate when they become excessive.

The consultant cardiologist at Ribsley General prioritised the patients on the CC waiting list into two categories, routine elective and urgent elective, and attempted to catheterise patients in order of clinical priority. However, if the waiting time approached the *Patient's Charter* maximum of 12 months, it was necessary to distort clinical priority. This practice has been reported in the literature (CSAG 1993, 1996). Figure 7.4 presented the average waiting times for Ribsley General, which were for some periods excessive. It is perhaps difficult to appreciate this, given that averages are plotted and that they fall far short of the 12 month maximum. However, it is possible to deduce relative pressures from the shape of the graph. For example, waiting times obviously presented a greater problem in September 1995 compared with March 1997. Moreover, it can be deduced that the scale of this problem was significant, given that efforts were made to bring the waiting time down dramatically, and further interventions were made when the average waiting time rose again.

The consultant cardiologist at Veinbridge General also prioritised his patients on his CC waiting list. He prioritised into three categories, routine, soon and urgent.

Numerical data on waiting lists and waiting times for invasive treatments were not available. The consultant cardiologist at Heartwick Hospital stated that the average waiting times for coronary angioplasty were low, at 1 to 2 months, but the delays for bypass surgery were excessive, at approximately 1 year. The delay for a patient requiring invasive elective treatment may involve: a delay to be seen in an OP appointment; a delay to undergo catheterisation; and, a delay to undergo treatment. Reducing the waiting time to catheterisation will obviously be beneficial in reducing the overall delay.

In discussing the appropriateness of cardiac services, it is important to consider the sizeable number of undiagnosed patients with significant CHD, which was highlighted in §5.3.2. Concerns are frequently expressed by cardiologists and cardiac surgeons about the need to 'tap into' this pool of unmet need. Therefore, there is a natural tendency to take advantage of increased access to diagnostic facilities and thus reduce the referral threshold. However, there has to be a balance. During discussions of appropriateness, the consultant at Ribsley General expressed concerns about another service shift, open-access ECG testing. These have 'opened the flood gates' of inappropriate demand from GPs.

The consultant at Ribsley General accepted that some demand for CC could be postponed. He knew of some hospitals that used guidelines and protocols to suppress low priority demand. He expressed a preference for the former because they are more flexible.

The appropriateness of demand was not explored with the consultant cardiologist at Veinbridge General. However a comment can be made. Unlike the Ribsley General case, Veinbridge General was under pressure from the increase in referrals from GPs for OP appointments. The fact that Veinbridge General had responded by increasing the OP rate could suggest that this increase in demand was considered appropriate. On the other hand, the appropriateness could be questioned if these increases in activity were associated with waiting time targets distorting clinical priorities.

7.6 SUMMARY

This chapter described the experiences of district CC services at the case study centres. Whilst the two DGHs presented two contrasting histories of the use of district services, evidence was presented from both cases that the shift in CC services was not a simple service shift but involved the stimulation and suppression of demand for services. Three feedback mechanisms by which demand was stimulated were identified. These involved responses to: changes in waiting times; the increased knowledge of GPs and patients; and, changes in the skills of doctors who select patients for CC. The third feedback mechanism has not been described in the literature.

Understanding the interactions of these feedback mechanisms, their long-term implications, and the impact of changes to supply and demand variables is non-trivial. They involve dynamic complexity. As discussed in Chapter 4, dynamic complexity is the focus of SD. Therefore, there was potential for an SD analysis of the shift in CC services, based upon the case studies. Chapter 8 describes the conceptualisation process of the SD study.

CHAPTER 8

CONCEPTUALISATION IN SYSTEM DYNAMICS TERMS

8.1 INTRODUCTION

In Chapter 7, the case study experiences of district CC services were described, and the potential for an SD analysis was demonstrated. This chapter presents the first phase of the SD study, the conceptualisation phase, which followed well established guidelines (Randers 1980, Richardson and Pugh 1981, Sterman 2000).

As stated in §5.4.2, to embark upon conceptualisation, it is necessary to describe the context and characteristics of the central focus of the study verbally. The central focus was the effects of the shift in CC services in the NHS. Its context and characteristics have been described in previous chapters. The key policy questions were stated in §5.4.2.

The following sections explain how the conceptualisation process was completed. By producing reference modes, the central focus was described in graphical terms (§8.2). Reference modes corresponding with several simple uses of district services were constructed (§8.2.1) before those for the more complicated cases of Ribsley General and Veinbridge General (§8.2.2 and §8.2.3 respectively). A conceptual model was produced to convey the basic mechanisms (or structure) which were understood to be responsible for the system behaviour (§8.3). Both the model structure (§8.3.1) and the process by which the model was constructed (§8.3.2) are discussed. The causal hypothesis, which was encapsulated in the research hypothesis (see §5.2) also formed part of the conceptualisation process by describing the assumed relationship between the behaviour and structure (§8.4). Finally, the intended purpose of the model was clarified (§8.5.). The chapter is summarised in the final section (§8.6).

8.2 DERIVATION OF THE REFERENCE MODES

Chapter 7 described the history of the shift in CC services to Ribsley General and Veinbridge General. In SD, for problems and issues that have a history, historical reference modes are constructed to present an unambiguous graphical description of the problematic behaviour. An SD study could have two further sets of reference modes (Richardson and Pugh 1981). A second set could define more desirable behaviour. In cases where different policies have been used in the past, a third set of reference modes would be produced showing observed policy behaviour. Reference modes provide a key focus for the study. They indicate what factors are of interest, and therefore what should be included in the model. They have an important role in testing the simulation model. It is essential that the simulation model can qualitatively replicate the historical reference modes. The reference modes also provide a target for the policy analysis process by giving a graphical description of more desirable behaviour. Ideally, reference modes are constructed using numerical data. However, such data are not always available. Hypothetical reference modes may be drawn to substitute for, or supplement, the modes that are based on the available numerical data.

8.2.1 Representing the Effects of Different Uses of District Services

Different uses of district services may be defined in terms of the duration of the district service and its impact on the CC investigation rate. Complicated uses of district services were employed at Ribsley General and Veinbridge General involving several shifts and expansions in activity. Figure 8.1 illustrates some simple uses that follow on from the discussion in §6.3.1, supporting: a *temporary expansion* in activity by augmenting the tertiary-based service; a *temporary shift* in workload away from the tertiary level; a *permanent shift* away from the tertiary level; and, a *permanent shift and expansion* in activity.

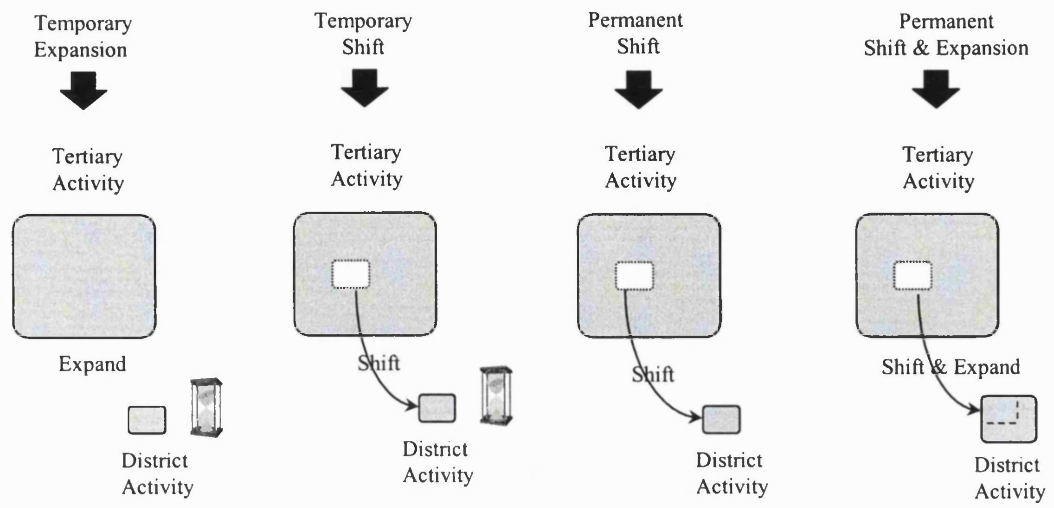


Figure 8.1 Simple Uses of District Services
(Permanent also refers to long-term, semi-permanent)

Defining reference modes for the above simple examples provided a focus for the construction of a *general* model of the shift in CC services. For this study, the intention was to construct a general model of the shift in the balance of CC services, and to calibrate it to the cases of Ribsley General and Veinbridge General.

Figures 8.2 to 8.4 and 8.6 illustrate the basic principle of the use of reference modes. Only a selected number of variables are shown. In order to focus on the basic trends, it is assumed that there is no random variation in the monthly referral rates and activity rates. For simplicity, only waiting list removals that constitute patient activity are considered; all other waiting list removals such as deaths on the waiting list are ignored. Furthermore, the delays in establishing the district service are omitted. The focus is on patients who are screened for CC at the DGH of interest. How spare tertiary capacity, released by the shift in activity to the district level, is used remains an open question. The time frame for the effects of the development of district services to propagate is estimated to be a few years.

Figure 8.2 shows the modes of desirable behaviour implicit in each use of district services represented in Figure 8.1. The modes refer to the elective CC investigation referral rate, total investigation rate, district-based and tertiary-based investigation rates and average CC investigation waiting time. The graphs for the elective referral rate and investigation rate are superimposed, so that changes in the waiting list and average waiting time may be deduced. Also shown is the degree of pressure imposed by patients and GPs to refer and

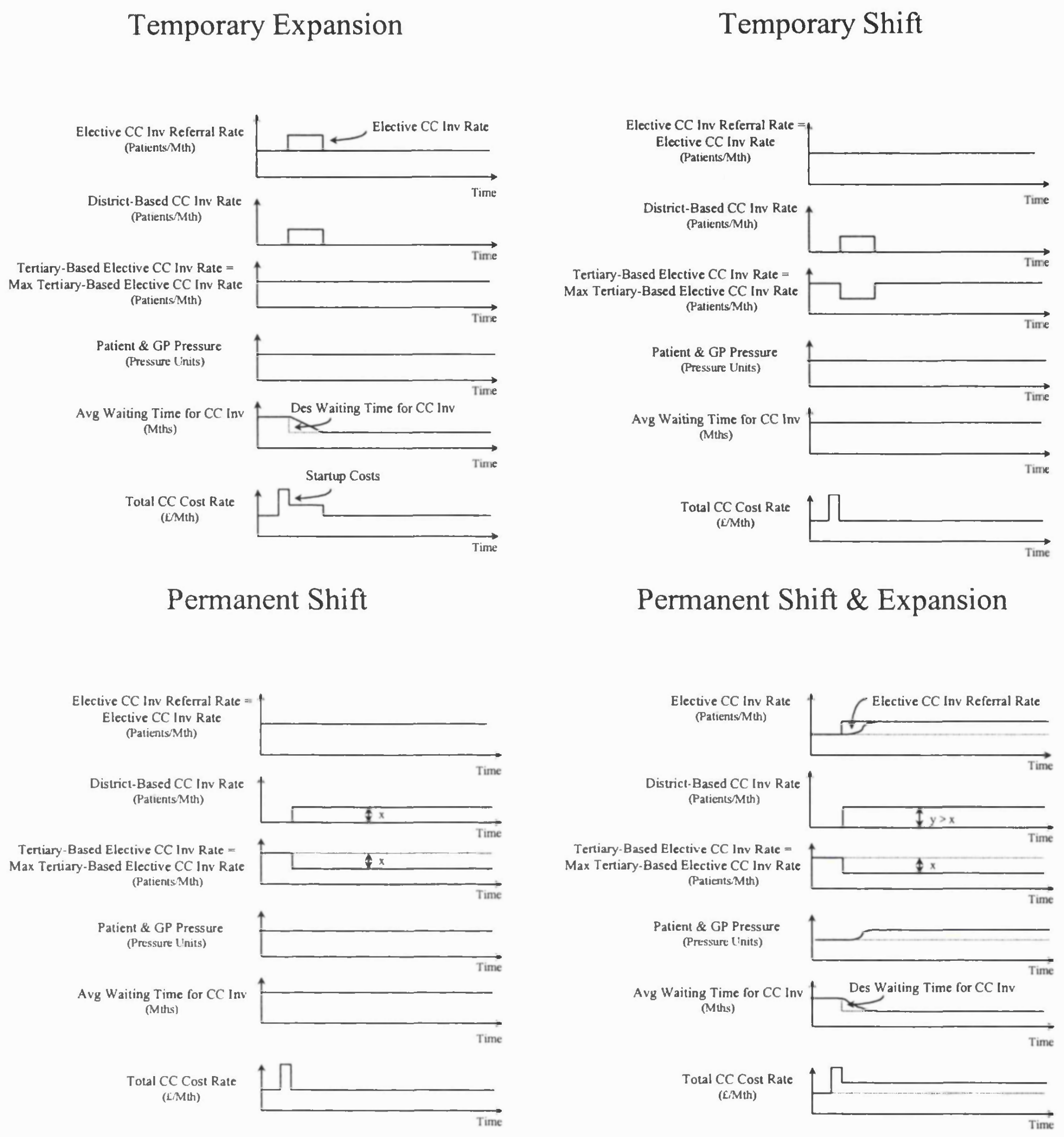


Figure 8.2 Simple Uses of District Services: Desired Behaviour Modes

the overall monthly cost rate for CC services. The latter reflects the costs of having district services. Start-up costs refer to the initial costs incurred to set up the district service, such as the costs of preparing the site for the mobile catheter laboratory and hire costs for the electricity panel.

The figure shows expansions in activity (Temporary Expansion and Permanent Shift & Expansion) producing a desired reduction in the average waiting time (5th graphs). By contrast, shifts in workload alone (Temporary Shift and Permanent Shift) involve the use of district services (2nd graphs) to ensure that reductions in tertiary-based activity (3rd graphs) do not lead to increases in the average waiting time. In three cases, the reference modes reflect the desire that the elective referral rate (1st graphs) and pressure to refer (4th graphs) remain constant so that changes in the average waiting time would be attributed to changes in the investigation rate alone. The exception is the case of the permanent shift and expansion. To support the permanent increase in activity levels, it is assumed that referral rate (1st graph) would rise so that the waiting list would not be drained completely. Therefore, an increase in the pressure to refer (4th graph) would be welcomed.

The system behaviour will be considerably different to that desired, if excessive levels of latent demand are stimulated by the district service and insufficient capacity, either in terms of funding or expertise, is available to maintain the desired waiting time. The expected problem behaviour shown in Figure 8.3 corresponds with the permanent shift and expansion policy. This reflects the assumption that there is insufficient capacity for elective CC investigations. The stimulation of demand could also lead to capacity shortages with OP services. Although OP services are not represented, they would follow the same principles.

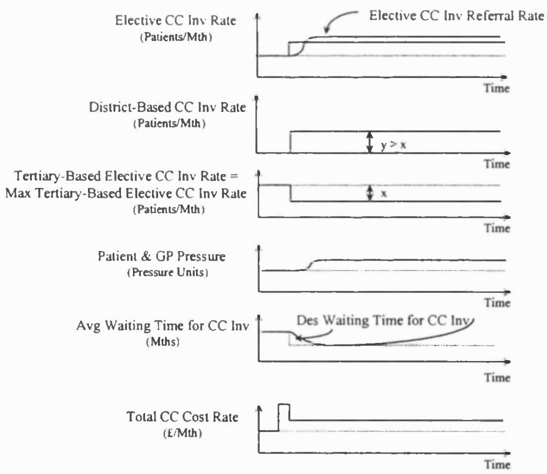


Figure 8.3 Expected Problem Behaviour With Insufficient Funding

8.2.2 Ribsley General Reference Modes

District services at Ribsley General supported temporary expansions and shifts in CC services on two occasions. The district service was initially used to sustain and expand upon a temporary increase in activity that had originally begun at the tertiary level, in order to bring the average waiting time down to a more reasonable level. After the district service was withdrawn, the average waiting time rose again. This was reversed when the district service was reintroduced to produce a further increase in activity. The shifts in workload were intended to both compensate for the temporary closure of tertiary facilities and release tertiary resources for other uses, both of which would have been reflected in reductions in tertiary-based CC investigation rates.

Just considering the first expansion and shift in CC services and assuming the second did not take place, the above description could be represented by the reference modes shown in Figure 8.4 (applying the same simplifying assumptions as those above). These reference modes also extend to OP services.

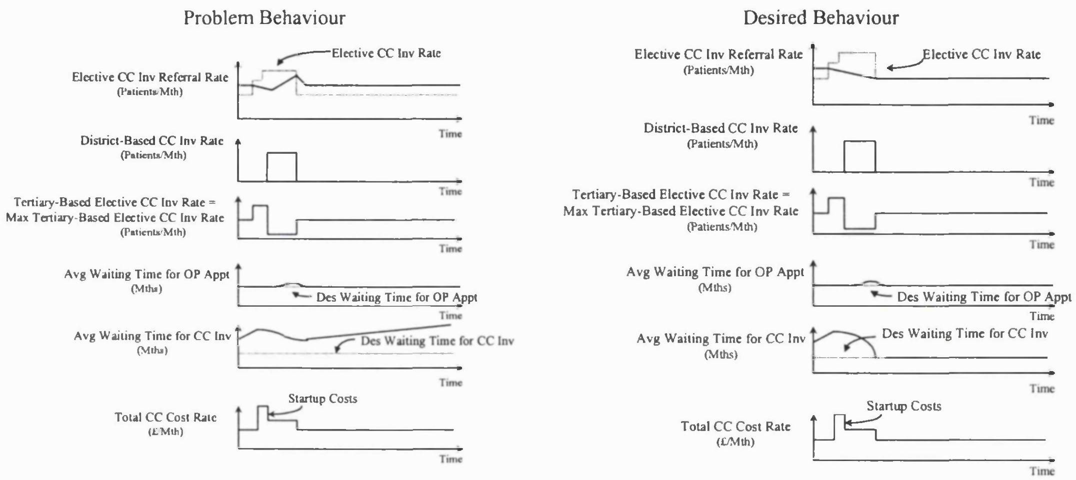


Figure 8.4 Reference Modes Associated with a Temporary Expansion Followed by a Shift Policy

The problem of excessive waiting times for a CC investigation (5th graph: Problem Behaviour) arises from the tendency for referrals for a CC investigation to exceed the available capacity (1st graph: Problem Behaviour) so that capacity increases are repeatedly called upon. Even when additional capacity is available by the use of the district facility, the benefits are cancelled out to some extent by the district service stimulating further demand for CC (1st graph: Problem Behaviour). A small temporary increase in the OP waiting time might be tolerated (4th graph: Desired Behaviour) as demand would only be stimulated temporarily and there would be some slack in the system to bring the waiting time back down to the desired level. Therefore, only the stimulation of demand for CC services would constitute a problem.

It was assumed that there was a desire for temporary increases in CC activity (1st graph: Desired Behaviour) to solve the problem of the excessive waiting time and that, when the target average waiting time had been achieved, it was maintained (5th graph: Desired Behaviour). Implicit in this desire was the assumption that after the district service has been withdrawn, the elective referral rate will not exceed the elective investigation rate (1st graph: Desired Behaviour). Furthermore, ideally, an improvement from the problem behaviour will be achieved without the need for additional resources (6th graph: Desired Behaviour).

Let us consider the removal of all the simplifying assumptions that applied to Figures 8.2 to 8.4 and add the second shift and expansion in CC services. Historical reference modes of the problem behaviour for the Ribsley General case were constructed from the graphs that were introduced in Chapter 7 for the CC services, and these were supplemented with simple hypothetical modes for the OP services (see Figure 8.5). The modes for the OP services present an ideal situation with no OP capacity shortages. However, small temporary increases in the waiting time and waiting list could also be considered to reflect no OP capacity shortages as these increases would not cause concern.

Note that, these reference modes differentiate between the average time spent on the waiting list (waiting time for existing waiting list patients) and the average estimated waiting time for new patients joining the waiting list (waiting time for new waiting list patients). Furthermore, as stated in §5.4.3, the length of the waiting list was also considered in addition to the average waiting time because both reflect different aspects of access times. The latter represents the delay to a health service, whilst the former represents the expressed need for that service. Therefore, more desirable behaviour would involve both the waiting list and waiting time goals being achieved, ideally, without increasing resource levels, and demand being reduced to more manageable levels.

These reference modes refer to the period May 1995 to March 1998. A longer time scale was considered for the model-based experiments. A simulation model that can reproduce problematic behaviour over one particular time frame may then be employed to predict future trends and thus extend the time scale. Obviously, this will be subject to certain assumptions about the future. The model's ability to replicate the historical reference modes is demonstrated in Chapter 9 (see §9.4.2). The time scale for the problem reference modes was extended as part of the base case analysis which is presented in Chapter 10 (in §10.2.1).

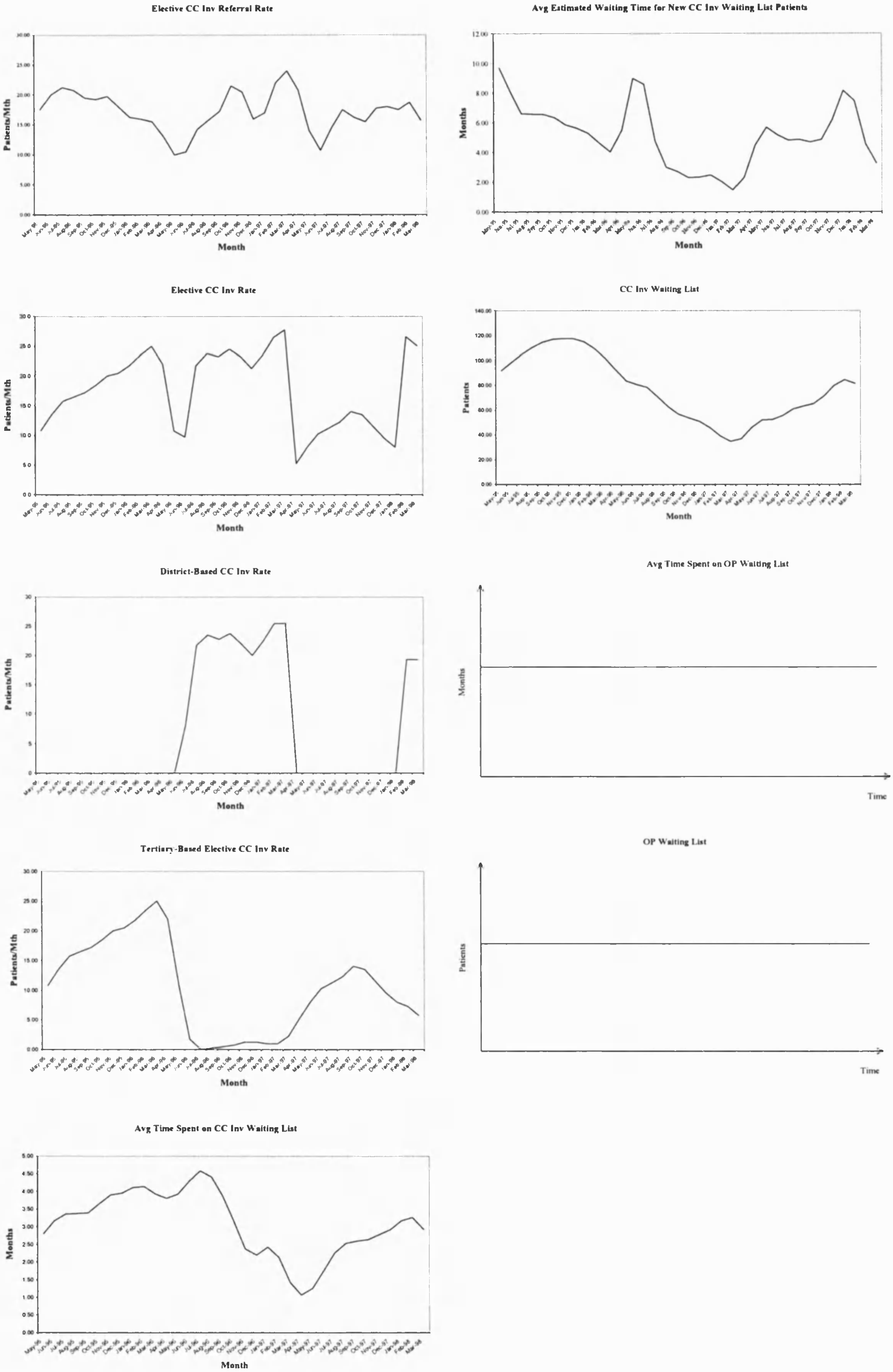


Figure 8.5 Historical Reference Modes for Ribsley General
(Real data for the CC investigation variables and hypothetical data for the OP variables. The real data has been smoothed with a centred 2-point moving average)

8.2.3 Veinbridge General Reference Modes

District services at Veinbridge General supported permanent shifts and expansions of CC services. These shifts and expansions were not intended to reduce the average waiting time for a CC investigation. Instead, as part of a long term strategy, they were intended to increase the availability of CC services. Firstly, by shifting the routine workload to the district level, tertiary resources could be released for more complex cases. This was particularly important during the temporary closure of the tertiary facilities for essential repair work. Secondly, by increasing the overall capacity, more routine investigations could be carried out.

First considering the shifts and expansion that occurred when the service first opened (and applying the same simplifying assumptions that referred to Figures 8.2 to 8.4), the reference modes might look something like those in Figure 8.6.

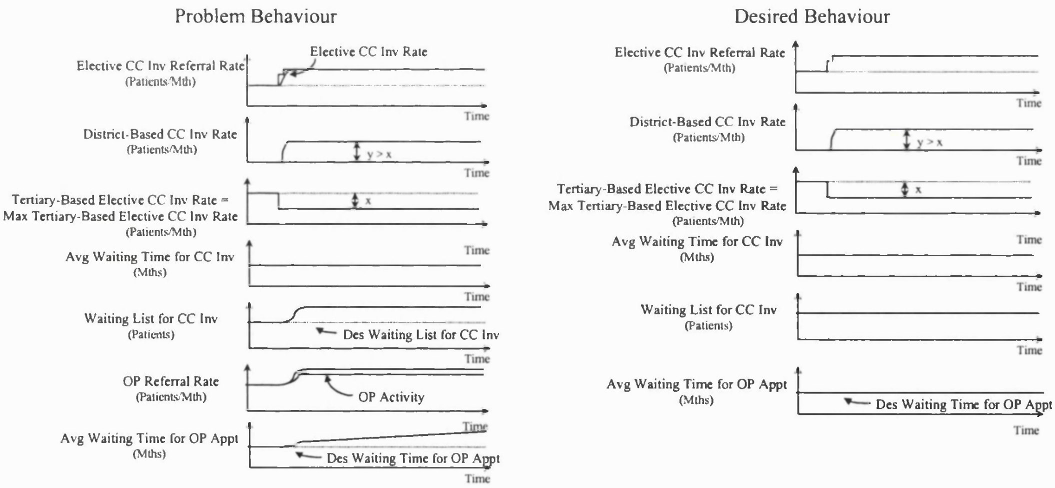


Figure 8.6 Reference Modes Associated with a Permanent Shift and Expansion Policy

The shift and expansion in elective CC capacity would be desired to support an increase in referrals for routine CC investigations (1st graph: Desired Behaviour) without compromising the average waiting time (4th graph: Desired Behaviour). This increase in referrals could reflect the investigation of more patients already in the system (selection of more 'grey area' cases) as soon as the additional capacity was available. A further increase in referrals could reflect an increase in new patients coming into the system (due to the increase in OP referrals, stimulated by the introduction of district services). The OP rate would have to rise to bring more patients forward for a CC investigation and also ensure that the OP waiting times were not compromised (6th graph: Desired Behaviour). However, if the level of stimulated demand for OP appointments exceeded the available capacity (6th graph: Problem Behaviour) then the average OP waiting time would rise (7th graph: Problem Behaviour). Although the CC waiting time goal would be maintained (4th graph: Problem Behaviour) as desired (4th graph: Desired Behaviour), the CC investigation waiting list would exhibit increases (5th graph: Problem Behaviour). This would be due to periods where the elective CC investigation rate lagged behind the elective CC referral rate (1st graph: Problem Behaviour). The base case analysis revealed a further cause (see §10.3.3).

A hospital consultant might not consider the increased waiting list to constitute a problem as the desired waiting time would have been maintained. However, someone who would be more concerned about costs, typically a hospital manager or purchaser, might disagree. It is the increase in the waiting list that requires the elective CC investigation rate to rise in order to maintain the desired waiting time. A further rise in the investigation rate, to exceed the referral rate, would be necessary to bring the waiting list back down. Therefore, an increase in the CC investigation waiting list could be viewed as another symptom of the problem behaviour and the maintenance of the waiting list goal would reflect another aspect of desired behaviour (5th graph: Desired Behaviour).

Let us now consider the removal of the simplifying assumptions and add the second shift and expansion in CC capacity. The available numerical data was deemed inadequate for the purpose of constructing reference modes of the Veinbridge General case. Subsequently, hypothetical data was used.

Figure 8.7 shows the historical reference modes for the Veinbridge General case. These graphs represent the period April 1995 to August 1999 and are based upon descriptions of the behaviour of the system, by the Veinbridge General collaborators. As with the case of Ribsley General, after demonstrating the model's ability to replicate the historical reference modes (see §9.4.2), the time scale for the problem reference modes was extended (see §10.3.1).

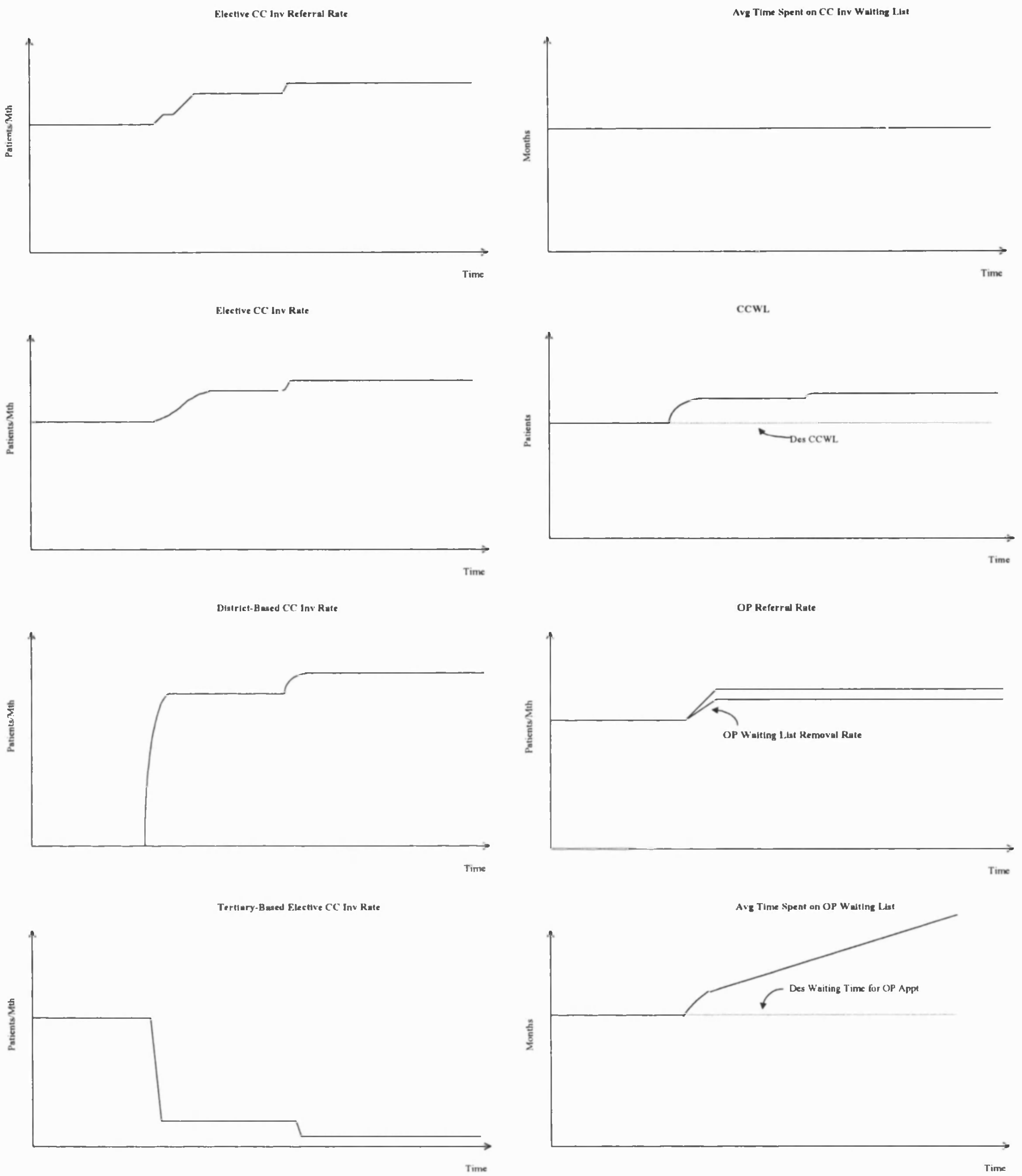


Figure 8.7 Assumed Historical Reference Modes for Veinbridge General

As with the case of Ribsley General, meeting the desired waiting times and waiting list lengths, ideally, without increasing resource levels and controlling demand to more manageable levels, would constitute more desirable behaviour.

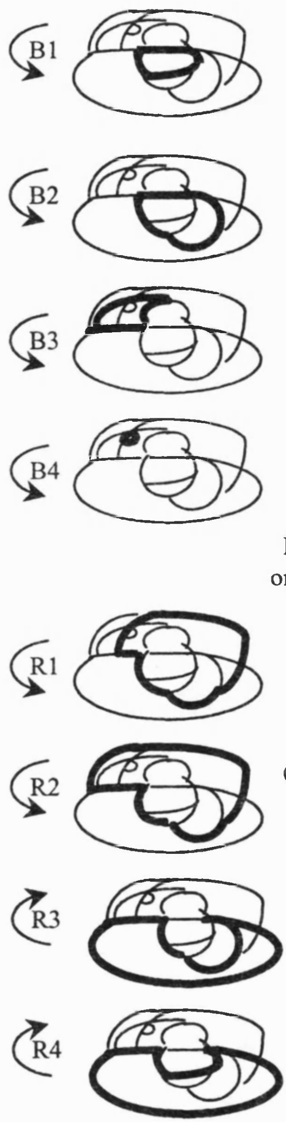
8.3 CONSTRUCTION OF A CONCEPTUAL MODEL

The stimulation of demand led to CC capacity shortages for Ribsley General patients and, OP capacity shortages and increases in the CC investigation waiting list for Veinbridge General patients. Although the effects of the shift in CC services at the two case study centres differed, there existed a common structure underlying these effects. In SD, a conceptual model in the form of a causal-loop diagram (also known as an influence diagram) is often used to present the basic feedback structure that is understood to underlie the problematic behaviour. The conceptual model formed the basis of the simulation model which was used to replicate the different effects (model outputs) for the two case studies by specifying two different sets of model parameters (model inputs).

A preliminary causal loop diagram was constructed portraying the generation of referrals for elective CC investigations at the district level and the delivery of elective CC investigations at both the tertiary and district levels. As the focus was on the use of district services, the model only considered elective investigations. To explicitly add emergency investigations would have cluttered the model with unnecessary detail. This preliminary model was based upon the insights from: the literature; observational work conducted at the collaborative centres; interviews with collaborators about their experiences of district services; and, analysis of various data supplied by the collaborators. Revisions were made in response to comments made by collaborators. The resulting conceptual model is presented in §8.3.1. The actual process of its development is described in §8.3.2.

8.3.1 The Basic Feedback Structure

Figure 8.8 shows the revised causal loop diagram. It is composed of four balancing information feedback loops (labelled 'B') and four reinforcing information feedback loops (labelled 'R'). In §4.3.3, the basic structure of an information feedback loop was described, simple illustrations of balancing and reinforcing loops were provided, and the labels 's'and 'o' were explained. The eight mini replicas of the model on the left hand side, indicate where the individual loops lie.



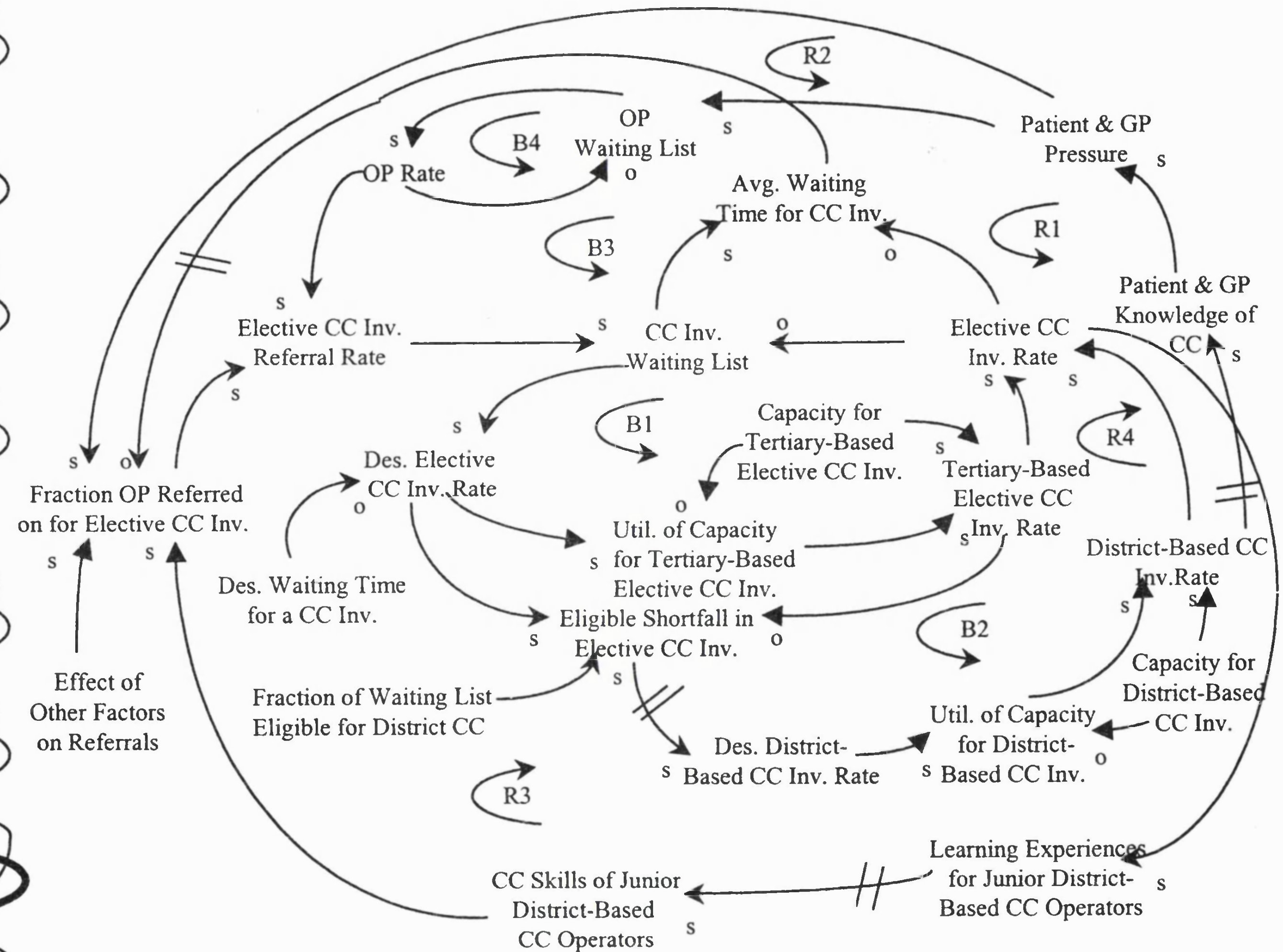


Figure 8.8 The Conceptual Model: Seeking a Desired Waiting Time (2 lines - Delay)

Loop B1 represents the *balancing* process which ensures that for patients referred for an elective CC investigation from a given DGH, the tertiary-based elective CC investigation rate is adjusted to its desired level, provided sufficient capacity is available. The desired investigation rate is determined by an implicit waiting time goal for new patients joining the waiting list. For example, if there were 60 patients on the waiting list and it was desired to investigate a new patient just joining the waiting list in 3 month's time, then the desired activity rate would be 20 patients per month (for simplicity, all deaths and other waiting list removals are ignored).

The variable "Avg Waiting Time for CC Inv" represents the average estimated waiting time for new patients joining the waiting list. The average time spent on the waiting list (waiting time for existing patients on the waiting list) is not shown although it is represented in the simulation model. When the system is in equilibrium, the average waiting time for new patients joining the waiting list will equal the average waiting time for existing patients on the waiting list.

It should also be noted that the consideration of maximum waiting times (rather than average waiting times), such as those which are specified in a contractual agreement or the *Patient's Charter,* is not beyond the capability of a SD analysis. However, average waiting times were easier to model and, therefore, presented a good starting point.

Loop B2 depicts the development of CC services at the DGH to compensate for shortfalls in tertiary activity. It thus introduces a further *balancing* process. The shift in CC activity is only relevant to the patients who are eligible. The overall capacity to deliver elective CC investigations is determined by both physical and funding constraints. Shortfalls in tertiary capacity may be triggered by a capacity loss due to the tertiary catheter laboratory undergoing repairs, or other construction work, or a desire to reallocate capacity to more complex cases. Shortfalls may also be triggered by a reduction in the desired waiting time. Delays may occur in both perceiving a shortfall in activity, with respect to the desired level, and in producing a service at the district level. The co-ordination between capacity adjustments at the district and tertiary levels is based on the assumption that there are close links between the tertiary centre and its referring DGH. This is consistent with the British Cardiac Society guidelines on district services (BCS 1994a, 1997).

The balancing loops B3 and B4, and reinforcing loops R1, R2, R3 and R4 all relate to side-effects of the new service development which may affect the demand for elective CC.

The *balancing* loop B3 represents elective CC investigation referral rates adjusting according to changes in the perceived waiting times for a CC investigation. The development of district services may result in increases in overall (district + tertiary) capacity for elective CC investigation. Capacity influences patient throughput, which in turn affects the average waiting time for a CC investigation. The cardiologists, who evaluate and screen patients for CC, may respond to shorter waiting times by increasing their referral rates. Excessively high waiting times may induce cardiologists to suppress demand. Therefore, the first demand inducement process, which has been discussed (relating to the waiting time effect on demand), is represented by loop B3.

Feedback loops R1 and R2 collectively represent the second demand inducement process which has been discussed (concerning the knowledge effects on demand). These loops act to *reinforce* the growth in demand and elective CC activity rate. Opening a service facility at the local DGH will lead to patients and GPs becoming more knowledgeable about CC, especially those from the host district. Loop R1 represents increasing knowledge about CC resulting in increased demand for cardiology OP appointments where patients are screened for a CC investigation. Higher levels of cardiology OP activity will subsequently arise assuming that the desired cardiology OP waiting time is to be maintained. This balancing process, labelled B4, is similar to that represented by loop B1. Loop R2 depicts the impact of increased knowledge about CC on the fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation. Increasing knowledge leads to patients and GPs imposing greater pressure on cardiologists to recommend a CC investigation. A higher proportion of patients may also be encouraged to accept their cardiologists' recommendation for a CC investigation. It is typical for some patients to refuse to be catheterised due to anxiety about the procedure and its associated risks. Some of this small patient group may be persuaded to undergo a CC investigation, especially given the opportunity to have it carried out at their local hospital, in familiar surroundings and remain within the care of their local cardiologist.

The third demand inducement process discussed earlier (concerning the skills effect on demand) is represented by feedback loops R3 and R4. These feedback loops represent the processes which *reinforce* increases in the elective CC investigation demand and activity levels. Increasing the number of CC investigations carried out by district-based CC operators, most typically achieved by the use of a district facility, will increase the number of learning experiences for district-based CC operators in training. This will accelerate their gain in expertise in identifying patients who could benefit from being catheterised. Increasing their exposure and involvement in CC investigations will also increase their confidence levels. Both these effects may result in higher numbers of referrals. If the desired waiting time is to be maintained, then these increases in demand will reinforce the growth in district-based activity and demands for increases in tertiary-based activity.

The conceptual model also depicts the effect of other factors on referrals such as the development of a permanent district facility (this factor would be endogenised in a more sophisticated model).

Let us briefly return to the *balancing* feedback process represented by loop B1. An alternative goal which may drive the desired activity rate is a desired waiting list length rather than a desired waiting time. For this policy, the desired activity rate equals the perceived referral rate (to maintain the existing waiting list size) plus an adjustment (to address any discrepancies between the desired and actual waiting list size). The corresponding causal loop diagram is shown in Figure 8.9. Compared with Figure 8.8, the differences are the way in which the desired activity rate is calculated (see variable "Des Elective CC Inv Rate"), and the introduction of further feedback processes (these are not highlighted). The policy that the cardiologists used was that which sought the desired waiting time (represented in Figure 8.8). However, preliminary simulation analysis suggested that there were some advantages to seeking a desired waiting list length (represented in Figure 8.9). The analysis of this issue is presented in Chapter 11.

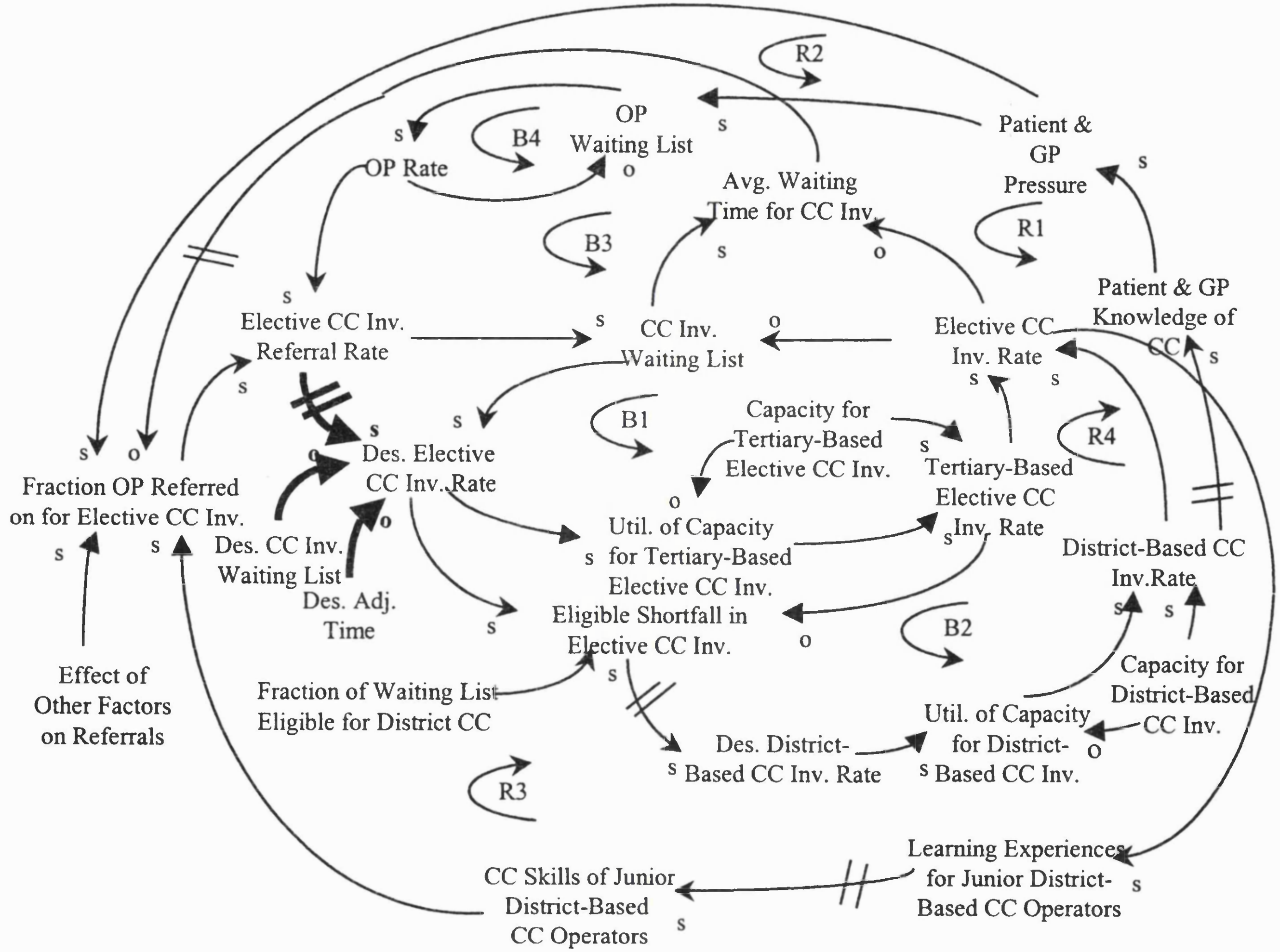


Figure 8.9 The Conceptual Model: Seeking a Desired Waiting List Size
(Two lines - Delay)

8.3.2 Conceptual Model Development

The initial causal loop diagram was refined by seeking feedback from a consultant cardiologist from each of the three collaborative centres, Ribsley General, Veinbridge General and Heartwick Hospital. The model was revised to incorporate the responses given at each stage.

The broad aim of these meetings was to convey the focus of the study (and model) and present the model in a comprehensible form so that their views of the model could be elicited. First, the key policy questions (see §8.1) were stated to indicate the focus of the study. To explain how these policy questions would be addressed, a brief overview of the processes of SD modelling was given. The importance of checking each stage for errors and promoting a degree of model 'ownership' was emphasised and these meetings were presented as part of this process.

It was also explained that, although the model would be calibrated to the experiences of the two DGH case studies, the aim was to produce a general model of the feedback mechanisms involved in the evolution of district CC services. This point was made to avoid the potential pitfall that the cardiologists would be 'blinkered' by their personal experiences. Stock and flow diagrams were introduced, and the differences between them and causal loop diagrams were explained. A stock and flow diagram, depicting the basic patient flows represented in the model, was then presented to introduce the basic SD concepts of stocks and flows. Reference was made to the bath tub analogy which is commonly used in SD. The stock is compared to the water level in the bath tub and the flows are compared to the flow of water from the taps into the bath (in-flow) and out of the bath via the plug hole (out-flow).

The stock and flow diagram was also used to describe the level of aggregation of the model, representing an overview of the system and not emphasising individual patient events. The entire causal loop diagram was not introduced immediately. Instead, it was introduced in stages to avoid confusing the cardiologists as they were unfamiliar with these diagrams, and also to avoid producing cognitive overload (Sterman 2000). A series of partial causal loop diagrams were shown, starting with a single loop, then adding a further loop and so on. The rationale for each feedback loop was given. During the course of the meeting, references were made to the graphs, which were shown in Chapter 7, and to comments that arose during previous meetings. Several amendments were subsequently made to the conceptual model to incorporate the comments obtained from the cardiologists. These involved conceptual changes, the addition of further structure and the aggregation of the preliminary model. These three types of amendments are discussed in the remainder of this section.

Conceptual changes related to two issues. The first concerned the concept "Patient & GP Knowledge of CC". This was originally referred to as "Convenience of CC Services". The consultant at Ribsley General insisted upon this change. He stated that high patient expectations and patient pressure were important factors in determining the levels of referral rates, but that changes in knowledge rather than convenience was the key issue. Furthermore, he stated that this also applied to GPs. The consultant at Veinbridge General endorsed this change in concept. The second conceptual issue concerned the use of the term "CC Operator" which was originally labelled "CC Practitioner". The consultant at Heartwick Hospital requested that the term "Practitioners" be re-labelled to the more recognised term "Operators". Having recognisable terms is important in promoting a sense of model ownership.

There were two main *additions of further structure*. The first related to the method of entry into the system. Generally patients who are eligible to undergo district investigation (low risk patients) are derived from the OP route. This was originally understood to be the exclusive method of entry into the system. However, the consultant at Veinbridge General stated that, as the service is established at his hospital, he is also able to catheterise inpatients whose condition has stabilised. The consultant at Ribsley General said that, if he had a regular district service in place, he would also catheterise stable inpatients at Ribsley General. Therefore, low risk patients are also derived from the inpatient, emergency admission route. This second group of patients was thus incorporated into the analysis. However, this is not shown in the conceptual model because it does not relate to the main feedback structure.

The second addition of further structure involved the inclusion of the link between "Patient & GP Pressure" and "OP Waiting List". The consultant at Ribsley General argued that patient and GP knowledge about CC has also impacted on the demand for OP appointments at hospitals with established CC services. The consultant at Veinbridge General endorsed this view. This link had originally been omitted because it was under review. This was because the hospital manager at Veinbridge General had suggested that, perhaps, the increase in demand was due to other factors. She had observed that increases in demand had applied across various specialities. When this issue was raised with the consultant cardiologist at Veinbridge General, he acknowledged that other factors were involved and that it was difficult to separate the two. Therefore, the link was added to the model.

The *level of aggregation* of the model was also revised. The initial conceptual model focused on patients who were eligible to undergo investigation at the district level - low risk patients. These form a subgroup of those who undergo CC electively. In contrast, high risk electives cannot undergo investigation at the district level but they also need to be considered as their utilisation of tertiary resources impacts upon the availability of resources for low risk patients. Low risk and high risk elective patients could be considered either separately or together. Adopting the latter approach is the most sensible strategy because an aggregated model is smaller and therefore easier to manage and understand. If necessary, a disaggregated model could be produced at a later stage.

8.4 THE CAUSAL HYPOTHESIS

It was discussed how the development of district CC services may solve some problems, but also create others. These problems include excessive treatment delays, pressures imposed by high expectations, contractual obligations and cost constraints, bed 'blocking' and the undesirable fragmentation of specialist patient care. Furthermore, these problems are inter-linked and evolve over time. Consequently, there are no straightforward answers to the two policy questions that were presented in §5.4.2.

Associated with the first question is a causal hypothesis. This is a verbal statement of the assumed relationship between the reference behaviour modes, which were presented in §8.2, and the underlying structure which was summarised by the causal loop diagram in Figure 8.8. This causal hypothesis formed the part of the research hypothesis that encapsulated the theories about the effect of the shift in CC services (see §5.2.2).

These theories were based upon a review of the health policy and medical literature which documented the influence of various factors on referral rates. At this point, the study had already generated new insights into the stimulation of demand via the interviews and preliminary modelling. The causal hypothesis could thus have been revised to incorporate these new insights. However, this would only have been based upon a static analysis and it is well known in SD that there is a danger of making erroneous inferences about dynamic behaviour from static analyses. By exploring the feedback mechanisms with the simulation model, it was possible to test the causal hypothesis and refine the understanding of the relationship between the system structure and behaviour.

8.5 CLARIFICATION OF THE MODEL PURPOSE

The model purpose outlines the broad aims for the study, the target audience, the policy levers of interest and the desired outcomes. In formulating a formal simulation model from the informal conceptual model, a well-defined purpose is essential. It provides a clear focus on what should be included and what should be excluded from the simulation model (Richardson and Pugh 1981). Without it, the model may become cluttered with unnecessary detail thus undermining the ability to seek useful policy insight.

The two policy questions provided a focus for the model purpose. Several aims for the study were established in order to address these questions, and test the causal hypothesis. The first aim was to offer a framework in which to investigate the effects of the development of district CC on the delivery of cardiac services within the NHS. The second aim was to study the sensitivity of different aspects of service delivery to changes in referral patterns, waiting time goals and capacity constraints. The third aim was to calibrate the model to the experiences of district services at Ribsley General and Veinbridge General. Further aims were to evaluate the current district policy and potential refinements to this initiative using a balanced set of performance measures, and to test whether aiming for improvements in a single performance measure and/or short-term goals could only give an illusion of progress. The final aim was to assist in identifying leverage points, where policy makers can intervene effectively to improve the delivery of services.

The target audience for this study was primarily NHS purchasers and providers of cardiac services at the strategic level of decision making, given the strategic nature of SD. This would involve senior managers of purchasing authorities and hospitals, and hospital consultants. The broad audience for the study also encompassed other interested groups, such as the managers of companies involved in the development of district services and health services researchers. The policies of interest included different uses of district services. Other policies related to attempts to suppress the levels of low priority demand and changes in the desired waiting times. A further policy involved employing the available information about the system differently to consider seeking a desired waiting list length rather than a desired waiting time goal. The associated structural change was illustrated in Figure 8.9. Finally, the desired outcomes from the development of the model were a combination of increased awareness, improved general understanding, and the eventual adoption of a set of policy recommendations.

8.6 SUMMARY

This chapter described the conceptualisation phase of the shift in CC services SD study. Reference modes were constructed to represent the problematic and desired behaviours for several simple uses of district services and the two case studies, which reflect more complicated uses. The structure which was understood to be responsible for the problematic behaviour was presented with a simple conceptual model. This encapsulated the basic processes of adjustment in activity and referral rates which underlay the primary and secondary effects of the evolution of district services. The process by which collaborative input was incorporated into this simple model was also discussed. The purpose of the model was clarified. Several broad study aims were established. NHS purchasers and providers were declared as the key audience for the study. A number of policies that were planned to form model-based experiments were highlighted including changes to capacity constraints, demand management stategies and changes to the forces that drive activity rates. The intended final outcome was established as a combination of several general policy lessons and specific policy recommendations.

The next phase of the SD study involved the conversion of the informal conceptual model into a more formal computer simulation model. This will be described in the next chapter.

CHAPTER 9

THE SHIFT IN CARDIAC CATHETERISATION SERVICES SIMULATION MODEL

9.1 INTRODUCTION

Chapter 8 presented a conceptual model that depicted the basic mechanisms that were understood to generate the primary and secondary effects of the shift in CC services (this model is reproduced in Appendix D in D1). The purpose of this chapter is to illustrate how this informal conceptual model was developed into a formal simulation model, and describe the procedures that were applied to gain confidence in this model.

First, an overview of the simulation model is provided (§9.2), before describing it in further detail (§9.3). This section focuses on the model representation of: adjustments in activity (§9.3.1); stimulation and suppression of demand (§9.3.2); waiting time calculations (§9.3.3); gain and loss of CC operator skills (§9.3.4); and, generation of costs (§9.3.5). The rationale underlying the model structure and parameter values is discussed in a separate section (§9.3.6). The next section outlines the procedures by which confidence was gained in the model (§9.4). Using well-established SD tests, both the model's structure (§9.4.1) and its behaviour (§9.4.2) were subjected to close scrutiny. The chapter is summarised in the final section (§9.5).

This chapter does not focus on every single model equation, as the aim is to explain the overall structure and to highlight the important equations. Appendix E contains further details about the simulation model including two fully documented listings of the model equations - one parameterised to the Ribsley General case and the other to the Veinbridge General case. A glossary of modelling terms is provided in Appendix B. Note that all references to OP services refer to cardiology OP services.

9.2 MODEL OVERVIEW

The simulation model was constructed using the *STELLA RESEARCH* software *v. 5.1.1* (High Performance Systems 1997). With this software, the model may be viewed at varying levels of detail, as illustrated in Figure 9.1.

Level 1: Sector Diagram	Increasing Detail ↓
Level 2: Stock & Flow Diagram	
Level 3: Model Equations	

Figure 9.1 The Simulation Model: Three Levels of Detail

The sector diagram shows the model divided into several modules or sectors that group together functionally related portions of model structure. As the conceptual model was converted into stock and flow terms, 5 distinct sectors emerged, as shown in Figure 9.2: Waiting Times; Loss & Gain of District CC Operator Skills (this is referred to as the Skills Sector); Referrals for OP Appts & Elective CC Investigations (the Referrals Sector); Delivery of Elective CC Investigations (the Delivery Sector); and, Costs.

Within the *Referrals Sector,* referrals for OP appointments, OP activity, and referrals for elective CC investigations from both the outpatient and inpatient routes are modelled. The waiting time, skills and knowledge effects on referrals for CC investigations and OP appointments are also represented within this sector. The *Delivery Sector* contains the structure that generates the elective CC investigation rates at both the tertiary and district levels, in addition to the preparation, introduction and withdrawal of the district facility. This sector connects with the Referrals Sector via patient flows and information links to provide inputs for the knowledge effects on referrals.

Waiting times are calculated in a separate sector, labelled *Waiting Times*. This comprises waiting time calculations for OP appointments and CC investigations. This sector connects with the Referrals Sector to provide inputs for the waiting time effect on demand. The turnover of junior district CC operators and the associated aggregate loss and gain in skills at the district hospital are modelled within the *Skills Sector*.

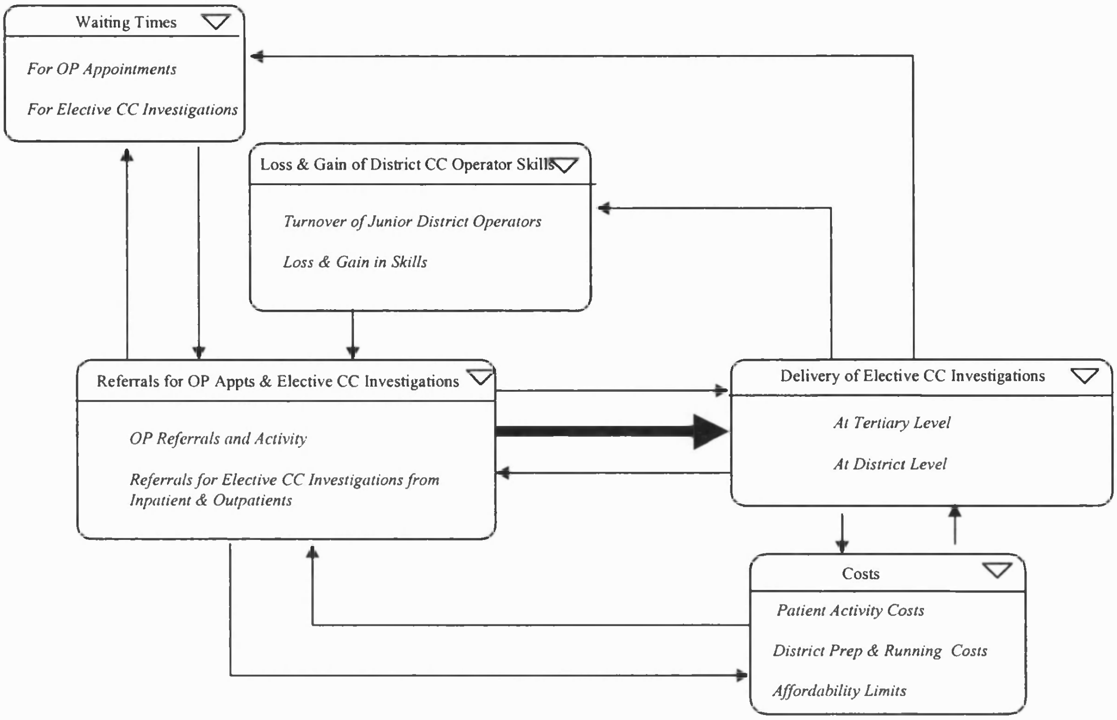


Figure 9.2 The Main Sectors

(Arrows depict connections between the different sectors. The dark arrow indicates a physical flow, in this case, a flow of patients, and the light arrows represent information flows)

The Delivery Sector connects with the Skills Sector to provide learning experiences upon which junior district CC operators gain skills. The Skills Sector connects with the Referrals Sector to provide inputs for the skills effect on demand. The sector labelled *Costs* generates patient activity costs, district preparation costs and district running costs for the duration of the simulation. It also checks for the affordability of district services and patient activity. Consequently, this sector connects with the Referrals Sector and Delivery Sector by only permitting activity when it is affordable.

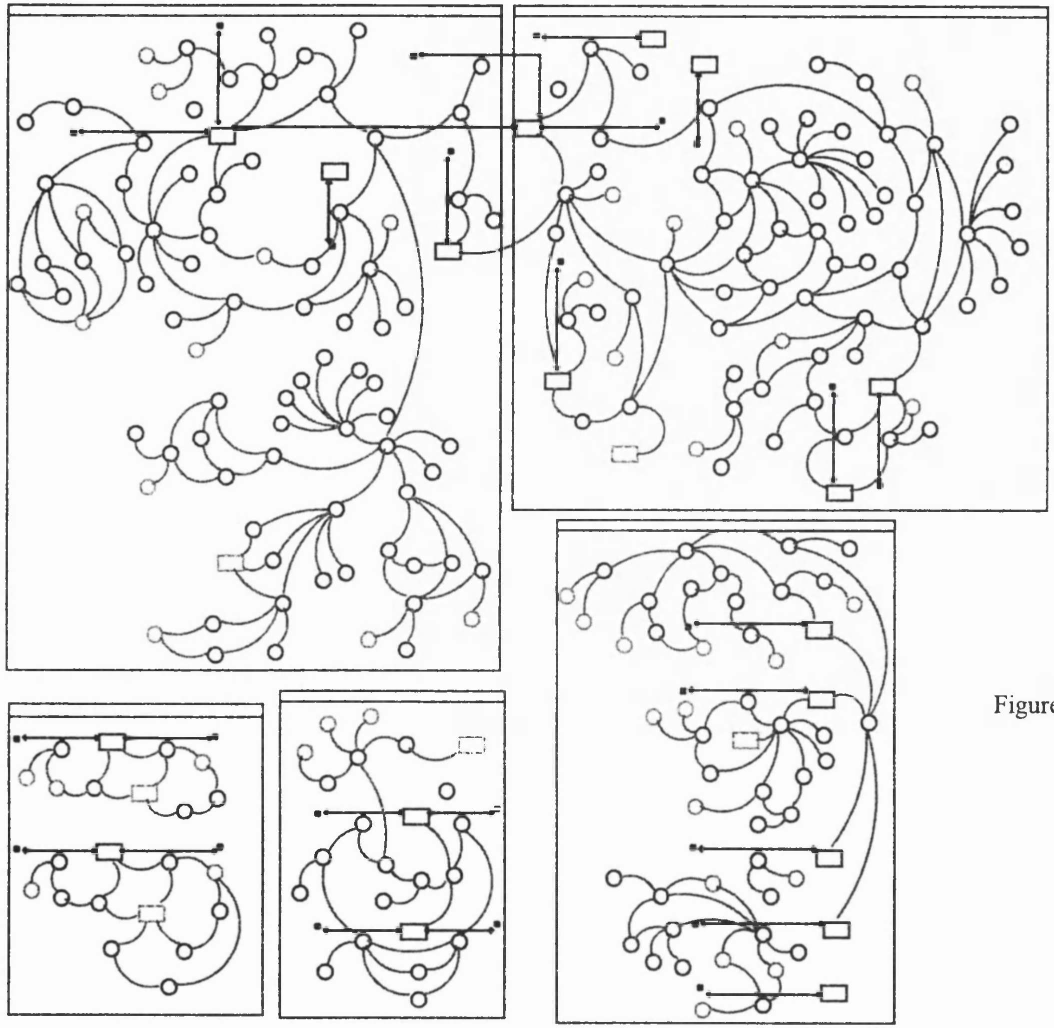
The model also contains four further functional sectors for the model-based experiments. One sector, *Mass Balance Checks,* contains the structure required to check that the flows of skills and patients are conserved (see §9.4.2). Another sector, *Parameters for Experiments,* contains various switches and other variables that act as controls for the experiments. A number of additional measures for evaluating the simulation runs are calculated in the sector, *Parameters for Evaluating Experiments*. Finally, the model output is presented in graphical and tabular form in the sector *Graphs & Tables*.

Figure 9.3 provides a glimpse at the corresponding stock and flow diagram (the 5 main sectors only) which is the model viewed from the next level of detail. The *STELLA* software provides the ability to zoom in and out from this diagram. The figure shows how it appears from a distance such that the variable names are not visible. It illustrates the considerably higher level of detail compared to the sector diagram by highlighting the numerous model components and connections that lie within the 5 main sectors. The relatively high degree of detail complexity also demonstrates the greater rigour required with stock and flow diagrams, compared to conceptual models.

Note that all the feedback loops and connections between the sectors are not apparent, as some links have been superficially broken by 'ghosting' variables. Ghosting involves making copies of variables. This can serve several purposes. In this model, ghosts were used to uncross some links and shorten others to avoid the stock and flow diagram resembling a bowl of spaghetti! In addition, using ghosts, a sector was created (Parameters for Experiments) to collect together all the controls for the experiments. This avoided the inconvenience of repeatedly having to navigate around the model searching for parameters.

Referrals Sector

Delivery Sector



Waiting Times Sector

Skills Sector

Costs Sector

Figure 9.3 Stock and Flow Diagram

To complete the simulation model overview, the key patient flows represented in the model are considered. These are shown in Figure 9.4.

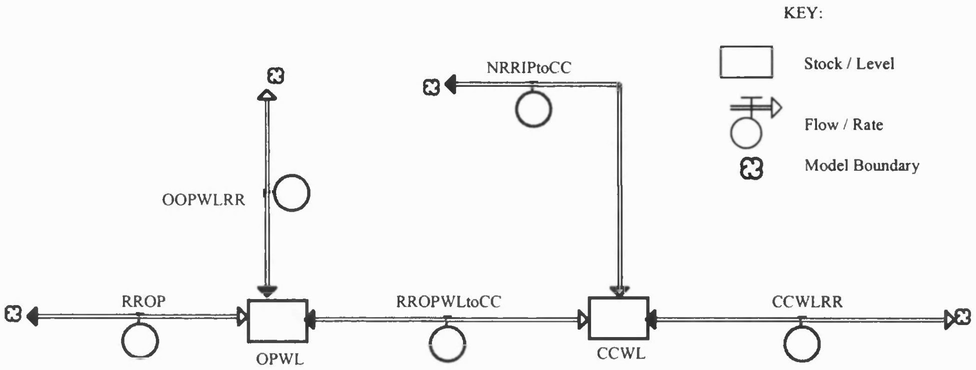


Figure 9.4 Key Patient Flows

where:

CCWL	CC investigation waiting list length [pats]
CCWLRR	CC investigation waiting list removal rate [pats/mth]
NRRIPtoCC	New referral rate from inpatients to an elective CC investigation [pats/mth]
OOPWLRR	Other OP waiting list removal rate [pats/mth]
OPWL	OP waiting list length [pats]
RROP	Rate of referrals for an OP appointment [pats/mth]
RROPWLtoCC	Rate of referrals from OP waiting list to an elective CC investigation [pats/mth]

The patient referral chain represents patient pathways through the processes of care as described in §2.3.3. Referring to the referrals between the primary/secondary/tertiary levels (described in §2.3.2), in the simulation model, only the relevant sections of the cardiac referral chain are represented. These are those which concern referrals for and the delivery of elective CC investigations and the responses to the availability of district services. For the purpose of this study, the relevant flows of patients across the primary/secondary interface are represented explicitly and the patient flows across the secondary/tertiary interface are represented implicitly.

The key patient flows span across the Referral and Delivery Sectors. Two stocks, also known in SD as levels, represent the waiting list for OP appointments (OPWL) and the waiting list for CC investigations (CCWL). Several flows, also known as rates, regulate the flows of patients to and from the stocks. The white arrowheads indicate the direction of flow. The rates are specified as biflows, rather than uniflows, in order to check that the levels do not become negative).

The OP waiting list is increased by a single flow representing referrals for OP appointments (RROP) aggregating new and follow-up referrals, and it is reduced by two separate flows. One represents referrals for elective CC investigations from the OP waiting list (RROPWLtoCC) and the other depicts all other removals from the OP waiting list including deaths on the waiting list (OOPWLRR). The destination of the latter flow is not of interest so it is directed to beyond the boundary of the model.

The waiting list for a CC investigation is increased by two flows of patients. In addition to the referrals from the OP waiting list (RROPWLtoCC), there are new referrals for elective investigations from inpatients (NRRIPtoCC). "New" refers to patients that are not already known to the cardiologists. Therefore, this excludes patients who were previously waiting on the OP waiting list and had deteriorated, undergone hospital admission, restabilised and were subsequently referred on for an elective investigation; they would already be accounted for (within RROPWLtoCC). Also excluded is the potential outflow of patients already on the CC investigation waiting list who have deteriorated, become hospital admissions and then restabilised. As they would remain classified as in need of an elective investigation, they would already be accounted for (within CCWL). Although new referrals for elective investigations from inpatients need to be considered to ensure that the flows of patients are conserved, the source of these patients is not of interest with regard to the purpose of the study. Their source, therefore, lies beyond the boundary of the model. Finally, the CC investigation waiting list is reduced by the waiting list removal rate (CCWLRR). This comprises both removals which constitute elective patient activity and those which do not, such as deaths on the waiting list and patients who deteriorated whilst waiting for their investigation and were subsequently reclassified as emergency cases.

9.3 MODEL DETAIL

In this section, the stock and flow structure is explored in greater detail by presenting a selected number of small stock and flow sub-structures. Fuller stock and flow sub-structures are given in Appendix E where all the main feedback processes, as depicted in the conceptual model, are highlighted. The key to the symbols used is given in Figure 9.5.

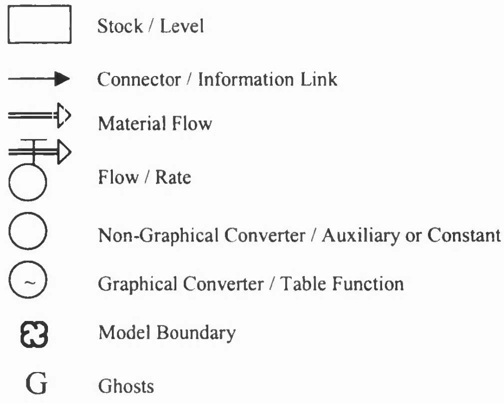


Figure 9.5 Symbols Used in Stock and Flow Diagrams

Note that, regarding the model formulation, a number of gross discontinuities are produced by the specification of 'IF... THEN... ELSE' statements in the model equations. Such statements are inconsistent with aggregated behaviour which is the typical focus of SD. However, they were appropriate in this study in order to model single hospitals and the behaviour of individuals.

9.3.1 Representing Adjustments in Activity

The process of changes in the OP activity rate (depicted as loop B4 in the conceptual model) is represented in the Referrals Sector (see Figure 9.6).

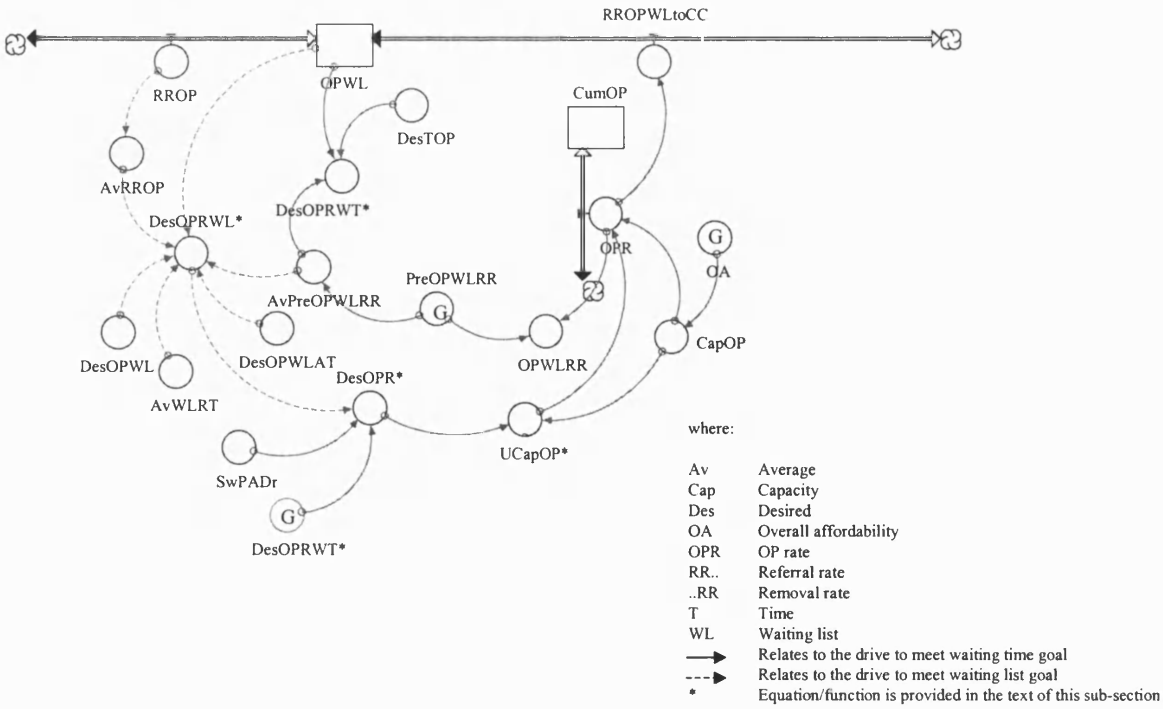


Figure 9.6 Adjustments in OP Activity Rate (OPR)

The feedback loop appears broken because a ghost (for DesOPRWT) has been introduced to avoid overlapping links. In modelling the adjustment in the OP activity rate (OPR), two feedback process are represented as the adjustment in the OP activity rate could be driven by the desire to meet a waiting time goal (DesTOP) or a desired waiting list size (DesOPWL). The latter relates to a policy experiment. In fact, the model contains several variables and structures that are intended for policy experiments; these components were dormant when simulating the base case behaviours. The goal that drives the desired OP activity rate is selected via the use of a switch (SwPADr). The formulations are as follows:

DesOPR = SwPADr*DesOPRWL+ (1-SwPADr)*DesOPRWT
DesOPRWL = MAX(MIN(AvRROP+(OPWL-DesOPWL)/DesOPWLAT-
AvPreOPWLRR,OPWL/AvWLRT+AvRROP),0)
DesOPRWT = IF(DesTOP=0) THEN 999 ELSE ((OPWL/DesTOP)-AvPreOPWLRR)

where:

AvPreOPWLRR	Average pre-appointment OP waiting list removal rate [pats/mth].
AvRROP	Average rate of referrals for an OP appointment [pats/mth].
AvWLRT	Average waiting list removal time [mths].
DesOPWL	Desired OP waiting list length [pats].
DesOPWLAT	Desired OP waiting list adjustment time [mths].
DesOPR	Desired OP rate [pats/mth].
DesOPRWL	Desired OP rate driven by the waiting list goal [pats/mth].
DesOPRWT	Desired OP rate driven by the waiting time goal [pats/mth].
DesTOP	Desired waiting time for an OP appointment [mths].
OPWL	OP waiting list length [pats].
SwPADr	Switch for patient activity driver [-].

It was assumed that when determining the desired OP activity rate, allowances are made for the existence of other waiting list removals (PreOPWLR); otherwise more activity than is actually required would be sought. This rate is averaged (APreOPWLR) because as it is instantaneous, as such, it cannot be observed. Considering the calculation for the activity rate desired to meet the waiting time goal (DesOPRWT), a desired waiting time (DesTOP) of zero would call for an infinitely large activity rate. For the model to accommodate this extreme case and enable the simulation to proceed (i.e. avoid a division by zero), an IF statement is used involving the assignment of a very large number to the desired activity rate.

In seeking a waiting list goal (DesOPWL), the desired activity rate (DesOPRWL) is composed of: (1) the average number of patients joining the waiting list (in order to maintain the waiting list at its existing level); plus (2) any additional adjustment required to meet the desired waiting list size, and, minus (3) any other removals from the waiting list (otherwise, more activity may be carried out than is necessary). However, there are two situations which place bounds on the actual values that the desired activity can take. The first situation is where there are insufficient patients available to meet the calculated desired activity rate. In this case, the actual activity rate will be derived from the existing waiting list and new patients joining the waiting list. This is formulated using the MIN( ) function. The second situation is when the calculated desired activity rate works out as being negative. For this, the actual desired activity rate will be zero. This is represented by the use of the MAX( ) function.

Associated with the adjustment in OP activity is a financial constraint that would suspend all OP activity if it were exceeded. This constraint is located in the Costs Sector and it connects with the Referrals Sector via a ghosted variable, overall affordability (OA). If this financial constraint is exceeded, the OP capacity (CapOP) becomes zero. The OP rate (OPR) is calculated by multiplying the combined capacity of doctors (CapOP) by the capacity utilisation fraction (UCapOP).

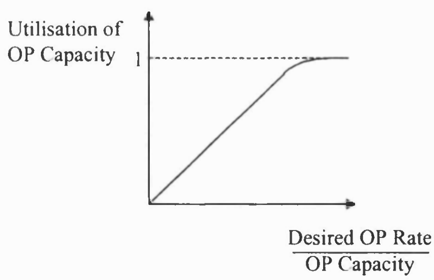


Figure 9.7 Basic Form of Utilisation of OP Capacity (UCapOP)

This function (its basic form is shown in Figure 9.7) reflects how the capacity utilisation increases as the demand for OP appointments (DesOPR) rises relative to the capacity available (CapOP), but it can never exceed 1. Furthermore, it reflects how demand can be accommodated when it lies sufficiently below the capacity but as the limits on supply are approached, it becomes more difficult to actually deliver the full capacity due to practicalities such as staff scheduling problems.

The same basic structure as for the OP activity is used to represent the adjustment in the tertiary-based elective CC investigation rate (TCCInvR, as shown in Figure 9.8).

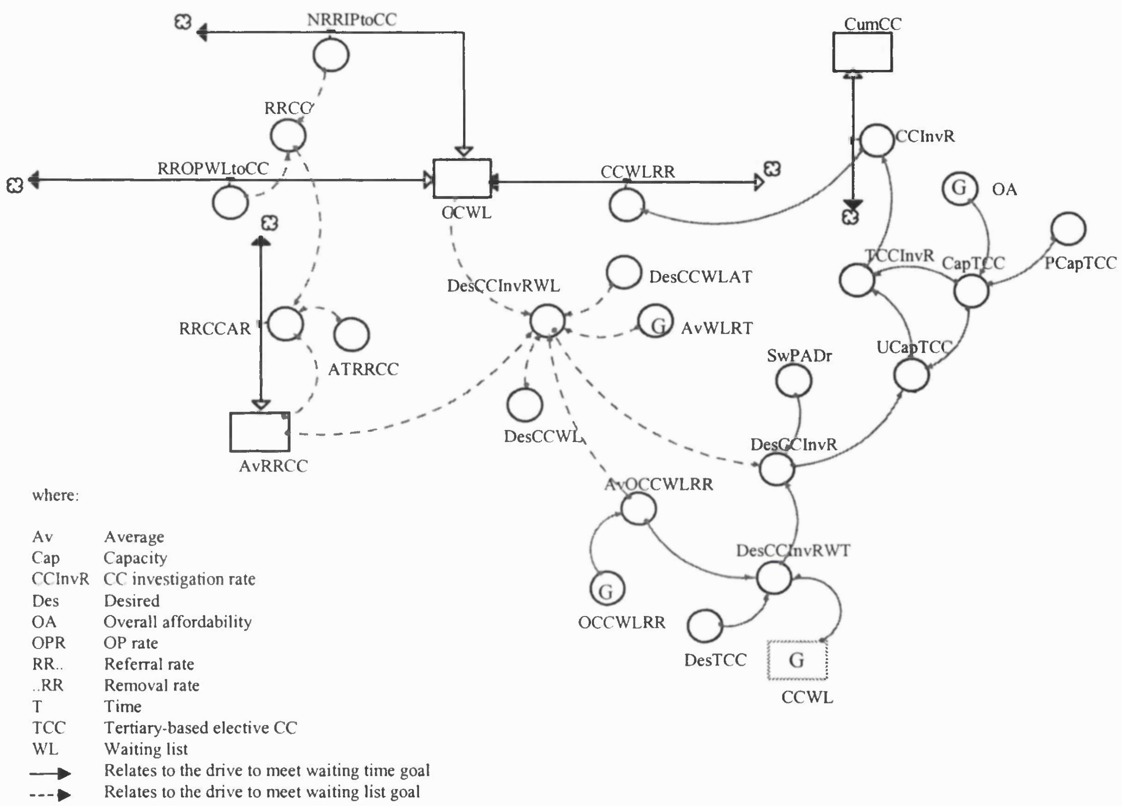


Figure 9.8 Adjustment in Tertiary-Based CC Investigation Rate (TCCInvR)

Unlike the OP case, the structure includes the facility to reduce the waiting time and waiting list goals (DesTCC and DesCCWL respectively) when a district service is available (Figure 9.9). This would represent the desire to exploit the opportunity of the capacity increases associated with the availability of a district service. As an adjustment in the goal would not be instantaneous, the smoothed availability of the district CC facility (SDCCFA) is considered.

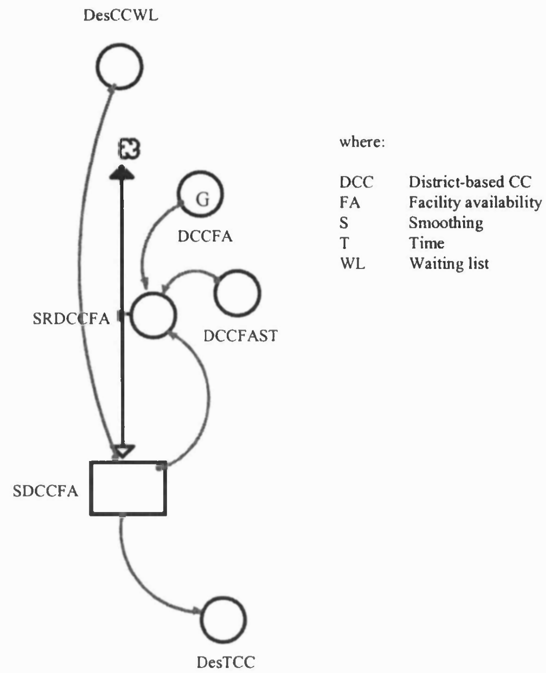


Figure 9.9 Adjustment in Waiting List and Waiting Times Goals

The formulation for the desired district-based CC investigation rate (DesDCCInvR) is more complicated (Figure 9.10).

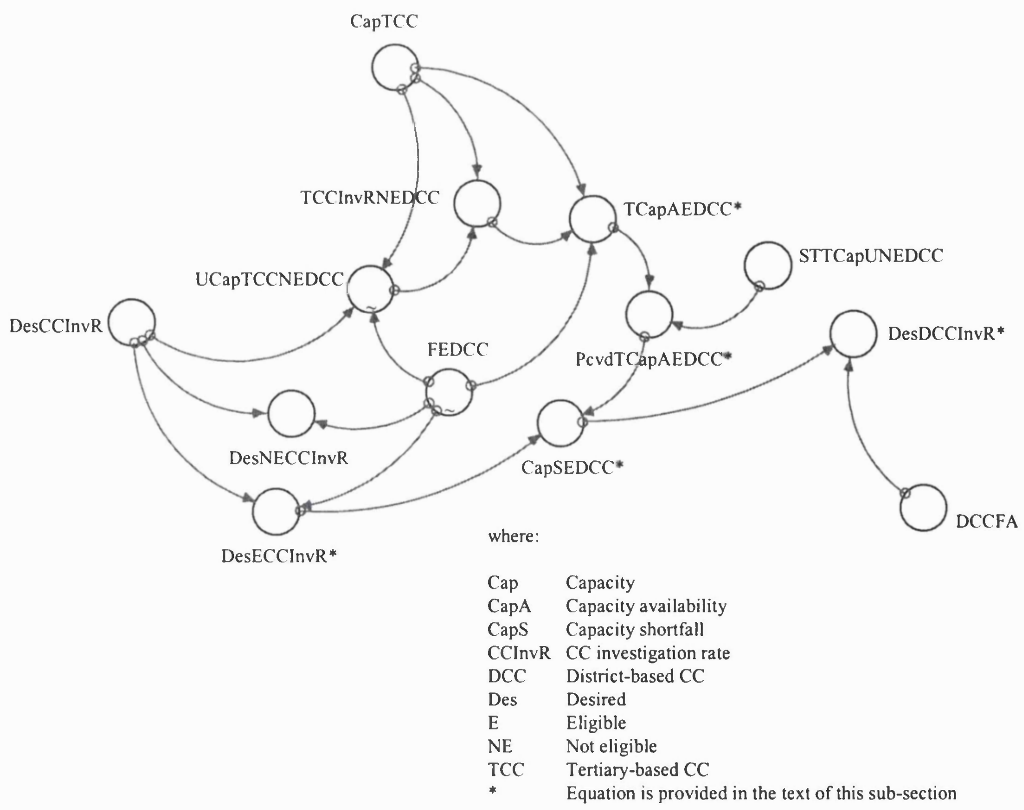


Figure 9.10 Desired District-Based CC Investigation Rate (DesDCCInvR)

A desire for district-based activity will arise from a capacity shortfall at the tertiary level during times that a district service is available. In general, a capacity shortfall is the desired activity level minus the maximum activity that it is perceived to be able to do. However, that is not what is being considered in the context of a shift in CC services to the district level. The shortfall of interest is that which is eligible to be shifted to the district level - only that which constitutes low risk elective cases. Furthermore, high risk elective cases (those not eligible to be investigated at the district level) will take precedence over the low risk cases in using the available capacity at the tertiary level. It was assumed that the delay to perceive changes in the available capacity for eligible patients will be shorter than usual in cases when these changes are anticipated. This produces the following formulation:

DesDCCInvR = CapSEDCC*DCCFA
CapSEDCC = DesECCInvR - PcvdTCapAEDCC
DesECCInvR = DesCCInvR*FEDCC
PcvdTCapAEDCC = SMTH1(TCapAEDCC,STTCapUNEDCC)
TCapAEDCC = IF (FEDCC=0) THEN 0 ELSE (CapTCC-TCCInvRNEDCC)

where:

CapSEDCC	Capacity shortfall (at tertiary level) with respect to patients who are eligible to undergo district-based CC investigation [pats/mth]
CapTCC	Capacity for elective tertiary-based CC investigations [pats/mth]
DesCCInvR	Desired elective CC investigation rate [pats/mth]
DesDCCInvR	Desired district-based CC investigation rate [pats/mth]
DesECCInvR	Desired eligible CC investigation rate [pats/mth]
DCCFA	District CC facility availability [-]
FEDCC	Fraction of CC investigation waiting list that are eligible for district-based investigation [-]
PcvdTCapAEDCC	Perceived tertiary-based elective CC investigation capacity available for those eligible to undergo district-based CC [pats/mth]
STTCapUNEDCC	Smoothing time of tertiary-based elective CC investigation capacity use by patients not eligible to undergo a district-based CC [mths].
TCapAEDCC	Tertiary-based elective CC investigation capacity available for those eligible to undergo district-based CC [pats/mth]
TCCInvRNEDCC	Tertiary-based elective CC investigation rate of those not eligible to undergo district-based CC [pats/mth]

where:

Cap	Capacity
CapS	Capacity shortfall
CCInvR	CC investigation rate
CF	Completed fraction
DCC(P)	District CC facility (preparation)
Des	Desired
E	Eligible
Ph1	Phase 1
ST	Start time
T	Time
*	Equation is provided in the text of this sub-section

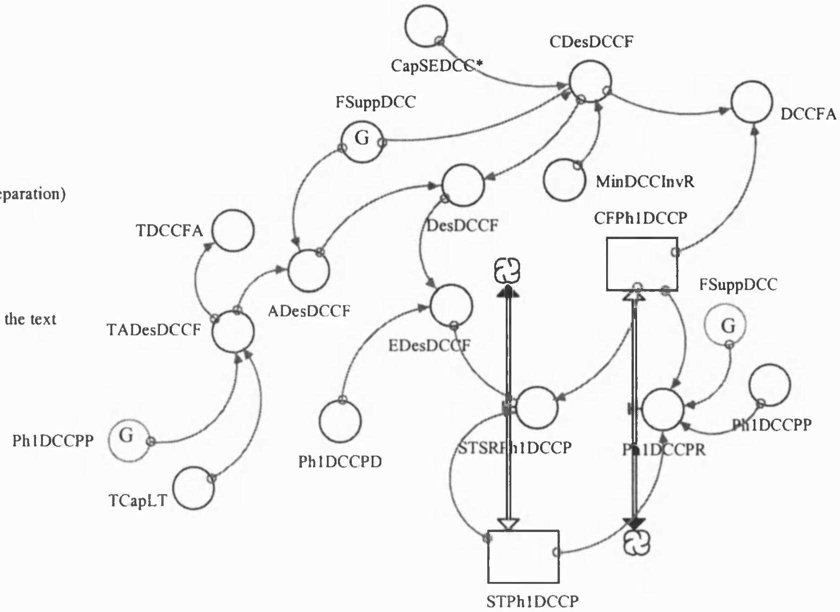


Figure 9.11 Development of District-Based CC Facility

In the model, a desire for a district CC facility (DesDCCF) is formulated as either being anticipated (ADesDCCF) corresponding with a planned closure of a tertiary facility in the future, or current (CDesDCCF) corresponding to an existing capacity shortfall (as shown in Figure 9.11). After a delay to carry out the necessary arrangements such as negotiations with suppliers of mobile cath labs (Ph1DCCPD), a desire for a district facility initiates the preparation of a phase 1 district facility, provided that the preparation for such a facility has not already begun. The model retains the phase 1 preparation start time (STPh1DCCP) and uses this time to initialise the development of a phase 2 facility, if planned, after a specified delay. The model thus reflects the assumption that phases 1 and 2 would be co-ordinated within a programme of development. The preparation of a phase 2 facility, which only applies to the Veinbridge case, is implicitly represented in the Costs Sector. The model reflects the assumption that a district facility will be available (DCCFA=1) once 95% of the phase 1 preparation has been completed (CFPh1DCCP>=0.95) and there exists a current desire for a district CC facility (CDesDCCF=1) and staff are available (PCapDCC>0).

9.3.2 Representing Stimulation and Suppression of Demand

The model depicts a number of factors that determine the fraction of patients assessed at an OP appointment who are then referred on for an elective CC investigation (FOPtoCC, as shown in Figure 9.12).

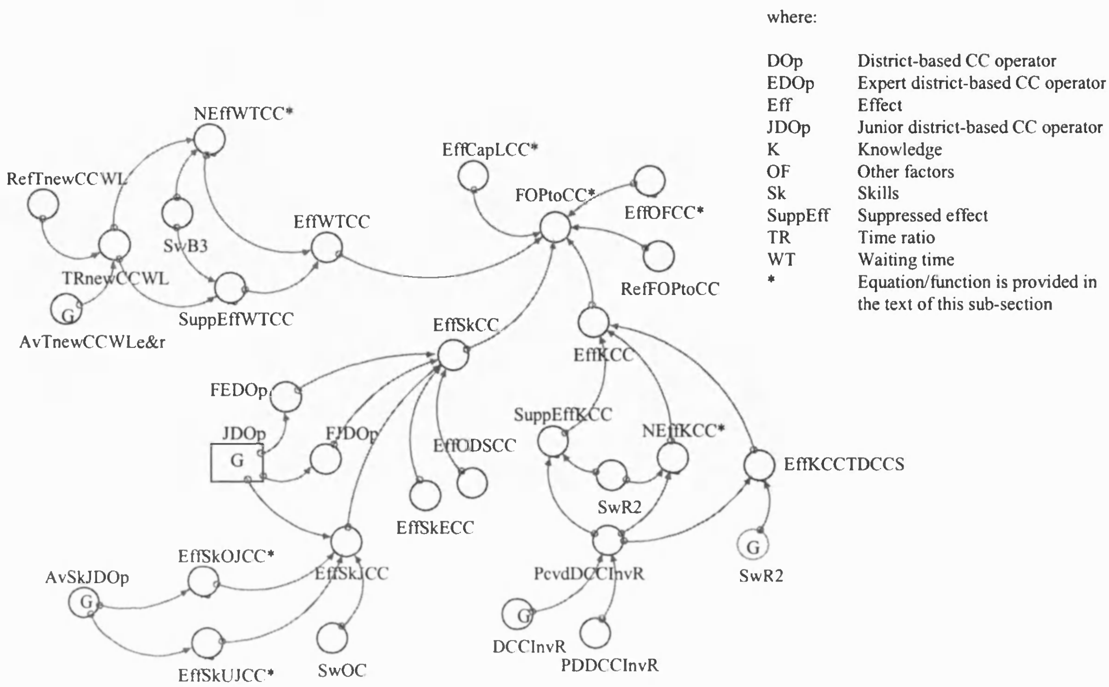


Figure 9.12 OP to CC Referral Fraction (FOPtoCC)

Figure 9.13 shows the basic form of the *base case* functions for these factors. For the waiting time effect, a non-linear function (NEffWTCC, Figure 9.13a) of the ratio (TRnewCCWL) of the average waiting time (AvTnewCCWLe&r) and a reference waiting time (RefTnewCCWL) quantifies the demand multiplier. The reference waiting time is that which would neither stimulate nor suppress demand.

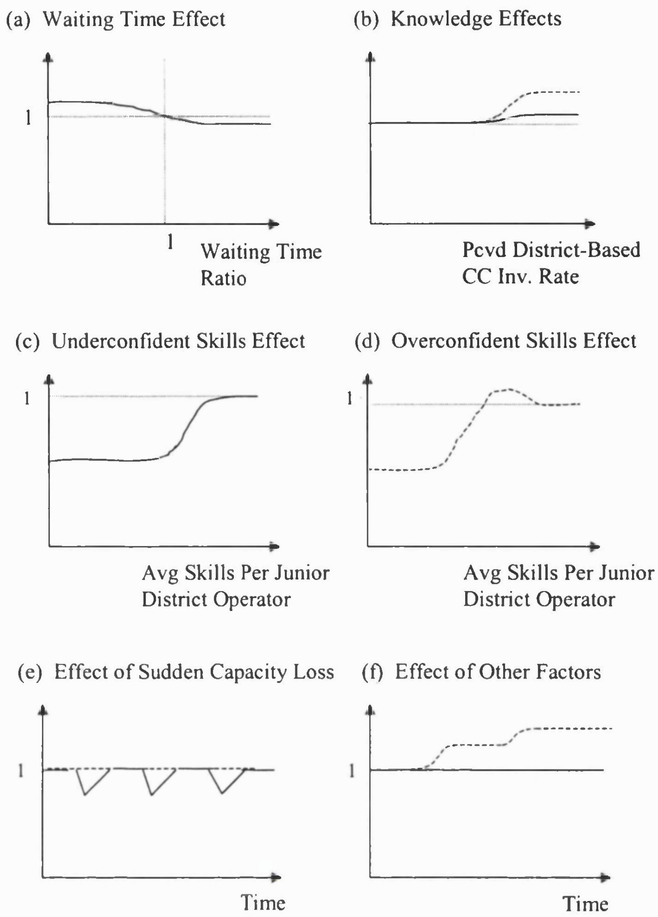


Figure 9.13 Base Case Referral Multipliers

(Continuous Line - Ribsley General; Dashed Line - Veinbridge General;

Values above 1 - Stimulation of demand; Values below 1 - Suppression of demand)

For the knowledge effect, a non-linear function (NEffKCC, Figure 9.13b) of the perceived district-based CC investigation rate (PcvdDCCInvR) quantifies the demand multiplier. The reduced effects on demand due to the use of new referral guidelines are modelled with two other non-linear functions (SuppEffWTCC and SuppEffKCC). Another function models an increased knowledge effect on demand which was used as part of the sensitivity analysis (IncrEffKCC). It was assumed that the effects on demand will vary according to the duration of the district service and the referral tradition at the host hospital. Therefore, further functions represent the assumed effects that would be generated by a permanent district service at Ribsley General (EffKCCPDCCS) and a temporary district service at Veinbridge General (EffKCCTDCCS). See model listings for further details. Switches are employed to select the relevant functions for the simulation runs.

In modelling the effect of skills on demand for CC investigations (EffSkCC), three categories of staff were assumed to make referrals for CC investigations: expert CC operators; junior trainee CC operators; and, others who would be non-CC operators. The effect of skills on demand is a weighted average considering the skills multipliers and proportions of patient decisions made by these three categories of staff. The parameters reflect the assumption that expert operators will identify more patients in need and thus refer more patients than non-CC operators. Allowances are made for the case of no trainee CC operators. Furthermore, the inclusion of two non-linear functions of the average skills per junior district CC operator (AvSkJDOp) reflect different referral patterns as trainee operators climb up the learning curve. More specifically one involves a period of under-confidence (EffSkUJCC, Figure 9.13c) and another also involves a period of over-confidence (EffSkOJCC, Figure 9.13d). The former function is used to represent the typical referral behaviour of junior CC operators at Ribsley General and the latter is used to represent that at Veinbridge General. It should be noted that for the case of Veinbridge General, the expert CC operator makes the final decision about referrals for CC investigations (FEDOp=1) so this part of the model structure is inactive. However, this function (EffSkOJCC) is included in the model so that generalisations may be considered to other hospitals and service shifts. In other cases, this function might have an impact.

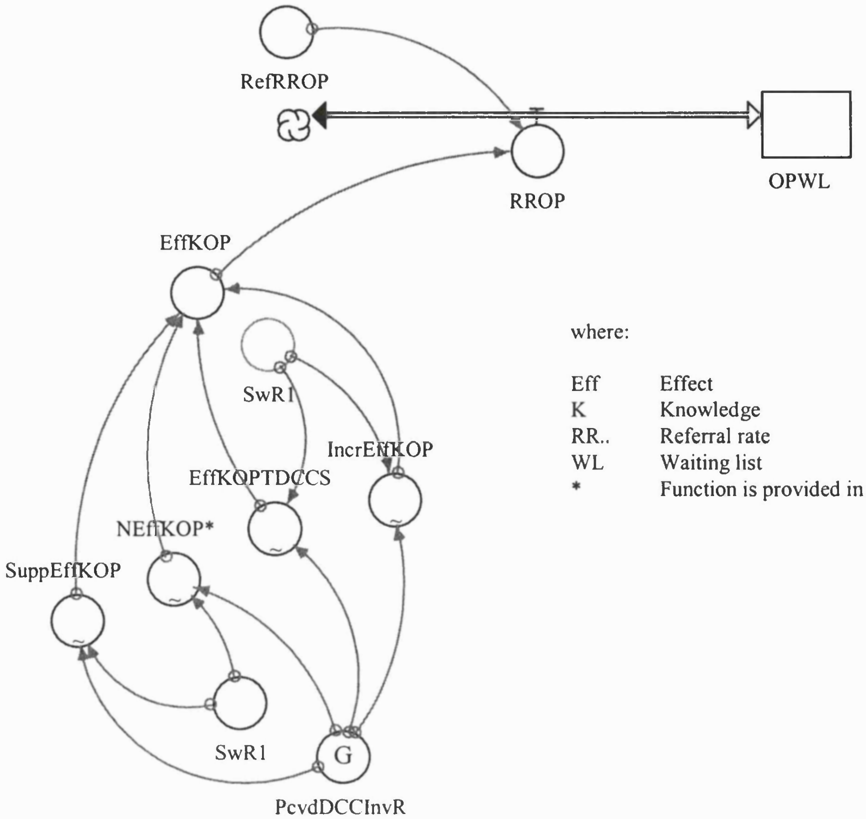
Also represented in the model, in addition to the waiting time (EffWTCC), skills (EffSkCC) and knowledge (EffKCC) effects on referrals, are an effect of significant capacity losses on referrals (EffCapLCC, base case function is shown in Figure 9.13e) and an effect of other factors (EffOFCC, Figure 9.13f). It was assumed that a significant loss of capacity will result in a reduction in referrals as a 'knee jerk' reaction. For the purpose of the policy runs, several functions are included to correspond with different combinations of capacity losses. An example of another factor which might influence the referral threshold is the introduction of a permanent district service, especially with an integrated cath lab. This might encourage the referral threshold to drop so that slightly higher risk cases (and also more 'grey area' cases) would be investigated at the district level. For simplicity, this effect is modelled exogenously. For the case of Ribsley General, given that district services were only temporary, this is set to the default value of 1 (indicating a zero effect). In the Veinbridge General model, it is represented as a non-linear smoothed step function where the changes correspond with the introduction of district services and opening of the integrated lab. This factor would be represented endogenously in a more sophisticated model to connect with these events.

It was assumed that these five factors act as multipliers on a reference referral fraction (RefFOPtoCC) which is the referral fraction that was assumed to exist during periods where: there was no district service; normal capacity levels existed at the tertiary level; all district screeners were fully skilled; and, there was neither stimulation nor suppression of demand due to the waiting time or knowledge effects. This would correspond with a situation for which GPs' and patients' knowledge of CC relied totally on that derived from tertiary activity and the waiting time was at a level so that it neither stimulated nor suppressed demand. The formulation chosen for the referral fraction (FOPtoCC) reflects the assumption that the 'knee jerk' reaction to the capacity losses dominates over the effects of waiting times, knowledge and other factors on referrals for an elective CC investigation. This avoids double counting, which is a quantification problem that is discussed by Coyle (1996). The referral rate calculation is as follows:

FOPtoCC = RefFOPtoCC*EffSkCC*
(IF(EffCapLCC<1) THEN EffCapLCC ELSE (EffCapLCC*EffKCC*EffWTCC*EffOFCC))

where:

EffCapLCC	Effect of significant capacity loss on referrals for CC investigation [-]
EffKCC	Effect of knowledge of CC on referrals for CC investigation [-]
EffOFCC	Effect of other factors on referrals for CC investigation [-]
EffSkCC	Effect of CC operator skills on referrals for CC investigation [-]
EffWTCC	Effect of waiting time for CC investigation on referrals for CC investigation [-]
FOPtoCC	Fraction of patients assessed at an OP appointment who are referred on for an elective investigation [-]
RefOPtoCC	Reference fraction of patients assessed at an OP appointment who are referred on for an elective investigation [-]



where:

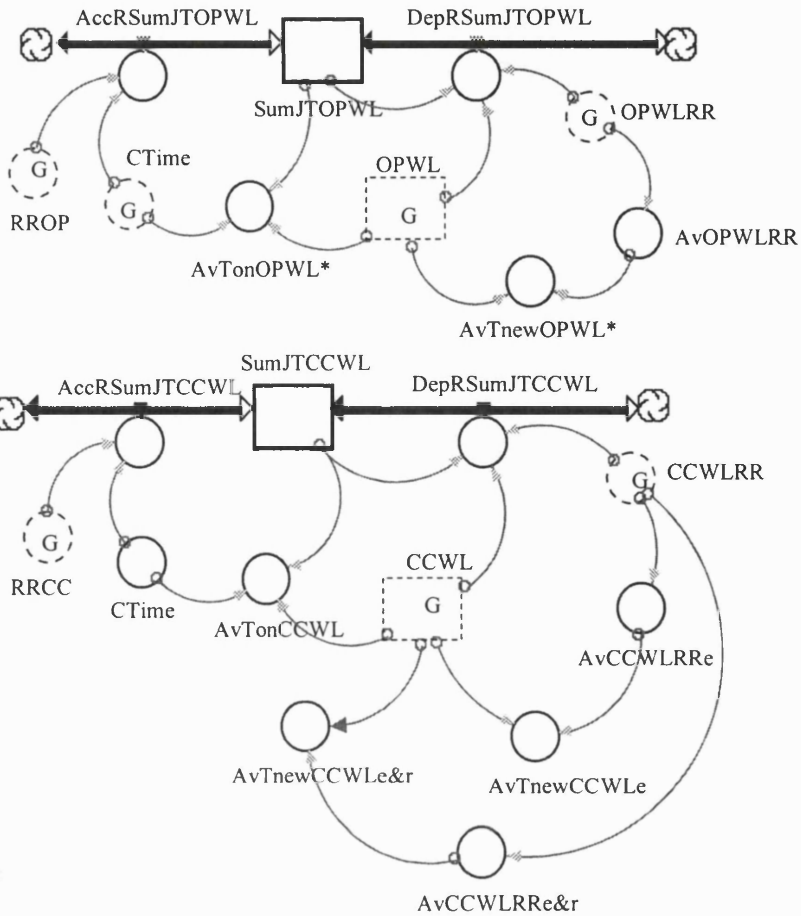
Eff	Effect
K	Knowledge
RR..	Referral rate
WL	Waiting list
*	Function is provided in the text of this sub-section

Figure 9.14 Stimulation of Demand for an OP Appointment

To represent the stimulation of demand for OP services (Figure 9.14), a non-linear function (NEffKOP, also shown by Figure 9.13b) of the perceived district-based CC rate (PcvdDCCInvR) quantifies the demand multiplier. The reduced effect on demand due to the use of new referral guidelines is modelled with another non-linear function (SuppEffKOP). Further functions model the response associated with the use of a permanent district service at Ribsley General (EffKOPPDCCS) and a temporary district service at Veinbridge General (EffKOPTDCCS). The same logic that applied to the magnitudes of the knowledge effects on demand for CC investigations applies to these functions. Switches are employed to select the relevant function for the simulation runs.

9.3.3 Representing Waiting Times

The Waiting Times Sector (Figure 9.15) comprises waiting time calculations for OP appointments and CC investigations, considering both the average time spent on these waiting lists and average time estimated for new patients joining these waiting lists.



where:

AccR	Accumulation rate
AvTnew	Avg est. waiting time for new (waiting list patients)
AvTon	Avg time spent on (waiting list)
DepR	Departure rate
e	Evaluation
e&r	Evaluation and response
RR..	Referral rate
..RR	Removal rate
SumJT	Sum of (waiting list) join times
WL	Waiting list
*	Equation/function is provided in the text of this sub-section

Figure 9.15 Waiting Times Sector

In modelling the average time spent on these waiting lists (AvTonOPWL and AvTonCCWL), co-flow (co-incident flow or rate-to-rate) formulations represent the accumulation and depletion of the sum of waiting list join times which occur in parallel with referrals onto and removals from the waiting lists. In SD, co-flow formulations are employed to represent a process that runs in parallel with some primary process or to track an attribute associated with a flow. Allowances are made for the extreme case of a waiting list being empty, in which case the average time spent on that waiting list would be zero.

The model reflects how the average estimated waiting times for new patients joining the waiting lists (AvTnewOPWL, AvTnewCCWLe and AvTnewCCWLe&r) are calculated by considering the size of the waiting lists and the average waiting list removal rates at the time of entry onto the waiting list. The waiting list removal rates have to be averaged because they are instantaneous rates and as such are unobservable. Allowances are made for the extreme case of a zero average waiting list removal rate (all activity suspended and no other waiting list removals); the estimated waiting time would be infinity because, at that point, the removal of a new patient joining the waiting list would not be anticipated. A very large waiting time is thus specified to accommodate this extreme case and also enable the simulation to proceed (to avoid a division by zero). The model calculates two average estimated waiting times for new patients joining the CC investigation waiting list. One is used as a summary performance measure to *evaluate* pressure on the system (AvTnewCCWLe) and for this the averaging period for the waiting list removal rate was assumed to be one month. The second measure (AvTnewCCWLe&r) is used to model the *evaluation* of pressure on the system and *response* to that pressure which is used to calculate the waiting time effect on demand for CC investigations. For this, the waiting list removal rate is averaged over a longer period of 3 months.

The OP waiting time calculations are as follows (the CC investigation waiting time calculations have similar formulations):

AvTonOPWL = IF (OPWL<>0) THEN (CTime-(SumJTOPWL/OPWL) ELSE 0
AvTnewOPWL = IF (AvOPWLRR<>0) THEN 999 ELSE (OPWL/AvOPWLRR)

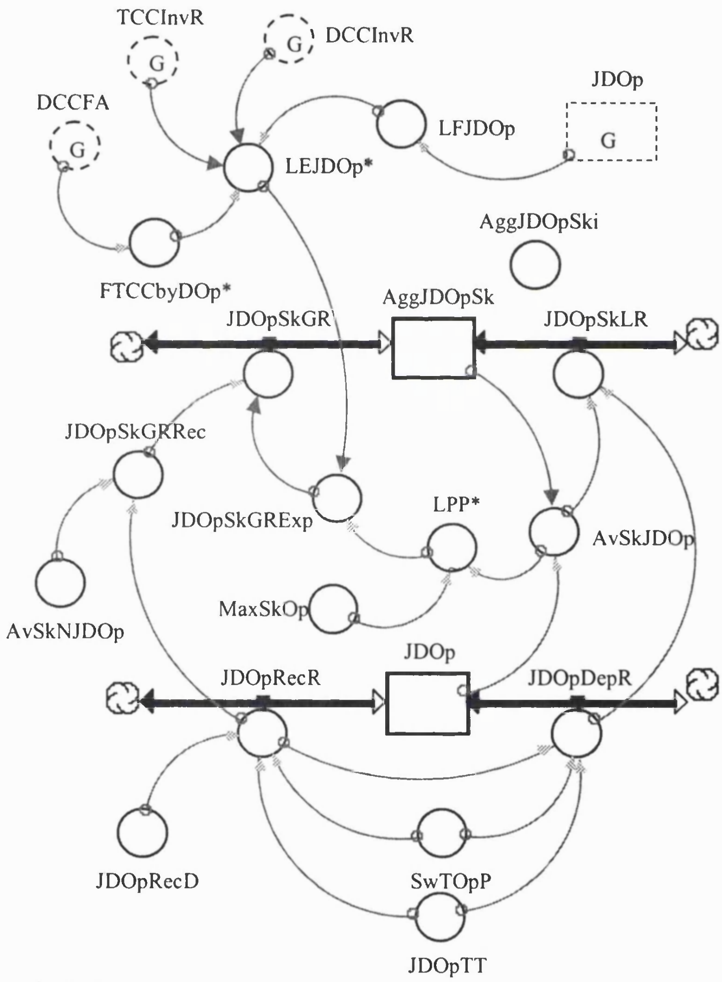
where:

<>	Signifies "not equal to"
AvOPWLRR	Average OP waiting list removal rate [pats/mth]
AvTnewOPWL	Average estimated waiting time for new OP waiting list patients [mths]
AvTonOPWL	Average time spent on OP waiting list [mths]
Ctime	Current time [mths]
OPWL	OP waiting list length [pats]
SumJTOPWL	Sum of join times for patients on OP waiting list [pat.mths]

9.3.4 Representing the Gain and Loss of Skills

It is essential to model the gain and loss of CC operator skills as the level of skill and confidence of junior CC operators may influence their referral rates for an elective CC investigation. Obviously, this is an intangible variable but the SD methodology does allow efforts to be made to incorporate such variables into the analysis.

The skills effect on demand is a function of the average skills per junior operator (AvSkJDOp), which is calculated in the Skills Sector (Figure 9.16).



where:

Agg	Aggregate
DCC	District CC
DepR	Departure rate
FTCC	Fraction of tertiary-based elective CC inv.
GR	Gain rate
GRExp	Gain rate via experience
GRRec	Gain rate via recruitment
(J)DOp	(Junior) district-based CC operator
LE	Learning experiences
LF	Learning fraction
LPP	Learning per patient
LR	Loss rate
NJDOp	New junior district-based CC operator
RecD	Recruitment delay
RecR	Recruitment rate
Sk	Skill
TOpP	Trainee (district) operator programme
TT	Training time
*	Equation/function is provided in the text of this sub-section

Figure 9.16 Skills Sector

This sector uses a co-flow formulation to model the loss and gain of CC skills of the junior district CC operators associated with their turnover and the gain in experience of new trainees. New CC operator trainees periodically join the district hospital to gain skills and then leave at the end of their training period to be replaced by new trainee operators.

The basic structure is composed of two stocks. One represents the number of junior operators (JDOp). This stock is increased by the recruitment of juniors (JDOpRecR) and reduced by the departure of juniors (JDOpDepR). Departures follow recruitment after a fixed training period (JDOpTT) and recruitment delay (JDOpRecD). The second stock represents the aggregate junior district CC operator trainee skills (AggJDOpSk). This stock is increased by the gain of skills (JDOpSkGR) and reduced by the loss of skills (JDOpSkLR). The gain in skills is the sum of skills gained via recruitment (JDOpSkGRRec) and skills generated with experience (JDOpSGRExp). The former depends upon the average skill per new recruit (AvSkNJDOp - a value of zero reflects all new recruits arriving as complete novices). The latter depends upon the number of learning experiences to which the trainee operators are exposed (LEJDOp) and the learning per experience i.e learning per patient (LPP). The number of learning experiences depends upon the levels of district and tertiary activity of patients referred from the district hospital for an elective CC investigation and the degree of involvement of the district operators, both trainees and experts, as shown in the following formulation:

LEJDOp = (DCCInvR+TCCInvR*FTCCbyDOp)*LFJDOp

where:

DCCInvR	District-based CC investigation rate [pats/mth]
FTCCbyDOp	Fraction of tertiary-based elective CC investigations carried out by a district-based CC operator [-]
LEJDOp	Learning experiences for junior district-based CC operators [pats/mth]
LFJDOp	(Patient activity) learning fraction of junior district-based CC operators [-]
TCCInvR	Tertiary-based elective CC investigation rate [pats/mth]

The fraction of tertiary-based elective CC investigations carried out by a district-based CC operator (FTCCbyDOp) depends upon several factors (see Figure 9.17).

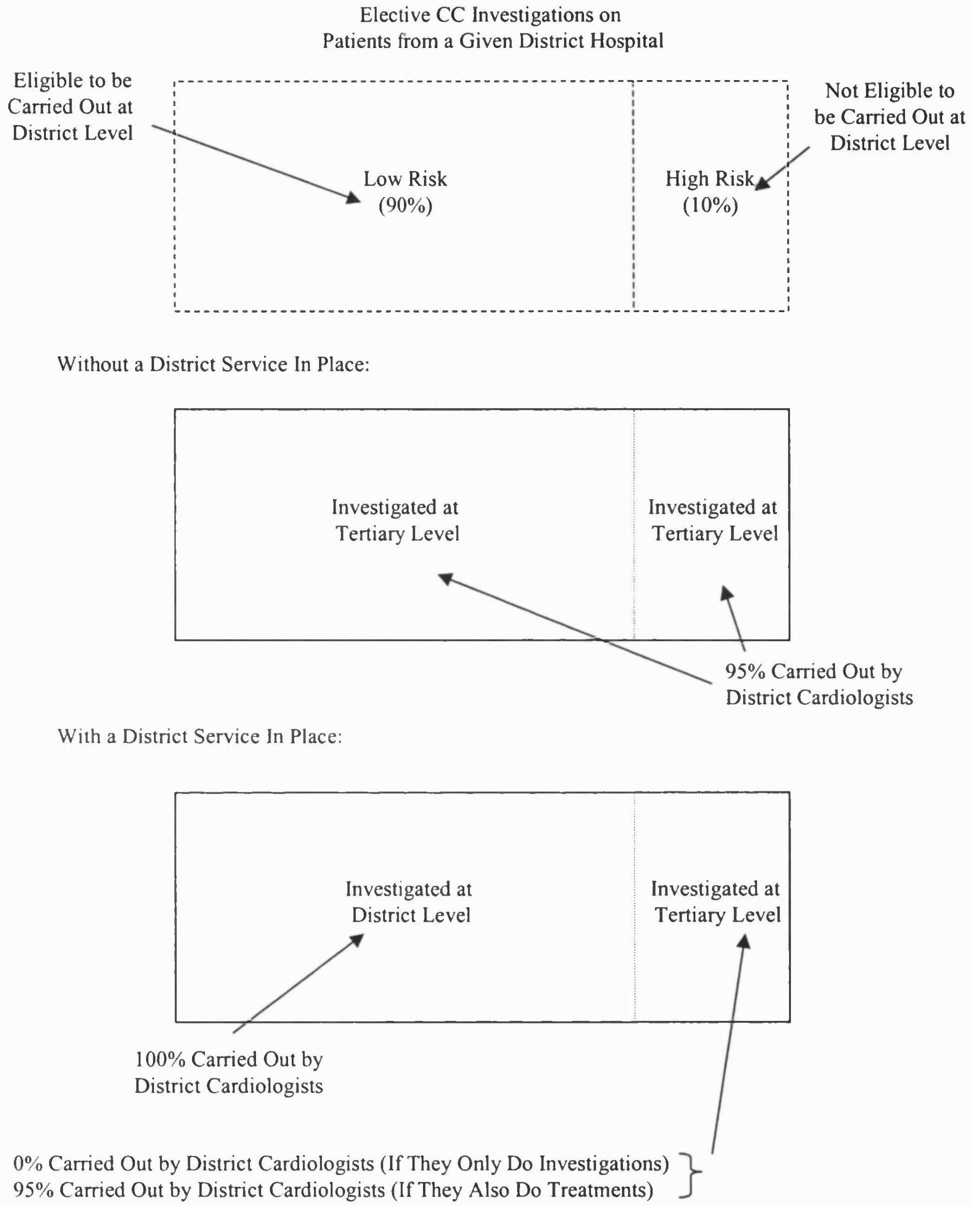


Figure 9.17 District Operator Fractions of Elective CC Investigations

The fraction will be lower if a district service is in place, as district-based cardiologists would not wish to spend time travelling to the tertiary centre unnecessarily. Furthermore, with a district service in place, a district-based cardiologist who only does interventional procedures may decide to abdicate responsibility for investigating high risk cases to tertiary-based cardiologists as these cases might be more likely to require synchronous investigation and treatment. A further factor to consider is allowances for absences due to sickness and holidays. It was estimated that overall 5% of the workload would be reallocated to tertiary-based CC operators due to these absences. Therefore the following formulation was used:

$$FTCCbyDOp = \begin{cases} \text{IF (DCCFA<>0) THEN 0 ELSE 0.95 (Ribsley General)} \\ \text{IF (DCCFA<>0) THEN 0. 95 ELSE 0.95 (Veinbridge General)} \end{cases}$$

where:

DCCFA	District CC facility availability [-]
FTCCbyDOp	Fraction of tertiary-based elective CC investigations carried out by a district-based CC operator [-]

The learning fraction of junior district-based CC operators (LFJDOp), specified by an expert estimate, reflects their degree of exposure to cases directly by actually carrying out CC investigations or indirectly by attending case review meetings and informal discussions about patients.

The learning per patient (LPP) is specified in the model by a non-linear function of the average skills per junior district-based CC operator (AvSkJDOp) as a proportion of the maximum skills per CC operator (MaxSkOp). This function is shown in Figure 9.18.

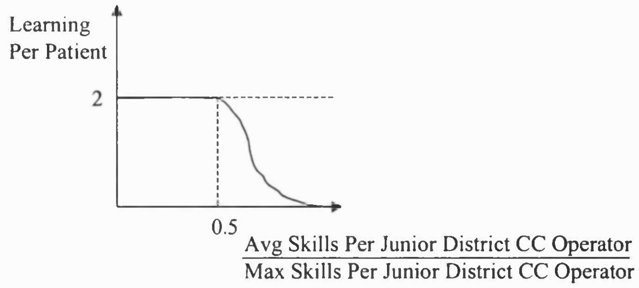


Figure 9.18 Basic Form of Learning Per Patient (LPP)

This function was constructed from estimates, provided by the consultant cardiologist, about the typical trainee CC operator's learning curve. Zero skill units was set to represent a complete novice CC operator and 100 skill units was set to represent a fully skilled CC operator. Within these two limits, expert estimates provided the number of skill units that they would expert junior trainee operators to accumulate after being involved in *n* patients where *n* ranged from 0 to 100 (Table 9.1).

Table 9.1 Estimated Gain in CC Operator Skills

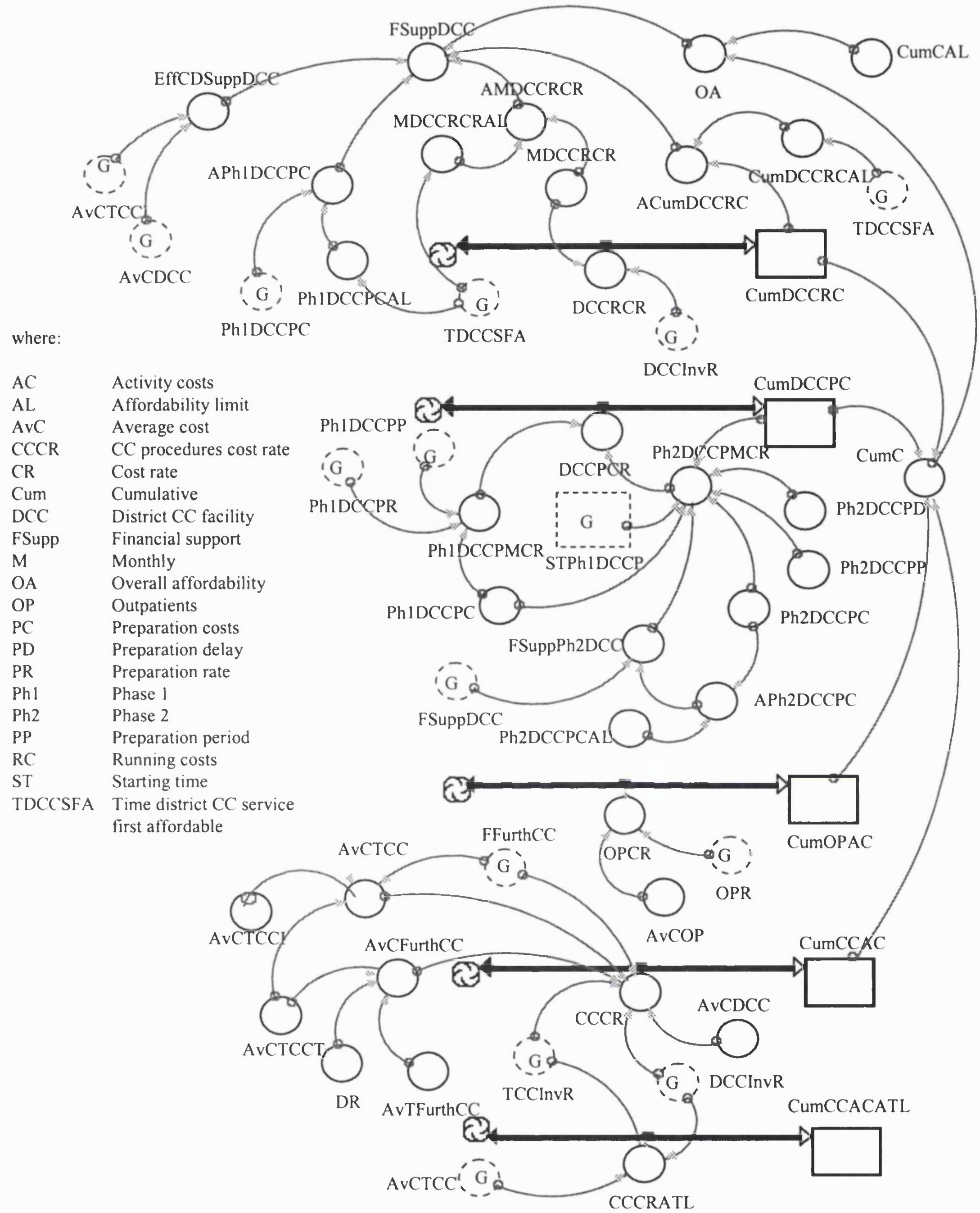
Total Procedures	Skill Gained
0	0
10	20
30	60
50	80
70	90
100	100

The expert estimates indicated that trainee operators first acquire skills at a fixed rate and then the rate of gain of skill tapers off as they become more expert. This occurs because gaining further skill would then require the junior operator to encounter more complex cases which would not arise as often as the more routine cases which led to their initial gain in skill. A continuous approximation of the rate of learning per patient was derived from this table and the input to this function was standardised by dividing the average skill per junior operator by the maximum skill per operator.

9.3.5 Representing Costs

Within the Costs Sector (Figure 9.19), four stocks are specified to track the cumulative district facility running costs (CumDCCRC), district site and facility preparation costs (CumDCCPC), OP activity costs (CumOPAC), and elective CC investigation costs (CumCCAC). These four costs are also aggregated to calculate the cumulative overall costs (CumC). A fifth stock will be discussed later.

Starting at the top of the sector with the cumulative district CC service running costs (CumDCCRC), the running cost rate (DCCRCR) involves a very simple formulation. Running costs of a specified amount each month (MDCCRCR) are associated with the monthly district CC investigation rate (DCCR).



where:

AC	Activity costs
AL	Affordability limit
AvC	Average cost
CCCR	CC procedures cost rate
CR	Cost rate
Cum	Cumulative
DCC	District CC facility
FSupp	Financial support
M	Monthly
OA	Overall affordability
OP	Outpatients
PC	Preparation costs
PD	Preparation delay
PR	Preparation rate
Ph1	Phase 1
Ph2	Phase 2
PP	Preparation period
RC	Running costs
ST	Starting time
TDCCSFA	Time district CC service first affordable

Figure 9.19 Costs Sector

Moving down the sector to the cumulative district site and facility preparation costs (CumDCCPC), the district site and facility preparation cost rate (DCCPCR) is the sum of the monthly costs of phase 1 preparation (Ph1DCCPMCR) and phase 2 preparation (Ph2DCCPMCR), if relevant. Once phase 1 preparation has commenced (modelled in the Delivery Sector and connects with the Costs Sector via the phase 1 preparation rate, Ph1DCCPR), the total phase 1 preparation costs (Ph1DCCPC) are spread evenly over a specified preparation period (Ph1DCCPT). Provided there is financial support for a phase

2 service (FSuppPh2=1), phase 2 preparation takes place commencing at a specified time after the preparation of phase 1 (Ph2DCCPD). The total phase 2 preparation costs (Ph2DCCPC) are spread evenly over a specified preparation period (Ph2DCCPT). Obviously, financial support is also necessary for a phase 1 district service (FSuppDCC=1). This link is also specified in the Delivery Sector and connects with the Costs sector via the phase 1 preparation rate (Ph1DCCPR).

Moving on to the cumulative patient activity costs (CumOPAC and CumCCAC), the OP cost rate (OPCR) is calculated as the OP activity rate (OPAC) multiplied by the average cost of an OP appointment (AvCOP). In formulating the elective CC activity cost rate (CCCR), allowances are made for patients who are investigated at the district level and are found to require treatment and therefore need to undergo a further CC procedure. The cost and timing of the second procedure (AvCFCC) will differ from that of a district-based investigation (AvCDCC). The cost of the second procedure is discounted using an illustrative discount rate (DR). Allowances are also made for the opportunity for patients investigated at the tertiary level to undergo synchronous investigation and treatment. The cost of a synchronous procedure (AvCTCCT) was assumed to equal the cost of a treatment procedure, which would be more expensive than a tertiary-based investigation only (AvCTCCI).

A fifth stock facilitates a cost comparison between the presence and absence of a district service under ideal conditions. This is achieved by considering the cumulative CC costs (CumCCACATL) if all the elective CC activity were carried out at the tertiary level (CCCRATL), assuming it were possible to provide the same levels of capacity.

The Costs Sector also calculates two key financial variables that determine whether or not patient activity and district services are deemed affordable and are thus permitted to take place. The first, an overall affordability factor (OA) situated at the top of the sector, relates to the total cumulative costs (CumC). Provided these costs remain within a specified limit (CumCAL), activity will be permitted to continue. Links representing this financial constraint on activity appear in the Referral Sector and Delivery Sector. This financial constraint also links with the second key financial variable which is the financial support for the district service (FSuppDCC). Support is only given on certain conditions. The total phase 1 preparation costs, monthly running costs and cumulative running costs have to lie within their respective affordability limits (Ph1DCCPCAL, MDCCRCRAL and CumDCCRCAL respectively) and the cost of a district-based CC investigation (AvCDCC) must not exceed that of a tertiary-based investigation (AvCTCCI).

9.3.6 Sources and Use of Knowledge Underlying Model Structure and Parameters

The structure of the conceptual model (reproduced in D1 in Appendix D) reflected the collaborators' composite mental map of the basic mechanisms underlying changes in demand in response to the shift in CC services. As I stated in Chapter 5, interviewing GPs was not possible due to the time constraints for the research. Therefore, this model included some assumptions that were made by the collaborators about GP referral behaviour. The structure that reflected activity rates being driven by waiting list goals (reproduced in D3 in Appendix D) represented a policy experiment.

In translating these structures into the more rigorous stock and flow terms, various links were disaggregated and further structure was added. The new structure arose from: the collaborators' descriptions of how the system worked; assumptions about the appropriate representation of certain policy changes; and, the application of some basic common sense. For example, in constructing the basic patient flows, it was clear that deaths on the waiting lists and other waiting list removals had to be accounted for. Furthermore, the different sources of referrals for a CC investigation had to be made explicit, considering both the inpatient and outpatient routes. The development of the district facility, its inherent delays and associated costs also had to be explicitly represented in the model structure.

For the policy analysis, often the same sets of parameter changes were made repeatedly, as the model underwent revisions and different policies were combined. Rather than repeatedly changing the parameters of certain variables (typically non-linear functions), different functions were added to the model accompanied by switches so that the appropriate functions could be selected for each simulation run. This involved the functions that specified the CC capacities, the effects of sudden capacity losses on referrals (the number and timings of the sudden capacity losses varied), and the knowledge effects on demand.

The justification underlying the model parameters varied. Various parameters arose from numerical data provided by the collaborative centres. This included all the affordability limits (except those where a very large number was specified to indicate no effective limit), CC capacities, CC operator staffing levels, the average procedural costs and, for the Ribsley General case, the initial value of the average time spent on the CC investigation waiting list.

Other parameters were based upon expert estimates. They included the various response times, the reference OP to CC referral fraction for the Ribsley General case, junior CC operator training period and recruitment delays, district facility preparation times, the non-linear functions for the waiting time and knowledge effects on demand and the passage up the CC operator learning curve (from which the function 'Learning Per Patient' was derived), and the initial CC investigation waiting list length for the Ribsley General case.

In several cases where numerical data did not exist, parameter values were derived from simple calculations. This involved working backwards along the referral chain from the actual activity rates and following descriptions that parts of the system was in equilibrium and the desired waiting time goals were maintained. This referred to the reference OP rate and initial length of the OP waiting list for the Ribsley General case. The calibration of several parameters for the Veinbridge General case resulted from the descriptions of equilibrium and the assumption that the cardiologists there referred 50% more patients than those at Ribsley General for an elective CC investigation. The latter assumption was made because the expert estimate proved to be unreliable. This assumption reflected the fact that cardiologists at Veinbridge General referred more 'aggressively' and it produced a calculated OP rate of similar magnitude to that of the Ribsley General case (the OP rate could not be verified but served for the purpose of the model). These parameters included the initial length of the OP waiting list, the OP capacity level, the reference OP to CC referral fraction and reference OP referral rate. Note that the data shown in Figure 7.9 could not be used to specify the final variable, as the data was incomplete by only referring to new OP referrals.

A number of parameter values were derived from simulation runs. For example, the model was run for an initialization period to produce the starting values of the sum of the waiting list join times (to set the starting values of the average time spent on the waiting lists) and the initial value of the current simulation time (which included the initialization period). Further examples involved the use of sensitivity analysis and partial model testing. The former was used to derive the appropriate magnitude of the effect of 'other' factors on demand to produce the reported capacity utilisation rates for the Veinbridge General case. The latter involved the magnitude of the effect of significant capacity losses on demand for the Ribsley General case.

The policy variables reflected the possible effects of various policy changes (reflecting interventions that could have been made) and their specified values were for illustrative purposes only. This included alternative functions for the waiting time, knowledge, effect of sudden capacity losses and 'other' effects on demand, OP and CC capacities and the affordability limits of various costs relating to the district service.

The limitations that the model assumptions imposed on the study are discussed in §12.2.3. Further details about the justification underlying the model structure and its parameters may be found in the model documentation.

9.4 TESTING THE MODEL

It is essential that the model is rigorously tested in order to gain confidence in the insights and recommendations that emerge from its use. Sensitivity analysis and partial-model testing play important roles in testing SD models in addition to a series of formal tests. These tests provide an indication of the appropriate time to stop refining the model. The formal process of model testing is often referred to as model validation. Validation, in the sense of confirmation, can never be absolute (Popper, 1959); a model cannot be proved to be right, it can only fail to be proved to be wrong. In simulation modelling, a pragmatic approach is adopted to establish confidence in whether the model is sufficiently accurate for its intended purpose (Forrester 1961; Richardson and Pugh 1981; Neelamkavil 1987; Pidd 1998; Coyle and Exelby 2000).

As stated in §4.2.2. and §5.4.2, the process of building confidence in a model is an on-going, iterative process that is embedded in the SD approach. It does not rely upon a single test or performance measure. Confidence in the model develops as the number of tests it withstands increases. Furthermore, the model has to be acceptable to both the modeller and the target audience (Forrester and Senge 1980; Richardson and Pugh 1981; Barlas 1996). The model was constructed and tested with synthetic parameters initially in order to provide some illustrative model output to present to the collaborators. This was deemed very useful as they had not been exposed to SD modelling before. This also facilitated the discussion of the face validity of the model structure and the process of calibrating the model.

There are a number of established tests for SD models and these can be classified in several different ways. Forrester and Senge (1980) differentiated between tests of the model structure, those that focus on the simulated behaviour, and those that consider the policy implications that emerge from the use of the model. In making clear connections with the importance of the model purpose in the process of validation, Richardson and Pugh (1981) subdivided both the model structure and behaviour tests into two groups. The first group are those that consider the model's suitability for its purpose. The second group are those that evaluate the model's consistency with reality by comparing the model's structure and behaviour with the available information about the real system. Richardson and Pugh also argued that beyond suitability and consistency are two other important issues. These are the effectiveness of the model in achieving the purpose of the study and the utility (usefulness) of the model and the outputs of the modelling process. This overlaps to some extent with Forrester and Senge's tests of the policy implications.

Another classification of SD model tests was presented by Barlas (1996). He referred to model structure tests as direct structure tests. He also subdivided behaviour tests into structure-oriented behaviour tests and behaviour pattern tests. The former set evaluates the model structure indirectly by applying particular behaviour tests on the simulated behaviour patterns. The latter consider the ability of the model to reproduce the reference modes. The various model tests follow a logical sequence. Direct structure tests precede structure-oriented behaviour tests and these are followed by behaviour pattern tests.

SD has been criticised for the absence of statistical significance testing in model validation. These tests assume the availability of past time series for all input variables which is rare in SD. Furthermore, system dynamicists argue that the use of statistical significance testing in SD model validation is inappropriate for various philosophical and technical reasons. For further discussions on this topic, see Barlas (1996).

Time and cost constraints may prevent all the available tests being carried out. However, there exists a core (or minimum) set as highlighted by Forrester and Senge (1980). Table 9.2 lists the tests that were applied during the course of the model development. These included all the core tests. The tests are arranged within the Richardson and Pugh (1981) framework.

Table 9.2 Tests Applied to Build Confidence in System Dynamics Model

	Model Structure	**Model Behaviour**
Suitability for Model Purpose	Dimensional consistency test* Extreme conditions in equations test* Boundary adequacy for structure test*	Structural (in)sensitivity test* Parameter (in)sensitivity test*
Consistency With Reality	Face validity of structure test* Parameter verification test*	Replication of reference modes test* Surprise behaviour test* Extreme conditions test (including conservation of mass)
Utility and Effectiveness	Appropriateness for audience test	Generation of insights test* Counter-intuitive behaviour test Family-member test

(Sources: Forrester and Senge 1980; Richardson and Pugh 1981; Coyle 1996. *Core tests)

The tests are briefly described in the following two sub-sections. For further details, see Forrester and Senge (1980), Richardson and Pugh (1981) and Coyle (1996).

9.4.1 Tests of Model Structure

To evaluate the suitability of the model structure, the model was required to pass three core tests. The first test considered the dimensional consistency of the model equations. The dimensions on both sides of all the model equations should balance. Furthermore, all parameters should have meaningful interpretations in the real world; 'fiddle factors', designed to make equations balance, should not be employed. In this way, the dimensional consistency test is carried out in conjunction with another test, the parameter verification test.

The second test on the suitability of the model structure ensured that the equations made sense when subjected to extreme conditions even if they seemed unlikely. This test can highlight the need to include non-linear functions in order to incorporate saturation effects into the model. For example, the non-linear formulation of the learning per patient function (LPP) saturated the gain in junior district CC operator skills as the average skills per operator (AvSkJDOp) approached and reached the maximum level of skills (MaxSkOp).

For the third test of suitability of model structure, the model boundary was checked to ensure that it contained all the necessary variables and feedback structure to address the purpose of the study. In addition to the variables that formed the feedback structure, the boundary was required to include many additional variables such as those for testing the model and evaluating the policy experiments.

Two further core structural tests evaluated the model's consistency with reality. With these tests verification was sought into both the model's basic structure and its parameter values. Both need to be recognisable to those who are familiar with the real world system. As described in §8.3.2, some face validity issues were addressed in the development of the conceptual model which formed the basis of early versions of the simulation model. In verifying the model structure it is also essential that resource flows obey physical laws such as the conservation of mass; matter should neither be created ('free lunches') nor destroyed (leakages). For example, patients who, waiting for an OP appointment, deteriorated and were referred on for an elective CC investigation following a hospital admission (RROPWLtoIPtoCC) would not be accounted for in new elective CC investigation referrals from inpatients (NRRIPtoCC). Therefore the omission of the former would constitute a leakage from the flow of patients to the OP waiting list (RROP) and then from the OP waiting list to elective CC investigations (RROPWLtoCC). Parameter values must not be contrived but conceptually sound. Furthermore, their numerical values should be derived from reliable information sources. If hard data is not available, expert estimates are required.

Finally, to contribute to the model structure's utility and effectiveness, it was important to ensure that the level of detail of the model was appropriate for the target audience. This concerned issues of the model's size, its degree of complexity and level of aggregation.

Careful balances had to be maintained in deciding upon the appropriate level of model detail. A high level of model detail might impress some audiences. However, excessive model detail may inhibit the ability of both the target audience and modeller to understand the model and its analyses. For example, explicitly representing the delivery of emergency CC investigations and differentiating between priorities of elective cases would clutter the model with unnecessary detail.

9.4.2 Tests of Model Behaviour

It is recommended that before testing the simulated (model) behaviour, a clear set of *a priori* expectations should be established. This will provide a suitable basis upon which to address any unanticipated behaviour. All instances of unanticipated behaviour should be questioned and resolved. Furthermore, hypotheses about their causes should be thoroughly tested. It is important to note that unanticipated model behaviour may not necessarily indicate a failure of the model. Instead, it may suggest the discovery of a useful policy insight (Mass 1991).

In considering the suitability of the simulated behaviour for the model purpose, the sensitivity of the model's structure and parameters to reasonable changes was tested. For these two core tests, it was considered whether reasonable changes in parameter values or alternative model formulations altered the modes of behaviour and, more critically, altered the policy conclusions. Parameter sensitivity may be overcome by justifying the use of an exact parameter value, although parameter insensitivity is more desirable. However, a model that displays policy sensitivity is deemed unsuitable for policy analysis.

The consistency of the simulated behaviour with reality was tested with three tests, two of which were core tests. For one test, it was necessary to demonstrate the ability of the model to replicate the historical reference modes. This represented a core test. For both the Ribsley General and Veinbridge General cases, there was a good qualitative fit between the simulated problem behaviour and historical reference modes.

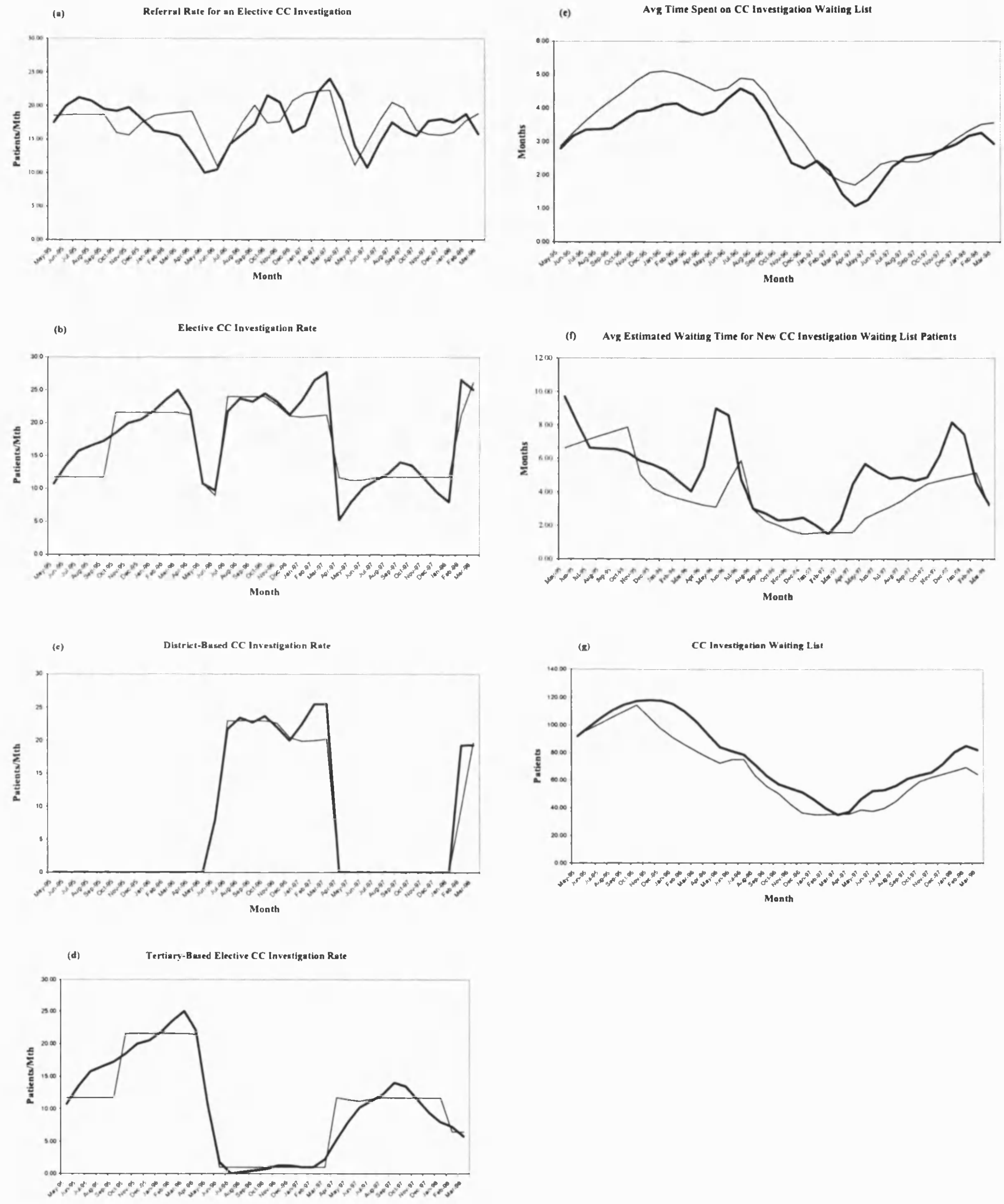


Figure 9.20 Historical Fit for Ribsley General: CC Variables

(Thick lines indicate real data which have been smoothed with a 2 point-centred moving average and thin lines indicate simulated data)

The historical reference modes for the Ribsley General case were introduced in §8.2.2. The historical fit is shown in Figure 9.20 and Table 9.3 provides several summary measures described by Sterman (1984).

Table 9.3 Statistics of the Historical Fit for Ribsley General

Variable	MAPE	Bias	Unequal Variation	Unequal Covariation	R^2	N
Figure 9.20(a)	0.16	0.02	0.04	0.94	0.24	35
Figure 9.20(b)	0.16	0.04	0.09	0.87	0.80	35
Figure 9.20(c)	0.10	0.08	0.11	0.80	0.96	35
Figure 9.20(d)	0.30	0.00	0.03	0.97	0.91	35
Figure 9.20(e)	0.18	0.60	0.09	0.31	0.88	35
Figure 9.20(f)	0.26	0.34	0.01	0.65	0.48	35
Figure 9.20(g)	0.13	0.68	0.01	0.31	0.93	35

(May 1995 to March 1998. Bias, unequal variation and unequal covariation refer to Theil's statistics. The failure to sum to unity is due to rounding errors.)

As stated in §7.3, the real data for Ribsley General excludes the patients who, over the three year period, had incomplete data. This involved 60 patients including 52 patients who did not undergo their CC investigation but left the waiting list for another reason i.e. other waiting list removals. By contrast, the simulated data includes other waiting list removals. Therefore, the historical fit graphs are not strictly comparing like with like. It would be inappropriate to define simulated variables with these other waiting list removals deducted for the analysis of the historical fit, as this would produce inconsistencies between the underlying dynamics of the real and simulated data. In other words, what happens tomorrow and on subsequent days is a consequence of what happened today so if the events of today are changed (i.e. changes to the starting values and so on) then this will also alter the events of tomorrow and thereafter.

Recall that the emphasis in SD is on reproducing data patterns, not individual data points. The former concerns the underlying trends, periods, frequencies, phase lags, amplitudes and so on, whilst the latter concerns isolated events. Given the purpose of the model, it was considered that it replicated the historical CC behaviour modes well.

Referring to Table 9.3, the bias (overestimates) in the average time spent on the CC investigation waiting list (AvTonCCWL, see Figure 9.20(e)) is due to two factors. The first factor is the early underestimation of the referral rate (RRCC, Figure 9.20(a)). Fewer patients are considered to contribute an individual waiting time of zero (as they have just joined the waiting list) so higher average waiting times result. The second factor is the underestimates of the tertiary-based CC investigation rate (TCCInvR, Figure 9.20(d)). Estimating fewer waiting list removals produces higher waiting times. The bias (underestimates) in the CC investigation waiting list (CCWL, Figure 9.20(g)) is due to the net effect of these two factors where the former dominates over the latter.

The estimates of the tertiary-based CC investigation rate (TCCInvR) result from the estimates of the tertiary capacity. As stated in the model documentation, the tertiary capacity (see PCapTCCB) is based upon an approximation of the historical activity data and the reports that the system operated at full capacity. The historical data were smoothed and then divided between five different situations and, for each situation, averages were taken to derive five different capacity levels. Corresponding to increasing levels of capacity, these situations were: (1) with a major reduction in capacity e.g. during a major closure of tertiary facilities, (2) with a moderate reduction in capacity e.g. during a moderate closure of tertiary facilities, (3) during the first month of a major closure of tertiary facilities, (4) normal capacity levels (5) elevated capacity levels. For the early period, the model reflects the reports of normal capacity levels (situation 4) followed by elevated capacity levels (situation 5) which were achieved using Waiting List Initiative funding. It is possible that a closer fit could have been achieved if more numerical data had been available for reported situations where 'normal capacity' levels applied.

Figure 9.17 demonstrates that there was also a good fit between the simulated and hypothetical behaviour for the OP variables. It would not be appropriate to summarise the degree of fit with the summary measures that were used above, given that the historical reference modes were constructed with hypothetical data. Both the simulated average time spent on the OP waiting list and waiting list length exhibit small, temporary increases. As stated in §8.2.2, this behaviour is not inconsistent with the description that there were no OP capacity shortages. The actual sizes of the simulated increases in the OP waiting list and average waiting time arose from the model assumptions about changes in GP referral patterns in response to the introduction of district services (knowledge effects on demand). These assumptions reflected the description that the knowledge effect on demand was marginal.

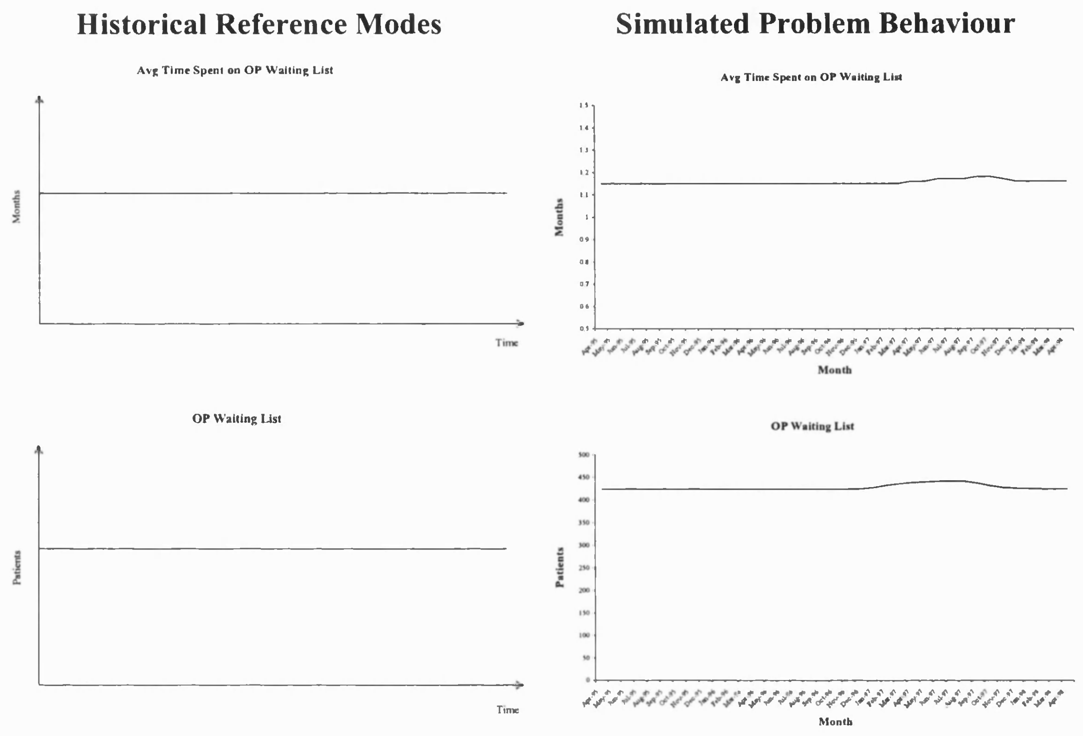


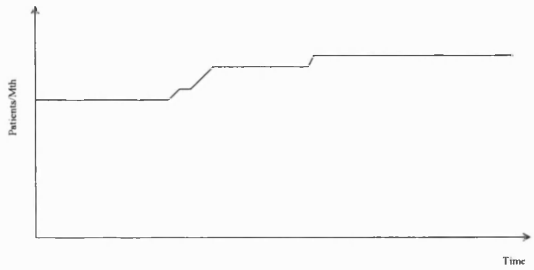
Figure 9.21 Historical Fit for Ribsley General: OP Variables

Historical Fit for the Case of Veinbridge General

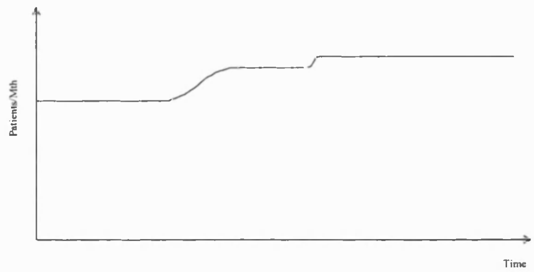
The historical reference modes for the Veinbridge General case were introduced in §8.2.3. Recall that these were generated using hypothetical data as real data was not available. As shown in Figure 9.22, there was a good qualitative fit with the simulated behaviour.

Historical Reference Modes

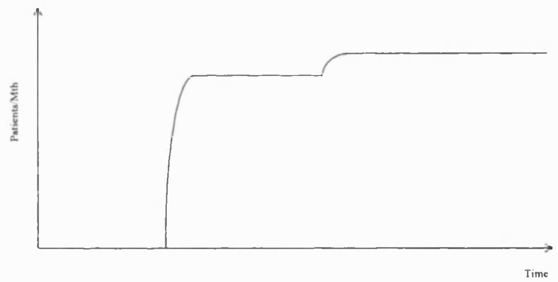
Referral Rate for an Elective CC Investigation



Elective CC Investigation Rate

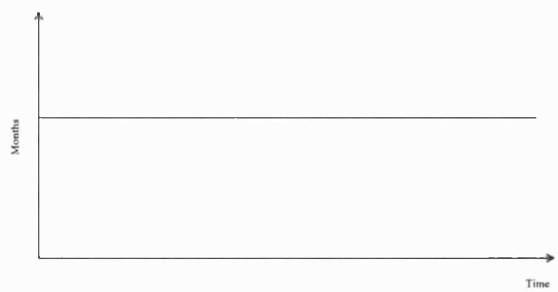


District-Based CC Investigation Rate



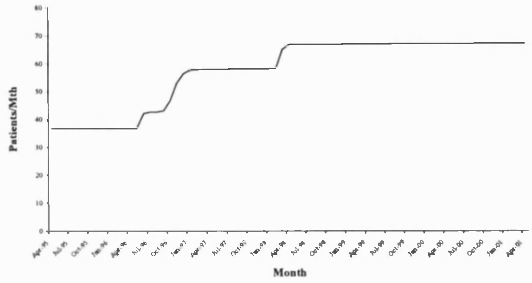
Tertiary-Based Elective CC Investigation Rate

Avg Time Spent on the CC Investigation Waiting List

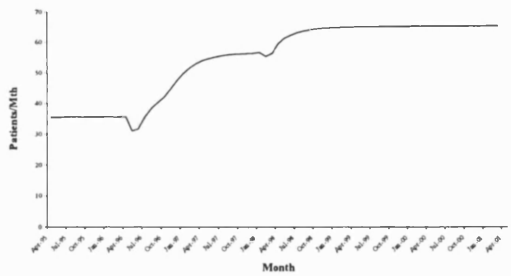


Simulated Problem Behaviour

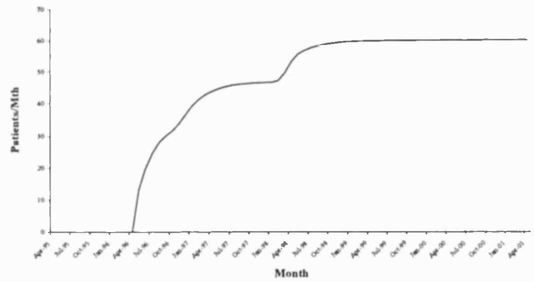
Referral Rate for an Elective CC Investigation



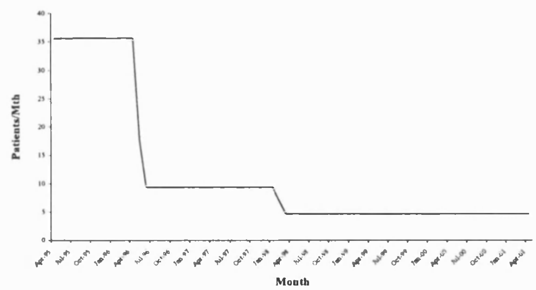
Elective CC Investigation Rate



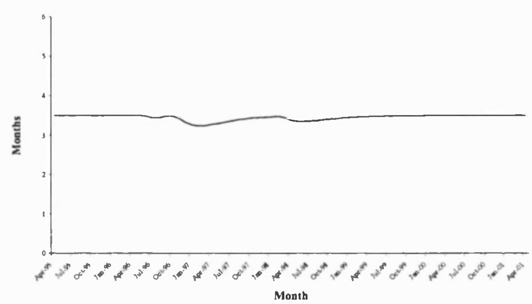
District-Based CC Investigation Rate



Tertiary-Based Elective CC Investigation Rate



Avg Time Spent on the CC Investigation Waiting List



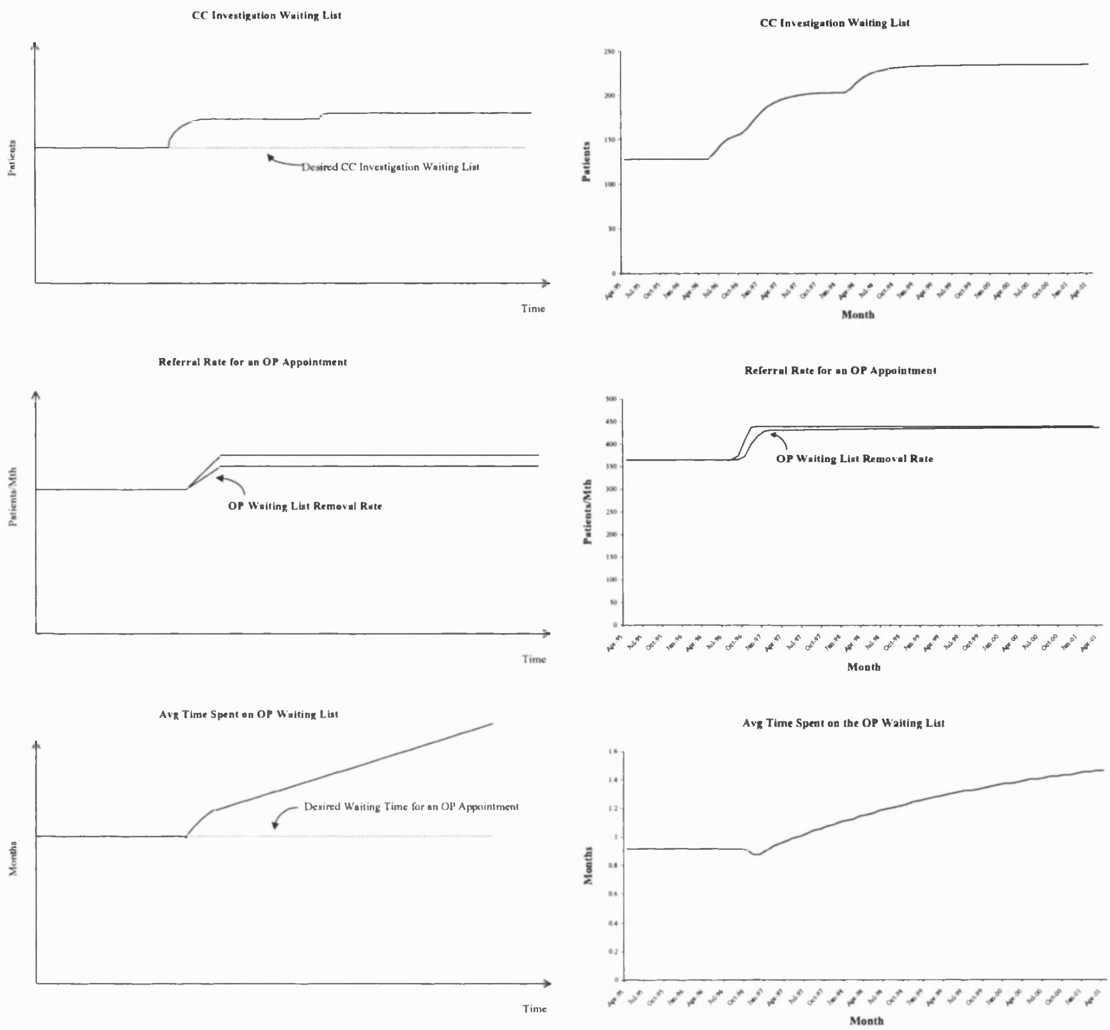


Figure 9.22 Historical Fit for Veinbridge General

In Figures 9.20-9.22, the simulated output is reported at monthly intervals to be consistent with the frequency of the real data. However, it should be noted that SD estimates real world phenomena approximately continuously (in this case, calculating at small intervals of DT=0.125 months) and not at discrete intervals. Therefore, reporting simulated data at discrete monthly intervals can obscure the simulated effects of delays in the system. For example, for the Veinbridge General case, the simulation output exhibits a brief delay in shifting the workload to the district level due to the perception delay in responding to the shortfall in capacity following the closure of the tertiary catheter laboratory.

Other Tests of Model Behaviour

Another core test targeted unexpected model behaviour. On occasion, during the course of the simulations, the model exhibited unexpected behaviour. The underlying mechanisms were closely considered to establish whether this indicated the presence of flaws in the model, or whether the mechanisms were consistent with the real system and therefore, correct. For instance, if a limited overall budget were imposed, so small that it was consumed before the district site had been completed, in the real world district site preparation would cease. Even if funds had been set aside to prepare a site, there would be no funding to use it so the preparation costs would be a waste of money. However, the simulated site preparation did not cease under these circumstances thus indicating the need for the creation of links between the district site preparation rate (DCCPR) and the overall affordability (OA).

To conduct the third test of the consistency of the simulated behaviour, the model was subjected to extreme conditions and extreme policies. Policy statements are expressed within the rate equations. The model was required to behave reasonably under such changes i.e. as the real system would be expected to behave under these circumstances, even those which have not been observed in the real system. As part of this test a mass-balance (conservation of matter) test was carried out by simulation, as opposed to by direct inspection which had formed part of a previous test (face validity of model structure). The unintentional creation of mass can result in negative stocks. Mass balance tests are particularly indicated in cases where flows bifurcate and merge such as the patient flows in this model. However, negative stocks can also occur in single source-sink flows. Therefore, mass balance tests were applied to both the patient flows (involving a bifurcation and a merger) and the flow of junior district CC operator skills (a single source-sink). The tests involved setting an extreme condition, formed by a single large PULSE, as the main input to the flows whilst setting the other inputs to zero. All relevant stocks were plotted to ensure that they remained non-negative. To also check that matter had not been destroyed calculations were carried out to the patient and skills flows which are in general terms:

$$CHECKSUM1_t = \Sigma STOCK_0 + \Sigma INFLOWS\ DURING\ t - \Sigma OUTFLOWS\ DURING\ t - \Sigma STOCK_t$$

$$CHECKSUM2_t = \Sigma STOCK_0 + \Sigma INFLOWS\ DURING\ t - \Sigma OUTFLOWS\ DURING\ t - \Sigma MAX(STOCK_t, 0)$$

In many circumstances, if these functions remain zero at all times (making allowances for the floating point accuracy of the simulation calculations) this will indicate that the flows have been conserved. Dangerfield and Fang (2002) discuss some situations where this will not happen, none of which applied to this model. CHECKSUM2 (by including the

MAX function) is the more robust as a negative value of a stock could produce cancelling out and calculate CHECKSUM1 as zero thus erroneously suggesting that matter had been conserved.

For example:

$STOCK_0 = 10$
ΣINFLOWS DURING T = 20
ΣOUTFLOWS DURING T = 40 (i.e. matter has been created)
$STOCK_T = STOCK_0 + \Sigma$INFLOWS DURING T-$\Sigma$OUTFLOWS DURING T = 10+20-40 = -10
$CHECKSUM1_T$ = 10+20-40-(-10) = 0 (i.e. suggests that matter has been conserved)
$CHECKSUM2_T$ = 10+20+40-0 = -10 (i.e. highlights that matter has not been conserved)

Three tests evaluated the utility and effectiveness of the model. The first test considered the ability of the model and modelling process to generate useful policy insights. This is a core test because the inability of a model to generate compelling evidence to support policy makers would render it useless. The degree of utility of the policy insights is discussed in Chapter 12.

The second test focused on counter-intuitive behaviour exhibited by the model. Counter-intuitive behaviour is that which, without the aid of the model, is considered to contradict intuition but, with the aid of the model, is regarded as having clear implications for the real system. Using the model it was possible to understand fully the basic mechanisms responsible for some counterintuitive behaviour patterns experienced by the CC waiting list. For example, the waiting list 'bouncing back' i.e. reducing and then lengthening again after an increase in CC capacity.

The final test in this category was the family member test. This involved the ability of the model to represent a general theory of a family (or class) of problems. Key questions were how the shift in CC services differed from other family members (shifts in other services), and how the model would exhibit the characteristic behaviour of each family member when policies were altered in accordance with their known decision making rules. The results of this test are also discussed in Chapter 12.

9.5 SUMMARY

The purpose of this chapter was to describe the simulation model and outline the procedures by which confidence was gained in this model. After providing a brief overview, the model was discussed in further detail. The model comprised structure representing the referrals and delivery of OP appointments and elective CC investigations, the associated waiting times, costs and financial constraints. The key equations were explained and these were accompanied by the relevent stock and flow sub-structures. The rationale underlying the model structure and parameters was given before describing the series of well-established SD tests that were applied. These assessed both the model's structure and its behaviour.

The next two chapters demonstrate how the simulation model formed an experimental tool with which insight was provided into: (a) understanding the base case behaviours for the two case studies and (b) designing ways in which the behaviour of the system could have been improved.

CHAPTER 10

BASE CASE ANALYSES

10.1 INTRODUCTION

Chapter 9 introduced the simulation model and described the process by which confidence in this model was gained. The purpose of this chapter is to present the base case analyses which were generated by the use of the model. Note that for both case studies, the problem behaviour is referred to as the base case behaviour. The base case analysis for the case of Ribsley General is described first. Using the simulation model, the time scale for the problem reference modes was extended (§10.2). Several assumptions underlying this simulation run are highlighted (§10.2.1). The insights into the base case behaviour that were generated by the model are described (§10.2.2) with references made to the underlying causal structure (§10.2.3). This chapter also explains how the understanding of the causes of the base case behaviour was tested and explored further via sensitivity analysis (§10.2.4). In the next section (§10.3), the Veinbridge General base case analysis is presented. The chapter is summarised in the final section (§10.4).

The causal structure, which was first presented in Chapter 8, is reproduced in Appendix D (see D1) and is accompanied by a diagram which depicts the potential interactions between the different feedback loops (see D2). The difference between potential and actual interactions between two loops is that the latter rely upon both loops being active at the same time. As described in Chapter 5, the results of the experiments were evaluated on the basis of changes to the waiting list lengths, average waiting times, resource use and referral rates. The indices proposed in §5.4.3 were used to summarise, for a given time period, the instances when pressure was imposed by excessive waiting lists and waiting times. A selection of graphs and performance measures are presented. Further results and other details including the changes that were made to carry out the experiments may be found in Appendix E.

Note that demand increases are often referred to as raising pressure on the system. This description may be considered to have negative connotations. However, cardiologists often welcome increased referrals for their services as this may lead to the identification of further patients at high risk from cardiac events. As discussed previously, some patients with significant CHD do not display major symptoms. Therefore, it is important to ensure that they are brought into the health care system. The intention for this research was to contribute to the debate and not impose value judgements.

10.2 RIBSLEY GENERAL ANALYSIS

10.2.1 Simulating the Base Case Behaviour

(Exp R0)

In §8.2.2, the historical reference modes for the Ribsley General case were presented and in §9.4.2, it was demonstrated that the simulation model replicated these reference modes well. These reference modes were constructed using the available numerical data, and related to the period April 1995 to April 1998. As district services were introduced to Ribsley General in June 1996, these data only reflected the effects of district services over 23 months beyond its introduction. In order to consider the effects of policy changes over a longer time scale, the model was used to extrapolate over 17 months beyond April 1998 to the end of September 1999. The model thus produced base case behaviour over a period of 4½ years (54 months) from April 1995 to September 1999 inclusive. The extrapolations were based upon three assumptions.

The first assumption was that no further district services were provided to Ribsley General between its withdrawal at the end of May 1998 (t=37 where t indicates the simulation time) and October 1999 (t=54). The second assumption was that following May 1998, tertiary capacity levels for elective CC investigations for Ribsley General patients returned to levels which were consistent with previous periods where there were no facility closures and tertiary capacity levels were normal. "Normal" means that no additional funding, such as Waiting List Initiative funding, was available. Whilst it was not possible to collect further numerical data, contact with the Ribsley General consultant cardiologist continued until August 1999, so it was possible to collect further mental data.

By that time no further use of the district service had been reported and none was planned in the immediate future. The same applied to tertiary-based capacity increases. The final assumption related to all the new junior CC operators who were recruited to Ribsley General after May 1998. It was assumed that they continued the established conservative referral tradition at Ribsley General. More specifically, they displayed under-confidence in their referral behaviour initially, and gradually increased their referral rate as they gained experience and confidence as CC operators. There was no reason to believe that the referral tradition at Ribsley General would have changed.

Given the persistent capacity shortages at Ribsley General, it was expected that temporary improvements in capacity would occur at some time in the future. However, information about their timing and extent was not available. Therefore, in generating base case behaviour for Ribsley General, it was deemed inappropriate to extrapolate too far into the future. This was in contrast with the case of Veinbridge General, where there was more certainty about the future use of CC services (see §10.3.1).

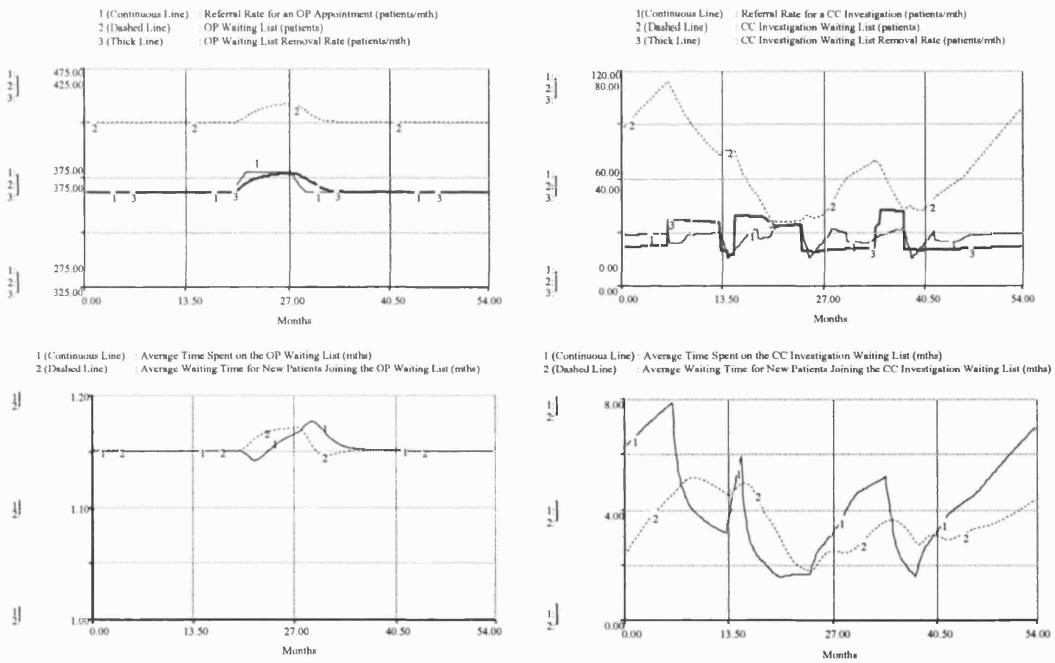


Figure 10.1 Ribsley General Base Case Behaviour

(Month 0 is April 1995 and Month 54 is October 1999. Figures are based upon simulated data that are reported at intervals of DT i.e. 0.125 months, unlike those in Chapter 9 that presented monthly data.)

Figure 10.1 shows the base case behaviour for the OP and CC investigation waiting lists, average waiting times, referral rates and waiting list removal rates. Following these assumptions, the number of waiting list joiners consistently exceeded the number of waiting list removals so the length of the waiting list and the average time spent on the waiting list rose. This was consistent with the behaviour that followed after the district service was withdrawn the first time at the end of March 1997 (t=23). It will be noted that the OP waiting list removal rate is very high relative to the referral rate for a CC investigation as only a small fraction are referred on for further investigation.

10.2.2 Basic Causes of the Base Case Behaviour

(Exps R1-R6)

April 1995 to end of April 1996 (t=0 to t=13): No district service

Between April 1995 and October 1995 (t=0 to t=6) the simulation indicated that the CC investigation waiting list rose from 88 patients to 114 patients (30% increase) and the average time spent on the waiting list rose from 2.4 months to just over 4.5 months (88% increase). These changes, which imposed significant pressure on the system, resulted from insufficient capacity. As the average waiting time was so high, demand was suppressed to the maximum extent, i.e. to saturation point. The tertiary level operated at full capacity delivering elective CC investigations because the average waiting time list far exceeded its desired level of 3 months. Due to financial constraints, the patients at Ribsley General had to rely solely on the tertiary level for the delivery of CC investigations.

Between October 1995 and April 1996 (t=6 to t=12), there was a considerable increase in the elective CC capacity at the tertiary level (approximately 84% on average), which was achieved by an injection of further funding. This capacity increase was a key factor that drove the observed decline in the CC investigation waiting list and average waiting time for new patients joining the waiting list. Because the latter, although falling, remained high, the waiting time effect facilitated the decline by continuing to suppress demand. As the average time spent on the waiting list is averaged over all the patients on the waiting list, it responded more slowly to the changes in the rate of waiting list removals. Therefore, a further period of increase was observed before its decline. The elective CC investigation service at the tertiary level continued to operate at full capacity. By the end of April 1996 (t=13), the waiting list was down to 72 patients and the average time spent on the waiting list stood at just over 4.5 months. Without the excessive waiting times suppressing demand, the waiting list would have only dropped to 77 patients and the average time spent on the waiting list would have stood at nearly 4.7 months.

In anticipation of the planned closure of tertiary facilities in May 1996 (t=13), preparations were carried out to provide a district-based CC service at Ribsley General. As it was estimated that preparations would take 3 months, they needed to commence in February 1996 (t=10) to have a district service in place in time to ensure that CC services were not adversely affected by the closure of tertiary facilities. However, there was a delay of one month before preparations were underway. This delay represented a combination of factors, in particular, the inertia from the local purchaser who was very sceptical about the value of district services. Therefore, one month's disruption of elective CC services for Ribsley General patients was inevitable.

May 1996 to end of Mar 1997 (t=13 to t=24): District service present

In May 1996 (t=13), the significant drop in capacity, due to the closure of the tertiary facilities and the delay in introducing the district service, caused increases in the waiting list and average waiting time for new patients joining the waiting list. The impact of the capacity loss was diminished, but only to a limited extent, by the 'knee jerk' reduction in referrals which occurred as a response. A district service was introduced for 10 months between June 1996 and March 1997 (t=14 to t=23). By offering a service solely devoted to routine elective care, it was possible to provide elective capacity levels which exceeded those which had been offered previously at the tertiary level. This contributed to further reductions in the waiting list and waiting times. Another factor that drove down the waiting time and waiting list was the reduction in the desired waiting time as efforts were made to make the most of the district service whilst it was available. By the end of March 1997 (t=24) when the district service was withdrawn, the waiting list was down to 35 patients and the average time spent on the waiting list was down to 1.7 months. Therefore, by compensating for the tertiary facility closures and offering further capacity, the district service had contributed to over 50% reductions in the waiting list and average waiting time over a 10 month period.

The district service often operated at full capacity. However, the simulation indicated that prior to its withdrawal, the capacity utilisation dropped because the average waiting time for new patients joining the waiting list had been reduced to a suitably low level.

The district service stimulated demand for cardiac services. The reduction in the average waiting time for a CC investigation stimulated further demand for that service. In addition to the waiting time effect, there was a knowledge effect on demand. As knowledge spread about the existence of a CC service at the local hospital, patients and GPs became more interested in CC and knowledgeable about its benefits, and thus more demanding. Therefore, to some extent, the stimulation of demand for CC investigations undermined the efforts to reduce pressure on CC services during the period that the district service was present. For example, when the district service was withdrawn at the end of March 1997 (t=24), the simulation showed that 4 of the 35 patients on the CC investigation waiting list (11%) could be attributed to the stimulation of demand due to the combined waiting time and knowledge effects.

The increase in knowledge about CC also led to higher demand for OP appointments. The simulation indicated that the demand for OP appointments was first stimulated just under 2 months later than that for CC investigations. This was due to the perception delay and the assumption that higher levels of district activity were required to persuade GPs to increase their referral rates. There was insufficient slack in the system to maintain the waiting time goal and the average time spent on the waiting list rose from 1.15 months to 1.18 months (nearly 3% increase). The OP waiting list rose from 424 patients to 442 patients (4% increase). However, the increase in demand was only temporary, after which the OP waiting list and waiting times returned to their desired levels and equilibrium was re-established. Demand was stimulated for just under 10 months in total and it led to 65 additional OP appointments being carried out. This contributed to 10 further referrals for an elective CC investigation.

The variation in referrals due to the annual recruitment of new trainee CC operators (who under-referred during their periods of under-confidence) periodically alleviated pressure on the system. The impact of this skills effect was evident on the CC investigation waiting list. For example, if the junior CC operator training programme had been withdrawn and the junior who was recruited in October 1994 had remained at Ribsley after completing their training, the waiting list would have been 2 patients higher (6% increase) at the end of March 1997 (t=24). Furthermore, the differential would have increased as time progressed to 16 patients (16% increase) at the end of September 1999 (t=54).

The duration for which junior CC operators alleviated pressure on the system by under-referring was influenced by the activity rates which in turn determined their rate of gain in skills. For example, the simulation indicated that the junior trainee operator recruited in 1996 took approximately 5 months to gain sufficient skills and confidence to saturate the skills effect on demand. By contrast, the junior trainee recruited in 1998 experienced lower patient activity rates to gain skills and thus took nearly twice as long.

April 1997 to January 1998 (t=24 to t=33): No district service

Following the withdrawal of the district service at the end of March 1997 (t=24), the capacity for CC investigations dropped sharply and the waiting list and waiting times rose in spite of the 'knee jerk' reduction in referrals which followed as a response. The capacity loss was the predominant factor responsible for the increases in the waiting list and waiting times. Another factor which reinforced these increases was the knowledge effect on demand which, although declining, still remained after the 'knee jerk' reaction in referrals had passed. The simulation indicated that nearly 5 months elapsed before the demand for OP appointments returned to their normal levels. The waiting time effect led to demand being suppressed as waiting times rose. However, there was a 6 month delay before the skills effect could provide additional relief in terms of reduced pressure on the system. This was because by April 1997 (t=24), the existing trainee operator had gained sufficient skills to saturate the skills effect on demand for CC investigations to its highest level. His departure and the arrival of a new novice trainee (and associated drop in referrals) was not due to take place until October 1997 (t=30).

February 1998 to May 1998 (t=34 to t=37): District service reinstated

By the time the district service was reinstated in February 1998 (t=34), the reduction in the CC investigation waiting list had been almost completely obliterated by rising to 69 patients. Meanwhile, the average time spent on this waiting list had risen to just over 3.5 months.

The additional capacity provided by the district service reversed the increases in the waiting list and waiting times. This was facilitated by the waiting time effect as demand was suppressed, although the degree of demand suppression reduced with the decline in waiting times. The district service was in place for an insufficient period for GPs and patients to perceive its existence and respond to this knowledge. Consequently, there was no further stimulation of demand for OP services during this period. The skills effect imposed increasing pressure on the system as the existing trainee CC operator who was recruited in October 1997 gained confidence. When the district service was withdrawn at the end of May 1998 (t=38), the CC investigation waiting list had been reduced to 41 patients and the average time spent on this waiting list had been reduced to 2.8 months. Therefore, four further months of the district service had contributed to a 41% reduction in the waiting list and 20% reduction in the average time spent on the waiting list.

June 1998 to October 1999 (t=38 to t=54): No district service

Based upon the assumptions outlined in the previous section, the simulation indicated that from June 1998 (t=38) onwards to October 1999 (t=54), the tertiary service operated at full capacity. However, this was insufficient to control the increase in the CC investigation waiting list and waiting times. Instead, both exhibited consistent growth over this period. As the average waiting time rose, the waiting time effect caused demand to be suppressed thus alleviating pressure on the system but only to a limited extent. The growth in the waiting list and waiting times was also slowed to a small extent by the associated increase in other waiting list removals. The simulation indicated that by October 1999 (t=54), whilst the OP end of the referral chain had returned to equilibrium, the CC investigation waiting list had more than doubled to 98 patients and the average time spent on the waiting list had increased over 1.5 times to 4.3 months. The return of CC capacity shortages was confirmed by the Risbley General consultant cardiologist during contacts that followed the collection of numerical data.

Generation of Costs Over Time

The reductions in the waiting lists and waiting times have to be traded-off against the various costs associated with having a district service. The introduction and use of district services incurred costs to prepare the site in advance of the introduction of the service (approximately £30,000), in addition to the costs of running the service (approximately £50/mth). Furthermore, there was the penalty associated with a district service, where synchronous investigation and treatment was not possible adhering to the under current guidelines. This inevitably required some patients to undergo a second CC procedure. Assuming that only one third of patients required inpatient treatment and one half had coronary stents inserted, conducting the same level of activity at the tertiary level, if possible, would have led to approximately a 2% saving in activity costs. This would have amounted to £12,957 over the 14 months that the district service was in place (average £925/mth). Higher stent fractions would have generated higher costs but slightly lower cost savings.

10.2.3 Emphasising the Structure-Behaviour Linkages

System dynamicists focus on the information feedback structure of a system. They seek to understand how it influences the behaviour of the system (the behaviour-structure linkage) and they thus develop endogenously-based insights. Reactions to exogenous events are studied but system behaviour that is purely generated exogenously is not interesting to system dynamicists.

This section highlights the structure-behaviour linkages underlying the base case behaviour. It should be noted that the viewpoint for this study was to examine the consequences of the shifts in CC services and the feedback effects that they engendered. Therefore, capacity changes were modelled exogenously. If the aim had been to consider the policy decisions to introduce a district service, capacity changes would have been modelled endogenously (see §12.9).

In the main feedback structure, which is reproduced in Appendix D (see D1), loop B1 represents the balancing process underlying attempts to meet the CC investigation waiting time goal with adjustments to the tertiary-based elective CC investigation rate. As stated in the previous section, the tertiary-based CC service for Ribsley General patients was pushed to operate at full capacity so loop B1 was dormant. Therefore, during these periods, changes in the tertiary-based elective CC investigation rate were driven exogenously by capacity changes and adjustments to the waiting time goal.

Loop B2 represents the process which controls adjustments in the CC investigation rate at the district level. It was also stated that the district service often operated at full capacity. During these periods, changes in the CC investigation rate at the district level were driven exogenously by changes to the capacity and waiting time goal. When the service was not operating at full capacity, changes in the CC investigation rates were driven endogenously.

When the CC investigation services were operating at full capacity, this rendered inactive other endogenous processes which shared the causal links between the capacity utilisation and activity rates. This affected all the four reinforcing processes. The tertiary service operating at full capacity affected the process driving the gain in district-based junior CC operator skills at the tertiary level (loop R4). The district service operating at full capacity affected the processes underlying changes to the knowledge effects on demand for OP appointments (loop R1) and CC investigations (loop R2) and, the gain in district-based junior CC operator skills at the district level (loop R3). Operating at full capacity meant that changes in the skills for district-based junior CC operators and knowledge effects were driven exogenously by subsequent further increases in capacity and adjustments in the waiting time goal.

Endogenous processes also featured and two of these generated further demand that forced the capacity utilisation to remain high. These processes thus formed further exogenous inputs to the processes of activity adjustment (loops B1 and B2), knowledge gain (loops R1 and R2) and skills gain (loops R3 and R4). They involved the balancing loop B3, which controls adjustments in the waiting time effect on demand for CC investigations. A second process involved the balancing loop B4, which controls attempts to meet the implicit OP waiting time goal with adjustments to the OP rate in response to increases in the referral rate. Increases in OP activity produce further referrals for a CC investigation. However, the analysis showed that the significance of the increases in demand from the waiting time effect (loop B3) was greater than that associated with the increases in OP activity (loop B4). Another endogenous process was the balancing process that generated other removals from the CC investigation waiting list (shown in the stock and flow diagrams as loop B. See E1 in Appendix E). This process alleviated pressure on the system to some extent by slowing down the rate of increase in the CC investigation waiting list and thus reduced the pressure to increase activity rates.

Therefore, the basic trend exhibited by the CC investigation waiting list was mainly as a result of exogenous factors. Firstly, the shortfalls and increases in elective CC capacities at both the tertiary and district levels. Secondly, the reduction in the desired waiting time for a CC investigation. Thirdly, the action of several endogenous processes which generated further demand for CC services. Moreover the endogenous processes interacted with one another thus generating further pressure on the system. For example, with the use of a district service and the associated capacity increases, the subsequent increases in referrals for CC investigations in response to reductions in the average waiting time drove the district activity to rise in attempts to meet the desired waiting time (interactions between loops B2 and B3). This generated a higher number of learning experiences for junior CC operators and thus reinforced the gain in CC operator skills (interactions between loops B2 and R3). Whilst several mechanisms existed which alleviated pressure on the system, only capacity increases were effective in helping to meet the desired waiting time.

The basic trend exhibited by the OP waiting list was generated endogenously by the process of adjustment in the OP rate towards achieving the waiting time goal (loop B4). The various factors that drove increases in the district CC investigation rates and thus generated further demand for OP appointments also provided exogenous inputs to increases in the OP waiting list (and various interactions).

Understanding the links between the behaviour and the underlying structure provided insight into how more desirable behaviour could have been achieved. Note that if a feedback loop is active, then it may be described as being *intensified* by increasing the size of its variables. Alternatively, it may be described as being *activated* by increasing the size of its variables if the loop was previously dormant.

The base case analysis suggested that three approaches could have been taken to alleviate pressure on the system: clarifying demand; meeting demand or controlling demand. Increasing the rate of other removals (intensifying loop B) by reviewing the waiting list more frequently would have clarified those who did and did not require an investigation.

This would have slowed down the rate of gain in the CC investigation waiting list and average time spent on the waiting list but this would not have produced significant improvements. Moreover, the improvements would have been numerical but not behavioural. Further capacity increases would obviously have alleviated pressure on the system by intensifying and activating the processes of adjustment in activity (loops B1 and B2). This would have proved costly and it might have stimulated further demand due to the knowledge and waiting time effects on demand. A more affordable intervention might have been to use new referral guidelines to prioritise demand. This intervention would have diminished the knowledge effects (loops R1 and R2) and waiting time effects (loop B3) on demand. It also would have reduced the calls for more activity directly and indirectly by weakening the interactions between different processes (e.g. between R3 and B3).

10.2.4 Sensitivity Analysis

Sensitivity analysis plays an essential role in SD in testing the robustness of the conclusions drawn from the model-based analyses (Tank-Nielsen 1980; Richardson and Pugh 1981). Sensitivity analysis was thus applied to evaluate the robustness of the base case behaviour to various assumptions. The understanding of the causes of the base case behaviour, as discussed in the preceding section, suggested several areas where sensitivity analysis could be directed.

This section reports upon the results of making alterations to: the availability of district services; availability of elective CC capacity; CC investigation waiting time goal; waiting time effect on demand; knowledge effects on demand; skills effect on demand; and, exogenous demand for an OP appointment.

Limiting the Availability of District Services (Exps R7 & R8)

It was stated that elective CC capacity increases were key factors in reversing the upward trends exhibited by the average CC investigation waiting time and waiting list in the base case behaviour. The importance of capacity was illustrated by comparing the base case with two alternative scenarios which resulted in significant changes in terms of fewer peaks and troughs. The first scenario involved the absence of a district service. This experiment isolated the effects of the tertiary capacity losses. In the second scenario, the use of the district service was restricted to a single occasion. This experiment, with the previous experiment, illustrated the importance of the district service in providing additional capacity.

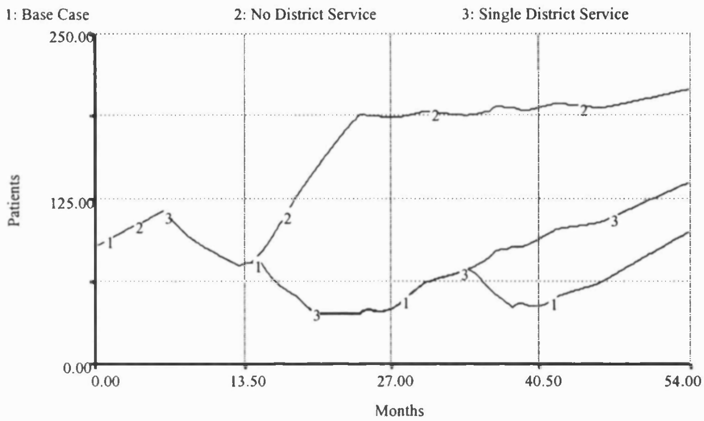


Figure 10.2 Limiting the Availability of District Services: CC Investigation Waiting List

Figure 10.2 illustrates how these changes led to large increases in the CC investigation waiting list. This figure also shows how the significance of the other removals from the CC investigation waiting list increased according to the size of the waiting list such that the sustained increase in the waiting list eventually curtailed its growth. Consequently whilst, at the end of May 1998 (t=38) when the district service was withdrawn, the waiting list was 152 patients lower than it would have been without a district service, at the end of September 1999 (t=54), the waiting list differential was reduced to 108 patients. Therefore, the sensitivity analysis demonstrated that capacity increases were crucial in controlling the waiting time and waiting list but that their importance diminished as the waiting list increased.

Limiting the Availability of Elective Capacity: A Winter Crisis (Exp R9)

The base case reflected the assumption that between the closures of the tertiary facilities, the tertiary elective capacity returned to normal levels. The model was used to consider a departure from this assumption. The model simulated a winter crisis over a 3 month period prior to the 1998 closure of tertiary facilities (from t=32 to t=35). It was assumed that a crisis would affect cardiac services by causing elective CC investigations to be cancelled as beds (needed for the post-operative recovery period) and other resources would be reallocated to higher priority cases. This crisis was represented in the model by a 75% reduction in tertiary elective capacity and the cancellation of the district service in February 1998 (t=34). Rather than cancelling all elective activity, allowances were made for higher risk cases to be investigated. Furthermore, given the cancelled activity, there would be insufficient patients to justify the hire of the mobile catheter laboratory.

The available capacity was insufficient for the system to cope during the crisis. For example, it caused the average time spent on the CC investigation waiting list to peak at 4.5 months, representing a 25% increase on the base case (Figure 10.3).

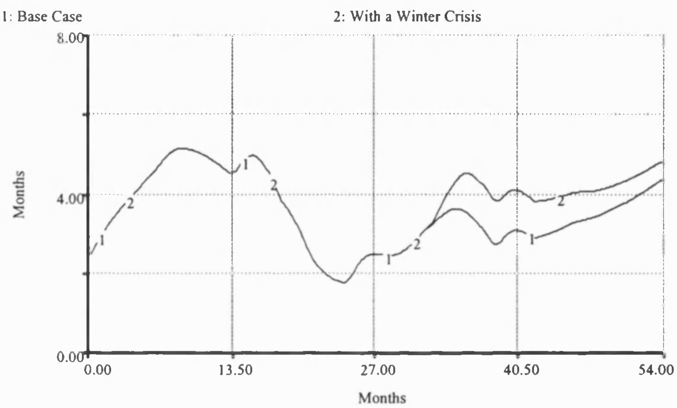


Figure 10.3 Effects of a Winter Crisis: Average Time Spent on the CC Investigation Waiting List

Furthermore, the effects on the crisis were still apparent, albeit diminishing, long after the crisis had passed. For example, the final waiting time (t=54) was 0.5 months higher (11% higher) than the base case.

Maintaining a Constant CC Investigation Waiting Time Goal (Exp R10)

In addition to the available capacity for elective CC investigations, the waiting time goal was a key exogenous factor in determining the behaviour of the system. Its assumed reduction, when the district service was present, contributed to increases in the CC investigation rate and the degree of demand that was stimulated. The model was used to test the effects of maintaining a constant waiting time goal.

Keeping the desired waiting time constant produced effects that were inconsistent with those that were reported by the cardiologists in the interviews and the effects that were reflected in the numerical data (shown in §7.3). The elective CC investigation rate was reduced as fewer calls were made to utilise the available capacity. Consequently, higher levels of the CC investigation waiting list and waiting times prevailed. For example, the minimum average time spent on the waiting list was 2.4 months as opposed to 1.7 months for the base case (42% higher). A consequence of higher waiting times was that no stimulated demand was associated with the waiting time effect. The knowledge effects on demand for CC investigations and OP appointments were delayed and reduced in magnitude. Lower increases in the OP waiting list and waiting times resulted. Compared to the base case, pressure on the system at the CC investigation end of the referral chain was higher whilst less pressure was exerted at the OP end of the referral chain. For example, the pressure imposed by excessive CC investigation waiting times increased by over 30% overall whilst that for OP appointments was reduced by 60%. "Pressure" refers to the index that was introduced in §5.4.3 to summarise the instances when there was an excessive waiting list (or average time spent on the waiting list) relative to its desired level.

The district service only briefly operated at full capacity. Therefore, maintaining a constant waiting time goal altered the mechanism underlying changes in district CC rates, knowledge about CC and skills gain from a combination of exogenous factors and endogenous processes (loops B2, R1 and R3 respectively) towards endogenous processes only. However, the mode of behaviour did not change and it was still to a large degree driven by the changes in capacity for CC services.

Altering the Waiting Time Effect on Demand (Exps R11 & R12)

In the base case, the waiting time effect on demand for CC investigations alleviated pressure on the system to some extent by suppressing demand when the expected waiting time was high. When the waiting time was low, demand was stimulated, thus increasing pressure on the system and undermining attempts to reduce the waiting time. To examine the sensitivity of the base case to alterations to the waiting time effect on demand, the response time to changes in the average waiting time was doubled and halved. This served to accelerate and decelerate the process underlying the effect of the waiting time on referrals (loop B3).

The effects were minor indicating numerical but not behavioural sensitivity. If the capacity had remained constant (apart from the initial increase which caused the average waiting time to drop), reducing the response time would be expected to generate greater pressure whilst increasing the response time would be expected to reduce pressure. However, this did not occur in the Ribsley General case as the capacity changed over time. Extending the response delay delayed changes in the waiting time effect in both adjusting from and returning to normal. Compared to the base case, the net effect was a 4.3% increase in the period of stimulated demand for an elective CC investigation whilst shortening the delay reduced this period by just over 2%.

Altering the Knowledge Effects on Demand (Exps R13-R15)

In the base case, demand was increased by the consequences of increased knowledge of GPs and patients about CC investigations, thus imposing further pressure on the system. Cardiologists were able to make general comments about the effects on demand for both CC investigations and OP appointments. However, they could only provide the necessary estimates to construct the non-linear function for the former. Consequently, sensitivity analysis played an essential role in addressing the uncertainties about the latter. This involved changes to the *delay* for GPs and patients to perceive changes in the availability of district services, and changes to the *extent* to which increased knowledge could stimulate demand. The first change altered the speed at which changes in knowledge affected demand for CC investigations whilst the second change altered the intensity of this feedback process (loop R2).

To consider the possibility that the perception delay may have been underestimated or overestimated, the model was rerun with a longer and shorter perception delay. The system was behaviourally sensitive to changes in this perception delay. This was in contrast to the effect of changes to the time for cardiologists to respond to changes in the waiting time. *Reducing the GP and patient perception delay* produced a change in the mode of behaviour. More demand was stimulated as the response arose earlier than the base case and spanned over a longer period. The mode of behaviour changed as demand was stimulated *twice* in contrast to the base case behaviour where the second district service was in place for an insufficient length of time for it to prompt a change in demand from GPs and patients. Consequently, the time for which the average time spent on the

OP waiting list exceeded its desired level increased by over 55% (from 12.6 months to 19.6 months). Meanwhile, the overall pressure from an excessive delay for an OP appointment increased by 33%. Increasing the average waiting time for an OP appointment prompted increases in OP activity which pushed more patients along the referral chain. This amounted to 3 additional referrals for an elective CC investigation. *Increasing the perception delay* reduced the amount of stimulated demand and the period for which the average waiting time was excessive was reduced by 3 months (22%). Pressure from an excessive delay for an OP appointment was reduced by 40%.

Although the sensitivity analysis unveiled a sensitive parameter it could not be concluded that the estimates used for the base case were inappropriate because stimulated demand for OP appointments was not observed twice. However, the fact that changes in this parameter could alter the mode of behaviour was interesting from a policy perspective. Changes in this parameter were considered again in the policy analysis (see Chapter 11).

For the base case, it was assumed that as the district service was not heavily marketed, the maximum knowledge effect on demand for OP appointments would be low. To examine the effect of a higher degree of stimulation (reflecting the effects of a more aggressive marketing effort), the magnitude of the knowledge effect on demand for an OP appointment was altered. The behaviour was less sensitive to this particular parameter change. It was numerically sensitive, obviously, but the basic mode of behaviour was unchanged. As expected, the district service stimulated a higher level of demand for OP appointments. For example, pressure from an excessive delay for an OP appointment was almost doubled.

Altering the Skills Effect on Demand (Exps R16-R19)

Sensitivity analysis focused on the processes underlying the skills effect on demand by altering their intensity and polarity (loops R3 and R4).

In the base case, associated with the annual replacement of experienced junior CC operators with novices were reductions in the referral rates for CC investigations which were followed by increased referrals as these trainees gained experience and confidence. This was how the referral behaviour of junior CC operator trainees at Ribsley General was described during the interviews. The length of time for which pressure was alleviated was determined by the rate at which these trainees gained CC skills. This was influenced by the number of learning experiences, which varied according to the number of tertiary-based investigations carried out by district operators, and the fraction of investigations from which the junior district operators learned. Reductions and increases in the latter by a modest 20% were considered thus altering the intensity of the effect of skills on demand. Reducing the learning fraction prolonged the periods during which novice CC operators lacked confidence and under-referred patients for CC, slowed their ascent up the 'learning curve', and delayed their approach to the saturation point. This alleviated 2.5% of the pressure from an excessive delay for a CC investigation. Increasing the learning fraction shortened the periods of underconfidence and produced 2.3% increase in the pressure. Although the changes from the base case parameter were symmetric, the results were asymmetric due to the non-linear nature of the 'learning curve'. The increase in the learning fraction was considered further as part of the policy analysis (see Chapter 11).

Exploring the effects of a different referral tradition at Ribsley General illustrated how the assumptions about the referral tradition affected the behaviour of the system. The base case involved inexperienced CC operators reflecting under-confidence in their referral patterns. As previously stated, this was consistent with a conservative attitude towards the use of CC investigations. The model was used to explore the effects of the presence of inexperienced operators who initially under-referred as with the base case, but prior to gaining sufficient confidence to refer the same proportion as expert operators, became over-confident and thus over-referred. This behaviour might be consistent with a more 'aggressive' attitude towards the use of CC investigations. This introduced a change of polarity of the process underlying the effect of skills on referrals (loops R3 and R4). Over-confidence in referral behaviour increased referral rates for CC investigations and thus increased the pressure on CC services. This raised the utilisation of the district service, when it was in place, and after it was withdrawn it led to increasingly higher levels of the CC investigation waiting list. For example, this produced 1 additional patient on the waiting list after the withdrawal of the district service at the end of March 1997 (t=24) and 9 additional patients at the end of September 1999 (t=54). The higher district CC investigation rates induced further demand for OP appointments. Therefore, a consequence of overconfidence in referral behaviour was slightly increased pressure on OP services.

Another experiment considered how delaying the recruitment of trainee CC operators by a month would affect the role of the skills effect in alleviating pressure on the system. It was assumed that this would not affect the levels of OP activity i.e. for the intervening period the trainee OP workload would be divided evenly between the expert CC operators and non-operators. This did not alter the mode of behaviour of the system but in understanding the effect on CC services, several factors need to be taken into account. Effectively, the turnover of junior operators (and associated drop in referrals) was less frequent, once every 13 weeks rather than once every 12 weeks. Potentially, this resulted in *increased pressure* on CC services. However, during the recruitment delay, rather than having all the junior patient workload assessed by a novice junior operator, a fraction of these patients were assessed by an expert (who would refer more patients than novice operators). Therefore, there was a periodic partial drop in referrals (prior to the arrival of the new trainees) as opposed to a complete drop. This contributed to *increased pressure* on CC services.

A further factor to consider was changes in the rate of gain of skills. Altering the timing of the arrival of the new trainees altered the timing of their initial training with respect to the elective CC capacity increases (which offered increases in learning experiences for these trainees). For example, in the base case, the new trainee who arrived in October 1996 (t=18) had the benefit of 5 month's-worth of the greater volume of learning experiences (associated with the capacity increases with the district service in place). With a recruitment delay of one month, the new trainee arrived two months later and therefore only had 3 month's benefit so his rate of gain of skills was lower. Therefore, for this period, there was *reduced pressure* on the system. However, the situation was reversed with the next trainee. This new trainee arrived just before the period of increased activity rates and thus benefit from a higher gain in skills. For this period, there was *increased pressure* on the system. The simulation showed that the net effect of all these changes was slightly higher pressure on CC services (about 5% increase in pressure exerted by both an excessive waiting list and an excessive average waiting time).

Increase in Exogenous Demand for an OP Appointment (Exps R20a-R20c)

In the base case, the reference level of demand for an OP appointment (level for which knowledge about CC was only based on tertiary-based activity i.e. no knowledge effect on demand) was set at a level that produced behaviour that was consistent with that reported in the system (stability in OP services). The ability of the district service to alleviate pressure on the system very much depended on the level of demand for cardiac services. Sensitivity analysis also focused on considering how changes to the exogenous level of demand for OP appointments would potentially alter the ability of the system to cope. Several examples of exogenous increases in demand for OP appointments were examined. The results of three increases (1%, 4% and 7%) are presented in Figure 10.4. They were introduced in April 1999 (t=48) to ensure that these effects were not masked by the effects of the district service and the time scale was extended to allow sufficient time for the effects of this change to be observed.

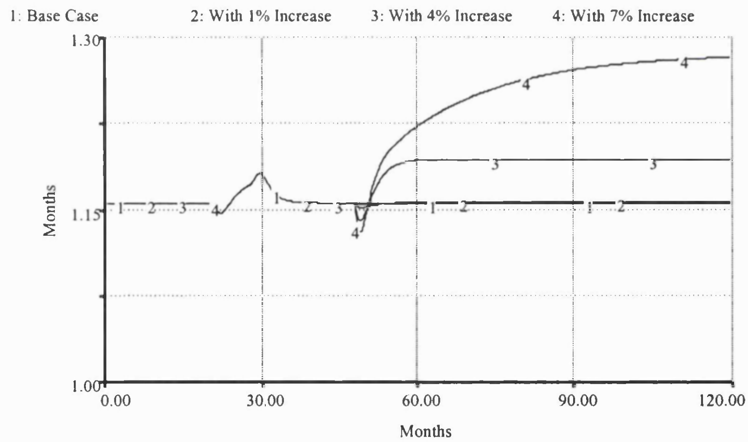


Figure 10.4 Exogenous Increase in Demand for OP: Average Time Spent on the OP Waiting List

A small increase in exogenous referrals (e.g. 1%) only slightly increased the average waiting time spent on the OP waiting list. The initial decrease was due to the increase in referrals temporarily destabilising the system such that, initially, there was a higher number of waiting list joiners (who each contributed a zero waiting time to the average) than removals. Moderate increases (2% to 6%) raised the average waiting time to above its desired level but there was sufficient OP capacity for the system to re-stabilise by raising the utilisation of OP capacity. However, for increases in demand of 7% or more, the OP capacity was insufficient to re-stabilise the system in the short-term. The OP waiting list and average waiting time exhibited a continuous rise. Equilibrium was only be re-established when the other waiting list removals had risen to balance the OP waiting list removals with the OP referral rate.

The increases in OP activity pushed further patients along the referral chain, so that demand for CC investigations increased but this did not produce changes in the mode of behaviour of CC services. Therefore, to conclude, low exogenous increases in demand for OP appointments led to a limited increase in pressure at the OP end of the referral chain but it did not significantly undermine the ability of the district service to alleviate pressure further along the referral chain. Higher exogenous increases in demand for OP appointments produced a sustained increase in pressure at the OP end of the referral chain. To some extent, the increase in demand for a CC investigation was constrained by the OP capacity so that pressure was held back to accumulate at the OP end. However, a few further referrals for a CC investigation arose by two mechanisms. Firstly, increasing the rate of referrals for an OP appointment led to the OP capacity being reached more quickly; further referrals for a CC investigation resulted as the OP rate would be pushed to full capacity for a longer period. Secondly, a higher OP waiting list contributed to higher numbers of referrals for an elective CC investigation from the inpatient route. Increases in the exogenous demand for OP services were considered further in the policy analysis (see Chapter 11).

To conclude, the sensitivity analysis demonstrated robustness in the understanding of the causes of the base case behaviour as described in §10.2.2. It also revealed some useful policy insights which will be considered again in the next chapter.

10.3 VEINBRIDGE GENERAL ANALYSIS

10.3.1 Simulating the Base Case Behaviour

(Exp V0)

Problem reference modes for the Veinbridge General case were presented in §8.2.3. They referred to the period April 1995 to August 1999. Having demonstrated that the simulation model was able to replicate these reference modes well (see §9.4.2), the model was then used to project beyond August 1999 to April 2001. This was based upon the assumptions that the capacities for OP and elective CC investigation services remained constant and that there were no further shifts in CC workload to the district level. The model thus produced a base case behaviour over a six-year period from April 1995 to April 2001 (see Figure 10.5).

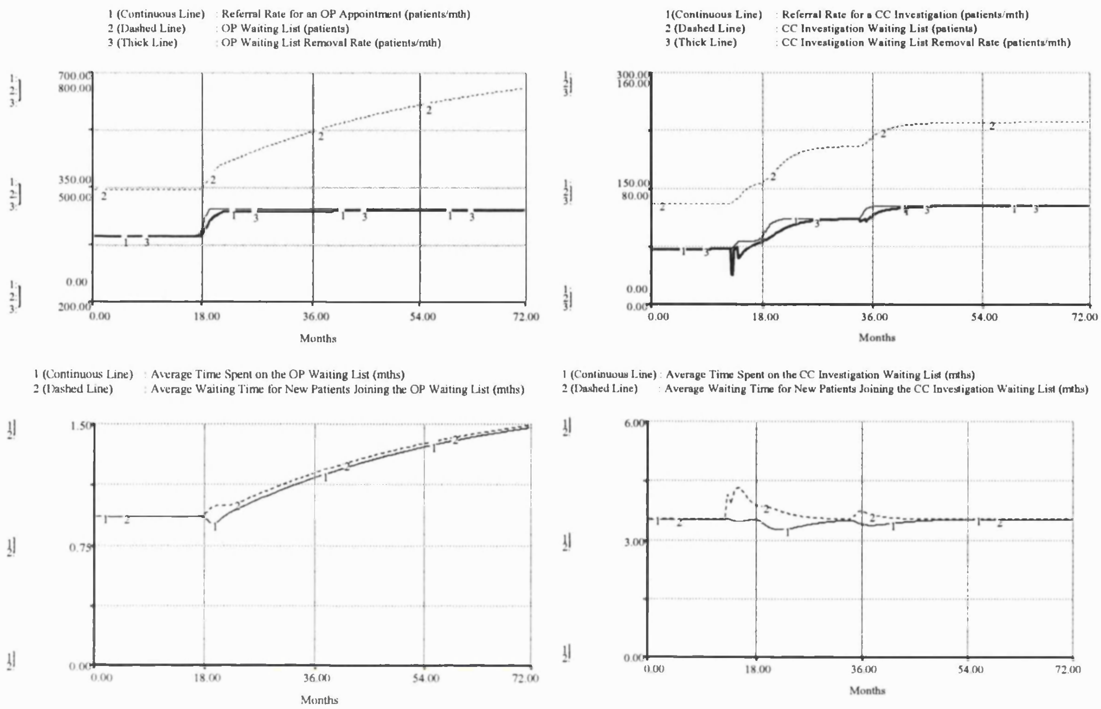


Figure 10.5 Veinbridge General Base Case Behaviour

(Month 0 is April 1995 and Month 72 is April 2001. Figures are based upon simulated data that are reported at intervals of DT i.e. 0.125 months, unlike those in Chapter 9 that presented monthly data.)

10.3.2 Basic Causes of the Base Case Behaviour

(Exps V1-V3)

April 1995 to April 1996 (t=0 to t=12): No district service

Prior to the introduction of district CC services, the system was stable at Veinbridge General. The CC investigation and OP waiting lists were estimated at 128 patients and 338 patients respectively, and the average time spent on these waiting lists was estimated at 3.5 months and 0.92 months respectively (each maintaining their desired levels). Furthermore, there was sufficient capacity to meet demand for both OP and elective CC investigation services. In fact, there was some slack in the system as neither service operated at full capacity. The OP service only utilised 85% of its capacity whilst the CC investigation service operated at 90% capacity. The stability in the system was also due to the absence of cyclic variation in demand for CC investigations associated with the skills effect, in contrast with the case of referrals from Ribsley General.

At both Ribsley General and Veinbridge General, a desire for a district service predated the closure of the tertiary facilities in May 1996 (t=13). In both cases, prior to this event, district services could not be offered due to financial constraints. For Ribsley General patients, the desire for a district service arose from the prevailing shortfall in elective CC capacity. Therefore, the desire was clearly apparent. The situation for Veinbridge General patients was quite different. CC capacity shortages did not exist and district services were desired to develop cardiac services at Veinbridge General. Therefore, this desire was not apparent. To be apparent, the tertiary-based elective CC capacity would have to be reduced (thus producing a capacity shortfall).

In anticipation of the planned closure of tertiary facilities in May 1996 (t=13) and with funding available for a district service, preparations were carried out at Veinbridge General to provide a district-based CC service. They were estimated to last 2 months. Unlike the case of Ribsley General, support for the service was such that preparations commenced in time for them to be completed in the same month that the tertiary facility was due to close. Therefore, access to CC investigations for Veinbridge General patients was not disrupted by the closure of the tertiary facilities.

May 1996 to Jan 1998 (t=13 to t=33): Phase 1 district service present

A phase 1 (mobile-based) district service opened in May 1996 (t=13) as part of a programme to develop a permanent phase 2 (integrated lab-based) service at Veinbridge General. The model, estimating the dynamics of the system approximately continuously (calculating at small intervals of DT) exhibited a brief delay in shifting the workload to the district level. This was due to the perception delay in responding to the shortfall in capacity following the closure of the tertiary laboratory. However, essentially, the model reflected that CC services for Veinbridge General patients were not adversely affected by the closure of tertiary facilities. The district service also supported an expansion in elective CC capacity for Veinbridge General patients. This expansion did not lead to reductions in the average waiting time for a CC investigation because demand for CC services was already satisfied within the normal capacity levels. Instead, it was intended to support increases in referrals.

There were several mechanisms underlying the referral rate increases. Initially, there was a reduction in the referral threshold towards including more 'grey area' cases. The district service provided more capacity and, therefore, more flexibility to investigate 'grey area' cases. In contrast, although there were no capacity shortages with the tertiary only-based service, the capacity utilisation was still high and its priority was to investigate patients for which CC procedures were clinically indicated. The simulation indicated that after a delay of nearly 4 months, the referral threshold began to drop further due to the increasing pressure from GPs and patients to refer as they became more knowledgeable about CC (the knowledge effect on CC demand). This effect reached saturation point, stimulating demand to the full extent, but this did not compromise the average waiting time for a CC investigation because there was sufficient capacity to cope with the increased pressure. In fact, this increased demand would have been encouraged by the district service being heavily marketed; given the plans to develop a permanent district service, it was important that there was sufficient demand to sustain the service.

The increase in knowledge about CC also led to increased referrals for an OP appointment. This prompted higher OP rates, as efforts were made to maintain the desired OP waiting time, and 921 (22% of the total) further elective referrals for a CC investigation were produced. This led to increased pressure on the CC services which was in contrast with the case of Ribsley General where the effect of the small temporary increase in OP activity rates on demand for CC services was marginal. The differences were due to the fact that the increases were higher and they were sustained. The OP activity rate was higher at Veinbridge General and a greater proportion of cases were referred on for a CC investigation as the referral behaviour was typically more 'aggressive'. The pressure on OP services was sustained because the district service, which generated the pressure, was permanent.

Although the desired waiting time for a CC investigation was maintained, the length of the waiting list exhibited increases. This was due to the delays between the adjustments in activity rate in response to the referral rate increases and the fact that efforts were made to meet the desired waiting time and not a desired waiting list length. The simulation indicated a rise in the CC investigation waiting list from 128 patients to 203 patients (59% increase) between the period of May 1996 (t=13) to the end of January 1998 (t=34). Furthermore, an increase of 53 patients could be attributed to the knowledge effects on CC demand and OP demand.

When the tertiary facility reopened in April 1997 (t=24), the CC workload was not shifted back to the tertiary level because sufficient funding was committed towards developing a permanent district service. Furthermore, the tertiary capacity for Veinbridge General patients was not restored to its previous levels because the capacity that had previously been devoted to routine investigations was reallocated to other uses. The tertiary capacity that remained available for Veinbridge General patients was fully utilised by high risk elective patients.

The stimulation of demand for OP services led to severe OP capacity shortages. As there was little spare capacity for OP services and no opportunity for expansion, the system was unable to cope with the demand which, the simulation indicated, was stimulated to the maximum extent (subject to the assumptions about GP referral behaviour). Given the assumption that demand could have increased by as much as 20%, by the time the integrated laboratory opened in February 1998 (t=34), the OP waiting list rose by 49% from 338 patients to 505 patients. In addition, the average time spent on the OP waiting list rose by 23% from 0.92 months to 1.13 months. To a large extent, the OP capacity constraints held back demand for CC investigations so that CC capacity shortages did not arise.

February 1998 to April 2001 (t=34 to t=72): Phase 2 district service present

The integrated catheter laboratory, which opened in February 1998 (t=34), provided opportunities for further expansion in CC capacity and prompted further reductions in the referral threshold. Not only were more 'grey area' cases referred for CC investigation, but slightly higher risk cases were shifted to the district level, i.e. more patients were considered eligible for district-based investigation. Given the reduced need for tertiary services by elective cases from Veinbridge General, further tertiary capacity was reallocated to other uses. As with the earlier reduction in the referral threshold, this prompted an increased CC investigation rate by the doctors working at a greater tempo so that the desired waiting time for CC investigation was maintained. However, whilst the referral rate exceeded the waiting list removal rate, the waiting list rose further. The simulation indicated a 12% rise in the CC investigation waiting list from 203 patients to 227 patients between February 1998 (t=34) and July 1998 (t=39). No more demand was associated with the knowledge effects as these were already saturated.

The OP waiting list and waiting times continued to escalate. By April 2001 (t=72), in the simulation, the length of the OP waiting list almost doubled from the pre-district service level to 651 patients and the average time spent on the OP waiting list increased by over 50% to just under 1.5 months. The OP waiting list and waiting times began to plateau. This occurred because the rate of other waiting list removals from the OP waiting list rose and eventually caused the number of waiting list removals to balance the number referrals onto the waiting list.

Generation of Costs Over Time

The preparation costs for the mobile service and integrated laboratory were quoted at approximately £6,500 and £1 million respectively and the district running cost rate was approximately £50/mth. There was a penalty associated with the district service as with the case of Ribsley General. As synchronous investigation and treatment was not permitted within current guidelines, some patients had to undergo a second procedure at the tertiary level. Applying the same assumptions for the case of Ribsley General (see §10.2.2), the same level of activity carried out the tertiary level would have produced a 9% reduction in activity costs. This would have amounted to £266,231 over the 59 months that the district service was in place (average £4,512/mth).

10.3.3 Emphasising the Structure-Behaviour Linkages

Of the 8 main feedback processes that were presented in the conceptual model (see D1 in Appendix D), only 5 influenced the base case behaviour exhibited by the Veinbridge General case. The waiting time feedback loop (B3, which controlled the waiting time effect on demand) remained dormant because the referrals for an elective CC investigation were not influenced by the average waiting time. The 2 skills loops (which controlled the skills effect on demand) were rendered inactive by the expert CC operator making all the final decisions about referrals for a CC investigation.

Prior to the introduction of district CC services to Veinbridge General, the 5 remaining feedback loops were dormant as the system was stable. Neither the OP service nor the elective CC service operated at full capacity. This indicated that there was some scope for the activation of the feedback processes to raise the tertiary-based elective CC and OP activity levels (loops B1 and B4 respectively), if desired.

The drop in the tertiary-based elective CC investigation rate, associated with the closure of the tertiary lab, produced a shift in elective CC investigations to the district level (loop B2) and pushed the remaining tertiary-based service to operate at full capacity (loop B1). The latter process was only briefly active as the tertiary-based utilisation was driven up to 100% instantaneously. These processes acted to ensure that the desired waiting time was maintained. The adjustment in district activity was also prompted by a change in an exogenous factor, namely the reduction in the referral threshold as the consultant cardiologist took advantage of the district service to investigate more borderline cases. In fact, this factor (EffOFCC) would be formulated endogenously in a more sophisticated model as its adjustment is linked to the development of the district service through its different phases. The development of the district services led to increased knowledge about CC among patients and GPs and this stimulated demand for both OP appointments and CC investigations (loops R1 and R2 respectively). These knowledge effects were driven to saturation point and, from then on, the underlying processes remained dormant.

The adjustments in the district and tertiary investigation rates were made quickly as they were controlled by cardiologists who were familiar with the capacity changes at the tertiary and district levels as and when they occurred. This was in contrast with the stimulation of demand for CC investigations and OP appointments that arose from increased knowledge about CC (loops R1 and R2). The activation of these processes was lagged by the perception delay of GPs and patients. As they were based in the community, a period elapsed before they became aware of the service reconfigurations within the hospital sector.

By the time demand was stimulated by GPs and patients, the tertiary service had already been driven to operate at full (albeit reduced) capacity. Therefore, the process underlying the knowledge effect on demand for elective CC investigations (loop R2) did not reinforce the adjustments in tertiary-based CC investigation rates (loop B1) as they were not active at the same time. By contrast, the former process interacted with the adjustment in district-based investigation rates (loop B2); more district activity generated more knowledge about CC which stimulated demand and thus led to calls for more activity in order to maintain the desired waiting time.

The processes underlying the knowledge effect on demand for CC (loop R2) and adjustments in district activity (loop B2) also interacted with the processes underlying the knowledge effect on demand for OP services (loop R1) and adjustments in OP activity (loop B4). More district activity generated further demand for an OP appointment which led to calls for more OP activity to maintain the desired waiting time. Associated with increases in OP activity were further referrals for CC investigations which contributed to calls for more district activity. When the knowledge effects reached saturation point and the OP service was driven to operate at full capacity, these calls for further district activity ceased.

The OP waiting list and average time spent on the OP waiting list exhibited steady increases due to the lack of OP capacity. These variables displayed asymptotic growth due to the action of a balancing process which controlled other waiting list removals. This process (labelled loop B in the stock and flow diagrams. See E1 in Appendix E) was driven by changes to the length of the OP waiting list. It only represented a minor feedback process whilst other processes were active, but as the saturation points were reached, a shift in loop dominance occurred such that this loop became dominant. The action of this loop caused the OP waiting list removals to rise towards the level of the waiting list referrals. This loop would become dormant when these two levels balanced and a new equilibrium would be achieved. The simulation indicated that this would not occur within the time scale considered.

Another endogenous process (represented in the stock and flow diagrams but not highlighted) was also driven by increases in the OP waiting list - the deterioration of waiting list patients who were admitted to hospital, subsequently restabilised and were then referred on for an elective CC investigation. The effects of this feedback loop, which contributed to reductions in the OP waiting list and increases in the CC investigation waiting list, were minor.

As the district service was not operating at full capacity, there was scope for further increases in the district investigation rates. This occurred when the integrated laboratory opened at Veinbridge General and the consultant cardiologist took advantage of the opportunity presented by the new facility to offer a CC investigation to more borderline cases. This prompted the district activity rate to increase (loop B2) in order to maintain the desired waiting time goal.

In contrast with the case of Ribsley General, exogenous factors played a minor role in producing the basic trend exhibited by the CC investigation waiting list at Veinbridge General. Several endogenous processes interacted to generate further pressure on the system (loops R1, R2, R3 and B2). Exogenous factors which also played parts were the increase in district CC capacity and the effect of other factors on referrals for an elective CC investigation (but a more sophisticated formulation would have represented the latter factor endogenously). The mechanisms that were responsible for the OP trends in the Veinbridge General case provided a further contrast to the Ribsley General experiences as different endogenous processes were responsible for the observed behaviour. At Veinbridge General, the process of adjustment in OP activity (loop B4) only acted briefly to increase the OP activity rate to full capacity. Thereafter, this process was rendered inactive whilst the emphasis shifted to the process of adjustment in the number of other waiting list removals (loop B in the stock and flow diagram. See E1 in Appendix E).

The base case analysis suggested that efforts to control demand or meet demand would have produced more desirable system behaviour for the Veinbridge General case. Directly weakening the process whereby demand was stimulated for OP services (loop R1) would have achieved the former and the latter would have been achieved by intensifying the process underlying increases in OP activity rates (loop B4).

Reducing stimulated demand for CC services would have led to fewer calls to increase the district activity which would in turn, have generated less stimulated demand for OP services. If this could have been achieved, CC resources could have been diverted to OP services. However, this would not have been acceptable. Furthermore, controlling the knowledge about the district service, by reducing the marketing of the district service (decelerating or weakening the process underlying the knowledge effect on demand), would not have been acceptable. This would have interfered with the efforts to produce sufficient demand for the service. A more acceptable approach to diminishing the stimulation of demand for OP services (loop R1) would have been to reduce the pressure to refer via the use of new referral guidelines. This would have limited the impact of the knowledge about the district service. Capacity increases would have enabled increases in the OP activity rates (loop B4). However, this intervention would have formed a less preferable approach, compared to the use of new referral guidelines, given the additional costs involved.

Another aspect of the undesirable behaviour was the rise in the CC investigation waiting list. It was the increases in the waiting list, produced by the increase in demand for an elective CC investigation that required the elective CC investigation rate to rise to maintain the desired waiting time (loops B1 and B2). Capacity increases would have failed to control the length of the waiting list. This is because the current decision rule was to adjust the investigation rate to meet a desired waiting time and not a desired waiting list length. To eliminate or reduce the increases in the waiting list, it would have been necessary to modify the process underlying adjustments in the investigation rate towards aiming to maintain a desired waiting list size rather than a desired waiting time. Doing so would have also controlled the average waiting time. This would have involved using the available information about the system in a different way and introducing further feedback effects. This suggestion is consistent with Wolstenholme's (1999a) experience in his community care study where changes to flow (or rate) variables had greater leverage than changes to stock variables (e.g. capacities).

10.3.4 Sensitivity Analysis

Sensitivity analysis was applied to explore the robustness of the base case behaviour to various model assumptions. As with the case of Ribsley General, the understanding of the causes of the base case behaviour provided pointers towards suitable areas for the use of sensitivity analysis. For the Veinbridge General case, the following issues were explored:

the availability of district services; availability of elective CC capacity; CC investigation waiting time goal; knowledge effects on demand; and, skills effect on demand.

Note that variations in the assumptions about the elective CC capacities were not explored as part of the sensitivity analysis although there were doubts about the reliability of the data provided as mentioned in §9.3.1. Experimenting with other capacity levels would have been pointless as those specified were appropriate for the purpose of this study.

Limiting the Availability of District Services (Exps V4-V7)

Four scenarios clarified the role played by district services in the OP capacity shortages and the rise in the CC investigation waiting list. These involved: the absence of district services at Veinbridge General; the temporary use of district services to compensate for the tertiary facilities closures in 1996/1997 and 1998 only; the temporary use of district services to support an expanded tertiary service (50% expansion); and, further district sessions in addition to those in 1996/1997 and 1998 thus producing a periodic district service. The additional district based capacities were set to provide the same levels as those during the 1996/1997 period. It was assumed that a temporary district service at Veinbridge General would have produced less stimulated demand due to the knowledge effects, compared to the base case (which involved a permanent district service). The district service would not have been promoted as much and less interest would have been generated. This is consistent with the differences in base case assumptions between Ribsley General and Veinbridge General.

Only the expanded tertiary service provided a permanent expansion in CC services whilst the temporary and periodic district services only provided short-term expansions. It was assumed that a temporary expansion in CC services at Veinbridge General would only have led the consultant cardiologist to temporarily reduce his referral threshold to investigate more 'grey area' cases. Furthermore, it was assumed that the service would have to have been in place for a reasonable period to prompt this change in referrals and therefore would only have been associated with the 1996/1997 tertiary facility closure.

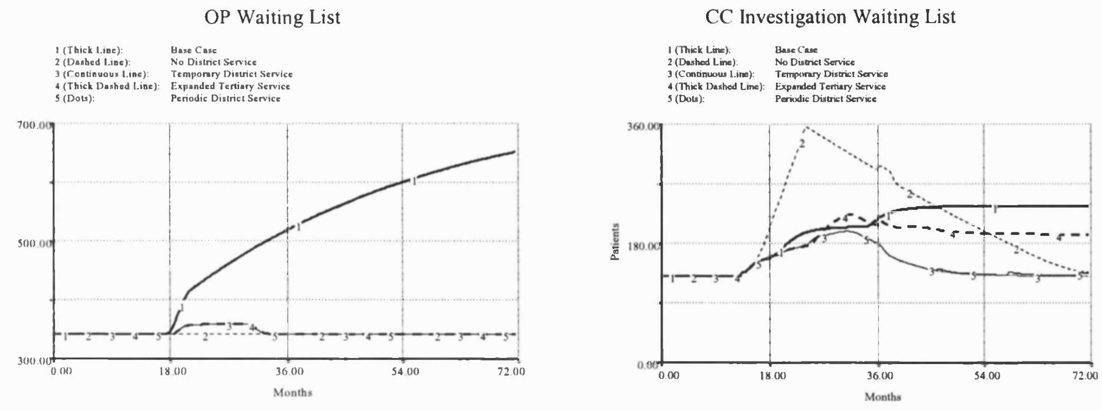


Figure 10.6 Limiting the Availability of District Services: OP and CC Intervention Waiting Lists (For the OP waiting list, the graphs for 3, 4 and 5 coincide.)

Figure 10.6 presents changes in the two waiting lists for the different scenarios. By limiting the use of district services, less demand was stimulated which altered both the OP and CC behaviour modes. The absence of a district service maintained the stability at the OP end of the referral chain whilst the other three scenarios only destabilised the OP system temporarily. The absence of a district service produced sharp increases in the CC investigation waiting list during the loss of tertiary capacity. However, when the tertiary facilities reopened, by pushing the system to operate at full capacity, the CC service gradually 'recovered' so that by April 2001 (t=72), the waiting list returned to the pre-district service levels (46% lower than the base case).

The other three scenarios also altered the asymptotic growth in the CC investigation waiting list to a rise and fall. For these, the fall in the waiting list was attributed to the decline in patient pressure following the withdrawal of the district service. With the temporary and periodic district services, the waiting list returned to its desired level. After the 1996/1997 sessions, when the service was reintroduced periodically, it was in place for an insufficient length of time to stimulate significant levels of demand. The CC waiting list only rose to 197 patients (16% lower than the base case) and the pressure imposed by an excessive waiting list was reduced by over 70%. The 1996/1997 district sessions stimulated demand and, after the district service (and the overall capacity increases it provided) was withdrawn, there was a delay before demand returned to the pre-district service levels.

Expanding the tertiary service led to the CC investigation waiting list stabilising at 192 patients which was 18% lower than that associated with the base case but in excess of the desired level. The waiting list did not fall further due to the assumption that the cardiologists would stimulate demand to justify the increased tertiary-based capacity. The experiment involved a 50% increase in tertiary-based capacity. Sensitivity analysis showed that, to maintain the same level of capacity utilisation as that prior to the expansion in services, the cardiologists would have to stimulate twice as much demand as that associated with the introduction of the integrated catheter laboratory (in the base case). Demand would also have to be stimulated earlier, compared to the base case, given the different timing of the increase in tertiary-based capacity and opening of the integrated catheter laboratory. Therefore, for the case of Veinbridge General, limiting the district service did not control the stimulated demand for CC services, it only altered its underlying mechanisms.

Limiting the Availability of Elective Capacity: A Winter Crisis (Exp V8)

The model was used to demonstrate how a winter crisis might impact upon the delivery of services. A crisis was introduced during the 3 month period just before the 1998 closure of tertiary facilities (t=32 to t=35). Dramatic reductions in elective capacity were considered - 50% at the tertiary level and 75% at the district level. Compared to the case of Ribsley General, it was expected that there would be fewer tertiary-based cancellations with the Veinbridge case as this would refer to higher risk electives only.

The effects of the crisis were apparent for some time after it had passed, and were diminished to some extent by the assumed 'knee jerk' reaction (reduction in referrals) to the capacity loss. The CC investigation waiting list dropped temporarily but there was insufficient capacity for the system to maintain the desired waiting time. The average time spent on the waiting list peaked at 4.9 months (39% higher than desired) and 9 months elapsed before it returned to the desired level. The experiment also showed that the duration of the drop in district activity was too short to alter the knowledge effects on demand. Therefore, the (endogeously generated) demand for an OP appointment was unaffected by the crisis.

Adjusting the CC Investigation Waiting Time Goal (Exp V9)

It was assumed that, for the Veinbridge General case, the desired waiting time for a CC investigation was not reduced when the district service was present. Unlike the case of Ribsley General, at Veinbridge General CC capacity shortages did not exist (the desired waiting time was maintained). Furthermore, as the district service was permanent, there was no need to 'squeeze' as much as possible out of the service in a short space of time. The impact of altering this assumption was considered. Seeking a reduced waiting time stimulated certain feedback processes. Higher levels of district activity were produced and this stimulated further demand for OP services overall as the saturation point was reached earlier and higher waiting times and waiting list sizes resulted.

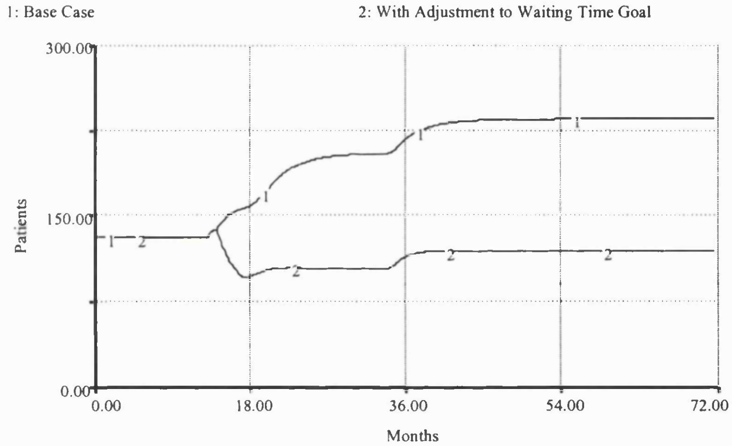


Figure 10.7 Adjusting the CC Investigation Waiting Time Goal: CC Investigation Waiting List

Figure 10.7 shows the effects on the length of the CC investigation waiting list. The figure shows that the increases in the waiting list, reflected in the base case, were eliminated and a final list length of 117 patients was produced which was 11 patients lower than the pre-district service level and 50% lower that the final list length within the base case behaviour.

Altering the Knowledge Effects on Demand (Exps V10-V12)

In the base case, demand was stimulated by the consequences of increased knowledge about CC investigations and this led to increased pressure on the system. As with the case of Ribsley General, assumptions were made about these knowledge effects on demand based upon information derived from the interviews. The experimental design did not extend to interviewing GPs and patients although the experiences of cardiologists and numerical data clearly showed that these effects existed (see §7.4.3). Sensitivity analysis was applied to address the uncertainties in these assumptions. Again, changes to the *delay* for GPs and patients to perceive changes in the availability of district services and changes to the *extent* to which increased knowledge could stimulate demand for OP appointments were considered. The perception delay was increased and reduced and the extent was increased. These changes altered the speed and intensity of the processes underlying the knowledge effect on demand (loops R1 and R2).

Unlike the case of Ribsley General, these changes only produced numerical changes and the modes of behaviour remained unaltered. Reducing the perception delay led to pressure on CC services to occur sooner and this was reflected in the CC waiting list rising sooner. The situation was reversed when the perception delay was extended. The changes were asymmetric due to the nonlinear nature of the knowledge effect on demand; the increases in pressure were generally greater than the reductions in pressure. For example, reducing the perception delay by 50% led to a 2.5% increase in the pressure exerted by an excessive CC waiting list whilst reducing the perception delay by 50% produced a lower decrease of 2.3%. Reducing the perception delay also led to OP capacity shortages to occur sooner and the OP capacity shortages were delayed when the perception delay was extended. The differences with the base case diminished as time elapsed due to the effect of other waiting list removals slowing down the growth in the OP waiting list and average time spent on the OP waiting list. The higher the OP waiting list, the quicker the time it took for that list and its constituent waiting time to plateau. Changes in the perception delay were also considered as part of the policy analysis (see Chapter 11).

The extent of the knowledge effect on demand for an OP appointment was doubled. As expected, this led to increased pressure on both OP and CC services. The average time spent on the OP waiting list reached the February 1998 levels (when the integrated lab opened) about 11 months earlier.

It was not possible to draw conclusions about the accuracy of the estimates used for the base case. However, these assumptions merely added to a number of other assumptions that had been made and which together produced behaviour modes which were consistent with those described by the collaborators. Therefore, it was concluded that, for the purpose of this study, the estimates were appropriate.

Introducing a Skills Effect on Demand (Exp V13)

The base case reflected the fact that the expert CC operator made all the final decisions about referrals for an elective CC investigation. Therefore, the skills effect on demand was absent. It was stated previously that this absence contributed to the stability of the CC waiting list and waiting times. To examine to what extent this was the case, a scenario was considered whereby a skills effect was present. This involved the expert delegating responsibility for making final decisions to both the junior operator and the other doctor who screened patients for a CC investigation. It was assumed that a third of decisions were each made by the expert, junior and the other doctor at Veinbridge General, who was another consultant cardiologist. The model had to be reinitialised to make allowances for the reduced skills effect on demand (from a value of 1 in the base case to 0.72). Introducing a skills effect led to periodic drops in the CC investigation waiting list. This resulted in a minimum waiting list of 118 patients (10 patients lower than the base case) and just over a 2% drop in the overall pressure from an excessive waiting list.

In conclusion, the sensitivity analysis supported the description of the basic causes of the base case behaviour. Furthermore, it revealed some useful insights which later formed the basis of some policy experiments. These will be addressed in the next chapter.

10.4 SUMMARY

This chapter presented the base case analyses for the two case studies. The basic causes of the contrasting problematic behaviours were explained with reference to the underlying feedback structure. The Ribsley General case had persistent capacity shortages at the CC investigation end of the referral chain which were alleviated by capacity increases. For the Veinbridge General case, the introduction of district services had stimulated demand to the extent to generate OP capacity shortages and rises in the CC investigation waiting list. The Ribsley problematic behaviour was mainly explained by exogenous factors and endogenous processes that acted exogenously. By contrast, the emphasis for the Veinbridge behaviour was on endogenous processes. Sensitivity analysis was applied to demonstrate the robustness of the explanations of the basic causes and explore the base case further.

The base case analyses provided insight into how more desirable behaviour could have been achieved. For the Ribsley General case, the analysis suggested parameter changes to diminish the intensity of the mechanisms underlying the increase in the CC investigation waiting list and waiting times. Whilst parameter changes could also have alleviated the undesirable behaviour for Veinbridge General, the analysis also suggested the potential for a structural change. These issues will be explored further in the next chapter.

CHAPTER 11

MODEL-BASED POLICY ANALYSES

11.1 INTRODUCTION

Chapter 10 presented the base case analyses for the two case studies. For each case, the problematic behaviour was explained with reference to the underlying feedback structure. This led to some suggestions into how more desirable behaviour could have been achieved. Further suggestions for improvement arose from the sensitivity analyses which were carried out to probe further into the base case behaviours. In this chapter, these suggestions are followed up with a series of model-based policy experiments (policy analyses). Their effects and causes are explained. Note that the resulting policy recommendations and policy lessons, and the operationalisation of the policy recommendations will be discussed in Chapter 12.

For both case studies, problems had arisen from the imbalance between supply and demand. In the case of Ribsley General, these problems predated the introduction of district services whilst the introduction of the district service was the cause of the problems in the case of Veinbridge General. The policy alternatives that were considered involved two basic strategies: aiming to *meet demand* and aiming to *control demand*. The former involved modifications to the supply of services and the goals that drive the patient activity rates whilst the latter involved alterations to the demand for services. It should be noted that the aim of this study was not to investigate all possible policy interventions and combinations of interventions. In order to illustrate the potential benefits of applying the SD approach, only a selected number of interventions were investigated.

As discussed in Chapter 4, an SD simulation model can provide a flexible framework in which to design robust policies by exploring the likely effects of a variety of different policy alternatives. Policy interventions in the real system may be represented in the model by changes to the model's parameters and/or its structure. Both types of interventions were considered in this study. A model parameter that is found to be sensitive may suggest a policy leverage point. This is the term given to a point where a change produces more desirable system behaviour. Structural changes involve changes to the form and number of model equations. They include the introduction of new feedback structure, which represents new ways of manipulating the available information in the real system. System dynamicists place great importance on structural changes. This is because the structure of a feedback system tends to be the strongest single determinant of its behaviour, whilst the behaviour tends to be insensitive to most parameter changes (as described in §5.4.2).

The Ribsley General policy experiments are described first. Parameter changes are considered as policy alternatives (§11.2). This comprises an investigation into elective CC capacity changes (§11.2.1), the use of demand management strategies (§11.2.2), changes to the CC operator skills base (§11.2.3), and OP capacity changes (§11.2.4). The next section (§11.3) is devoted to structural changes as policy alternatives. The structural changes that arise from parameter changes are highlighted (§11.3.1) before considering the effect of changes to the activity targets (§11.3.2-11.3.4). The case of Veinbridge General is then considered. The different circumstances of Veinbridge General are reflected in a different set of policy experiments. One section is devoted to parameter changes (§11.4) and another (§11.5) focuses on structural changes. In the final section (§11.6), the chapter is summarised.

As described in Chapter 5, the results of the experiments were evaluated on the basis of changes to the waiting list lengths, average waiting times, resource usage and referral rates. The indices proposed in §5.4.3 were used to summarise, for a given time period, the instances when pressure was imposed by excessive waiting lists and waiting times. In explaining the results of the experiments, references are frequently made to the basic mechanisms. These are reproduced in Appendix D. Note that whilst this chapter contains only a sample of the results, further results and other details about the experiments may be found in Appendix E.

11.2 RIBSLEY GENERAL ANALYSIS: PARAMETER CHANGES

For the case of Ribsley General, a number of suggestions for parameter changes arose from the base case analysis. These involved: changes to the capacity for elective CC investigations; use of demand management strategies; changes to the CC operator skills base; and, increases to the capacity for OP appointments.

11.2.1 Altering the Capacity for Elective CC Investigations

The problems in the case of Ribsley General involved unacceptable delays to undergo an elective CC investigation. In §10.2.4, I demonstrated the impact of the temporary losses of tertiary-based elective CC capacity and the importance of the use of the district service in compensating for these capacity losses and providing additional capacity. In this section, this analysis continues by presenting the results of several other experiments based upon capacity changes.

Reconfiguring the Base Case Capacity Increases (Exps R21-R23)

Before considering the effect of capacity increases, a different configuration of the base case capacity increases (a resource neutral scenario) was investigated. The aim of this experiment was to test whether or not fewer capacity changes could provide greater stability on the performance and thus generate less pressure on the system. The base case involved the provision of district services for 14 months, in total, over two periods between June 1996 and May 1998 inclusive (t=14 to t=37), and produced significant increases in capacity. For this policy experiment, the total capacity increases were averaged and spread over the 24 months, to represent a constant provision of district services for this period, and less dramatic capacity changes - a semi-permanent, reduced district service. The simulated effects on the average times spent waiting are shown in Figure 11.1.

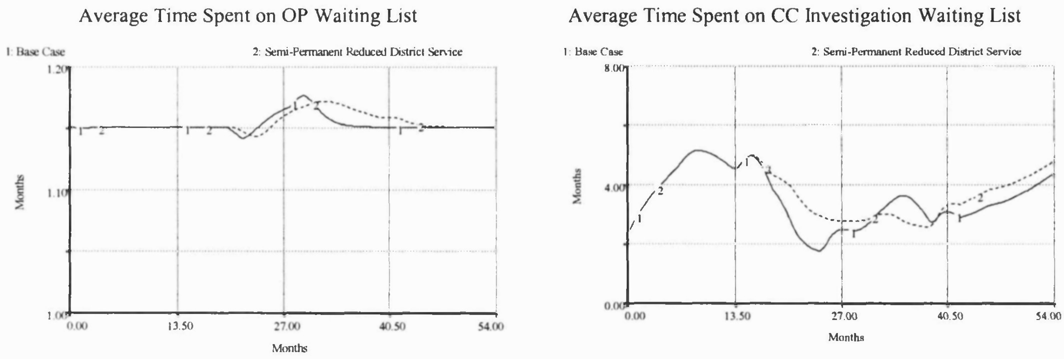


Figure 11.1 Some Effects of a Semi-Permanent Reduced District Service

Compared to the base case, this experiment produced numerical changes and phase shifts but it did not alter the basic modes of behaviour for OP services or CC services. Greater pressure was produced at the OP end of the referral chain, as demand was stimulated for a longer period. Demand was still stimulated to the maximum extent despite the reduced district-based investigation rate but the stimulated demand rose and fell from the maximum extent more slowly (due to the reduced district-based activity and the drop in activity when the tertiary facility reopened). Consequently, the average time spent on the OP waiting list exceeded its desired level for approximately 8 further months and 55 additional referrals for an OP appointment were produced. Furthermore, this led to 50 further OP appointments.

There was greater stability at the CC end of the referral chain and the utilisation of the district facility rose but the waiting list only dropped to 50 patients (over 40% higher than the base case). As with the OP end of the referral chain, demand for elective CC investigations was still stimulated to the maximum extent and the stimulated demand rose and fell from the maximum extent more slowly. Demand was stimulated by low waiting times to a lower degree but for a longer period. The lower activity rates led to CC operator skills and confidence being gained more slowly so the stimulation of demand due to the skills effect was delayed. The net effect on elective CC services was the average time spent on this waiting list exceeding its desired level for approximately 10 further months and 35 additional referrals arising, prompting a total of 19 more elective CC investigations to be carried out. The overall costs generated over the 54 months (the duration of the simulation run) rose by nearly £22,000 (nearly 1% increase).

Therefore, by reconfiguring the base case CC capacity changes over a longer period, whilst the monthy cost rate was lower, by generating costs over a longer period, greater costs were incurred in total. Furthermore, greater pressure was imposed on the system overall as more demand was stimulated. New referral guidelines could be used to ensure that the additional resources were used to deal with existing demand and not new demand (reflecting "joined-up thinking"). Whilst strict referral guidelines eliminated the increases in the OP waiting list and average waiting time (see §11.2.2. for definitions), only modest guidelines were required to produce improvements in the CC behaviour whilst the district service was in place i.e. a persistent downward trend.

Increasing Capacity (Exps R24-R32)

As the problems in the case of Ribsley General involved unacceptable delays to undergo an elective CC investigation, an obvious approach to improving the behaviour would be to increase the capacity. Experiments were carried out to examine the effects of three different ways of achieving capacity increases.

In the first experiment, a permanent district service was modelled by indefinitely maintaining the capacity levels that corresponded with the previous experiment. It was assumed that continuing the base case district levels would not have been affordable so this more modest scenario was considered. It was also assumed that a permanent district service would produce greater patient and GP pressure to refer than a temporary or semi-permanent service as more effort would be devoted to promoting the service and greater interest would be generated. Therefore, different knowledge functions were specified. The knowledge functions represented the combined effect of pressure from GPs and patients and the response to that pressure. A change in the response would depend upon the referral behaviour of the cardiologist and a cardiologist at Ribsley General, following the established conservative referral tradition, would only be expected to produce a moderate response. Therefore, for this experiment (involving a permanent district service), the maximum values of the knowledge functions were higher than the base case (which involved a temporary district service and therefore would be assumed to generate lower pressure to refer) but lower than those for Veinbridge General (which involved a permanent district service and assuming a similar degree of pressure but a more 'aggressive' response). It was also assumed that permanent capacity increases would not prompt a reduction in the waiting time and waiting list goals as, unlike the base case, there would not be the need to 'squeeze as much out of the system' and as quickly as possible. This assumption also applied to the next experiment.

For the second experiment, an expanded tertiary-based service was assumed with the district service only used to cover facility closures. The same total capacity levels as the previous experiment were provided in order to compare directly capacity increases at the tertiary and district levels.

In the third experiment, further temporary district sessions were added to the base case assumptions to produce a periodic district service. This provided approximately 8% lower capacity levels overall compared with the previous two experiments. It was assumed that providing the same capacity levels overall would have been unrealistic as this would have involved exceptionally high levels of district capacity. The effects on the CC investigation and OP waiting lists are shown in Figure 11.2.

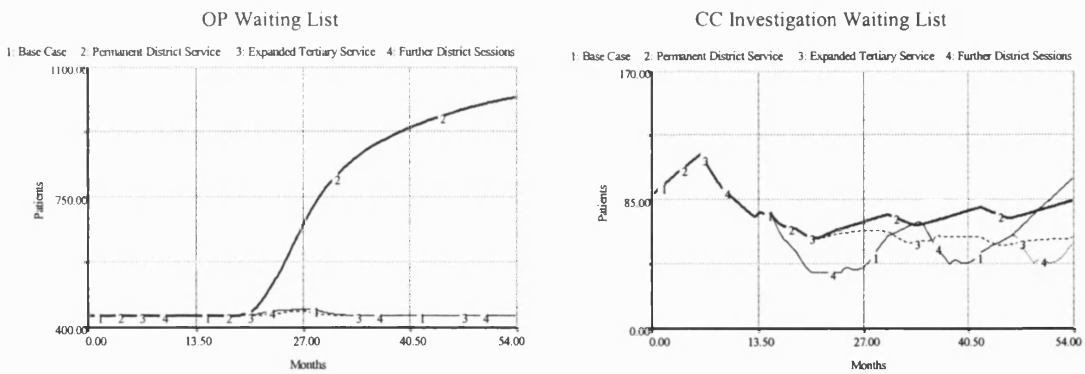


Figure 11.2 Some Effects of Increased Elective CC Capacity
(The OP waiting list graphs for 1 and 4 are the same)

Effects on OP Behaviour

Expanding the tertiary service did not alter the OP modes of behaviour. However, compared to the base case, less demand was stimulated as the level of district activity was lower. For example, the waiting list only rose to 437 patients (5 patients lower than the base case). Introducing further district sessions also did not alter the OP behaviour modes. Furthermore, this change did not stimulate any further pressure from GPs and patients to refer as, for each session, the district service was in place for an insufficient length of time to prompt a change in their behaviour. By contrast, a permanent district service stimulated further demand, and to such an extent that the OP variables exhibited steep asymptotic growth towards new equilibrium values. By October 1999 (t=54) both the OP waiting list and average time spent on the OP waiting list were over twice their base case value. These effects were alleviated to some extent by the use of new referral guidelines but only strict guidelines eliminated these problems.

Effects on CC Behaviour

All three experiments produced alterations in the CC behaviour modes from the base case. In the short-term and medium-term, the permanent district service and expanded tertiary service experiments exhibited a higher average waiting time and waiting list but the behaviour of these variables was more stable, albeit oscillatory. The oscillations were generated by the skills effect. Although the total capacity increases were equal, the permanent district service produced higher waiting list and waiting times relative to the base case due to the district service stimulating more demand. This also caused the OP activity rates to rise and thus push more patients along the referral chain. Furthermore, it caused more patients to deteriorate on the OP waiting list which then contributed to further referrals for an elective CC investigation. The OP activity rate was pushed to full capacity and the deterioration of patients rose with the rise in the OP waiting list. Moreover, as time progressed, this caused an increase in the differential between the CC waiting list and waiting times associated with the permanent district service and those associated with the expanded tertiary service.

Expanding the tertiary service stimulated demand for CC investigations due to the waiting time effect, but as there were no further knowledge effects on demand this was approximately one third of that which arose with the permanent district service. Given the assumed expectations on CC services, both experiments significantly reduced the pressure imposed by excessive waiting times compared to the base case. However, the permanent district service produced a marked increase in the pressure exerted by an excessive waiting list length.

Adding further district sessions on a temporary basis produced more marked oscillatory behaviour, compared to the other experiments as periodic capacity changes were added to the skills effect. This also resulted in phase differences in the average waiting time and waiting list compared to other experiments as the timing of the capacity increases differed to that of the changes in skills. Pressure on the CC service was reduced by the capacity increases provided by the district service and the 'knee jerk' reactions (reduction in referrals) prompted by the withdrawals of the district service. Compared to the base case, the pressure from an excessive waiting list and an excessive average waiting time for a CC investigation were reduced by about 11% and 2% respectively. These reductions would have increased over time. Whilst the average waiting time was generally lower than that associated with the permanent district service, greater pressure was imposed as it was assumed that the expectations would be higher. This was because it was assumed that if a district service was temporary, a lower average waiting time would be desired during periods that the district service was present as efforts would be made to squeeze as much out the system as quickly as possible.

Introducing new referral guidelines reduced the pressure on CC services to some extent but this did not produce significant changes in the CC behaviour modes.

To summarise, these experiments demonstrated that some ways of increasing capacity were more effective in alleviating pressure than others. Furthermore, the differences were not simply determined by the size of the capacity increase, but also the action of feedback effects and other changes prompted by the approach to increasing capacity.

Linking Structure to Behaviour

Exogenous factors played a large role in influencing the base case behaviour for Ribsley General. However, endogenous processes rather than exogenous factors tend to be the more powerful determinants of behaviour. These processes can reinforce or control behaviour; they are self-sustaining mechanisms whereas exogenous factors need to be repeatedly altered. Therefore, activating endogenous processes that *control* undesirable behaviour could provide a powerful means to improving the mode of behaviour of the system. However, activating endogenous processes that *reinforce* undesirable behaviour would be unhelpful.

Referring to the basic mechanisms in Appendix D, introducing a semi-permanent reduced district service did not alter the mode of behaviour nor the basic mechanisms that were responsible for that behaviour. Capacity changes (exogenous factors) continued to play a key role in reducing the CC investigation waiting list and waiting times (by influencing the causal links along loops B1 and B2). The tertiary service still operated at full capacity, so loop B1 remained inactive. Although the district service was prolonged, as it operated at full capacity for the whole period, adjustments in the levels of district-based activity were driven completely by exogenous factors. Although the district activity was reduced, the knowledge effects on demand were still pushed to operate at maximum intensity. A consequence of prolonging the stimulation of demand for OP appointments was an extended action of the process underlying adjustments in the OP activity rate (loop B4). The intensity of the processes underlying the waiting time effect on demand (loop B3) was diminished, but active for a longer period. In addition, the intensity of the links associated with the process of the gain in the skills effect on demand (loops R3 and R4) was also diminished, as the CC investigation rate was lower.

Adding further district sessions altered the mode of behaviour relative to the base case but did not alter the basic mechanisms that were responsible for the behaviour. Again, capacity changes (exogenous factors) continued to play a key role in reducing the CC investigation waiting list and waiting times (by influencing the causal links along loops B1 and B2). Adding more capacity merely extended that role.

The role played by capacity changes in reducing the CC investigation waiting list and waiting times was also extended with the permanent district service. The knowledge effects on demand were increased by the higher response associated with a permanent service. Changing the capacity levels altered the rate at which skills stimulated demand; compared to the base case, demand was stimulated more slowly when the district service was first introduced (as the investigation rate was lower) but subsequently stimulated demand more quickly (as the investigation rate was higher). Both the knowledge and skills effects (loops R1, R2, R3 and R4) continued to be generated by exogenous factors whilst the basic mechanism underlying the waiting time effect (loop B3) changed. In the base case, the rise in the average waiting time drove the waiting time effect to saturation point. With a permanent district service, the rise and fall in the average waiting time meant that the waiting time effect was not saturated (and subsequently generated by exogenous factors). Therefore, it continued to be generated endogenously. Furthermore, as the average waiting time persisted above its desired level, demand was only suppressed, and not stimulated, by waiting times.

The basic mechanisms underlying the OP behaviour also changed. The emphasis underlying changes in the OP waiting list and waiting times switched from endogenous processes to exogenous factors as the stimulated demand forced the system to operate at full capacity. The ability to control the rise in the OP waiting list and waiting times was thus removed and these variables exhibited sharp increases in the absence of sufficient OP capacity. This behaviour was only curtailed by the action of the endogenous process underlying the rate of other waiting list removals, which increased with the rise in the waiting list.

Expanding the tertiary service led to the utilisation of tertiary-based capacity dropping below 100% whilst in the base case, the tertiary-based service operated at full capacity. This altered the mechanisms underlying the adjustment in tertiary-based activity and changes in skills effect from being generated by exogenous factors to endogenous processes (activated loops B1 and R4). Consequently, the CC investigation waiting list and waiting times were controlled without the need for further capacity changes. The utilisation of district-based capacity also dropped so that it only reached 100% for a brief period. This altered the mechanisms underlying the adjustment in district-based activity and changes in the knowledge effects on demand and skills effect from exogenous factors to endogenous processes. The capacity utilisation actually dropped to 85% and it was assumed that this level would be sufficiently high not to warrant the further stimulation of demand to justify the capacity increases. Rather than operating at full capacity, having some slack in the system would possibly be welcomed in the case of an unexpected rise in demand.

In all cases, introducing new referral guidelines diminished the intensity of the causal links around the feedback loops. Strict referral guidelines deactivated the causal links around the loops that controlled the waiting time effect (loop B3) and the knowledge effects on demand (loops R1 and R2).

11.2.2 Using Demand Management Strategies

Further experiments investigated the use of demand management strategies representing efforts to control, rather than meet, demand. Depending upon the perspective taken, controlling demand could either mean reducing (or limiting) demand or supporting increases in demand if the aim was to identify more high risk cases. Identifying more high risk patients could be considered as a means to managing future demand and future costs by referring patients onto the necessary treatment before major problems arose.

Altering the GP and Patient Perception Delay (Exps R13 & R14)

Two of the experiments described within the sensitivity analysis in §10.2.4 may be regarded as demand management strategies. They involved altering the delay for GPs and patients to respond to changes in the availability of district services. As illustrated in §10.2.4, reducing the perception delay altered the mode of behaviour. This change accelerated the gain in knowledge about the district service and thus triggered the stimulation of demand for OP services on both occasions that the district service was in place. The demand was also stimulated earlier on the first occasion. This involved 29 further referrals for an OP appointment but only 3 further referrals for an elective CC investigation. In the base case, demand for OP services was only stimulated on the first occasion. As this led to an increase in OP activity rates, further demand for CC investigations was also stimulated indirectly.

By contrast, increasing the perception delay acted to limit and delay the stimulated demand. This involved 22 fewer referrals for an OP appointment but only 2 fewer referrals for an elective CC investigation. Compared to the base case, slightly greater pressure was imposed on CC services by an excessive waiting list and average waiting time. The reason for this result, which is counter-intuitive, is that reducing the number of referrals meant that the system was not pushed as hard.

Use of New Referral Guidelines (Exp R33 & R34)

Further ways of managing demand for services involve the use of referral guidelines specifying new referral criteria. I discussed referral guidelines in §6.6.3. The impact of the use of new guidelines was represented in two experiments by reductions in the levels of stimulated demand associated with the waiting time and knowledge effects on demand. The skills effect was not considered as this only suppressed demand. The operationalisation of referral guidelines is described in §12.3.4.

For the first experiment, it was assumed that all the stimulated demand was suppressed. This might be considered to reflect the implementation of very stringent rules about who should and who should not be referred for CC investigations and OP appointments; this is referred to as the use of *strict new guidelines*. This might be considered to reflect a very unrealistic policy intervention. However, this experiment still had value in illustrating the maximum possible effect that a referral guideline could have in managing stimulated demand. Some might consider this an ideal policy. Others might consider it less than ideal, given that some high risk patients might not satisfy the criteria for an investigation if very strict criteria were imposed. Therefore, these patients can only be diagnosed accurately by undergoing a CC investigation. As discussed before, given the unpredictable nature of heart disease, some patients with severe disease may only display minor cardiac symptoms. The second experiment reflected the assumption that half the stimulated demand was suppressed. This might be considered to reflect the use of less stringent referral guidelines; this is referred to as the use of *modest new guidelines*.

Returning to §6.5.2 can help to illustrate the effects of new guidelines. In this section, it was discussed how patients considered for a referral may be categorised into: those for which a referral would be clearly inappropriate; those for which a referral is clearly clinically indicated; or those in the 'grey area' for which the appropriate course of action is uncertain and therefore subject to debate. It was assumed that all patients for which a referral is clearly indicated will be referred and patients for which a referral is deemed inappropriate will definitely not be referred. Those in the 'grey area' might form further referrals depending on the degree of 'aggressiveness' of the cardiologist. It was also assumed that demand may be suppressed or stimulated around some normal referral fraction, determined by the referral tradition of the particular hospital.

Both the base case and the effects of new guidelines are illustrated in the context of a conservative referral tradition in Figure 11.3. The figure depicts the potential suppression and stimulation of the referral fraction around the normal referral fraction and the consideration of the referral of some 'grey area' cases as being inappropriate. Additional referrals that are regarded as inappropriate only refer to the views of cardiologists at the hospital of interest based upon their general attitude to referrals and their interpretation of the clinical guidelines in place. A more aggressive referral tradition would be reflected by smaller numbers of additional referrals deemed as inappropriate and a lower extent of demand suppression (see Figure 11.6 for the figure corresponding to Veinbridge General, where a more 'aggressive' referral tradition applies).

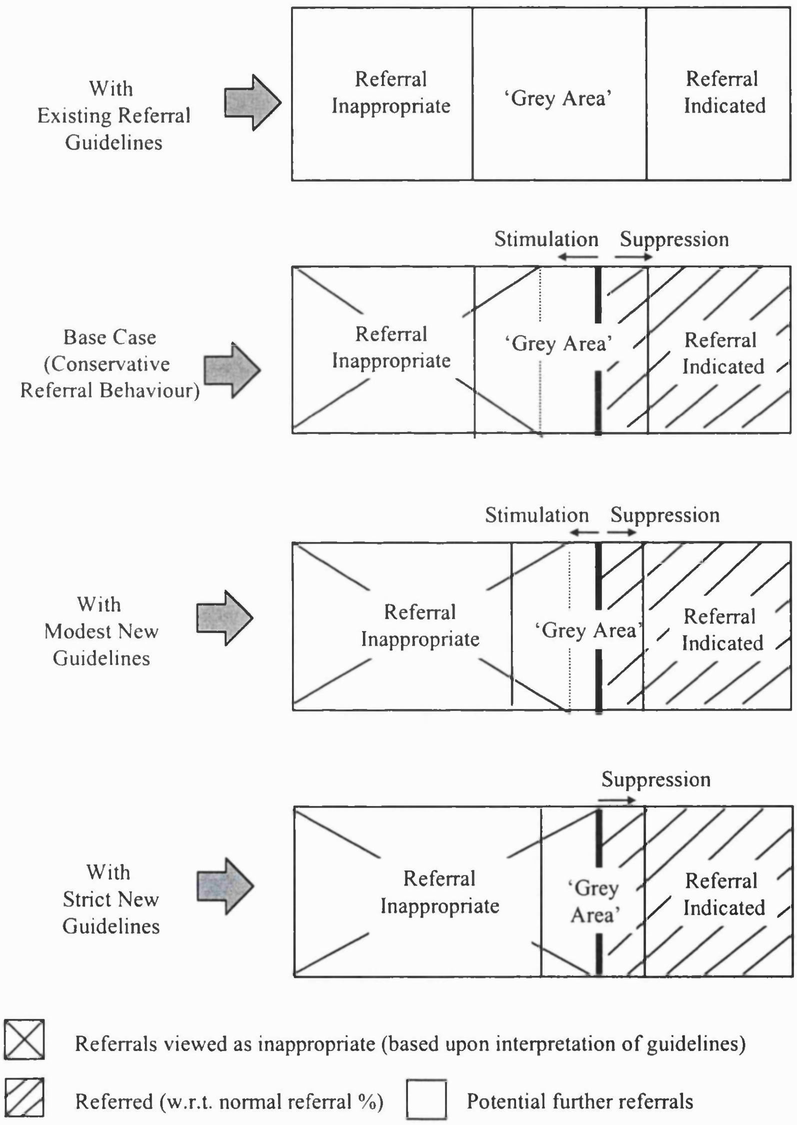


Figure 11.3 Constraining Demand: A Conservative Referral Tradition

(The dark line indicates the normal referral fraction. The relative sizes of the three regions should not be regarded as descriptive as the purpose is merely to illustrate the constraints on demand.)

It was assumed that the use of new referral guidelines would extend the proportion of inappropriate referrals for further investigation, thus restricting the degree of demand stimulation. However, allowances are made for the inevitable persistence of 'grey area' cases and variations in attitudes, as it would be unrealistic to assume that variations in referral behaviour could be eliminated by the introduction of new guidelines. For example, the new guidelines might state that a referral would be inappropriate for certain groups of patients and not strictly necessary for other groups. A conservative attitude to referrals would be reflected by the referral of fewer of the latter groups compared to a more aggressive attitude and consequently view a higher number of referrals as inappropriate.

These changes reduced the pressure on OP services and on elective CC services both directly and indirectly as the reduced demand to deliver OP appointments led to lower OP activity rates and thus produced fewer referrals for CC investigations. For example, the use of modest referral guidelines produced savings of nearly £3,200 in OP activity costs and nearly £4,900 in CC activity costs over the simulation (54 months).

Doubling the reductions in demand did not double the reductions in pressure from excessive waiting lists and waiting times or double the cost savings. This was due to the non-linear nature of the waiting time and knowledge effects on demand. In terms of qualitative changes, the effect on OP services was greater than that on elective CC services as, in the case of excessive waiting times and waiting list for OP services, it was possible to target the entire cause of the demand increases. Using strict referral guidelines altered the OP mode of behaviour from temporary instability to uninterrupted stability. The CC mode of behaviour was unchanged because the imbalance between the supply and demand, though reduced, persisted.

Introducing demand management strategies is analogous to controlling flow variables (more specifically, the referral rate). Some demand management strategies had a greater impact than others, given the extent of the capacity shortages at Ribsley General. However, they did not provide sufficient leverage to improve the CC behaviour, unlike the case of capacity changes (see §11.2.1). This was the opposite result to that of Wolstenholme's study (1999a) which was mentioned at the end of §10.3.3. However, demand management strategies could still have played an important role by improving the leverage of capacity increases.

Considering the basic feedback structure, demand management strategies diminished the intensity of the causal links and feedback processes that were responsible for the stimulation of demand, and diminished the intensity of the interactions between these processes. Increasing the GP and patient perception delay delayed the gain in knowledge about CC and the consequences of this gain in knowledge i.e. the stimulation of demand (loops R1 and R2) and adjustments in activity to address the demand increases (loops B1, B2 and B4). On the other hand, reducing the GP and patient knowledge perception delay intensified all these processes. The use of new guidelines to prioritise patients diminished the waiting time and knowledge effects on demand (loops B3 and R1 and R2). This also reduced the need to increase the OP rate (loop B4) but it did not significantly reduce the need to increase the CC investigation rates (loops B1 and B2) nor significantly reduce the gain in CC skills (loops R3 and R4) as the imbalance between supply and demand persisted.

With demand management strategies in place, exogenous factors (capacity changes) continued to play a key role in influencing the CC investigation waiting list and waiting times. As a number of these strategies reduced demand, this role was reduced to some extent. The use of strict new referral guidelines altered the OP modes of behaviour by disabling the process underlying the knowledge effects on demand (loops R1 and R2). It also affected the basic mechanisms underlying the OP behaviour as suppressing all the stimulated demand removed the need for adjustments in the OP rate, therefore, this structure (loop B4) also remained dormant.

11.2.3 Altering the CC Operator Skills Base

(Exp R17)

The effect of accelerating the gain in CC skills on referrals for CC investigations was considered in §10.2.4 as part of the sensitivity analysis. This involved a 20% increase in the fraction of investigations from which the junior district operators learned. This parameter change may also be recast as a policy intervention intended to boost the identification of more high risk cases. In practice, this might involve an increase in the proportion of clinical cases that are discussed among juniors. There might be several factors motivating this intervention. Juniors would welcome the opportunity to gain skills more quickly whilst the consultants could delegate more of their cases more quickly. In this experiment, the periods during which novice CC operators lacked confidence and under-referred patients for CC was shortened, and thus accelerated their ascent up the 'learning curve' towards the saturation point. This resulted in 7 additional referrals for an elective CC investigation.

Increasing the gain in CC skills reinforced the increase in referrals for CC investigations (loops R3 and R4). This resulted in a greater need to adjust CC activity rates in order to maintain the desired waiting time goal (intensifying the causal links along loops B1 and B2). The consequences of the increased activity rates were further stimulated demand due to the waiting time (loop B3) and knowledge effects (loops R1 and R2), and a greater need to adjust OP activity rates in order to maintain the OP desired waiting time goal (loop B4). However, the balance between the influences of exogenous factors and endogenous processes remained unchanged.

11.2.4 Increasing the OP Capacity

(Exps R35a- R35g)

The effects of increases in the exogenous level of demand for OP appointments were considered as part of the sensitivity analysis in §10.2.4. It was stated that whilst the system could cope with small increases in demand (1%), moderate increases (2% to 6%) raised the OP waiting list and waiting time to new levels above those desired. Furthermore, increases in excess of 6% resulted in a sustained increase in the waiting list and waiting times for a long period. Given that increases in the waiting list and waiting times resulted from an imbalance between supply and demand, as part of the policy analysis the effect of increasing the supply (i.e. OP capacity) under these scenarios was considered. Following the advice of the consultant at Ribsley General, the OP capacity was increased from 368 patients/month to 390 patients/month (6% increase).

Even with no exogenous demand increase (the base case assumption), the average waiting time was reduced as the demand on services was satisfied. In contrast to the case with normal capacity levels, the system could cope with small (1%) *and* moderate increases in demand (2% to 6%) by returning the waiting list and average waiting time to their desired levels. Increases between 7% and 12% raised the OP waiting list and waiting times to new levels whilst increases of 13% (rather than 7% under normal capacity levels) produced increases in the waiting list and waiting times for a long period. Equilibrium was only re-established when the other waiting list removals rose to achieve a balance between the referral rate and waiting list removal rate.

Referring back to the feedback processes in the system, increasing the OP capacity levels served to intensify the adjustment in OP activity levels towards meeting the desired OP waiting time goal (loop B4). However, by contributing to a higher CC referral rate, this also increased the delivery of patients along the referral chain towards CC investigations and thus reinforced other feedback processes. The increase in OP capacity also led to a greater reliance on the adjustment in OP activity levels, rather than the consequences of the rise in other waiting list removals (this feedback process is labelled as loop B in E1 in Appendix E), to re-establish equilibrium.

11.3 RIBSLEY GENERAL ANALYSIS: STRUCTURAL CHANGES

11.3.1 Parameter Changes that Produce Structural Changes

Highlighted in the previous section were a number of parameter changes that weakened or intensified feedback loops. Some parameter changes had a more dramatic effect by completely disabling (or 'switching off') structure within the system. These changes may also be regarded as producing structural changes. In the model, by setting parameter values to a particular value such as zero or unity, parts of equations, or whole equations are effectively cancelled out. For example, the use of strict new referral guidelines suppressed the stimulation of demand. This disabled the process whereby increased knowledge generated further demand for OP and CC services (loops R1 and R2). Furthermore, the process underlying increases in the OP rate, which would be required to meet the stimulated demand, also remained dormant (loop B4). Experiments were also carried out to investigate the effects of the more typical structural change in SD, involving the introduction of new feedback structure.

11.3.2 Seeking Different Activity Targets

(Exps R36-R52)

Experiments were carried to examine the effects of a change in the goal underlying adjustments in activity rates, from a desired waiting time to a desired waiting list size. The Veinbridge General base case analysis provided the motivation underlying this intervention and for the sake of completeness, it was also considered for the case of Ribsley General. The key structure for the decision to seek a desired waiting list is depicted in Appendix D in D3 and the basic equation for the desired activity rate is as follows:

$$\text{Desired Activity} = \text{Avg Referral Rate} + \frac{\text{Waiting List} - \text{Desired Waiting List}}{\text{Des. Waiting List Adj. Time}} - \text{Avg Other Waiting List Removal Rate} \quad \ldots\ldots (1)$$

The simulation formulation and its rationale were described in §9.3.1. For the purpose of comparison, the basic equation for the decision to seek a desired waiting time (a base case assumption) is as follows:

$$\text{Desired Activity} = \frac{\text{Waiting List}}{\text{Des. Waiting Time}} - \text{Avg Other Waiting List Removal Rate} \quad \ldots\ldots (2)$$

It is important to differentiate between the factors that *drive activity* and those that are used to *evaluate performance.* Several targets may exist but the focus here is on the crucial factor or factors that drive activity. For one decision rule, the waiting time goal drives activity levels whilst for the other decision rule, the key factor is the desired waiting list size. In evaluating the ability to meet the desired goals, several factors were monitored including both the average waiting time and length of the waiting list as stated in §5.4.3. Following on from the calls in the literature for the waiting time to be the key concern (see §2.5.2) and not the waiting list, using the simulation model, it was possible to address the value of shifting the emphasis completely away from waiting lists.

It should be noted that increasing the activity rate in order to meet a waiting list goal will reduce the average waiting time. Conversely, increasing the activity rate in order to meet a waiting time goal may also achieve reductions in the length of the waiting list. Therefore, some overlap exists between the underlying motivation and the outcomes associated with the two rules. Using the simulation model, the extent of this overlap was revealed.

A series of experiments produced comparisons between the effects of seeking a desired waiting list and a desired waiting time. In order to isolate differences in the effects, it was necessary to ensure that these goals and the paths to these goals were consistent. This required some minor parameter changes. It was calculated that a CC investigation waiting list goal of 56 patients accompanied by desired waiting list adjustment times of 3 months was equivalent to a waiting time goal for a CC investigation of 3 months (see Appendix E, E5d for the calculations). These parameters departed from those specified by the Ribsley General consultant by setting a lower waiting list goal (56 patients, as opposed to 60 patients) and a slower waiting list adjustment time towards its goal (3 months, as opposed to 2 months).

The first comparison involved the base case assumptions about supply and demand. Further comparisons probed further by altering these assumptions.

11.3.3 Effects of Seeking Different Activity Targets on OP Services

(Exps R36-R38)

Experiments showed that, when applying the base case assumptions about supply and demand, seeking a desired waiting list did not fundamentally alter the OP mode of behaviour. Seeking both activity targets led to the OP waiting list and average time spent on the OP waiting list returning to their respective targets. However seeking a desired waiting list overcompensated by temporarily causing the average time spent on the waiting list to be lower than its desired level.

Probing further with different demand scenarios, it became apparent that the outcomes were dependent upon the direction of change in demand and the ability to meet demand.

Altering Demand With Sufficient Capacity Available (Exps R41-R44)

When a small permanent increase in demand (0.5% increase) was introduced, as there was sufficient capacity for the system to cope, seeking a desired waiting list produced better results as shown in Figure 11.4(a). Note that although the *quantitative* differences in the OP waiting list are very small, the point to note is the significance of the *qualitative* differences. By seeking a desired waiting list, both targets were met (overcompensating on the average time spent on the waiting list) whilst seeking a desired waiting time, the desired waiting list was not met. The situation was reversed when a small permanent decrease in demand (0.5% decrease) was introduced; seeking a desired waiting time produced the better results as shown in Figure 11.4(b). Table 11.1 provides a summary.

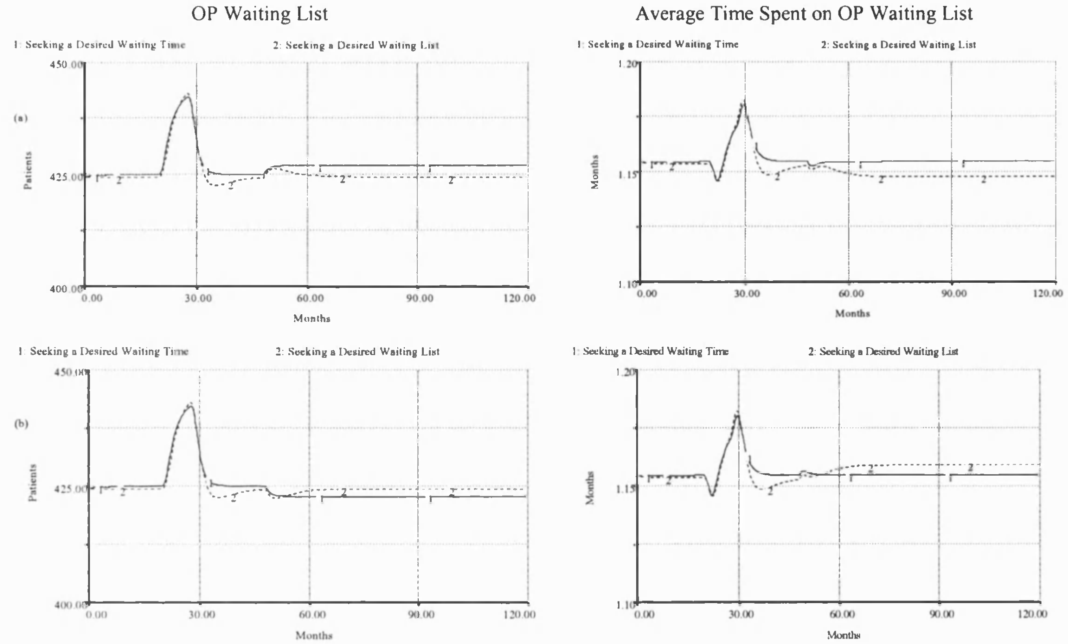


Figure 11.4 Seeking Different Activity Targets with Sufficient Capacity to Cope with Changes in Demand ((a) With 0.5% demand increase; (b) With 0.5% demand decrease. As described in Chapter 9, the desired OP waiting list length is 424 patients and the desired waiting time is just over 1.15 months (5 weeks converted to months). The initial differences are due to rounding errors. The simulation period is extended in order to show the effects propagate.)

Table 11.1 Targets Met When Sufficient Capacity Available

	Response to Increased Referrals		Response to Decreased Referrals	
	Waiting List	Waiting Time	Waiting List	Waiting Time
Seeking a Desired Waiting Time	Target Not Met	Target Met	Target Met*	Target Met
Seeking a Desired Waiting List	Target Met	Target Met*	Target Met	Target Not Met

(* Indicates overcompensation by producing value below desired level)

Given that there was sufficient capacity available, each decision rule met its respective target. However, seeking a desired waiting time when the *referral rate increased* produced a waiting list which was in excess of its desired level. This result is not surprising as seeking a desired waiting time did not focus on maintaining the desired waiting list. Considering how the average waiting time is calculated (= waiting list/average waiting list removal rate), it can be seen that increasing activity levels (and therefore increasing the waiting list removal rate) to lower the waiting list to its desired level will also produce reductions in the average waiting time. However, striving to reach the desired waiting time will not necessarily address increases in the waiting list. In fact, a waiting time goal could be maintained if increases in the waiting list were balanced by increases in the waiting list removals (i.e. waiting list/average waiting list removal rate remained constant). Therefore, a constant waiting time at its desired level could co-exist with an elevated or rising waiting list. This final point was highlighted by Hamblin *et al* (1998b).

Seeking a desired waiting time when the *referral rate decreased* produced a waiting list that was lower than its desired level i.e. overcompensated in meeting the waiting list target. This is not surprising as a constant waiting time at its desired level could co-exist with a reduced or decreasing waiting list, provided the waiting list is balanced by the waiting list removal rate.

Seeking a desired waiting list when the *referral rate decreased* produced an average waiting time which was in excess of its desired level. This occurred because to maintain the waiting list at its desired level, a reduced activity rate (and therefore reduced waiting list removal rate) was required to balance the reduced referral rate. Reducing the number of waiting list removals meant that the average waiting time rose. Similarly, to maintain the waiting list at its desired level when the *referral rate increased*, an increased activity rate (and commensurately increased waiting list removal rate) was required. Therefore, by seeking a desired waiting list, the average waiting time was reduced from its desired level and thus overcompensated in meeting the waiting time goal.

These experiments also showed the importance of monitoring both the waiting list and waiting times. In Figure 11.4(a), whilst seeking a desired waiting time controlled the average waiting time, this was only due to the activity rates rising (as reflected by the increased waiting list) to meet the increased demand. Therefore, maintaining the waiting time goal did not mean that the system was not under pressure.

Increasing the Demand with Insufficient Capacity Available (Exps R45-R48)

In experiments where there was insufficient capacity to cope with the demand increase, the waiting time and waiting list goals were not maintained but rose to new equilibrium values as shown in Figure 11.5. However, by contrast with the earlier experiments involving increases in demand, seeking a desired waiting list did not produce a lower waiting list and average waiting time. A 7% increase in demand pushed the system to operate at full capacity and both decision rules led to the same equilibrium values although seeking a desired waiting list led to these values being reached more quickly as shown in Figure 11.5 (b). With a smaller increase in demand, 4%, the calls to increase activity were insufficient to push the system to operate at full capacity. In this case, higher equilibrium values were produced by seeking a desired waiting list as shown in Figure 11.5 (a). These differences were due to the fact that seeking a desired waiting time led to greater calls for activity increases initially. By calling for more activity, more was delivered, therefore in the presence of capacity constraints, the discrepancy between the desired and actual activity rates was smaller. However, the activity target was never reached so the desired OP rate did not diminish but persisted in being higher than that called by seeking a desired waiting list.

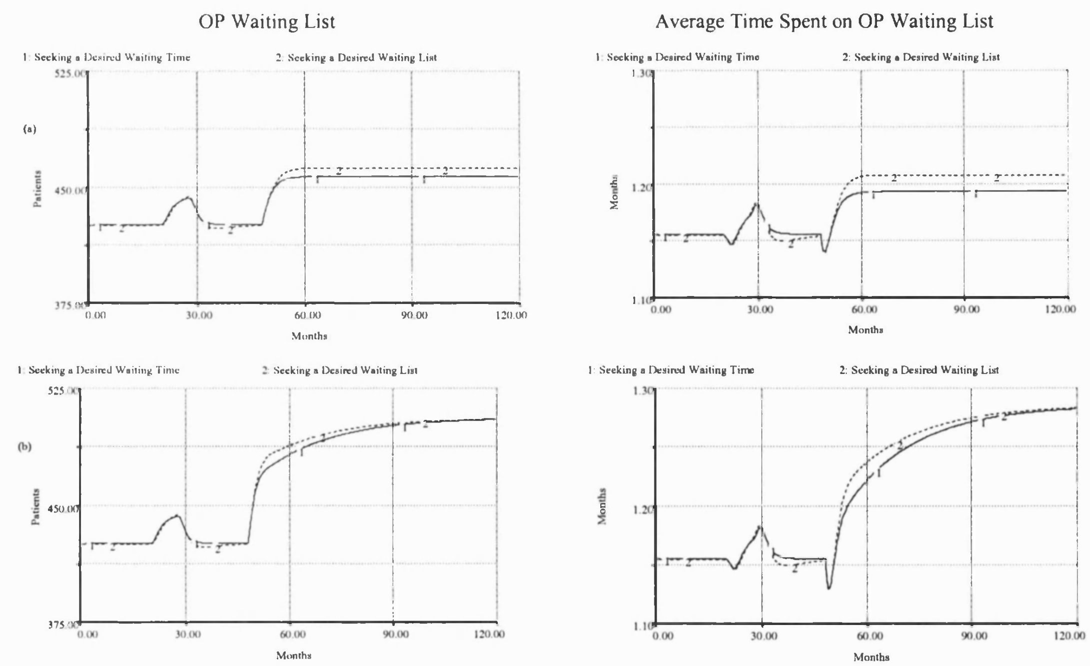


Figure 11.5 Seeking Different Activity Targets with Insufficient Capacity to Cope with Demand Increases

((a) With 4% demand increase and system not pushed to operate at full capacity;

(b) With 7% demand increase and system pushed to operate at full capacity)

Note that if the capacity shortages were such that the system was always pushed to operate at full capacity, then any differences between the desired activity rates would not have had any effect. In the experiments corresponding to Figure 11.5, there was initially spare capacity until the system was pushed to operate at full capacity.

It is possible to understand why seeking a desired waiting time in the context of demand increases led to greater calls for activity increases by re-examining the desired activity equations. These are basically as follows:

Seeking a desired waiting list:

$$\text{Desired Activity} = \text{Avg Referral Rate} + \frac{(\text{Waiting List} - \text{Desired Waiting List})}{\text{Des. Waiting List Adj. Time}} - \text{Avg Other Waiting List Removal Rate} \quad \ldots\ldots\ldots\ldots (1)$$

Seeking a desired waiting time:

$$\text{Desired Activity} = \frac{\text{Waiting List}}{\text{Des. Waiting Time}} - \text{Avg Other Waiting List Removal Rate} \quad \ldots\ldots\ldots\ldots (2)$$

In equation (1), as the referral rate is averaged, its impact will lag behind that on the waiting list.

To summarise: when there was sufficient capacity for the system to cope and demand increased, seeking a desired waiting list produced a lower waiting list and average waiting time compared to the outcomes of seeking a desired waiting time. The situation was reversed when demand was reduced. Waiting list and waiting time goals were met and in some cases the system overcompensated by producing lower levels than that desired. When there was insufficient capacity available and demand increased, in seeking both goals, neither the waiting list nor the waiting time goals were met. However, seeking a desired waiting time produced lower values or a slower ascent towards new equilibrium values in excess of those desired.

11.3.4 Effects of Seeking Different Activity Targets on CC Services

(Exps R37, R38, R49-R52)

The experiments showed that, when applying the base case assumptions about supply and demand, seeking a desired waiting list did not alter the CC modes of behaviour. Furthermore, it produced higher pressure on elective CC services. For example, the pressure exerted by an excessive CC waiting list was 10% higher and that exerted by an excessive time spent on the CC waiting lists was 14% higher. This result was consistent with the OP analysis described in the previous section. This demonstrated that seeking a desired waiting time produced a lower waiting list and average waiting time when there was insufficient capacity to cope.

Several other experiments compared the two decision rules in circumstances that would increase the pressure imposed on the system. One experiment involved a reduction in supply for CC services associated with a winter crisis. As with the previous experiment, seeking a desired waiting list did not alter the mode of behaviour but produced lower pressure on OP services and higher pressure on elective CC services. A further experiment, which involved the removal of various factors including the skills, waiting time and knowledge effects, demonstrated that it was changes in demand rather than capacity losses that would reveal differences between the two decision rules.

In conclusion, there was certainly some overlap between seeking a desired waiting time and seeking a desired waiting list. However, seeking a desired waiting list was the more effective in coping with increases in demand that were within the resources available. When the referral rate led to the capacity constraints being approached, seeking a desired waiting time produced better results. Seeking a desired waiting list only matched the performance of that from seeking a desired waiting time in the long term in situations when the system was pushed to operate at full capacity. With reductions in demand, seeking a desired waiting time produced a lower waiting list and average waiting time. Finally, focusing on waiting times alone and not also the waiting list length could lead to misleading conclusions.

11.4 VEINBRIDGE GENERAL ANALYSIS: PARAMETER CHANGES

For the Veinbridge General case, the problems and their underlying causes differed from those in the case of Ribsley General, so this called for a different set of parameter changes to be investigated as policy alternatives. The following changes are discussed: changes to the capacity for elective CC investigations; the use of demand management strategies; and, increases in the capacity for OP appointments. Unlike the case of Ribsley General, changes to the CC operator skills base were not investigated. These would modify the skills effect on demand for a CC investigation but as this effect was absent in the case of Veinbridge General, altering its influences would not affect the behaviour of the system.

11.4.1 Altering the Capacity for Elective CC Investigations

The key problems in the case of Veinbridge General arose from the permanent district service stimulating demand to the extent that unacceptable delays resulted for an OP appointment. Furthermore, although the desired waiting time for a CC investigation was maintained, significant increases in the CC investigation waiting list were observed. This influence was isolated in the base case analysis in §10.3.4 with two experiments which involved restricting the availability of district services. One experiment illustrated the importance of the district service in compensating for the tertiary facility closures. Another experiment demonstrated that less demand would have been stimulated had the district service been temporary. Some effects of these experiments were shown in Figure 10.6.

Two further experiments described in §10.3.4 showed how alternative approaches to capacity expansions could have produced more desirable behaviour. Both limited the use of district services. One involved an expanded tertiary-based service with the district service compensating for tertiary facility closures. Some effects of these experiments were also shown in Figure 10.6. The second involved the addition of further temporary district sessions to the use of the district service compensating for tertiary facility closures. It might be considered that these two experiments could be recast as policy experiments. However, this would be in conflict with the commitment that had been made to introduce a permanent district service and construct an integrated CC facility at Veinbridge General.

Therefore, whilst considering the restriction of district services had value in investigating the base case, it did not have value from a policy analysis perspective.

In fact, no changes to the capacity for elective CC investigations were considered suitable for the Veinbridge General policy analysis. Experimenting with expansions in district-based capacity was not considered useful. This was because in the base case, although the CC investigation waiting list rose, the desired waiting time goal, which drove the activity rate, was met without having to utilise a high level of district-based capacity. Tertiary-based capacity expansions in the context of the base case levels of district-based capacity were also not considered to have any potential as interesting policy alternatives. This was because the tertiary-based capacity levels adequately met the demand for high risk patients.

11.4.2 Using Demand Management Strategies

(Exps V10, V11, V14 & V15)

Alterations to the time for GPs and patients to perceive and respond to changes in the availability of district services, described within the base case sensitivity analysis in §10.3.4, may also be regarded as demand management strategies. It will be recalled that increasing the perception delay reduced demand for both OP and CC services because knowledge about the district CC service was obtained more slowly and the knowledge effects on demand thus accumulated less rapidly. Compared to the base case, 34 and 156 fewer referrals were made for an elective CC investigation and an OP appointment respectively. Reducing the perception delay could possibly contribute to the management of future demand by accelerating the stimulation of demand which could lead to the identification of more patients at risk. Compared to the base case, 36 and 166 more referrals were made for an elective CC investigation and an OP appointment respectively. Changes from the base case arose when demand was stimulated and diminished over time. These changes were more rapid at the CC investigation end of the referral chain. Altering the perception delay did not alter the modes of behaviour apart from a minor change to the CC waiting list mode by the reduction in the perception delay. Although reducing the perception delay increased the level of stimulated demand, the knowledge effect on demand for an OP appointment was already saturated.

The more obvious approach to managing demand is by targeting it directly with the use of new referral guidelines specifying referral criteria. The effect of new guidelines on referrals is illustrated in Figure 11.6 (the basic features were explained with the corresponding diagram for the Ribsley General case, Figure 11.3).

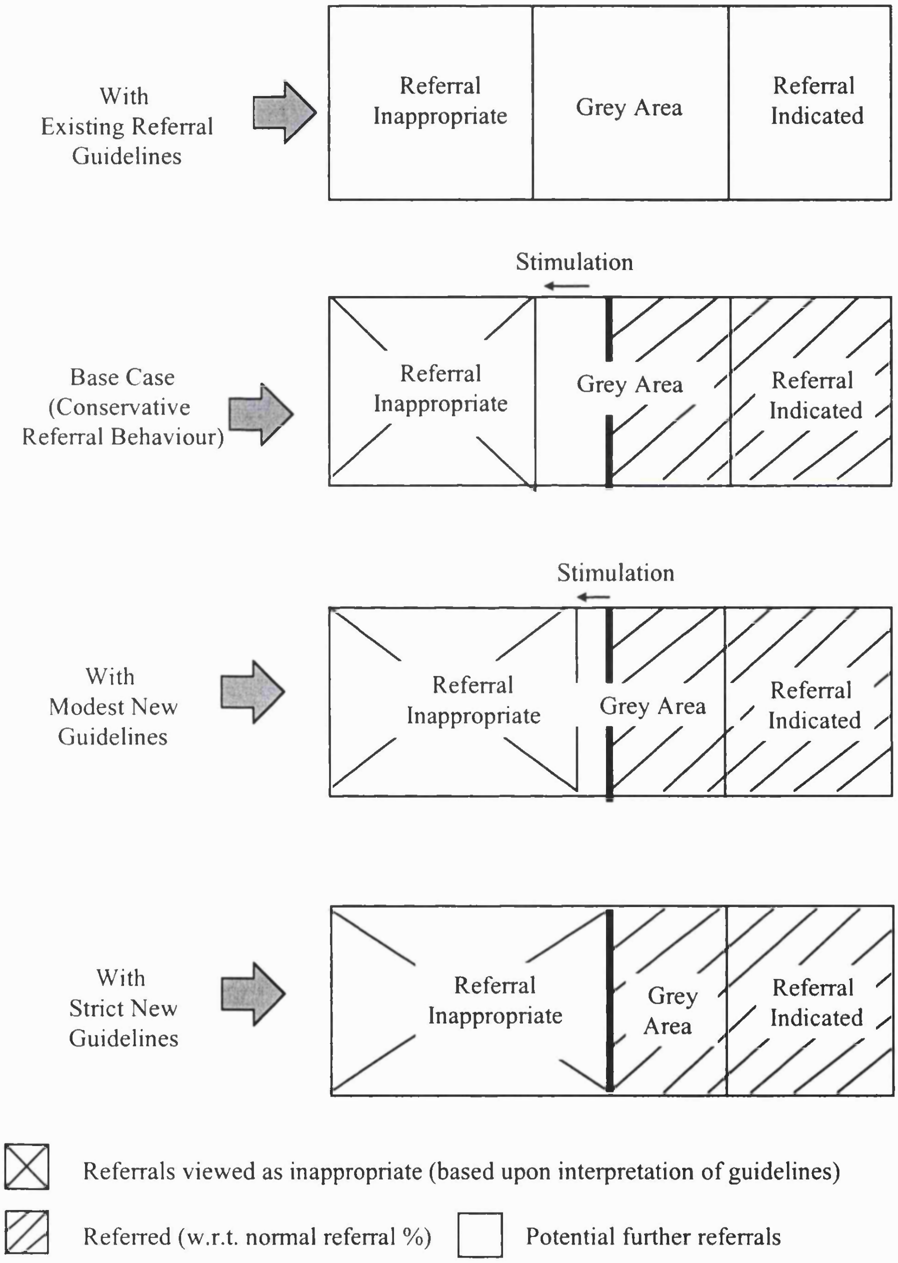


Figure 11.6 Constraining Demand: An 'Aggressive' Referral Tradition

(The dark line indicates the normal referral fraction. The relative sizes of the three regions should not be regarded as descriptive as the purpose is merely to illustrate the constraints on demand.)

Although the factors underlying the stimulation of demand for the Veinbridge General case differed to those in the Ribsley General case, the same set of new referral guidelines could be considered. However, their interpretation would vary given that guidelines could not eliminate a 'grey area' regarding the appropriateness of referrals. As with the case of Ribsley General, in the experiments, the impact of the use of new guidelines was represented by changes in the level of stimulated demand. For one experiment, which provided a benchmark, it was assumed that all the stimulated demand was suppressed (strict new guidelines), and for a second experiment, it was assumed that half the stimulated demand was suppressed (modest new guidelines). Significant savings were achieved with the use of modest new guidelines with the OP and CC activity costs reducing by £144,640 and £551,144 respectively over the simulation (72 months). These figures were increased to £333,702 and £1,035,115 with the use of strict new guidelines.

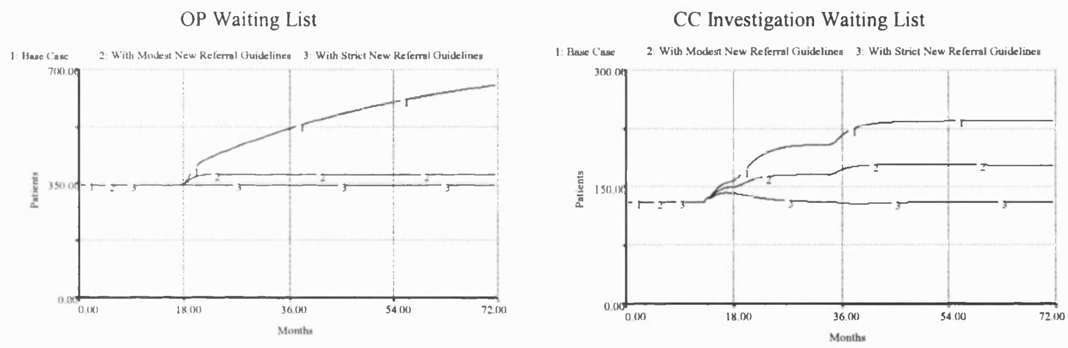


Figure 11.7 Some Effects of the Use of New Referral Guidelines

Figure 11.7 shows some examples where the use of new guidelines altered the behaviour of the system. Only the CC investigation waiting time goal was achieved in the base case. However, as all the causes of the demand increases could be targeted with the use of new referral guidelines, further goals could be achieved. The use of strict new guidelines resulted in the CC investigation waiting list, OP waiting list and average OP waiting time also being maintained at their desired levels. The use of modest new guidelines had a lower impact on the behaviour of the system, causing the OP waiting time goal to be achieved. This was in contrast with the case of Ribsley General where modest guidelines did not maintain the OP waiting time goal because there was insufficient slack in the system.

Therefore, it was possible to produce significant improvements in behaviour via the use of certain demand management strategies.

Referring back to the feedback structure, introducing demand management strategies diminished the factors that were responsible for stimulating demand, both the exogenous variable (effect of other factors on referrals) and endogenous processes (loops R1 and R2). Altering the GP and patient perception delay adjusted the speed of these endogenous processes whilst the use of new referral guidelines reduced their intensity. Suppressing all the stimulated demand went further by disabling these processes completely. Adjusting the intensity and speed of individual processes also resulted in adjustments in the interactions between different processes. For example, reducing the effects of knowledge of CC on demand (diminishing the intensity of loops R1 and R2) reduced the need for increases in activity rates (diminished the intensity of loops B1, B2 and B4) which in turn reduced the gain in the effect of knowledge of CC on demand.

11.4.3 Increasing the OP Capacity

(Exp V16)

Whilst several experiments dealt with capacity shortages by controlling demand, another experiment was based upon an obvious alternative approach, attempting to meet the demand by increasing capacity levels. Only increases to OP capacity were investigated. This extended the scope of the process of adjustment in the OP activity rate (loop B4) to the extent that its desired goal was reached. Activity rates were driven by waiting time goals. Therefore, as the desired waiting time for a CC investigation was maintained in the base case, increasing the elective CC capacity would not produce a lower waiting list.

In the base case, prior to the introduction of the district service, the waiting list and average waiting time were at their desired levels with the OP service operating at 85% capacity. After the district service was introduced, the referral rate for an OP appointment rose by 20%. This pushed the OP service to run at full capacity but this was insufficient to maintain the desired waiting time goal. In order to maintain the desired waiting time, it was not necessary to increase the capacity by 20%. In fact, a 10% increase was sufficient. With this higher capacity level, although there was some spare capacity (capacity utilisation was 93%), because the desired waiting time was maintained, further pressure to increase activity rates was not exerted. Consequently, the OP waiting list still rose above its desired level but to a considerably lower degree involving 245 fewer patients than the base case, as shown in Figure 11.8.

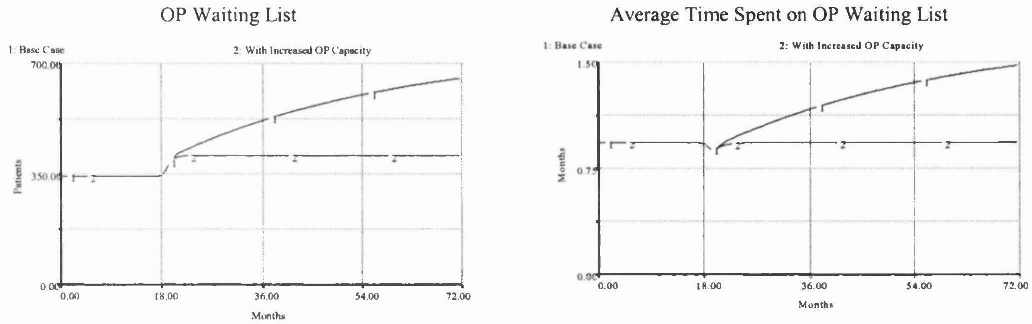


Figure 11.8 Some Effects of Increasing the OP Capacity

Furthermore, whilst pressure was decreased on the OP services in terms of the reduced waiting lists and waiting times (albeit with increased costs), the increased OP activity rate resulted to higher pressure on CC services as more patients were pushed along the referral chain. The pressure from an excessive CC investigation waiting list rose by 2.4% but the increased flow of patients did not alter the average waiting time.

Therefore, increasing the OP capacity only had a limited success in improving the behaviour of the system.

11.5 VEINBRIDGE GENERAL ANALYSIS: STRUCTURAL CHANGES

11.5.1 Seeking Different Activity Targets

(Exp V17)

As with the case of Ribsley General, a number of parameter-based policy interventions could be recast as structural changes as they disabled structure within the system. However, the main focus of the investigation of structural-based policy interventions involved the introduction of the same new feedback structure that was investigated in the case of Ribsley General – driving activity rates by seeking a desired waiting list length rather than a waiting time goal. This investigation was motivated by the Veinbridge General base case analysis (see §10.3.3). It was suggested that seeking a desired waiting list length would target the undesirable increases in the Veinbridge General CC investigation waiting list and at the same time, by raising activity rates, address increases in the average waiting time. The basic structure for this new decision rule is shown in Appendix D in D3 and the rationale and formulation were presented in §9.3.1 and, in simpler terms, in §11.3.2. Unlike the case of Ribsley General, parameter changes to ensure that the goals of the two decision rules and the paths to these goals were consistent were not necessary; consistent parameters already applied. The consistency arose during the calibration process from the derivation of parameters (in the absence of hard data) based upon various assumptions including the system initially being in equilibrium (see Appendix E, E5d).

Comparisons were made between the effects of seeking the two different activity targets under several different scenarios. The first comparison involved the base case assumptions about supply and demand (Figure 11.9). The insights were consistent with those obtained in the Ribsley General experiments, reported in §11.3.3, involving increases in referrals when there was sufficient capacity available. Both the elective CC investigation service and OP service for Veinbridge General patients had experienced increases in referrals. For the CC service, there was spare capacity and seeking a desired waiting list length ensured that this goal was maintained. Compared to the base case, nearly 95% of the pressure from an excessive waiting list was eliminated with the waiting list only rising to 148 patients (87 fewer patients). Seeking a desired waiting list also overcompensated by producing an average waiting time which was lower than that desired.

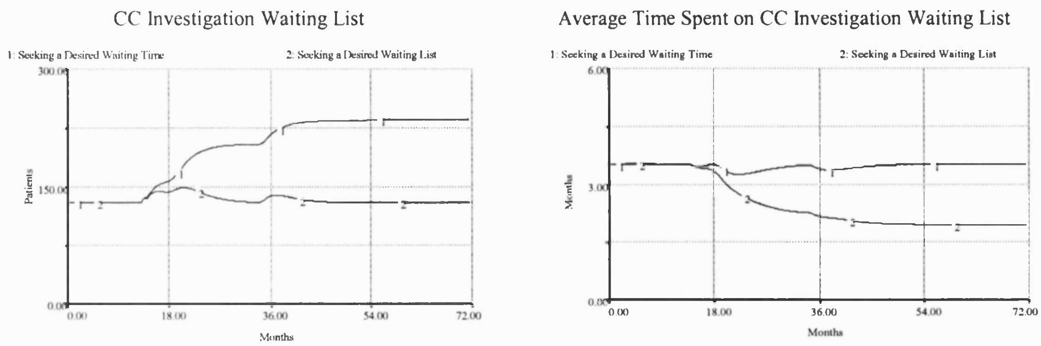


Figure 11.9 Some Effects of Changing the Activity Target

For the OP service, there was insufficient capacity and the system was pushed to operate at full capacity. Both decision rules led to the same equilibrium waiting list and waiting time values although seeking a desired waiting list led to these values being reached more quickly. For example, the pressure from an excessive OP waiting list rose by nearly 2%.

However, these reductions have to be traded-off against higher resource usage. For example, seeking a desired waiting list led to 149 further CC investigations being carried out over the 72 months and this generated £112,205 additional costs averaging £1,558 per month.

11.5.2 Seeking Different Activity Targets with Reduced Pressure on the System

Increased OP Capacity (Exps V16, V17 & V18)

Another comparison involved increasing the OP capacity so that there was sufficient capacity for OP services to cope. This produced circumstances whereby seeking a desired waiting list also improved the OP behaviour by controlling the OP waiting list and average waiting time (see Figure 11.10).

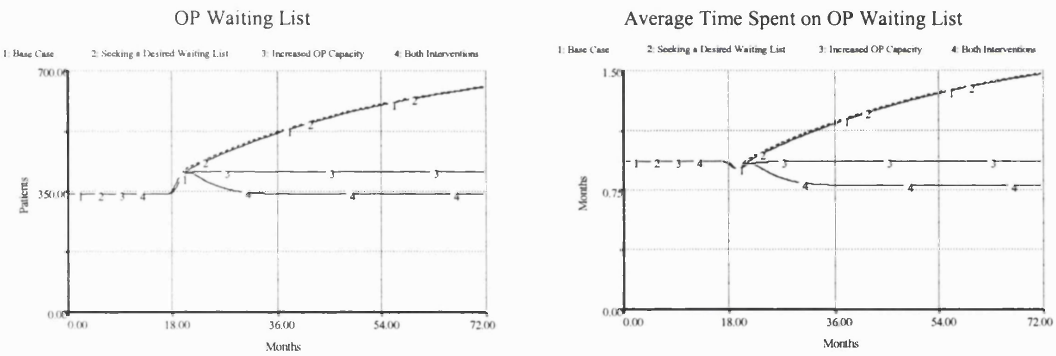


Figure 11.10 Comparing the Decision Rules with Increased OP Capacity
(For runs 1 and 3, a desired waiting time was sought. Runs 2 are the dashed lines.)

Therefore, co-ordinating a change in the forces that drive activity with OP capacity increases eliminated both the undesirable behaviour to CC and OP services. Seeking a desired waiting list controlled the level of the CC investigation waiting list, the capacity increases ensured that there was sufficient capacity to meet demand for OP services and thus controlled the rise in the OP waiting times, and the combination of the two interventions controlled the rise in the OP waiting list.

Use of New Referral Guidelines

(Exps V14, V17, V19 and references to R39 & R40)

Further comparisons involved suppressing some stimulated demand by using referral guidelines (controlling rather than meeting demand). This ensured that the benefits of seeking a desired waiting list were not offset by increased resource usage. Furthermore, the mode of behaviour improved since reducing demand to a manageable level ensured that both the waiting list and waiting time targets were maintained. Thus, as with the previous policy combination, there was synergy between the two interventions such that the CC investigation waiting list, OP waiting list and average waiting time for an OP appointment were controlled (see Figure 11.11).

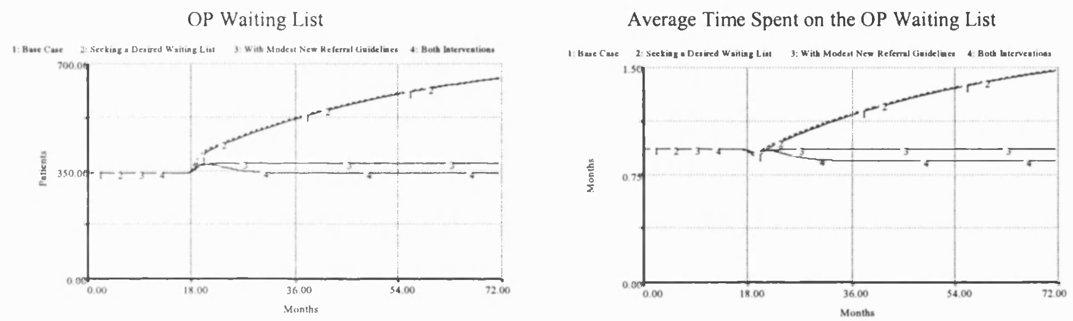


Figure 11.11 Seeking a Desired Waiting List Length and Using New Referral Guidelines
(Normal capacity levels apply. Runs 2 are the dashed lines.)

This demonstrated that it was possible to produce significant improvements in both the OP and CC behaviours without capacity increases. Moreover, the improvements were slightly greater than those obtained with the previous experiment that did involve capacity increases.

Both the use of the referral guideline and the change to the activity target were analogous to controlling rate variables (the referral rate and waiting list removal rate respectively). Therefore, this result was consistent with Wolstenholme's (1999a) experience that changes to flows (e.g. referral rates) have greater leverage than changes to stocks (e.g. capacities), as shown in Figure 11.8 (Runs 2 - change in stock variable) and Figure 11.11 (Runs 3 and 4 - change in flow variables).

It should be noted that repeating this experiment for the case of Ribsley General did not produce the same outcome; the OP behaviour improved (the increase in the average OP waiting time was eliminated and there was a temporary drop in the OP waiting list below its desired level) but the CC behaviour was unchanged. Even using a strict clinical guideline failed to alter the CC behaviour mode. These results indicated that the combined policy could not improve the behaviour in situations where there were extreme capacity shortages.

11.5.3 Seeking Different Activity Targets with Increased Pressure on the System

(Exps V8 & V21)

Finally, the use of the two decision rules were compared when the pressure on the system was increased by introducing a winter crisis (modelled by a sharp drop in elective CC capacity over a 3 month period). The winter crisis caused a rise in the average waiting time for both decision rules. However, seeking a desired waiting list caused an increase in the waiting list whilst seeking a desired waiting time caused a decrease. The differences were due to different responses, not to the capacity loss, but to the 'knee jerk' reduction in referrals that were the assumed reactions to the sudden capacity loss. In seeking a desired waiting list, the reduction in referrals led directly to a reduction in the desired activity rate and this resulted in further increases in the CC investigation waiting list. By contrast, in seeking a desired waiting time, the referral rate reduction merely contributed to reductions in the waiting list.

11.6 SUMMARY

This chapter reported and explained the results of the policy experiments for the two case studies. Both parameter changes and structural changes were investigated, following up suggestions that arose from the base case analyses. Experiments represented efforts to address the capacity shortages by controlling demand and meeting demand.

During the course of the policy analyses (as with the base case analyses), for both case studies, the model demonstrated behavioural insensitivity to parameter changes on a number of occasions, as is typical with feedback systems. However, exceptions were made when the parameter changes involved capacity changes. This was not surprising, given that the case studies had experienced extreme problems associated with under-capacity. However, in the case of Veinbridge General, experiments demonstrated that it was possible to control both the delay to services (meet the desired waiting time) and need for services (meet the desired waiting list) without capacity increases. This was achieved by introducing a new referral guideline (a parameter change) to suppress demand and altering the activity target to seek a desired waiting list length (a structural change) for both the OP and elective CC services. The former change ensured that the conditions were suitable (there was sufficient capacity for the system to cope) for the latter to be effective in reversing the upward trend in the waiting list and waiting time in response to rises in demand. These same benefits did not apply to the case of elective CC services for Ribsley General patients as the capacity shortages were too great. However, experiments did provide insight into the effects of different approaches to capacity increases and the effects of a reconfiguration of the base case capacity increases.

The next chapter will conclude the research. As part of this process, a series of policy recommendations and policy lessons will be derived and generalisations will be drawn from the case studies.

CHAPTER 12

DISCUSSION AND CONCLUSIONS

12.1 INTRODUCTION

The aims of this chapter are to draw inferences from the SD study of the shift in CC services and, finally, conclude the thesis.

In the next section (§12.2), the policy implications of the results of the model-based experiments are derived before assessing the usefulness of SD in terms of its ability to contribute to the policy making process (§12.3-§12.5). As stated in Chapter 5, in §5.2.1, this assessment probes beyond the issue of modelling power (§12.3) alone to also consider the value of the policy insights generated by the SD analyses (§12.4) and the ease of use of SD (§12.5). The premises that were stated in the research hypothesis, regarding the causal mechanisms and usefulness of the SD methodology, are then revised (§12.6). Moving on from the case studies, the findings of the research are generalised (§12.7) considering both the insights into the dynamics of service shifts (§12.7.1) and the usefulness of SD (§12.7.2). To conclude the thesis, the research contributions are highlighted (§12.8), and some suggestions are made for further research (§12.9).

In this chapter, in discussing the effects of service shifts, references are made to the 'fix that fails' systems archetype (an example was given in §4.4.2). Systems archetypes are described by Senge as:

> "certain patterns of structure [that] recur again and again" (Senge 1990, p.94).

They are used in SD to convey policy insights in simple terms. For examples, see Meadows (1982) and Senge (1990).

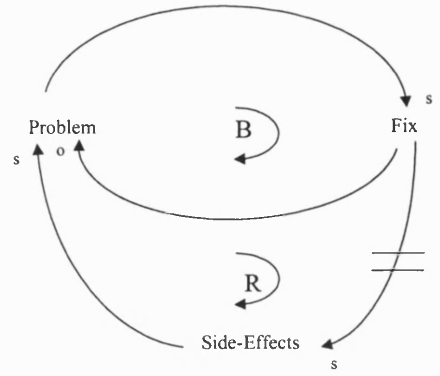


Figure 12.1 ‘Fix That Fails’ Systems Archetype

The structure of the ‘fix that fails’ systems archetype is shown in Figure 12.1. The structure depicts how a well-intentioned policy action, or ‘fix’, to solve a problem, is effective in the short-term (loop B). However, it has unintended long-term side effects which undermines the policy action and thus requires further actions i.e. more use of the same ‘fix’ (loop R). Therefore, it is a short-term ‘fix that…’ in the long-term ‘…fails’. In the case of the shift in CC services, the use of a district facility to increase activity rates may be regarded as a solution to the problem of poor access to elective CC services. The stimulation of demand for CC services represents a possible side effect that could undermine the efforts to improve access.

12.2 INTERPRETATIONS AND POLICY IMPLICATIONS

In Chapter 9, it was demonstrated that the simulation model could reproduce the base case behaviour for the two case studies. Chapter 10 described model-based experiments which were carried out to provide insight into this behaviour. Chapter 11 then presented the outcomes of a series of policy experiments that involved departures from the base case from the time that district services were first introduced. Assuming that the simulation model provided a suitably accurate reflection of the ‘real world’, with respect to the model purpose, these outcomes will portray those that would have occurred in the ‘real world’. With this degree of confidence, a series of policy lessons and recommendations can be derived from the base case and policy analyses.

Note that in interpreting the outcomes of the policy experiments, the aim is not to impose value judgements. Instead, an attempt is made to contribute to the debate by considering three agendas that prevail in the health services. The first is based upon the desire to control costs whilst working within a limited budget (a cost control agenda). The second is based upon the desire to improve health, irrespective of the costs involved (a health improvement agenda). A third agenda is driven by the desire to deliver services on the lowest cost/case basis (an efficiency improvement agenda).

Those pursuing a *cost control* agenda would want patient activity rates to remain within budget whilst meeting their contractual obligations regarding waiting time and waiting list targets. If the contracts only specified waiting time targets, the waiting list length would still be important. This is because, as stated previously, the size of the waiting list represents the need for activity; if the waiting list size doubled, then the number of waiting list removals (including activity) would also have to double in order to maintain the waiting time target. Those seeking *health improvements* would also be concerned about access, as treatment delays would cause distress to patients and possibly lead to their condition deteriorating. Furthermore, long waiting lists would raise concerns about unmet need. Seeking health improvements would also encapsulate several further desires. Firstly, the desire to identify more high-risk cases i.e. patients with advanced disease but only minor symptoms. Secondly, the desire to be able to utilise tertiary resources more effectively and thus devote those precious resources to the more complicated cases. Thirdly, the desire to meet higher treatment targets; increases in investigation rates are required to support increases in treatment rates. All these actions would be expected to produce reductions in morbidity and mortality and thus align with the aim to improve health. Those pursuing an *efficiency improvement* agenda would also want contractual obligations regarding waiting time and waiting list targets to be met. In addition they would want the use of district services to be restricted unless it provided investigations at a lower cost/case compared to that with a tertiary-based service.

It would be expected that conflicting views, about the value of stimulated demand, would prevail between those pursuing cost control and health improvement agendas. As explained in earlier chapters, stimulated demand could comprise low priority referrals and referrals which some might regard as inappropriate. On the other hand, it might also include those with major heart disease but minor symptoms. Adopting a cost control agenda, interventions that reduced stimulated demand might be preferable, as these would reduce the number of inappropriate referrals. These interventions would also be attractive as they would not involve increasing activity rates and activity costs i.e. resource neutral interventions and might even result in reduced activity costs. By contrast, interventions that met or encouraged stimulated demand might be favoured by those seeking a health improvement agenda. They would welcome these additional referrals as they could provide opportunities to identify further high risk patients and raise activity levels. From their perspective, it would be important that stimulated demand was met. Otherwise, the passage of high risk cases through the referral chain could be jeopardised by referrals of lower priority cases blocking the referral chain.

It could be argued that those following the health improvement agenda will have the upper hand given the Government's recommendation in its National Service Framework document (NHS 2000a) for substantial increases in the provision of CC services. However, these recommendations are not easily implemented. Given that resources are limited, purchasers have to balance many demands including local priorities and needs for other patients, some of which may also have National Service Framework standards. As explained by one of the collaborators, whilst tackling heart disease may be high on the national health agenda, local priorities may be skewed towards different needs as dictated by the profile of the local population.

12.2.1 Ribsley General Case

The Basic Problems and Their Causes

Prior to the introduction of district services at Ribsley General, there were no access problems to OP services; the waiting list and average waiting time were maintained at their desired levels. However, this was not the case further down the referral chain as demand persistently outstripped the supply for an elective CC investigation. Pressure on elective CC services was alleviated by capacity increases, initially at the tertiary level and subsequently by providing a temporary district service.

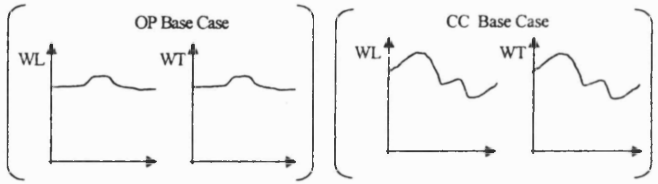
Demand for CC services was stimulated by two mechanisms. Firstly, the increased availability of CC led to patients and GPs becoming more knowledgeable about the benefits of CC and thus more demanding for a referral for further investigation. Secondly, when the average waiting time for a CC investigation dropped, cardiologists took advantage of the CC capacity increases to catheterise more patients. There were also three mechanisms whereby demand was suppressed. Firstly, by cardiologists informally reducing the number of referrals when the waiting time for a CC investigation was high. Secondly, by the periodic reduction in referrals associated with the replacement of experienced junior CC operators by complete novices; novices initially under-referred and gradually reduced their referral threshold as they gained experience and confidence. Thirdly, by the 'knee jerk' reaction to drops in capacity. The net result was a frequent rise and fall in the referral rate. It should be noted that although the district service at Ribsley General stimulated demand for services, it could not be described as a 'fix that fails' to the access problems to elective CC services. This was because there was adequate capacity to cope with both the new and existing demand.

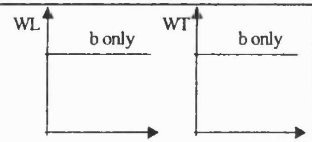
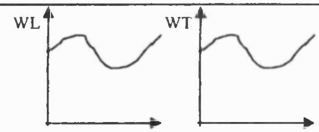
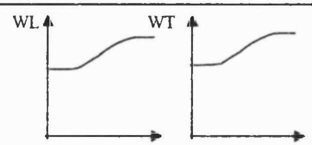
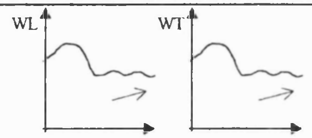
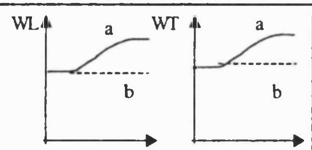
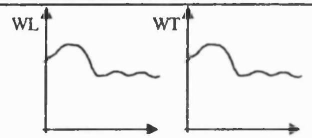
The increased patient knowledge about CC also stimulated demand for an OP appointment. Access to services was reduced but only temporarily and to a small extent, and was restored after the district service was withdrawn. Moreover, owing to the delay for GPs and patients to perceive changes in the availability of the district service, these changes in access only occurred when the district service was used for the extended period in 1996/1997.

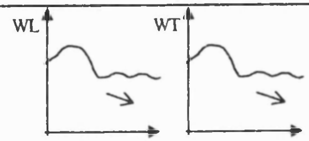
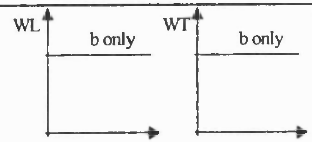
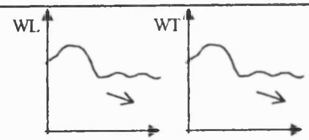
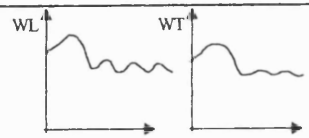
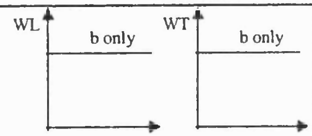
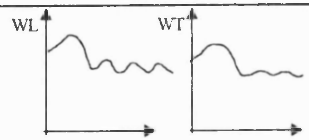
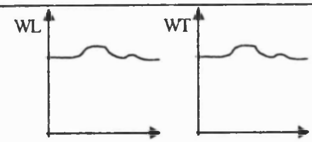
How The Situation Could Have Been Improved

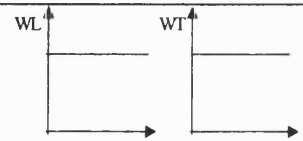
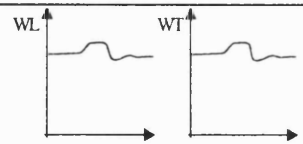
The imbalance between the supply and demand for CC services could have been addressed by intervening to meet, and/or control, demand. Table 12.1 summarises the results of a number of different interventions and highlights a selection of qualitative and quantitative *changes from the base case*. The table shows the degree of behavioural insensitivity to a number of interventions so that quantitative improvements were not necessarily accompanied by behavioural (qualitative) improvements. Regarding the resource use, changes in the cumulative costs are included in addition to activity rate changes as only the former reflects the extra costs associated with patients having to undergo a further CC procedure following a district-based investigation. More detailed results are listed in Appendix E in E5e.

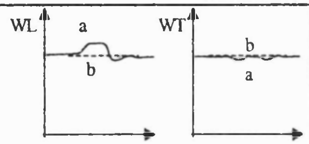
Table 12.1. Summarising the Changes from the Base Case for the Ribsley General Policy Experiments



Policy Intervention	*Δ Behaviour Mode*		*Δ Waiting List*		*Δ Waiting Times*		*Δ Resource Use*			*Δ Referral Rates*	
	OP	*CC*	*OP*	*CC*	*OP*	*CC*	*OP*	*CC*	*Cum£*	*OP*	*CC*
Semi-perm reduced district service			+	+	+	+	+*	+	+0.8%	+*	+
Semi-perm reduced district svce with											
a. modest guidelines			-	+	-	+	NoΔ	+	+0.6%	NoΔ	+
b. strict guidelines			-	+	-	+	-*	+	+0.2%	-*	+*
Perm district service *f*			+	+	+	-	+	+	+6.4%	+	+
Perm d service with *f*											
a. modest guidelines			+	-	+	-	+	+	+5.8%	+	+
b. strict guidelines			-	-	-	-	-*	+	+1.7%	-*	+

Policy Intervention	*Δ Behaviour Mode*		*Δ Waiting List*		*Δ Waiting Times*		*Δ Resource Use*			*Δ Referral Rates*	
	OP	*CC*	*OP*	*CC*	*OP*	*CC*	*OP*	*CC*	*Cum£*	*OP*	*CC*
Expanded tertiary service *f*			-	-	-	-	-*	+	1.7%	-*	+
Expanded tertiary service with *f* a. modest guidelines b. strict guidelines			- -	- -	- -	- -	-* -*	+ +	+1.5% +1.3%	-* -*	+ +
Periodic district service §			NoΔ	-	NoΔ	-	NoΔ	+	+1.0%	NoΔ	-
Periodic d service with § a. modest guidelines b. strict guidelines			- -	- -	- -	- -	-* -*	+ +	+0.7% +0.3%	-* -	- -
Decr GP and patient perception delay			+	+*	+	-*	+*	+*	+0.2%	+*	+*

Policy Intervention	*Δ Behaviour Mode*		*Δ Waiting List*		*Δ Waiting Times*		*Δ Resource Use*			*Δ Referral Rates*	
	OP	*CC*	*OP*	*CC*	*OP*	*CC*	*OP*	*CC*	*Cum£*	*OP*	*CC*
Incr GP and patient perception delay			-	+*	-	+	-*	-*	-0.2%	-*	-*
Use of modest new referral guidelines			-	-	-	-	-*	-*	-0.3%	-*	-
Use of strict new referral guidelines			-	-	-	-	-*	-	-0.6%	-*	-
Incr learning fraction (for CC trainees)			+*	+	NoΔ	+	NoΔ	+*	+0.1%	NoΔ	+*
Incr OP capacity			-	-*	-	-*	NoΔ	NoΔ	NoΔ	NoΔ	NoΔ
Seeking a des waiting list length †			-	+	-	+	NoΔ	-	-0.4%	NoΔ	-*

Policy Intervention	*Δ Behaviour Mode*		*Δ Waiting List*		*Δ Waiting Times*		*Δ Resource Use*			*Δ Referral Rates*	
	OP	*CC*	*OP*	*CC*	*OP*	*CC*	*OP*	*CC*	*Cum£*	*OP*	*CC*
Seeking a des waiting list length with †											
a. modest guidelines			-	+	-	+	-*	-	-0.7%	-*	-
b. strict guidelines			-	+	-	+	-*	-	-1.0%	-*	-

(Δ: Change; *f*: With same total capacity increases; §: With lower total capacity increases than *f*; †: Involved minor parameter changes to allow valid comparisons with seeking a desired waiting time. Changes are w.r.t. base case with same minor parameter changes; Modest (new) referral guidelines: Assumed a reduction of half stimulated demand; Strict (new) referral guidelines: Assumed a reduction of all stimulated demand; Blanks in Δ Behaviour Mode: No or only minor changes; Arrows in Δ Behaviour Mode: Slight upward or downward trends; -: Reduction from base case; +: Increase from base case; NoΔ: No changes i.e. 0% ≤ |Change| < 0.1%; *: Small changes i.e. 0.1% ≤ |Change| < 1% or 0< | Change | ≤ 1; Cum£: Cumulative costs)

With the development of district services at Ribsley General, there was conflict between those pursuing a cost control agenda and those pursuing a health improvement agenda. The former, typically the purchasers, were sceptical about the benefits of having a district service and were concerned about the service stimulating demand and possibly leading to inappropriate referrals. The latter, typically the cardiologists who represented the interests of patients, were keen to have a district service to provide a local service. They also welcomed the opportunity to investigate and treat more patients and more promptly. There was also potential conflict between those pursuing health improvement and efficiency agendas. The district service was only more efficient than a tertiary-based service under certain circumstances.

These circumstances were explained in §7.3.5. It was stated that based upon the data provided, the district service provided investigations at a lower cost/case compared to tertiary-based investigations. However, taking into account the need for some patients to undergo further CC, a different story emerged. A district service would only have been attractive to those pursuing an efficiency improvement agenda if it had avoided a high proportion of patients undergoing their CC investigation as an inpatient. Otherwise a tertiary-based service would have been more efficient. If that were the case, from a efficiency improvement perspective, the desire would have been to restrict the district service and to achieve improvements in access to CC services via an expanded tertiary-based service if possible.

The Need for a "Joined-up" Policy

Given the fundamental need to improve and maintain access to CC services, one policy lesson was clear from the analysis. The extent of the imbalance between the supply and demand was such that demand management strategies alone, even the use of the most stringent clinical guideline, could not have altered the undesirable rise in the CC waiting list and average waiting time. Frequent capacity increases were necessary. If the imbalance between the supply and demand had been smaller, then a demand management strategy could have offered greater and sustainable benefits. Therefore, it was not possible to achieve and maintain good access to services without the need for further capacity increases. However, a policy of tackling access problems directly with capacity increases would have to have been co-ordinated with efforts to ensure that the benefits of increasing supply were not cancelled out by stimulated demand. In other words, a "joined-up solution" to "joined-up problems" was required.

Increasing Capacity

An obvious approach to increasing capacity would have been to provide a permanent, rather than temporary, district service. The expectation would have been that a permanent service would have maintained the access targets permanently. However, from a cost control perspective, whilst providing a permanent district service could have controlled the average CC investigation waiting time, the benefits of increasing the supply would have been cancelled out by stimulated demand. The CC investigation waiting list would have exhibited a gradual rise thus indicating the need for further increases in the elective CC investigation rate in order to maintain the desired waiting time. In other words, the permanent use of district services would have been a 'fix that fails'. Furthermore, the stimulated demand would have created a new problem, as capacity shortages would have arisen at the OP end of the referral chain. This would have then called for further resources in an attempt to control access to OP services. From a health improvement perspective, the reduction in the CC waiting times and increases in activity associated with a permanent district service would have been attractive, but these benefits would have been undermined by the loss in access to OP services.

By using new referral guidelines, it might have been possible to suppress demand and generate considerably lower costs. However, whilst the use of new moderate guidelines would have enabled the access to CC services to be maintained, strict new guidelines would have been necessary to eliminate the OP capacity shortages. The feasibility of introducing strict new guidelines would have been doubtful even in a conservative referral environment such as Ribsley General. Therefore, even with realistic safeguards in place to control demand, a permanent district service could not have led to significant improvements from either the cost control or health improvement perspective.

The access problems generated by a permanent district service suggests that a more effective approach to increasing supply would have been to limit the use of district services. In theory, this could have involved either expanding the tertiary-based service, and just using the district service to compensate for tertiary facility closures, or providing a periodic district service. Compared to a permanent district service, carrying out the same capacity increases at the tertiary level would have generated fewer costs because by lowering demand, the service would not have been pushed as far. Therefore, this option would have been closer to meeting the goals of those pursuing a cost control agenda. However, in practice, expanding the supply for elective services at the tertiary level would have been difficult whilst meeting the demands for more urgent cases. Expanding the supply at the district level would have been easier to achieve, as the service would have been solely devoted to elective care. Those pursuing a cost control agenda would have favoured a periodic district service over the same overall capacity increases translated into a permanent expansion at the tertiary level. This would apply because the former would have generated lower costs due to the 'knee jerk' reductions in referrals in reaction to the capacity losses.

The preference to those pursuing a health improvement agenda would have been less clear. The greater use of a district service would have provided more opportunities to devote tertiary resources to more complicated cases. It would also have led to the stimulation of more demand for an OP appointment. Bringing more patients forward for assessment could have led to the identification of further high risk patients and also supported higher activity targets. However, fewer referrals would have been made for CC services, as by introducing more capacity losses there would have been more 'knee jerk' reductions in referrals in reaction to these losses. Although it could be assumed that these reductions would have referred to lower risk patients, their assessment as lower risk patients would have been based on incomplete information i.e. without the benefit of an angiogram. It would have been possible that some high-risk cases who presented minor symptoms would have slipped though the net. Therefore, from a health improvement perspective, a periodic district service would have involved trade-offs. Nevertheless, it would be expected that those pursuing a health improvement agenda would have conceded that, on balance, a periodic district service would have been the only practical way to achieve improvements in access.

The Value of Other Possible Interventions

Considering other possible interventions, it might be expected that increasing the delay for GPs and patients to perceive changes in the availability of district services would have led to reduced pressure on CC services by postponing and reducing the duration of stimulated demand. In fact, pressure on CC services would have increased. The explanation for this counter-intuitive result is that postponing the stimulated demand would have also eventually delayed the pressure to increase activity and thus missed the opportunity to make the most of the additional capacity whilst the district service was in place. The pressure on OP services would have been reduced but this reduction would have been insignificant, given that OP services at Ribsley General were not considered to have capacity shortages.

A reconfiguration, rather than expansion, in supply could have had some appeal. Given that temporary capacity increases had temporarily alleviated the CC capacity shortages for Ribsley General patients, it might be assumed that spreading out the district sessions over a longer period would have provided more sustainable benefits. The added appeal to those pursuing a cost control agenda would be that the costs of the capacity increases would have been distributed over a longer period. However, this intervention would have been a 'fix that fails' as demand would have been stimulated over a longer period. This would have imposed greater pressure on both OP and CC services and would have led to the generation of higher costs overall. Improvements could have been obtained by co-ordinating this policy with the use of new referral guidelines. Qualitatively, the outcome would have been a slower but longer descent in the waiting list and average waiting time. Therefore, there would have been a trade-off between short-term and medium-term effects. Furthermore, fewer 'knee jerk' reactions to capacity losses (sudden reductions in referrals) would have been associated with the greater stability, so that the overall pressure on the already hard-pressed CC service would have increased.

Those seeking health improvements might have appreciated increases in OP capacity. This would have reduced the extent of the increase in the OP waiting list and average waiting time due to the stimulated demand. The, albeit small, reduction in access would not have been eliminated, even with very large capacity increases, due to the inevitable delay in responding to the increases to the OP referral rate. Therefore, this intervention could not have produced qualitative improvements. Increasing OP capacity would not have been appealing to those pursing a cost control agenda. Given that the increases in the OP waiting list and average waiting time were not viewed as significant, intervening to reduce these increases would have been deemed an inappropriate use of resources.

Given the lack of slack in the system, other interventions might simply have compounded the CC capacity shortages. If the circumstances had been different, these same interventions might have offered some benefits. For example, those seeking health improvements might have valued interventions that would have led to increases in the referrals. Bringing more patients forward would possibly have led to the identification of further high-risk cases. It would have also driven and supported activity increases and thus helped to meet higher activity targets. Accelerating the learning process of junior CC operators and reducing the delay for GPs and patients to perceive changes in access to district services could have produced increases in referrals for CC investigations. It would be expected that the stimulated demand generated by reducing the perception delay would have consisted of more low priority cases than that resulting from an accelerated learning process. Therefore, the former would have represented the preferable strategy.

These two interventions would have been less attractive to those pursuing a cost control agenda as increasing the referral rate would have driven increases in activity and thus placed further pressure on purchasing budgets. Although it could be argued by those pursuing a health improvement agenda that bringing more patients forward for assessment could lead to the identification of further high risk cases, this would not be guaranteed. Confirmation could only have been sought by looking at an angiogram, which would have been a rather expensive means to justifying higher costs. Purchasers could have argued that, in addition to cardiac services, there are many other demands on their budgets, a number of which would present a greater likelihood of clinical benefit.

12.2.2 Veinbridge General Case

The Basic Problems and Their Causes

Prior to the introduction of district services at Veinbridge General, there were no access problems to OP or CC services; the waiting list and average waiting time were maintained at their desired levels. There was a long-term strategy to expand CC services and the development of a permanent district service formed a key role in the implementation of this strategy.

The district service stimulated demand via two mechanisms. Firstly, the increased availability of CC led to patients and GPs becoming more knowledgeable about the benefits of CC and thus more demanding for a referral for further investigation. This affected both CC and OP services. Secondly, cardiologists took advantage of the CC capacity increases to investigate more patients with CC. In fact, increased demand for CC services was encouraged, as it was necessary to support the expansion in services and thus justify the development of a permanent district CC service.

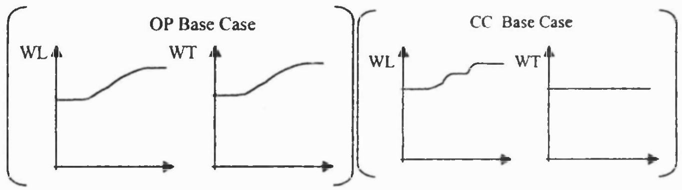
However, the attitude to the stimulated demand for OP services was quite different as the demand could not be met and thus caused significant rises in the waiting list and the delay for an OP appointment. The creation of OP access problems had not been anticipated in the development of the district CC service.

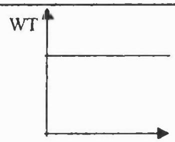
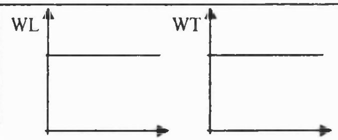
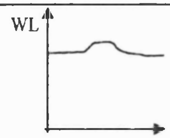
Another undesirable development was the rise in the CC investigation waiting list. Although there was adequate CC capacity to meet demand, the waiting list rose due to two factors: the inevitable delays between adjusting the activity in response to rises in the referral rate; and, the fact that effort had been devoted to maintaining the desired waiting time and not controlling the length of the waiting list. However, the district service at Veinbridge General could not be described as a 'fix that fails'. Although demand was stimulated for CC services, the desire to expand CC services was satisfied.

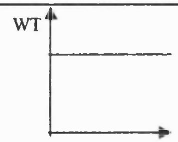
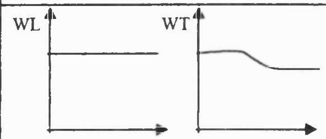
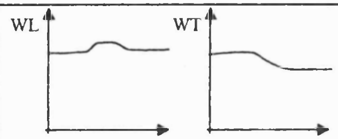
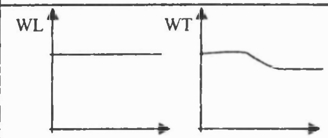
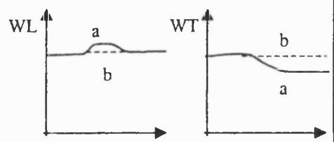
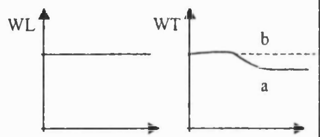
How The Situation Could Have Been Improved

As with the case of Ribsley General, the access problems could have been addressed by intervening to meet, and/or control, demand. Table 12.2 summarises the results of a number of different interventions.

Table 12.2 Summarising the Changes from the Base Case for the Veinbridge General Policy Experiments



Policy Intervention	*Δ Behaviour Mode*		*Δ Waiting Lists*		*Δ Waiting Times*		*Δ Resource Use*			*Δ Referral Rates*	
	OP	*CC*	*OP*	*CC*	*OP*	*CC*	*OP*	*CC*	*Cum£*	*OP*	*CC*
Decreased GP and patient perception delay			+	+	+	NoΔ	+*	+*	+0.6%	+*	+*
Increased GP and patient perception delay			-	-	-	+*	-*	-*	-0.6%	-*	-*
Use of modest new referral guidelines			-	-	-	+*	-	-	-10.2%	-	-
Use of strict new referral guidelines			-	-	-	+	-	-	-20.1%	-	-

Policy Intervention	*Δ Behaviour Mode*		*Δ Waiting Lists*		*Δ Waiting Times*		*Δ Resource Use*			*Δ Referral Rates*	
	OP	*CC*	*OP*	*CC*	*OP*	*CC*	*OP*	*CC*	*Cum£*	*OP*	*CC*
Increased OP capacity			-	+	-	NoΔ	+	+*	+1.0%	NoΔ	+*
Seeking a desired waiting list length			+	-	+	+*	+*	+	+1.7%	+*	+*
Seeking a desired waiting list length with incr OP capacity			-	-	-	+*	+	+	+3.1%	+*	+
Sought a desired waiting list length with a. modest new guidelines b. strict new guidelines			- -	- -	- -	+* +	- -	- -	-9.3% -20.1%	- -	- -

(Δ: Change; Modest new referral guidelines: Assumed a reduction of half stimulated demand; Strict new referral guidelines: Assumed a reduction of all stimulated demand; Blanks in Δ Behaviour Mode: No or only minor changes; -: Reduction from base case; +: Increase from base case; NoΔ: No changes i.e. 0% ≤ |Change| < 0.1%; *: Only small changes i.e. 0.1% ≤ |Change| < 1% or 0< | Change | ≤ 1; Cum£: Cumulative costs)

With the development of district services at Veinbridge General, compared to the case of Ribsley General, there was less conflict between those pursuing cost control and health improvement agendas. The development of the CC service at Veinbridge General was part of a long-term strategy to expand CC services. Therefore, the health improvement agenda was dominant to some extent whilst those pursuing a cost control agenda, typically the purchasers, were willing to fund this strategy. Nevertheless, at the same time, purchasers were concerned that the expansion of services had stimulated excessive levels of demand, beyond what they could afford.

Before the integrated catheter laboratory opened at Veinbridge General, the health improvement agenda possibly dominated the efficiency improvement agenda. As stated in §7.4.4, the district service provided CC investigations at the same cost as those at the tertiary level. Furthermore, as with the case of Ribsley General, taking into account the need for some patients to undergo further CC, a mobile-based district service at Veinbridge General was only more efficient than a tertiary-based service if it avoided a large proportion of patients being catheterised as inpatients. Increasing the interventional CC proportion cancelled out this potential advantage.

The opening of the integrated laboratory at Veinbridge General provided the opportunity to improve the efficiency of the district service as the cost/case declined with the volume of patient activity. This eliminated any conflict there might have been between those pursuing the health improvement and efficiency improvement agendas.

The Need for a "Joined-up" Policy

One policy lesson was clear from the Veinbridge General analysis. Whilst the long-term strategy to expand CC services relied upon increases in demand, the strategy would be undermined unless it was co-ordinated with controls to limit the stimulated demand. In other words, the strategy had to be based upon "joined-up thinking". Demand for OP services would have to be controlled rather than met because a long-term commitment to increased funding for OP services would not be available. Purchasers had only agreed to support an increase in CC services, not pour in further funds to OP services aswell.

Changing the Forces that Drive Activity

Even if it had been possible to increase the supply for OP services, this would have only eliminated the excessive delay for an OP appointment, not the excessive waiting list, thus achieving the same position as that for an elective CC investigation. This would have occurred because efforts would have been made to maintain the desired waiting time and not control the length of the waiting list. In general, seeking a desired waiting time will meet and maintain this goal provided there are sufficient resources available to respond to changes in the the waiting list length with the necessary changes in the waiting list removal rate.

However, maintaining the average *waiting time* at its desired level will not necessarily indicate that the *waiting list* goal is met. The length of the waiting list could, in fact, be elevated or rising above its desired level. Therefore, the desired waiting time would only be maintained due to the increases in the waiting list removal rate balancing increasing in the waiting list. With sufficient slack in the system, the waiting time and waiting list goals could be met by changing the forces that drive activity rates - seeking a desired waiting list length rather than a desired waiting time (see §11.3.3 for further details).

In the case of elective CC services for Veinbridge General patients, there was spare capacity, and introducing controls on demand would have produced some slack for OP services. Therefore, the OP and CC waiting list and waiting time goals could have been met by seeking a desired waiting list length. In fact, this policy would have overcompensated by producing an average waiting time that was lower than required. Of course, slack for OP services could also have arisen from removing the capacity constraint (meeting rather than controlling demand). However, as previously stated, this would not have been feasible.

Controlling Demand

Demand for OP services could have been reduced in two different ways. One approach would have been to delay the time for GPs and patients to perceive the introduction of district services. However, given the circumstances at Veinbridge General, this intervention would have only delayed the inevitable, so the improvements in access to OP services would have only been marginal. A more effective approach would have been to use new referral guidelines. Only the use of modest new guidelines would have been necessary to enable the benefits to be derived from seeking a desired waiting list length. The use of modest new guidelines alone would have led to some improvements but fewer than those derived from the combined policy. The use of strict new guidelines would have produced significant qualitative improvements. However, it would not have been feasible to introduce strict new guidelines for two reasons. Firstly, they would not have been accepted in such an 'aggressive' referral environment as Veinbridge General. Secondly, if they had applied to CC services, they would have suppressed the very demand that was necessary to meet the commitment to expand CC services and justify the development of a permanent district service at Veinbridge General.

Supporting the Expansion of Services

Therefore, the implementation of the long-term strategy to expand CC services could have been improved by co-ordinating the shift in CC services with the use of new referral guidelines and changes to the forces that drive activity rates - a "joined-up" policy. This would have produced significant and sustainable improvements in behaviour that would have appealed both to those pursuing cost control and health improvement agendas. The effects of this policy would have been particularly attractive from a cost control perspective, as it would have led to improvements in access and reductions in costs. For those pursuing a health improvement perspective, there would have been trade-offs. They would have valued the improvements in access to OP services and reduction in the CC investigation waiting list but the reductions in referrals and activity would have been in conflict with the desires to meet higher activity targets and identify more high risk patients.

Changing the forces that drive activity and the use of new referral guidelines are analogous to changes in flow variables. The finding in the case of Veinbridge General that changing flow variables had more leverage than changing stock variables (capacity) echoes Wolstenholme's (1999a) experience but for different reasons. Wolstenholme argued that adjustments in flow variables were better because they had longer lasting effects. In the case of CC services for Veinbridge General patients, the significance of the greater leverage was not a question of the duration of an improvement but its very existence. The adjustments in flow variables would have eliminated the increase in the CC waiting list whilst capacity increases would have had no effect.

12.2.3 Robustness of the Model Assumptions

In §9.3.6, I described how efforts were made to compensate for the lack of real data when constructing and calibrating the model. In many cases, as the purpose of the model was to explore qualitative changes and not produce point predictions, there was no need for absolute accuracy. However, the study was limited to some extent by the absence of direct input by GPs into the modelling process.

As stated in Chapter 10, the assumed magnitudes of the extent to which knowledge could stimulate demand and the delay for GPs and patients to perceive changes in the availability of district services served for the purpose of the model but it is possible that some feedback process may have been inadvertently omitted. For example, in addition to the effects of increased knowledge about CC, referrals for an OP appointment could have been influenced by GPs' perceptions of the average waiting time (stimulating demand when the average waiting time was low and suppressing demand when the average waiting was high). This would reflect the need for a further balancing process in the model. However, the possible omission of a waiting time effect on demand for OP appointments did not affect the policy conclusions. Its presence would only have had a marginal effect on the Ribsley General base case behaviour as the changes in access to OP services were negligible. As for the Veinbridge General base case behaviour, whilst it is possible that high average waiting times could have suppressed demand, the knowledge effect on demand would have dominated so the problems with the excessive waiting list and waiting times would have still occurred.

12.3 MODELLING POWER OF SYSTEM DYNAMICS

12.3.1 A Necessary Condition For Usefulness

Having completed the SD study of the shift in CC services, it is possible to review the study to assess how useful SD was in terms of its ability to contribute to the policy making process. The demonstation of modelling power is a necessary condition for a method to offer a contribution to policy makers.

As stated in §5.2.1, assessing the modelling power of SD involves considering the ability to both explain the effects of service shifts and inform purchasers about how they could improve the situation. Chapter 7 provided evidence of feedback effects associated with the shift in CC services to the two case study centres. This indicated that SD could be potentially useful; if feedback effects had been absent from the results of the shift in CC services, SD would have been irrelevant and of limited, if any, use in providing policy insight. The SD-based analyses of the shift in CC services demonstrated that SD did, indeed, provide policy insight. Chapter 10 described how the SD model was used to explain how the shifts in CC services helped and hindered the provision of cardiac services over time. Furthermore, Chapter 11 reported on the effects of a series of policy experiments and §12.2 outlined the policy implications of these experiments to explain how NHS purchasers and providers could have effectively intervened to alleviate pressure on the system.

As stated in §5.2.1, the extent of the modelling power of SD is assessed on the basis of the quality of the analysis, its significance and its completeness. These criteria are dealt with in turn.

12.3.2 The Quality of the Analysis

A lack of analytic rigour would undermine the results of an analysis and it could call into question its conclusions. Some criticise SD as lacking analytic rigour, for example, on the grounds of the poor use of statistical tests. These critics fail to recognise that, given the purpose of SD modelling, statistical analyses play only a minor role, unlike the case of econometrics. Many criticisms of SD are unwarranted and although there are examples of sloppy SD analysis, this simply reflects bad modelling, not an intrinsic weakness of the SD method.

This study was based upon good modelling practice. As stated in §8.1, the conceptualisation process followed established guidelines. In constructing the model, data was derived from a broad range of sources including the experiences and expert knowledge of various health professionals involved in the shift in CC services. The quality of the data obtained was checked for consistency. The study proceeded beyond static analysis, where erroneous inferences could have been made, to dynamic analysis where the power and flexibility of simulation modelling was exploited. The simulation model was subjected to a series of rigorous tests. Moreover, sensitivity analysis played a key role in both testing the model and generating insight into the behaviour-structure relationship. Therefore, it may be concluded that the study was of sound quality.

12.3.3 The Significance of the Analysis

The significance of an analysis may be considered in terms of its focus and the amount of improvement derived from the analysis. Regarding the focus of the analysis, SD would have been of limited use if it had only been used to explain trivial issues. This was not the case in this study as SD was employed to tackle key policy issues including the access to services, the allocation of resources and the management of demand. Moreover, the analysis demonstrated the ability of SD to support health care policy makers engage in "joined-up thinking".

In terms of improvements derived from the analysis, sustainable improvements are more significant than temporary improvements. Furthermore, greater significance is associated with qualitative changes (obtaining more desirable behaviour modes) rather than mere quantitative changes. In this study, the improvements were significant as sustainable improvements were achieved in the modes of behaviour. In the case of Ribsley General, insight was provided into how greater stability could have been obtained in the CC investigation waiting list and average waiting time that had both exhibited a tendency to rise. In the case of Veinbridge General, the analysis showed how the asymptotic growth in the waiting list for a CC investigation, the OP waiting list and average waiting time for an OP appointment could have been eliminated.

12.3.4 The Completeness of the Analysis

For the purpose of this thesis, the completeness of the analysis is assessed in terms of whether or not it provides the necessary detail to translate the policy recommendations that were generated into operational procedures. Moreover, all the policy changes that were discussed are considered, even those that did not form policy recommendations, as they could have been recommended if the circumstances had been different.

For some policy changes that were discussed, operationalisation would easily follow on from the SD analysis. For others, operationalisation would not follow on automatically as the policy change would relate to the strategic level of decision making rather than the operational level. This would call for an analysis of the finer detail using some other method. As suggested in Chapter 4, DES could be applied to complement SD by addressing the micro issues that arise from the macro insights that are typically generated by SD analyses. Achieving capacity increases is one such example.

Achieving Capacity Increases

In the previous section, capacity increases to OP services, district-based CC services and tertiary-based CC services were discussed. These would have relied upon securing the availability of beds and staff, as well as additional funds to pay for the subsequent activity increases. Unfortunately, an SD analysis could not offer assistance on questions such as: How should the hospital bed provision be reconfigured to allow more beds to be allocated to cardiac services? What is the best staffing schedule to accommodate the addition of new duties without interfering with existing duties? Answers to these questions could be sought via a DES analysis. In this way, DES analyses could be applied sequentially to an SD analysis to complete the operationalisation of SD-based policy recommendations. DES could also be applied to improve the efficiency of resources. However, this would require the SD analysis to be repeated, as changes to the efficiency of resources would alter the capacity utilisation functions in the SD model (by narrowing the degree of curvature of the functions). This would produce quantitative changes to the output of the SD model, but it would not alter the behaviour modes. In considering the operationalisation of SD-based insights, only the sequential use of DES is relevant.

Operationalising increases in elective CC capacity at the tertiary level would be more challenging compared to increases at the district level. After all, the raison d'être of a district service is often the inability to provide tertiary-based capacity expansions. Whilst, tertiary-based catheter lab capacity could be increased easily using a mobile lab, mobilising the necessary staff and beds would present far greater difficulty. Resources would typically be juggled between meeting targets for elective cases and satisfying demands from more urgent cases. As resources would already be stretched towards the limit, it would be expected that improvements using existing tertiary-based resources would be minor. Therefore, expanding the capacity of a tertiary-based service would rely heavily upon injecting new resources.

An extended district service would be easier to operationalise as the service would be exclusively devoted to elective care so that elective cases would not have to compete with more urgent cases for resources. To develop a periodic or semi-permanent district service, catheter lab capacity could be secured by booking further sessions with a mobile unit. To provide a permanent district service, the construction of an integrated catheter lab would not be essential as less costly options would be available, as described in §6.4.1, such as the regular use of a mobile lab.

As regards the other resources, again, DES analyses could be carried out to help secure the necessary beds and staff for the service. Specified changes in capacity for services would translate into specific changes in resources. For example, consider CC capacity increases at the district level. A specified increase in capacity would translate into specific levels of funds, bed-days, mobile catheter lab sessions, nursing staff, laboratory technicians, cardiologists and so on.

It should be noted that it was assumed that capacity increases would be driven by factors that could be mobilised relatively quickly, such as beds and staff, and not, for example, increasing staff numbers if it involved recruitment and training delays. This would relate to further structure, which would lie outside the boundary of the model.

Achieving Changes to the Perception Delays

Changes in the delay for GP and patients to perceive changes in the availability of the district facility could be achieved in several different ways. For example, a reduction in the delay could arise from improving the communication channels between the district hospital and general practice by sending out follow-up letters more promptly. Another way would be to raise the profile of the district service through the media. On the other hand, limiting the exchange of information between the district hospital and general practice, and not actively promoting the district service would achieve increases in the perception delay. The changes that were specified in the model were intended for illustrative purposes only. Unlike the case of capacity changes, it would be impossible to be specific about say, how many local newspaper features on the district service would be required to halve the perception delay.

Achieving Changes to the Learning Fraction

There are also several approaches to increasing the fraction of CC investigations from which the junior CC operator learns. For example, increasing the proportion of clinical cases that are discussed among juniors via longer and more frequent case review sessions. A DES analysis could be employed to assist in the design of a suitable timetable to ensure that sessions devoted to training and case review did not interfere with other duties. Another way would be to delegate the more complicated cases to juniors more quickly. The increase that was specified in the model was intended for illustrative purposes only. It would be impossible to establish the instances when a junior was actually learning and not daydreaming, or being exposed to a case that they had already heard about through some other source such as the internet or a private conversation.

Developing New Clinical Guidelines

The impact of the use of new referral guidelines was modelled by a reduction in the level of stimulated demand. It was assumed that stimulated demand would refer to referral decisions about 'grey area' patients, that is cases for which the appropriate course of action is unclear, neither clearly indicated nor clearly inappropriate. Reducing the stimulated demand involved extending the existing criteria of patients for which a referral was deemed inappropriate. Therefore, it included a sub group of 'grey area' patients, specifically, those who would be considered to be least likely to have advanced CHD. It was also assumed that the new guidelines would state that for another sub group of 'grey area' patients, a referral was not strictly necessary. This would allow for variations in referral practice, as conservative referral fractions would not encompass this sub group.

The new guidelines considered effectively divided the 'grey area' patients into three groups: those for which a referral was inappropriate; those for which a referral was not strictly necessary; and, those for which the appropriate course of action was unknown. Therefore, a 'grey area' would still persist. These three groups could be defined using an appropriateness scoring system (see §6.6.3).

Changes to the Goals Driving Activity

Finally, driving activity by seeking a desired waiting list length rather than a waiting time goal simply involves changing the way in which the desired activity is calculated. The additional information required for this calculation would be readily available. Cardiologists will have in mind a desired waiting list goal and they will typically monitor the referral rate so that they would be able to provide an estimate of the average referral rate.

An Assessment of the Completeness of the Analysis

Therefore, in a number of cases, the SD analysis had not provided the necessary detail to translate the policy changes into operational procedures. This is not uncommon in SD given its emphasis on the strategic level of decision making (Morecroft 1984). It would be difficult to claim that an SD analysis had been useful if it had failed to provide any insight into the base case behaviours or what should have been done to improve the situation; if there had been weaknesses in the analysis; if SD could only address trivial issues; or, if it could have only produced minor improvements. However, it would be misleading to conclude that SD was useless because the analysis could not provide the necessary detail to translate policy recommendations into operational procedures. This conclusion would only be correct from an operational perspective, but incorrect from a strategic perspective. The focus of SD tends to be on strategic problems and it is designed for that specific purpose. It is important to acknowledge that no modelling method is a panacea to policy problems. Each method has its strengths and there is a limit to how far it may be stretched; beyond that limit, the method loses its effectiveness.

12.4 THE VALUE OF THE POLICY INSIGHTS

12.4.1 A Necessary Condition for Usefulness

The demonstration of modelling power is a necessary, but not a sufficient, condition for usefulness. It is also essential that SD can offer valuable policy insights, and as stated in §9.4.2, this forms the basis of a formal test of an SD model. As stated in §5.2.1, valuable insights are considered on the basis of involving feasible policy recommendations and the provision of new information to policy makers.

12.4.2 The Feasibility of the Policy Recommendations

Explaining what should have been done to improve the situation is of no benefit if the recommended course of action is infeasible. Feasible policy recommendations were proposed in this study. The analysis also considered policy changes that would have been infeasible in practice but they were included for comparative purposes.

In the case of Ribsley General, it was stated that a periodic district service, to provide increases in capacity for CC services, co-ordinated with the use of new moderate referral guidelines, to control demand, could have produced more desirable behaviour. Increases in tertiary-based CC capacity would have probably represented an infeasible intervention, given the extreme pressures on tertiary-based resources. However, the analysis demonstrated how the more feasible intervention (a periodic district service) could have achieved comparative qualitative improvements in access to CC services. The use of strict new referral guidelines would have been unrealistic, even given the conservative referral environment at Ribsley General. Therefore, the use of moderate new referral guidelines was proposed.

It was suggested that, if the circumstances had been different and there had been adequate capacity to meet demand at Ribsley General, the other interventions that were discussed could have yielded benefits to those pursuing a health improvement agenda. However, they would have also generated higher costs but this would not necessarily indicate that these interventions were infeasible. The increases in costs could have been minor or beyond the control of the purchasers' influence. For example, efforts could have been made to increase the rate of learning of junior CC operators with the aim of identifying more high risk cases. Purchasers could not have controlled how many clinical review sessions were conducted and whilst they would have controlled the budgeted activity, they might have been forced to support increases in activity in order to meet their waiting time targets.

In the case of Veinbridge General, the conclusions were that the undesirable behaviour would not have occurred if the activity rates had been driven by waiting list goals and if modest new referral guidelines had been in place. Given that seeking a desired waiting list would have also led to the waiting time goal being met, this intervention would not be expected to have been contentious. Therefore, it would have been feasible. The use of modest new referral guidelines would have met with some resistance given the 'aggressive' referral environment at Veinbridge General. Nevertheless, given the obvious need to control demand, these objections would not be expected to have occurred to the extent to have rendered the recommendation infeasible.

12.4.3 The Originality of the Policy Insights

For the analysis to be considered useful, the policy insights need to be original; the analysis would be of little use if it simply confirmed or provided an elaborate explanation of what the policy makers already knew. The findings of this study to some extent corroborated the existing knowledge about the shift in CC services and they also provided a number of new insights, some of which were counter-intuitive and thus challenged existing knowledge.

The study probed into the processes and causative forces at play across the different health service boundaries. This developed a more advanced understanding of the feedback mechanisms underlying the stimulation of demand whilst demonstrating the circumstances under which a shift in CC services would form a 'fix that fails'. New insights were also offered into how access to services could have been improved.

In the case of Ribsley General, those involved were aware that the imbalance between the supply and demand for CC services was such that frequent capacity increases were the only way to reverse the persistent rise in the CC waiting list and average waiting time. However, the analysis showed that the most obvious approach to increasing capacity (a permanent district service) would have created further problems and thus would not have constituted an effective solution. The analysis also explained how increasing the delay for GPs and patients to perceive changes in the availability of district services would have led to increased pressure on CC services and not a reduction in pressure as one might expect.

Whilst capacity increases formed the key to avoiding the problems at Ribsley General, the analysis revealed that this did not apply to Veinbridge General as one might expect. On the contrary, no amount of capacity increases would have prevented the rise in the CC investigation waiting list. Instead, the study showed how the Veinbridge General problems could have been avoided by using the existing information about the system in a different way (driving activity rates by a waiting list goal, rather than a waiting time goal) in tandem with the implementation of modest new clinical guidelines.

Therefore, the different effects of the introduction of district CC services and the different abilities to improve access to services without capacity increases were not due to the different referral traditions at the two case study centres (conservative verses 'aggressive'). The key to these differences was the balance between supply and demand for services. Where there was spare capacity, permanent demand increases could have been met, and driving activity rates by a waiting list goal could have controlled both the average waiting time and waiting list length (e.g. CC services in the Veinbridge General case). In situations where the demand persistently approached the supply or exceeded the supply by a small extent, the use of demand management strategies could have produced the necessary conditions for both aspects of access to be met by driving activity rates by a waiting list goal (e.g. OP services in the Veinbridge General case). In situations where the imbalance between supply and demand was persistently excessive, only capacity increases could have maintained access (e.g. CC services in the Ribsley General case). Finally, in situations where there was a temporary imbalance between supply and demand, the departures from the waiting time and waiting list goals would only have been temporary (e.g. OP services in the Ribsley General case).

12.5 THE EASE OF USE OF SYSTEM DYNAMICS

12.5.1 A Debatable Determinant of Usefulness

Another factor that determines the usefulness of a method is its ease of use. However, the weight placed upon this factor will be very subjective. Some might reject a method that has various practical difficulties as being useless whilst others might accept these challenges as an inevitable part of the process of deriving important insights - a 'no pain, no gain' attitude. System dynamicists argue that the benefits of SD modelling can be considerable since they claim that the linkage between the structure of a system and its behaviour is the key to long term success or failure. As stated in §5.2.1, the assessment of the ease of use is on the basis of the skill, time and client involvement requirements and the need to modify the SD paradigm. These factors are dealt with in turn.

12.5.2 Skill Requirements

Applying SD is a non-trivial process. Given the availability of user-friendly purpose-built SD software that can produce a useable simulation model in a matter of minutes, it is tempting to assume that building an SD model is a straightforward process. However, this is not true as the underlying assumptions can be easily violated and the inexperienced analyst can easily succumb to a number of possible modelling pitfalls. Therefore, a certain level of skill is required to ensure that SD is applied correctly and that the model adheres to good modelling practice.

Specialist knowledge of SD would not be necessary if a completed and validated SD model was delivered to the client as an ongoing policy analysis tool, known in SD as a microworld. In this study, the purpose was not to develop a microworld. Furthermore, the necessary skills were available because basic skills in SD were acquired prior to the study and these skills developed during the course of the study.

12.5.3 Time Requirements

The process of SD modelling can be very time consuming. As with simulation modelling in general, time has to be devoted to data collection and preliminary analysis for consistency checks, and the careful construction and testing of the simulation model. In SD, the data collection procedures are particularly resource intensive due to the emphasis on mental data. Mental data can be collected through formal and informal channels. In this study, a series of interviews were conducted with a number of different health professionals, several on more than one occasion, and observation work was carried out at several different sites.

12.5.4 Client Involvement Requirements

In modelling studies, effort also needs to be devoted to gaining the clients' (or collaborators') confidence in the model and securing their participation in the study. Without client confidence, the analysis becomes pointless, as the policy recommendations will be ignored. Client participation ensures that the analysis maintains relevance. There are well established guidelines to securing client confidence and participation. However, in SD, there is a particular difficulty as the aggregated, deterministic modelling perspective, which is a characteristic of the SD paradigm, could conflict with clients' desire for detail. Moreover, this conflict could undermine their confidence in the model and discourage their participation in the study. Health care clients would be expected to be particularly demanding given the emphasis in health care on individual patient detail. The SD modelling perspective is adopted for a specific purpose. The aggregated view aims to isolate the feedback structure whilst the deterministic view emphasises causality rather than randomness. Furthermore, the exclusion of unnecessary and confusing detail avoids the model becoming cluttered and obscuring the dynamic elements of interest (Forrester 1961, 1968; Richardson 1991).

The measures that were taken to involve the collaborators in this study were described in Chapter 8 (see §8.3.2). The collaborators did not object to the modelling perspective of SD. They accepted the focus on aggregate patient flows rather than individual patients. This was perhaps due, to some extent, to the fact that the health professionals involved were strategic decision makers. The key medical collaborators were hospital consultants. Whilst they work at the operational (clinical) level of decision making, as senior health professionals they also need to have a strategic perspective on patient care. Moreover, the collaborators accepted the focus on elective patients collectively and they were satisfied that, given the purpose of the model, the pressures imposed by emergency cases should be considered implicitly and not explicitly. Efforts were not made to work interactively with the *STELLA* software and the collaborators due to time constraints.

12.5.5 The Need to Refine and Extend the SD Paradigm

Adopting the modelling perspective of SD could not only potentially cause conflict with clients, or collaborators, but also impose restrictions on the feedback phenomena that may be studied. For example, Coyle (1992) claimed that some feedback problems are not predominantly continuous (the aggregate view) but involve a combination of discrete and continuous elements. He presented a study of the best use of aircraft carriers in a major conflict where he contends that carriers should be considered in discrete rather than continuous terms, given that they are rare and expensive objects. In another example, Allen (1988) insisted that focusing on average behaviour (the deterministic view) is inadequate for understanding evolving systems and anticipating structural changes. In assessing the origin and nature of evolutionary processes, he argued that evolution is driven by the inherent microscopic variability and randomness by bestowing upon the system the ability to learn and adapt. Rahn (1985) provided a further example. He adhered to the aggregate, deterministic view but argued that system dynamicists should also consider how stochastic variation may affect the behaviour of the system. His interest concerned the formulation of the rate equations and the exogenous influences on both the policy structure and the decision streams. In SD, the emphasis is on endogenous processes, not exogenous factors.

Calls to refine and extend the SD paradigm have arisen from the need to satisfy both clients' desires for further detail and the desire to extend the range of feedback phenomena that can be studied with SD. Varying degrees of departure have thus emerged involving the incorporation of discrete and stochastic elements into SD models and greater disaggregation (e.g. Wolstenholme and Coyle 1980; Wolstenholme 1980, 1990; Crawford 1991; Scholl 1992, 1995; Coyle 1992, 1999). In health care, greater disaggregation might involve splitting a single patient flow into parallel flows, reflecting different clinical priorities or treatment strategies, or into sequential flows, reflecting different stages of care.

In this study, some modifications were made to the SD paradigm but, as stated in the previous section, these were not motivated by the need to satisfy the collaborators' desire for further model detail. They arose due to the modelling perspective, which was on decisions and processes at the local (individual hospital) level rather than the national level. This resulted in the introduction of discrete elements into the model. For example, the arrival and departure of trainee CC operators involved single individuals so these flows were specified in the model using PULSE functions. Other examples were the affordability variables. These referred to single affordability limits corresponding to single hospitals so they were specified in the model by IF functions. Other discrete elements related to the development of the single district CC facility.

12.6 RETURNING TO THE RESEARCH HYPOTHESIS

The assumptions that were made prior to the SD study of the shift in CC services, regarding the causal mechanisms and usefulness of applying SD, were articulated in the research hypothesis. This was stated in §5.2.2. Given the findings of the research, these assumptions may be revised to produce the following statement:

> The application of SD has shown that health service shifts, intended to improve access to services, may actually reduce access by stimulating further demand unless sufficient capacity is available to meet the demand, and efforts are made to control both the waiting time and waiting list length. Demand may be stimulated by several different feedback mechanisms that interact with each other. Under certain conditions, these mechanisms may also suppress demand.
>
> By shifting services closer to home, patients and health professionals become more knowledgeable and, consequently, more demanding. Those who refer patients on for services, from the number of requests for assessment, may stimulate demand in response to this increased pressure. The increased knowledge of patients and health professionals may also lead to higher demand for assessment thus potentially causing access problems further down the referral chain. Demand may also be stimulated by reduced waiting times and suppressed in response to excessive waiting times.
>
> Another mechanism underlying changes in demand relates to the skills of those who refer patients on for services. Service shifts may stimulate demand if they produce increases in the skill of identifying patients in need. Demand may be stimulated either as a result of the increased knowledge or increased confidence associated with the gain in skills. Some service shifts lead to the development of new skills as those who refer patients assume new responsibilities. Other service shifts provide a new location for the gain of

existing skills. Service shifts may accelerate the gain of skills (and associated increases in demand) by providing opportunties to increase activity. Skills may vary periodically due to the existence of a training programme and rotation of junior staff. Their degree of inexperience may be reflected by the number of under-referrals or over-referrals. The former would typically arise in a conservative referral environment whereas periods of the latter would reflect the over-confidence which would typically arise in a more 'aggressive' referral environment. Whether or not skills actually influences demand will depend upon the degree of autonomy granted to junior staff.

The stimulation of demand will impose increasing calls for further funding. The duration of the service shift will determine whether this pressure is sustained or only temporary.

A clinical guideline may be introduced in an attempt to suppress the inappropriate use of services. However, this may only have a limited impact in reducing pressure because the mechanisms underlying secondary effects are so complex. By applying SD, it is possible to explain the primary and secondary effects of policy changes and thus inform the policy maker about how to intervene more effectively in the system. For example, in cases where there is a persistent imbalance between supply and demand, qualitative improvements in access cannot be achieved without increases in supply. Therefore, the effectiveness of the service shift may be improved by co-ordinating it with supply increases (to meet the existing demand) and with the use of new referral guidelines (to control demand so that supply increases target the existing demand).

In cases where access problems have resulted from the service shift and not a persistent imbalance between supply and demand, more desirable behaviour may be achieved without supply increases. The effectiveness of the service shift may be improved by co-ordinating it with the use of new referral guidelines (to control demand) and with changes to the forces that drive activity rates (to ensure that both the average waiting time and waiting list length are controlled).

SD thus presents a useful planning and evaluation tool for exploring health service shifts. It can help policy makers to understand and assess the past and present, and also plan for the future with more effective policies. It can tackle important issues and generate significant improvements. As SD-based analyses are generally designed for strategic support, some of the policy recommendations do not easily translate into operational procedures. However, they may lend themselves to the analysis by another method, more appropriately aligned with the analysis of detail complexity such as DES. SD can offer valuable policy insights in terms of feasible policy recommendations and new insights into service shifts, not simply confirming what policy makers already know. The process of applying SD is non trivial but none of the practical difficulties associated with its use are excessive.

12.7 GENERALISATIONS

It is necessary to consider whether the research findings are generalisable beyond the two case studies. Generalisations maybe drawn from the insights into the dynamics of service shifts and the conclusions regarding the usefulness of SD as a tool for exploring service shifts. In this section, only generalisations in the context of health care are discussed. Extensions beyond health care could relate to future research (See §12.9).

12.7.1 Dynamics of Service Shifts

Generalising from the insights into the dynamics of service shifts may be achieved by considering the external validity of both the causal theory embodied in the model and the case study findings derived from that theory.

External Validity of the Causal Theory

The external validity of the causal theory embodied in the model may be considered on two different dimensions: behaviour and structure. Behavioural external validity relates to the range of reference modes that the theory is capable of explaining. This was demonstrated by the base case analyses and policy analyses where the model exhibited several different reference modes: equilibrium/stability; asymptotic growth; growth followed by decline; and, oscillatory behaviour. The policy parameters may be considered to correspond with the use of different policies and different circumstances. Therefore, policy behaviour could be recast as base case behaviour for the shift in CC services to other hospitals.

Structural external validity relates to the variety of service shifts that may be accurately represented in the model structure. The structure represented a theory of shifts in health services to improve access and it was parameterised to two cases of the shift in CC services. Service shifts that would not be represented by this theory are those that eliminated delays along the patient pathway.

For this study, it was necessary to use variable names that referred specifically to the shift in CC services to ensure that the model had face validity. However, references to CC services could be considered, more generally, as the health service of interest. The tertiary and district levels could be considered as the established and new levels respectively. "Level" could refer to either a service level (primary, secondary or tertiary levels) in the context of shifts between service levels or it could refer to a level of care by a particular health professional (e.g. GP or nurse) in the context of shifts within service levels. References to the OP waiting list could be recast as the number of patients awaiting a preliminary investigation and possible selection for the health service of interest. Furthermore, references to the CC investigation waiting list could be recast more generally as the number of patients awaiting the health service of interest.

Incorporated in the model structure were demand suppression and stimulation mechanisms associated with waiting time, knowledge and skills effects on demand and the effect of other factors. The re-parameterisation of the model to another service shift would select and quantify the relevant effects; the structure relating to effects that did not apply would be rendered inactive by the specification of zero switching parameters. The model also represented two phases of development of the shift in services. If only a single phase applied, as in the case of the shift of CC services to Ribsley General, the specification of a very large phase 2-development time would ensure that the structure for phase 2 developments remained dormant. It would still be appropriate to include this structure, as the generation of further development costs would not be inconceivable.

As stated in §9.4.2, the family member test (Forrester and Senge 1980) is a formal test of external validity. It considers the ability of an SD model to represent a general theory of a family (or class) of problems. Key questions are how the shift in CC services differs from other family members (shifts in other services), and how the model would exhibit the characteristic behaviour of each family member when policies were altered in accordance with their known decision making rules. Table 12.3 lists some examples of service shifts in the NHS and their assumed structural characteristics and thus highlights differences between different family members. The structural characteristics of service shifts in the NHS will typically differ from those in other health care systems by the absence of the waiting time effect.

Considering the characteristic behaviour for each family member, the trends followed by the key variables (average waiting times and the numbers of patients waiting for the service of interest and waiting for investigation and for possible selection for that service) would depend upon how the supply for services compared with demand. This, in turn, would depend upon various factors including the conditions prior to the service shift, the extent and duration of the stimulated demand and the existence and impact of demand management strategies. The two case studies illustrated how differences in these factors could generate contrasting behaviour. The average waiting times and waiting lists would exhibit equilibrium/stability if there was sufficient capacity to meet demand and, in the context of referral rate increases, the activity rates were driven by waiting list goals. A persistent capacity shortfall would produce asymptotic growth. A pattern of growth followed by decline would correspond with a period of sufficient capacity preceded by a period of insufficient capacity. Finally, oscillatory behaviour would arise if there were temporary periods of insufficient capacity.

Table 12.3 Examples of Different Service Shifts and Their Structural Characteristics

	CC Investigations	Cancer Services	ECG Testing (Open-Access)	Minor Procedures in General Practice	Testing in General Practice	Physiotherapy in General Practice	GP Services (NHS Direct)
Type of Service Shift	T→S	T→S	S→P	S→P	S→P	S→P	P→P
Knowledge Effect	✓	✓	✓	✓	✓	✓	✓
Waiting Time Effect	✓	x[1]	✓	✓	✓	✓	✓
Skills Effect	✓	✓	✓	✓	✓	x[2]	x[3]
Other Effects on Demand	✓	x[4]	✓	✓	✓	✓	x[3]
Stimulation of Demand	✓	✓	✓	✓	✓	✓	✓
Suppression of Demand	✓	x[1]	✓	✓	✓	✓	x[3]

(T→S - Tertiary to secondary shift; S→P - Secondary to primary shift; P→P - Shift within primary level;
1 - Cannot delay due to high risk; 2 - Professionals already fully skilled; 3 - Based upon strict guidelines;
4 - Would expect all 'grey ares' cases to be already referred on due to high risk)

External Validity of the Case Study Findings

Examining the external validity of the case study findings derived from the causal theory involves generalising to broader theoretical issues, of which there are a number of possibilities. In terms of aiming for effective policy intervention, the case of Ribsley General illustrated the need to tackle persistent problems with long-term, sustainable solutions; temporary solutions will only offer temporary relief. The case studies also illustrated the general need to account for the consequences, or knock-on effects, of policy changes and thus design co-ordinated or "joined-up" policies. Improvements in access to health services will often stimulate further demand. Therefore, policies that are intended to improve access to services need to be co-ordinated with demand management strategies. Furthermore, in designing "joined-up" policies, it is necessary to consider the fact that some consequences of policy changes are more subtle than others. For example, policies that alter activity rates will also affect the rate at which junior staff gain skills and thus will alter any influence of skills (and confidence) on referral rates.

To consider the consequences of policy changes effectively, it is necessary to use multiple performance measures to evaluate the effects of policy changes. Evaluating on too narrow a basis can produce misleading conclusions. Calls to monitor complex systems in such a sophisticated manner are not a new idea (Ashby 1956; Kaplan and Norton 1992). However, there a persistent tendency in health care towards a narrow focus on isolated events, short-term results and single performance measures.

Recently, calls have been made to shift the emphasis from the length of the waiting list on to the waiting time. The case studies demonstrated how this would be misguided as it could produce misleading results and ineffective policies. The importance of monitoring both the waiting time and waiting list arises from the fact that each represents different, though interrelated, aspects of pressure on the system associated with access times. The former represents the delay to undergo investigation (or treatment) whilst the latter represents the need for investigation (or treatment).

The case studies demonstrated that driving activity rates by seeking a desired waiting list length is more effective than seeking a desired waiting time in the context of referral rate increases when there is sufficient capacity available. In general, seeking a desired waiting time will meet and maintain this goal provided there are sufficient resources available to respond to changes in the length of the waiting list with changes in the waiting list removal rate. However, maintaining the average waiting time at its desired level will not necessarily indicate that the waiting list goal is met. The length of the waiting list could, in fact, be rising above its desired level. Therefore, the desired waiting time will only be maintained due to the increases in the waiting list removal rate balancing the increases in the waiting list. This result was not specific to the case of CC services but a general consequence of the interplay between supply and demand variables that determine the waiting list length and average waiting time. Therefore, the recommendation to drive activity rates by seeking a waiting list goal rather than waiting time goal could be transferred to other service shifts.

The case studies also illustrated the influence of pressure by patients and GPs on clinical decisions and the problems that can arise from the inability to cope with this pressure and the poor management of demand. There is currently a movement in health care that is campaigning for clinical and policy decisions to be driven by the preferences of patients and the public (Kassirer 1983; Hornberger *et al* 1995). Questions thus arise about how the shift in the balance of care can continue whilst providing high quality care to patients who are not, traditionally, conservative.

Note that the generalisability of this research is not undermined by the hospital data being old or by the increasing prevalence of district CC facilities. The problems with demand being stimulated by improvements in access are recurrent and have existed since the inception of the NHS. Furthermore, the shift in the balance of care is a trend, affecting many different services, which will continue to develop as long as there is a demand and ability to bring services closer to home. This ability will be sustained by the constant advances in medical technology. Therefore, the findings of this research could potentially have broad current and future relevance. To explore this potential, it is necessary to conduct further studies into service shifts to establish if these research findings can be replicated or if they require some revision.

12.7.2 Usefulness of System Dynamics

To generalise the conclusions regarding the usefulness of SD, the first issue to consider is the modelling power of SD. This involves the transferability of the conclusions about the ability of SD to explain, rather than the transferability of the explanations themselves, which has already been addressed in the previous section. There is no reason to believe that an SD analysis would not provide policy insight into other service shifts. The characteristics of the case study behaviour and some, if not all, of the feedback mechanisms underlying that behaviour also relate to other service shifts.

There is also no reason to believe that the points made about the extent of the modelling power would not transfer to other service shifts. For example, provided a new SD study was based upon good modelling practice, it would be of sound quality. In this study, SD addressed significant policy issues which were not specific to the CC case such as access to services and the management of demand. Regarding the completeness of another SD analysis, if recommendations involved capacity increases, as in the CC study, the analysis might well call for a DES analysis. In terms of the ability to generate valuable insights into other service shifts, there is no reason to believe that SD could not offer feasible policy recommendations. The same could be said for the ability to offer original insights, especially given that SD has not yet been applied to other service shifts.

Regarding the ease of use of SD, to apply SD to other service shifts, fewer skills would be required, as the model would simply need to be recalibrated but some skills would be necessary as this would be a non-trivial process. In applying SD to another service shift, it would not be possible to economise on the time requirements for data collection or the effort to secure the involvement of collaborators. On these issues, there is no reason to believe that the CC study was atypical. Finally, concerning the comments made about the need to modify the SD paradigm, a similar number of refinements would generally apply. Fewer refinements would only apply if the analysis were to focus on service shifts at the national or regional level.

12.8 RESEARCH CONTRIBUTIONS

This work has produced several contributions, some more substantial than others. The main contribution is an assessment of the usefulness of applying SD to support "joined-up thinking" in planning for and evaluating health service shifts. Based upon the detailed analysis of the shift in CC services in the NHS, SD was shown to be able to contribute to the policy making process by offering a means to design "joined-up solutions" to "joined-up" problems associated with service shifts. This finding is transferable to other health service shifts.

The SD simulation model represents a first attempt to integrate into a testable framework a set of propositions about the stimulation and suppression of demand for health services associated with shifts in health services. SD thus offers a new "joined-up" perspective on health service shifts as previous studies have only focused on isolated parts of the system.

This research has considered the existence of several different feedback mechanisms underlying changes in demand and, with a dynamic analysis, provided insight into the interaction between these mechanisms. These mechanisms are associated with waiting time, knowledge and skills effects on demand and they can lead to the stimulation or suppression of demand. In the literature, discussions of changes in demand have tended to focus on the stimulation of demand not its suppression. Discussions have also tended to concentrate on waiting time and knowledge effects, not skills effects. In discussing service shifts to the primary sector, Hamblin *et al* (1998b) provide an exception by highlighting a skills effect on demand associated with the gain in knowledge via the development of new skills. This research offers new insight into skills effects by considering the process underlying the acceleration of the gain in skills and the effects of training programmes and the rotation of junior staff. This research also demonstrates that the effect of skills on demand may be due to either the associated changes in knowledge or confidence or both. Hamblin *et al* (1998b) only discuss the former.

Using the SD model, new insight was obtained into how the shift in CC services helped and hindered the delivery of cardiac services. It was also shown how purchasers and providers could have intervened effectively to improve the behaviour of the system by coordinating the service shift with other policy changes. For example, it was revealed that, under certain conditions, permanent reductions in waiting lists and waiting times could have been achieved without capacity increases. In some cases, the same improvements could have been achieved by controlling referrals via the use of new referral guidelines alone (controlling, rather than meeting, demand). In other cases, using new referral guidelines and changing the forces that drive activity, from seeking a desired waiting time to seeking a desired waiting list would have been effective. In fact, these two interventions combined could have generated synergy by producing greater improvements together than the sum of the improvements generated by each intervention alone.

This work provides a review of the shift in the balance of care in the NHS, which extends beyond the usual focus on the developments in primary care, to shifts across the primary, secondary and tertiary levels. Another contribution, which formed the basis of published work (Taylor and Lane, 1998), is a clarification of the role for SD in health care and as a complement to the traditional approach to simulation modelling. Finally, contributions have been made to the field of SD (see Richardson 1996) by offering a new application and by proposing a new graphical summary measure.

12.9 SUGGESTIONS FOR FURTHER RESEARCH

The work presented in this thesis could be developed in several different ways, thus providing possibilities for future research. These could involve efforts to: generate further insight into shifts in the balance of care; continue model development; address issues relating to the SD modelling process; and, consider issues beyond health care.

Shifts in the Balance of Care

Although this research involved carrying out a number of experiments, they were not exhaustive as they only involved a few combinations of interventions. Therefore, further research could explore other combinations of interventions into the shift in CC services. The current model was only applied to the shift in CC services in the NHS at two hospitals. Therefore, attempts could be made to employ the model to study shifts in CC services to other hospitals and shifts in other NHS services. Numerous examples of service shifts were described in §3.2 and Table 12.3. Following on from the comments made in §12.7.1, this would serve to verify if the research findings could be replicated or indicate if they required some revision. Replicating the research findings would increase the evidence base into supporting the suggestion that service shifts can lead to overall increases in demand, which has important policy implications.

As this research only focused on service shifts within the NHS, research efforts could examine the dynamics of service shifts that cross into the private sector. An example is the development of 'walk-in' clinics which are privately run.

As part of this research, GPs were not interviewed. Therefore, by interviewing GPs, a closer investigation could be carried out into the changes in GP referral behaviour in response to service shifts.

Adopting a regional perspective on the shift in CC services, SD could be applied to provide insight into the stimulation and transfer of demand between different district hospitals. Research could focus on the connections between the tertiary centre and its referring hospitals. Alternatively, the use of a district CC facility by cardiologists from neighbouring hospitals could be investigated. It was reported that in order to generate enough patient activity to sustain the permanent district service at Veinbridge General, neighbouring hospitals were permitted to book laboratory sessions at the catheter laboratory. These studies would generate hospital network models. Furthermore, capacity increases would be represented as endogenous processes rather than exogenous factors as in this research.

Model Development

As a number of simplifying assumptions were made in the current model, future research could focus on model extensions and refinements. For example, the model boundary could be extended to endogenise the follow-up process of patients after their discharge from an OP appointment. Coyle (1984) shows how the arrivals of new and follow-up patients could be represented in SD in qualitative terms. Another example would be to endogenise the process of the introduction of phase 1 and phase 2 district services prompting changes in the referral threshold for CC and district CC. A further example would be to disaggregate the model to elucidate the dynamics of changes in clinical priority between routine and urgent elective cases.

The SD Modelling Process

Several possibilities for future research could focus on the process of SD modelling, such as the use of the pressure summary index. Efforts could also be directed towards improving the usefulness of SD in analysing service shifts. For example, it was suggested that DES analyses could be employed to operationalise capacity increases and achieve improvements in the efficiency of capacity usage. Therefore, further research could be directed towards exploring how DES and SD could complement each other, and the practicalities involved. Related work would include that by Mak (1992). Another example is an investigation of the usefulness of SD-based analyses of other health care problems and issues, beyond shifts in services.

Several other research avenues relate to the unresolved issues in SD that were highlighted in §4.6. Whilst some insight was offered into some of these issues, as they were not the focus of this research, they inevitably remain unresolved to some extent. They include the practicalities involved in conceptualising problems and working with professionals in the health service. As the methods and results of an economic appraisal are easily understood, it is important that SD models and their analyses are transparent for SD to provide an effective complement to economic appraisal.

In this research, it was found that graphs of hospital data provided a fruitful basis for discussion and reflection about the mechanics of the system. Further research could examine the effectiveness of different diagrammatic tools in eliciting information from experts and in facilitating learning about the system.

Due to the time constraints for this research, efforts were not made to work interactively on the simulation model with the collaborators so only the model output was presented. If interactive work had been conducted, then some of the output graphs would have been simplified and the names of the evaluation and policy variables would have been changed from abbreviations to full names to make them instantly transparent. Currently, all the variable names are abbreviations with the full names given in the extensive model documentation. Whilst efforts have been made to ensure consistency in the abbreviations, non-modellers would be expected to find full names more transparent. Specifying full names is not beyond the capability of the STELLA software. However, they would have to be relatively short in order to fit easily on the stock and flow diagrams. More informative variable names can be assigned using abbreviations. Therefore, there would be a trade-off between the transparency and usefulness of variable names.

Another SD process issue concerns how to effectively convey the results of SD-based analyses. In this research, in order to summarise the improvements over the base case behaviour, pressure summary indices were proposed. Further work could focus on testing these indices and evaluating their usefulness.

Whilst this research aimed to highlight the trade-offs involved in the results of the policy experiments and the potential conflict between those pursuing different agendas; no attempts were made to impose value judgements. Therefore, another example of future work would be to investigate the proposal to combine SD with decision analytic methods to attempt to select the 'best' policy change (Gardiner and Ford 1980; Reagan-Ciricione *et al* 1991).

Issues Beyond Health care

Future work could involve comparisons between mechanisms underlying changes in demand within and outside health care. For example, in manufacturing, the order backlog and delivery delay are analogous to the waiting list and waiting time respectively. Manufacturing differs from health care in two different respects. Firstly, in certain situations, an increased delivery delay will lead to over-ordering to compensate or else customers will go elsewhere. This is the opposite of the waiting time effect on demand in health care (an increased waiting time can suppress demand). Secondly, the signals differ as in manufacturing, the 'market' sees the delivery delay but not the order backlog. In health care, both the waiting time and waiting list may be monitored. Research could draw comparisons with other industries and consider the implications of these differences.

Research could also consider comparisons between service shifts within and those outside health care. The development of free legal advice in Citizens Advice Bureaux represents an example of the latter.

REFERENCES

Notes:

Sloan Management Review, BMJ and *Heart* were formerly known as *Industrial Management Review, British Medical Journal* and *British Heart Journal* respectively.

Aaron HJ, Schwartz WB. *The painful prescription: rationing hospital care.* Washington: The Brookings Institution 1984.

Abel-Smith B. *An introduction to health: policy, planning and financing.* London: Longman 1994.

Abel-Smith B, Figueras J, Holland W, *et al. Choices in health policy: an agenda for the European Union.* Aldershot: Dartmouth 1995.

ACC/AHA 1988. American College of Cardiology and American Heart Association. Guidelines for percutaneous transluminal coronary angioplasty. *Journal of the American College of Cardiology* 1988; 12: 529-545.

ACC/AHA 1991. American College of Cardiology and American Heart Association. Guidelines for cardiac catheterization and cardiac catheterization laboratories. *Circulation* 1991; 84: 2213-2247.

van Ackere A, Smith P. Making static models dynamic: the case of the National Health Service. Discussion paper 158, Centre for Health Economics, University of York 1997.

van Ackere A, Smith PC. Towards a macro model of National Health Service waiting lists. *System Dynamics Review* 1999; 15:225-252.

Adams ME *et al.* Economic analysis in randomised clinical trials. *Medical care* 1992; 30: 231-243.

Ackoff R. Towards a system of systems concepts. *Management Science* 1971; 17: 11: 661-671.

Ackoff R. The future of operational research is past. *Journal of the Operational Research Society* 1979; 30: 93-104.

Allen PM. Dynamic models of evolving systems. *System Dynamics Review* 1988; 4: 109-130.

Altman DG. *Practical statistics for medical research.* 4th edition. London: Chapman and Hall 1993.

Anderson TF, Money G (eds). *The challenges of medical practice variations.* Macmillan 1990.

Ansoff HI, Slevin DP. An appreciation of industrial dynamics. *Management Science* 1968; 14: 383-397.

Babes M, Sarma G. Outpatient queues at the Ibn-Rochd Health Center. *Journal of the Operational Research Society* 1991; 42: 845-855

Backhouse ME, Backhouse RJ, Edey SA. Economic evaluation bibliography. *Health Economics* 1992; 1: supplement.

Badri MA, Hollingsworth J. A simulation model for scheduling in the Emergency Room. *International Journal of Operations and Production Management* 1993; 13: 13-24

Bailey J, Black M, Wilkin D. Specialist outreach clinics in general practice. *BMJ* 1994; 308: 1083-1086.

Banks J, Carson JS. *Discrete-event simulation.* Englewood Cliffs (NJ): Prentice Hall 1984.

Barlas Y. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review* 1996; 12: 183-210.

BCIS 1992. The Council of the British Cardiovascular Intervention Society. Surgical cover for percutaneous transluminal coronary angioplasty. *British Heart Journal* 1992; 68: 339-341

BCS 1991. Report of Working Party of the British Cardiac Society. Coronary angioplasty in the United Kingdom. *British Heart Journal* 1991; 66: 325-331.

BCS 1994a. British Cardiac Society Council. Strategic planning for cardiac services and the internal market: role of catheterisation laboratories in district general hospitals. *British Heart Journal* 1994; 71: 110-112

BCS 1994b. Report of a Working Group of the British Cardiac Society. Cardiology in the district hospital. *British Heart Journal* 1994; 72: 303-308.

BCS 1994c. British Cardiac Society Council. *The demand and need for cardiac services and the development of a waiting list strategy for cardiac disease.* London: BCS, July 1994.

BCS 1997. A working group of the British Cardiac Society with the Royal College of Physicians of London and Edinburgh and Royal College of Physicians and Surgeons of Glasgow. The changing interface between district hospital cardiology and the major cardiac centres. *Heart* 1997; 78: 519-523

BCS/BCIS 2000. Joint Working Group on Coronary Angioplasty of the British Cardiac Society and British Cardiovascular Intervention Society. *Heart* 2000; 83: 224-235.

BCS/RCP 1993. Report of the Working Party of the Joint Audit Committee of the British Cardiac Society and the Royal College of Physicians of London. The investigation and management of stable angina. *Journal of the Royal College of Physicians* 1993; 27: 267-273.

Beaglehole R. International trends in coronary heart disease mortality, morbidity and risk factors. *Epidemiologic Review* 1990; 12: 1-15.

Beech R, Morgan M. Constraints on innovatory practice: the case of day surgery in the NHS. *International Journal of Health Planning and Management* 1992; 7: 133-148.

Beech R. Using operational research modelling to improve the provision of health services: the case of DNA technology. *International Journal of Epidemiology* 1995; 24: S90-S95.

Beech R, Rudd AG, Tilling K, Wolfe CD. Economic conseqences of early discharge to community-based rehabilitation for stroke in an inner-London teaching hospital. *Stroke* 1999; 30: 729-735.

Beecham L. Tories extend general practice fundholding. *BMJ* 1994; 309: 1039

Bensley DC, Watson PS, Morrison GW. Pathways of coronary care- a computer simulation model of the potential for health gain. *IMA Journal of Mathematics Applied in Medicine & Biology* 1995; 12: 315-328.

Benzeval M, Judge K, Whitehead M (eds). *Tackling inequalities in health: an agenda for action.* London: King's Fund 1995.

Bernard JC, Camiran F, Hosios AJ, *et al.* Experi-mental: a simulation of the distribution of services for mentally deficient children. *Behavioral Science* 1977; 22: 356-366.

Bernstein SJ, Hilbourne LH, Leape LL, *et al.* The appropriateness of use of coronary arteriography in New York State. *Journal of the American Medical Association* 1993; 269: 766-769.

BHF 1996. British Heart Foundation. *What is angina?* Heart information series no. 4 1996.

BHF 1999. British Heart Foundation. *The heart - technical terms explained.* Heart information series no. 18 1999.

Bittl JA. Advances in coronary angioplasty. *New England Journal of Medicine* 1996; 335: 1290-1302.

Black M, Leese B, Gosden T, Mead N. Specialists outreach clinics in general practice: what do they offer? *British Journal of General Practice* 1997; 47: 558-561.

Black N. Observational Studies. Methodologies for evaluating health care interventions. St Thomas' Hospital, London. 15 April 1996.

Blake JT, Carter MW. An analysis of emergency room wait time issues via computer simulation. *INFOR* 1996; 34: 263-272.

BMA 1996. General Medical Services Committee. *Defining core services in general practice – reclaiming professional control.* London: BMA 1996.

BMA 1997. BMA Health Policy and Economic Research Unit. *The interface between primary and secondary care: changing workload and changing locations.* London: British Medical Association, 1997.

Boldy D. A review of the application of mathematical programming to tactical and strategic health and social services problems. *Operational Research Quarterly* 1976; 27: 439-448.

Bolger PG, Davies R. Simulation model for planning renal services in a district health authority. *BMJ* 1992; 305: 605-608.

Bonner J. Keeping the blood flowing. *New Scientist* 25 June 1994; 32-35.

de Bono D on behalf of the Joint Audit Committee of the British Cardiac Society and Royal College of Physicians of London. Complications of diagnostic cardiac catheterisations: results of 34 401 patients in the United Kingdom confidential enquiry into cardiac catheter complications. *British Heart Journal* 1993; 70: 297-300.

de Bono D. Development and future of open access echocardiography. *Hospital Medicine* 1998; 59: 600-601.

de Bono D on behalf of a Working Party of the British Cardiac Society and Royal College of Physicians of London. Investigation and management of stable angina: revised guidelines 1998. *Heart* 1999; 81: 546-555.

de Bono D, Hopkins A on behalf of a Working Party of the Joint Audit Committee of the British Cardiac Society and Royal College of Physicians of London. The investigation and management of stable angina. *Journal of the Royal College of Physicians of London* 1993; 27: 267-273.

de Bono D, Ravilious B, El-Zoubi I, *et al.* A prioritisation system for elective coronary angiography. *Heart* 1998; 79: 448-453.

Bowling A, Stramer K, Dickinson E, *et al.* Evaluation of specialists' outreach clinics in general practice in England: process and acceptability to patients, specialists, and general practitioners. *Journal of Epidemiology and Community Health* 1997; 51: 52-61.

Brailsford SC, Shahani AK, Roy RB, Sivapalan S. Simulation modelling for HIV infection and AIDS. *International Journal of Biomedical Computing* 1992; 31: 73-88.

Brook RH. Appropriateness: the next frontier. *BMJ* 1994; 308:218-219.

Brook R, Lohr K. Efficiency, effectiveness, variations and quality. *Medical Care* 1985; 23: 710-722.

Brook RH, Kosecoff JB, Park RE, *et al.* Diagnosis and treatment of coronary disease: comparison of doctors' attitudes in the USA and the UK. *Lancet* 1988; i: 750-753.

Brown A, Armstrong D. Telephone consultations in general practice: an additional or alternative service? *British Journal of General Practice* 1995; 45: 673-675.

Bryman A. The debate about quantitative and qualitative research: a question of method or epistemology? *British Journal of Sociology* 1984; 35: 75-92.

Butler TW, Karwan KR, Sweigart JR, *et al.* An integrative model based approach to hospital layout. *IIE Transactions* 1992; 24: 144-152

Buttery R, Snaith A. Waiting for surgery. *British Medical Journal* 1979; 2: 403-404.

Buttery R, Snaith A. Surgical provision waiting times and waiting lists. *Health Trends* 1980; 12: 57-62.

Cairns J. Discounting and health benefits: another perspective. *Health Economics* 1992; 1: 76-79.

Calman KC. Quality: a view from the centre. *Quality in Health Care* 1992; 1 Supplement: S28-S33.

Cardiovision. It's good to talk. *Vision Newsletter*, Cardiovision, Summer 1995.

Carvel J. Doctor's abuse leads to calls for register of complaints. *The Guardian*. 31 August 2001.

Casiro OG, McKenzie ME, McFadyen L, *et al.* Earlier discharge with community-based intervention for low birth weight infants: a randomised trial. *Pediatrics* 1993; 92: 128-134.

Cavana RY, Davies PK, Robsen RM, Wilson KJ. Drivers of quality in health services: different worldviews of clinicians and policy managers revealed. *System Dynamics Review* 1999; 15: 331-340.

Charles RG, Marshall AJ. *Cardiology.* Oxford: Heinemann 1989

Chassin MR, Kosecoff J, Park RE, *et al.* Indications for selected medical and surgical procedures – a literature review and ratings of appropriateness. *Coronary angiography.* The RAND Publication Series. Santa Monica: RAND Corporation, 1986.

Chawda SJ, Watura R, Lloyd DCF. Magnetic resonance imaging for the lumbar spine: direct access for general practitioners. *British Journal of General Practice* 1997; 47: 575-576.

Checkland PB. *Systems thinking, systems practice.* Wiley: Chichester 1981.

Chen K, Garrison WL. Urban modeling. In: Chen K (ed). *Urban dynamics: extensions and reflections.* San Francisco: The San Francisco Press 1972.

Christie LG, Carlson KL, Michels LG, *et al.* Cost-effectiveness and safety of inpatient verses outpatient coronary angiography. *Circulation* 1985; 72: 401.

Clark DA, Moscovich MD, Vetrovec GW, *et al.* Guidelines for the performance of outpatient catheterisation and angiographic procedures. *Catheterization Cardiovascular Diagnosis* 1992; 27: 5-7.

Clark J, Cole S. *Global simulation modes: a comparative study.* Chichester: Wiley 1975.

Clayden D. Unpredictable change? *OR Insight.* Special issue on simulation in health 1995; 8: 2-4.

Cohen S. *Who's life is it anyhow?* London: Robson Books 1993.

Corr L. New methods of making blocked coronary arteries patent again. *BMJ* 1994; 304: 579-583.

Coulter A. Shifting the balance from secondary to primary care: needs investment and cultural change. *BMJ* 1995; 311: 1447-1448.

Coulter A. Managing demand at the interface between primary and secondary care. *BMJ* 1998; 316: 1974-1976.

Coyle D, Drummond MF. Does expenditure on pharmaceuticals give good value for money: current evidence and policy implications? *Health Policy* 1993; 26: 55-75.

Coyle RG. *Management system dynamics.* Chichester: Wiley 1979.

Coyle RG. A systems approach to the management of a hospital for short-term patients. *Socio-Econ Plan Sci* 1984; 18: 219-226.

Coyle RG. A system dynamics model of aircraft survivability. *System Dynamics Review* 1992; 8:193-212.

Coyle RG. *System dynamics modelling*. London: Chapman and Hall 1996.

Coyle RG. System dynamics at Bradford University: a silver jubilee review. *Journal of the Operational Research Society* 1999; 50: 296-301.

Coyle RG, Morecroft J (eds). Special issue: system dynamics for policy, strategy and management education. *Journal of the Operational Research Society 1999; 50:291-449*

CSAG 1993. Clinical Standards Advisory Group. *Coronary artery bypass grafting and coronary angioplasty: access to and availability of specialist services*. HMSO 1993.

CSAG 1996. Black N, Langham S, Coshall C, *et al.* Impact of the 1991 NHS reforms on the availability and use of coronary revascularisation in the UK (1987-1995). *Heart* 1996; 76 (Suppl. 4): 1-30.

Crawford CM. Endogenous safety processes: a model of regulation and safety in industrial firms. *System Dynamics Review* 1991; 7: 20-40.

Crisp AH. Uncertainty is an important symptom in patients awaiting revascularisation procedures. *Heart* 1996; 75: 221.

Curnow RN. Economics and operational research in the health services. In: Hauser MM (ed). *The economics of medical care*. London: Allen and Unwin 1972.

Dale J, Green J, Reid F *et al.* Primary care in the accident and emergency department: I. Prospective identification of patients. *BMJ* 1995 311: 423-426.

Dangerfield BC, System dynamics applications to European health care issues. *Journal of the Operational Research Society* 1999; 50: 345-353.

Dangerfield B, FangY. System dynamics modelling: a problem with delay functions used in bifurcating flows. 2002. Submitted for journal review.

Dangerfield BC, Roberts CA. Relating a transmission model AIDS spread to data: some international comparisons. In Isham V, Medley G (eds). *Models for infectious human diseases: their structure and relation to data*. Cambridge: CUP 1996: 473-476.

Dangerfield and Roberts 1999a. Dangerfield B, Roberts C. Optimisation as a statistical estimation tool: an example in estimating the AIDS treatment-free incubation period distribution. *System Dynamics Review* 1999; 15: 273-292.

Dangerfield and Roberts 1999b. Dangerfield B, Roberts C. Health and health care dynamics (eds). *System Dynamics Review.*1999; 15: 197-340

Davidoff F, Case K, Fried PW. Evidence-based medical: why all the fuss? *Annals of Internal Medicine* 1995; 122:727.

Davidoff F, Haynes B, Sackett D *et al.* Evidence based medicine: a new journal to help doctors identify the information they need. *BMJ* 1995; 310: 1085-1086.

Davies HTO, Crombie IK. Assessing the quality of care. *BMJ* 1995; 311: 766.

Davies RA. Study of a renal unit. *Journal of the Operational Research Society* 1979; 30: 873-884.

Davies R. An assessment of models in a health system. *Journal of the Operational Research Society* 1985; 36: 679-687.

Davies R. Simulation for planning services for patients with coronary artery disease. *European Journal of Operational Research* 1994; 71: 323-332.

Davies R, Brailsford S, Roderick R *et al.* Using simulation modelling for evaluating screening services for diabetic retinopathy. *Journal of the Operational Research Society* 2000; 51: 476-484.

Davies R, Davies H. Modelling patient flows and resource provision in health services. *Omega* 1994; 22: 123-131.

Davies R, Davies T. Using simulation to plan health service resources: discussion paper. *Journal of the Royal Society of Medicine* 1986; 79: 154-157.

Davies R, Flowers J. The growing need for renal services: the use of simulation modelling to aid purchasing for renal replacement therapy. *OR Insight.* Special issue on simulation in health 1995; 8: 6-11.

Davies R, Roderick P. Planning resources for renal services throughout UK using simulation. *European Journal of Operational Research* 1998; 105:285-295.

Davies R, Sullivan P, Canning CR. Simulation of diabetic eye disease to compare screening policies. *British Journal of Ophthalmology* 1996; 80: 945-950.

Detsky AS, Naglie IG. A clinician's guide to cost-effectiveness analysis. *Annals of Internal Medicine* 1990; 113: 147-154.

DICE 1994. Diabetes Integrated Care Evaluation Team. Integrated care for diabetes: clinical, psychosocial, and economic evaluation. *BMJ* 1994; 308: 1208-1212.

Dixon J. The British NHS: a funding crisis? *Eurohealth* 1997; 3: 36-37

Dixon J, Harrison AH. A little local difficulty? *BMJ* 1997; 314: 216-219.

Dixon J, Holland P, Mays N. Primary care: core values: developing primary care: gatekeeping, commissioning, and managed care. *BMJ* 1998; 317: 125-128.

van Doorslaer EKA, van Vliet RCJA. A built bed is a filled bed? An empirical re-examination. Social Science and Medicine 1989; 28: 155-164.

Doyle JK, Ford DN. Mental models concepts for system dynamics research. *System Dynamics Reviews* 1998; 14: 3-29.

Drummond MF. *Principles of economic appraisal in health care.* Oxford: Oxford University Press 1980

Drummond MF, Stoddart GL, Torrance GW. *Methods for the economic evaluation of health care programmes.* Oxford: Oxford University Press 1987.

Drummond MF. *Economic analysis alongside controlled trials.* Leeds: Department of Health 1994.

Drummond MF, Brandt A, Luce BR, Rovira J. Standardizing economic evaluations in health care: practice, problems and potential. *International Journal of Technology Assessment in Health Care* 1993; 9: 26-36.

Dumas MB. Hospital bed utilization: an implemented simulation approach to adjusting and maintaining appropriate levels. *Health Services Research* 1985; 20; 43-61.

Dupuis G, Kennedy E, Perrault J *et al.* The hidden costs of delayed bypass surgery Abstract. *Clinical and Investigative Medicine* 1990; 13: C35.

Earwicker SC, Whynes DK. General practioners' referral thresholds and choices of referral destination: an experimental study. *Health Economics* 1998; 7: 711-722.

EBM 1992. Evidence-Based Medicine Working Group. Evidence-based medicine: a new approach to teaching the practice of medicine. *Journal of the American Medical Association* 1992; 268: 2420-2425.

The Economist 1998. Sick of waiting. *The Economist* 1998; 348: 29-30.

Edwards N. The growth in emergency admissions - a challenge for health services research. *Journal of Health Services Research and Policy* 1996; 1: 125-126.

Edwards N, Hensher M. Managing demand for secondary care services: the changing context. *BMJ* 1998; 317: 135-138.

Elixhauser A *et al.* Health care CBA/CEA: an update on the growth and composition of the literature. *Medical Care*. 31: supplement JS1-JS11.

Ellis SG, Cowley MJ, Whitlow PL, *et al.* Prospective case-control comparison of percutaneous transluminal coronary revascularization in patients with multivessel disease treated in 1987-1987 verses 1991: improved in-hospital and 12 month results. *Journal of the American College of Cardiology* 1995; 25: 1137-1142.

Erens B. Primatesta. *Health survey for England: cardiovascular disease '98*. London: Stationary Office 1999.

ESC 1997. Task Force of the European Society of Cardiology. Management of stable angina pectoris: recommendations of the Task Force of the European Society of Cardiology. *European Heart Journal* 1997; 18: 394-413.

Evans R, Barer M, Marmor T. Why are some people healthy and others not? *The determinants of health populations*. Berlin: de Gruyter 1994

Every NR, Larson EB, Litwin PR, *et al.* The association between on-site cardiac catheterisation facilities and the use of coronary angiography after acute myocardial infarction. *New England Journal of Medicine* 1993; 329: 546-551.

Fairfield G, Hunter DJ, Mechanic D, Rosleff F. Managed care: origins, principles and evolution. *BMJ* 1997; 314: 1823-1826.

Ferguson B, Posnett J, Sheldon T. *Concentration and choice in the provision of hospital services: summary report.* CRD report 8 (summary). York: Centre for Health Economics, University of York 1997

Finkelstein S, Homer JB, Sondik EJ. Modelling the dynamics of decision-making for emerging medical technologies. *R & D Management* 1984; 14: 175-191.

Fitzpatrick MA. Audit of prioritisation for coronary revascularisation procedures: implications for rationing. *New Zealand Medical Journal* 1992; 105: 145-147.

Flood RL, Jackson MC. *Creative problem solving - total system intervention*. Chichester: Wiley 1991.

Foale R. The district general cardiac centre - a changing profile. *Vision Newsletter*, Cardiovision, Summer 1998.

Forrester JW. *Industrial dynamics.* Cambridge (MA): MIT Press 1961.

Forrester JW. Industrial dynamics - after the first decade. *Management Science* 1968; 14: 398-415.

Forrester JW. Market growth as influenced by capital investment. *Industrial Management Review* 1968; 9: 80-105.

Forrester JW. *Urban dynamics.* Cambridge (MA): MIT Press 1969.

Forrester JW. Policies, decisions, and information sources for modeling. In: *Collected papers of Jay W. Forrester.* Cambridge (MA): Wright-Allen Press 1975.

Forrester JW. 'The' model verses the modelling 'process'. *System Dynamics Review* 1985; 1: 133-134

Forrester JW. Nonlinearity in high-order models of social systems. *European Journal of the Operational Research* 1987; 30: 104-109.

Forrester JW. System dynamics, systems thinking, and soft OR. *System Dynamics Review* 1994; 10: 245-256.

Forrester JW, Senge PM. Tests for building confidence in system dynamics models. In: Legrastro AA, Forrester JW, Lyneis JM (eds). *TIMS studies in the management sciences* 1980; 14: 209-228.

Frostick SP, Radford PJ, Wallace WA (eds). *Medical audit: rationale and practicalities.* Cambridge: Cambridge University Press 1993.

Gallagher M, Huddart T, Henderson B. Telephone triage of acute illness by a practice nurse in general practice: outcomes of care. *British Journal of General Practice* 1998; 48: 1141-1145.

Gardiner RC, Ford A. Which policy is best, and who says so? In: Legrastro AA, Forrester JW, Lyneis JM (eds). *TIMS studies in the management sciences* 1980; 14: 241-257.

Gillam SJ, Dunne H, Ball M, *et al.* Investigation of benefits and costs of an ophthalmic outreach clinic in general practice. *British Journal of General Practice* 1995; 45: 649-652.

Glennerster H. Health care 2000: an examination. *Eurohealth* 1996; 2: 21-22.

Glennerster H. Matsaganis M, Owens P, Hancock S. GP fundholding : wild card or winning hand? In: Robinson R, Le Grand J (eds). *Evaluating the NHS reforms*. London: King's Fund Institute, 1994.

Godber E, Robinson R, Steiner A. Economic evaluation and the shifting of balance towards primary care: definitions, evidence and methodological issues. *Health Economics* 1997; 6: 275-294.

Goddard JA, Tavakoli M. Referral rates and waiting lists: some empirical evidence. *Health Economics* 1998; 7: 545-549.

González-Busto, García R. Waiting lists in spanish public hospitals: a system dynamics approach. *System Dynamics Review* 1999; 15: 201-224.

Graboys TB, Biegelsen B, Lampert S, *et al.* Results of a second-opinion trial among patients recommended for coronary angiography. *Journal of the American Medical Association* 1992; 268: 2537-2540.

Grace AA, Hall JA, Schofield PM. *Cardiology*. Edinburgh: Churchill Livingstone 1993

Graham AK. Parameter estimation in system dynamics modeling. In: Randers J (ed). *Elements of the system dynamics method*. Cambridge (MA): MIT Press 1980.

Gray D, Hampton JR, Bernstein SJ, *et al.* Audit of coronary angiography and bypass surgery. *Lancet* 1990; 335: 1317-1320.

Gray D, Hampton JR. Methods of establishing criteria for purchasing coronary angiography in the investigation of chest pain. *Journal of Public Health Medicine* 1994; 16: 399-405.

GRASSIC 1994. Grampian Asthma Study of Integrated Care (GRASSIC). Integrated care for asthma: a clinical, social, and economic evaluation. *BMJ* 1994; 308: 559-564.

Grieve R, Beech R, Vincent J, Mazurkiewicz J. Near patient testing in diabetes clinics: appraising the costs and outcomes. *Health Technology Assessment* 1999; 3:1-74.

Grimshaw and Russell 1993a. Grimshaw JM, Russell IT. Effect of clinical guidelines on medical practice: systematic review of rigorous evaluations. *Lancet* 1993; 342: 1317-1322.

Grimshaw and Russell 1993b. Grimshaw JM, Russell IT. Achieving health gain though clinical guidelines I: developing scientifically valid guidelines. *Quality in Health Care* 1993; 2: 243-248.

Grimshaw and Russell 1993c. Grimshaw JM, Russell IT. Achieving health gain though clinical guidelines II: ensuring guidelines change medical practice. *Quality in Health Care* 1993; 3: 45-52.

Grüntzig AR. Transluminal dilatation of coronary artery stenosis. *Lancet* 1978; i: 263

Grüntzig AR, Senning A, Siegenthaler WE. Nonoperative dilatation of coronary-artery stenosis. *New England Journal of Medicine* 1979; 301: 61-68

Gunnell D, Harvey I. Variation in purchasing for the invasive management of coronary heart disease. *Public Health* 1996; 110: 13-16.

Gunnell D, Harvey I, Smith L. The invasive management of angina: issues for consumers and commissioners. *Journal of Epidemiology and Community Health* 1995; 49: 335-343.

Haines A, Iliffe S. Innovations in services and the appliance of science. *BMJ* 1995; 310: 815-816.

Hall RJC, Boyle RM, Webb-Peploe M, *et al*. Guidelines for specialist training in cardiology. *British Heart Journal* 1995; 73 (Suppl 1): 1-24.

Halvorsen PA, Kristiansen IS. Radiology services for remote communities: cost minimisation study of telemedicine. *BMJ* 1996; 312: 1333-1336.

Ham C. *The new National Health Service: organisation and management.* Oxford: Radcliffe Medical Press 1990.

Ham C. The organisation of the NHS. In: Ham C, Merry P (ed). *NHS handbook 1998/1999*. 13th edition. Tunbridge Wells: JMH Publishing 1997: 27-36.

Ham C, Shapiro J. The future of fundholding. *BMJ* 1995; 310:1150-1151

Ham C, Smith J, Temple J. *Hubs, spokes and policy cycles: an analysis of the policy implications for the NHS of changes to medical staffing*. A paper for the King's Fund London Commission. London: King's Fund, 1998.

Hamblin R, Harrison A, Boyle S. The supertanker's not for turning. *The Lancet* 1997; 350: 1493-1494.

Hamblin *et al* 1998a. Hamblin R, Harrison A, Boyle S. *Access to elective care: why waiting lists grow.* London: King's Fund, 1998.

Hamblin *et al* 1998b. Hamblin R, Harrison A, Boyle S. The wrong target. *Health Service Journal* 1998; 108: 28-31

Harris A. Specialist outreach clinics. *BMJ* 1994; 308: 1053.

Harrison A. Making the right connections in modernisation. *British Journal of Health Care Management* 2001; 7: 486-489.

Harrison AH, Dixon J, New B, *et al.* Can the NHS cope in future? *BMJ* 1997; 30: 295-334

Harrison A, New B. *Access to elective care: what should really be done about waiting lists?* London: King's Fund 2000.

Hawkins JD. *Computer simulation of trachoma.* PhD dissertation. Southampton: University of Southampton 1989.

HEA 1993. Health Education Authority. *Health update 1: Coronary heart disease.* London: HEA 1993.

Heginbotham C, Ham C, Cochrane M, *et al.* Purchasing dilemmas. A special report from the King's Fund College and Southampton and South West Hampshire Health Authority 1992

Helliwell PS. Comparison of a community clinic with a hospital outpatient clinic in rheumatology. British Journal of Rheumatology 1996; 35: 385-388.

Henderson RA, Raskino C, Hampton JR. Variations in the use of coronary arteriography in the UK: the RITA trial coronary arteriogram register. *Quarterly Journal of Medicine* 1995; 88: 167-173.

Hensher M, Fulop N, Coast J, Jefferys E. Better out than in?: alternatives to acute hospital care. *BMJ* 1999; 319: 1127-1130.

High Performance Systems. *STELLA software manuals 1997.* High Performance Systems, 145 Lyme Road, anover NH 03755, USA.

Hillman BJ, Joseph CA, Marby MR *et al.* Frequency and costs of diagnostic imaging in office practice - a comparison of self referring and radiologist-referring physicians. *New England Journal of Medicine* 1990; 323: 1604-1608.

Hine C, Wood VA, Taylor S, Charny M. Do community hospitals reduce the use of district general hospital inpatient beds? *Journal of the Royal Society of Medicine* 1996; 89: 681-687

Hodgkin D. Specialized service offerings and patients' choice of hospital: the case of cardiac catheterization. *Journal of Health Economics* 1996; 15: 305-332.

Hoffmeyer U, Lloyd A. Health care systems in Canada and the United Kingdom: common problems, common solutions? In: Lee K (ed). *Health care systems in Canada and the UK.* Keele: Ryburn Publishing 1994.

Holmes L, Loughead K, Treasure T, Gallivan S. Which patients will not benefit from further intensive care after cardiac surgery? *Lancet* 1994; 344: 1200-1202.

Homer JB. A dynamic model for analysing the emergence of new medical technologies. PhD dissertation. Sloan School of Management, MIT. Cambridge(MA): MIT 1983.

Homer JB. A diffusion model with application to evolving medical technologies. *Technological Forecasting and Social Change* 1987; 31: 197-218.

Homer J, Coyle R. Maps and models in system dynamics: a response to Coyle. *System Dynamics Review* 2001; 17:347-355

Homer J, Richie-Dunham J, Rabbino H *et al.* Toward a dynamic theory of antibiotic resistance. *System Dynamics Review* 2000; 16: 287-319.

Hopkins A. *Measuring the quality of medical care.* London: Royal College of Physicians Publications 1990.

Hornberger JC, Habraken H, Bloch DA. Minimum data needed on patient preferences for accurate, efficient medical decision-making. *Medical Care* 1995; 33: 297-310.

HSM 1996. Acute Services reconfiguration and reviews. *Health Services Manager* 1996; 4 (15 Februrary): 4-5.

Huang X-M, Taylor C, Stewart I. Computer simulation of an A&E department: towards shorter waiting in an accident and emergency department. *OR Insight.* Special issue on simulation in health 1995; 8: 18-23.

Hubner PJ. Cardiac interventions in the United Kingdom during 1990. *British Heart Journal* 1992; 68: 436-486.

Hughes J, Gordon P. *Hospitals and primary care: breaking down the boundaries*. London: King's Fund Centre, 1993.

Hutton J. Economic evaluation of health care: a half-way technology. *Health Economics* 1994; 3: 1-4.

Jennett B. Health technology assessment: the rule should be no evaluation - no technology. *BMJ* 1992; 305: 67-68.

Jackson, G. *Angina*. London: Martin Dunitz 1991

Jones LM, Hirst AJ. Visual simulation in hospitals: a managerial or political tool? *European Journal of Operational Research* 1986; 29: 167-177.

Jun JB, Jacobson SH, Swisher JR. Application of discrete-event simulation in health care clinics: a survey. *Journal of the Operational Research Society* 1999; 50: 109-123.

Kadanoff, LP. An examination of Forrester's urban dynamics. *Simulation* June 1971.

Kaplan RS, Norton DP. The balanced scorecard-measures that drive performance. *Harvard Business Review* January-February 1992: 71-79.

Kassirer JP. Adding insult to injury: usurping patients' prerogatives. *New England Journal of Medicine* 1983; 308: 898-901.

Keys P. System dynamics as a systems-based problem-solving methodology. *Systems Practice* 1990; 3: 479-493.

King SB, Talley JD. Coronary arteriography and percutaneous transluminal coronary angioplasty: changing patterns of use and results. *Circulation* 1989; 79 (Supplement I): I19-I23.

King's Fund Consensus Development Conference Panel. Coronary artery bypass grafting. *British Medical Journal* 1984; 289: 1205-1208.

Kitson A. Playing by the rules, *Quality in Health Care* 1992; 1: 149-152.

Kleijnen JPC. *Statistical techniques in simulation Part 1*. New York: Dekker 1974.

Konnitten M, Merkallio E. Return to work after open heart surgery: impact of long waiting lists? *Theoretical Surgery* 1990: 5: 192-195.

Kwak N, Kuzdrall P, Schmitz H. Simulating the use of space in a hospital surgical suite. *Simulation* 1975; 24: 147-152.

Lambo E. An optimization-simulation model of a rural health centre in Nigeria. *Interfaces* 1983; 13: 29-35.

Lane DC. Modelling as learning. *European Journal of Operational Research* 1992; 59: 64-84.

Lane DC. With a little help from our friends: how system dynamics and soft OR can learn from each other. *System Dynamics Review* 1994; 10: 101-134.

Lane DC, Monefeldt C, Rosenhead JV. Looking in the wrong place for health care improvements: a system dynamics study of an accident and emergency department. *Journal of the Operational Research Society* 2000; 51: 518-531

Langham S. *The impact of the NHS reforms on social welfare: the case of coronary revascularisation services.* PhD dissertation. London: London School of Hygiene and Tropical Medicine 1995.

Langham S, Normand C, Piercy J, *et al.* Coronary heart disease. In: Stevens A, Raftery J (eds). *Health needs assessment. The epidemiology based needs assessment review.* Vol 1 1993

Langham S, Thorogood M. Bypassing the time. *Health Service Journal*, 21 March 1996, p.33

Law AM, Kelton WD. *Simulation modelling and analysis.* 2nd ed. New York: McGraw-Hill 1991

Lee K, Mills A. *Policy-making and planning in the health sector.* London: Croom Helm 1982.

Lehaney B, Hlupic V. Simulation modelling for resource allocation and planning in the health sector. *Journal of the Royal Society of Health* 1995: 382-385.

Lehaney B, Paul R. Using soft systems methodology to develop a simulation of out-patient services. *Journal of the Royal Society of Health* 1994; 114: 248-251.

Lenaghan J. *Rationing and rights in health care.* London: Institute of Public Policy Research 1996

Levin G, Hirsch GB, Roberts EB. *The persistent poppy: a computer aided search for heroin policy.* Cambridge (MA): Ballinger 1975.

LIG 1993. London Implementation Group. *Report of the cardiology specialty review group.* London: HMSO 1993.

Linstone H, Turoff M. *The delphi method: techniques and applications.* New York: Wiley 1975.

Little D. Evidence and objectivity in the social sciences. *Social Research* 1993; 60: 363-396.

Lowy A, Brazier J, Fall M, *et al.* Minor surgery by general practitioners under the 1990 contract: effects on hospital workload. *BMJ* 1993; 307: 413-417.

Luce BR, Elixhauser A. *Standards for the socio-economic evaluation of medicines.* Berlin: Springer-Verlag 1990.

Luft HS, Garnick DW, Mark DH, *et al. Hospital volume, physician volume and patient outcomes: assessing the evidence.* Ann Arbor MI, Health Administration Press Perspectives, Michegan 1990.

Mahacheck AR, Knabe TL. Computer simulation of patient flow in obstetrical/gynecology clinics. *Simulation* 1984; 43: 95-101.

Mak HY. *System dynamics and discrete event simulation modelling*. PhD dissertation. London: London School of Economics and Political Science 1992.

Mann J. Pathology of ischaemic heart disease. *Medicine International* 1993; 21: 376-378.

Manning WJ, Li W, Edelman RR. A preliminary report comparing magnetic resonance coronary angiography with conventional angiography. *New England Journal of Medicine* 1993; 328: 828-832.

Marks L. *Home and hospital care: redrawing the boundaries*. Research Report 9. London: King's Fund 1991.

Mason J, Drummond M, Torrance G. Some guidelines on the use of cost-effectiveness league tables. *BMJ* 1993; 306: 570-572.

Mather D. A simulation model of the spread of Hepatitis C within a closed cohort. *Journal of the Operational Research Society* 2000; 51: 656-665.

Maxwell R. Quality assessment in health. *British Medical Journal* 1984; 288: 1470-1472.

Maynard A. A primary need for knowledge. *Health Service Journal* 1994; 26 May, p19.

Maynard A, Bloor K. Introducing a market to the United Kingdom's National Health Service. *New England Journal of Medicine* 1996; 334: 604-608

McGrath PD, Wennberg DE, Dickens JD *et al.* Relation between operator and hospital volume and outcomes following percutaneous interventions in the era of the coronary stent. *Journal of the American Medical Association* 2000; 284: 3139-3144.

McKeigue, PM. Coronary heart disease in Indians, Pakistanis, and Bangladeshis: aetiology and possibilities for prevention. *British Heart Journal* 1992; 67: 341-2.

McPherson K. How should health policy be modified by the evidence of medical practice variations. In: Marinker M (ed). *Controversies in health care policies: challenges to practice*. London: British Medical Journal Publishing Group 1994

Meadows DH. Whole earth models and systems. *CoEvolution Quarterly* Summer 1982: 98-108

Meadows DH. System dynamics meets the press. *System Dynamics Review* 1989; 5: 69-80.

Meadows DH. *The global citizen*. Washington DC: Island Press 1991.

Meadows DH, Robinson JM. *The electric oracle: computer models and social decisions*. Chichester: Wiley 1985.

Merry P. Improving access to services. In: Merry P (ed). *NHS Handbook 2001/2002*. 16th edition. East Sussex: JMH Publishing 2001: 165-166

Miller P, Graig N, Scott A, *et al*. Measuring progress towards primary care-led NHS. *British Journal of General Practice* 1999; 49: 541-545.

Mills P. Should coronary angiography be performed in district hospitals? *British Heart Journal*. 1990; 63: 73.

Mojtahedzadeh MT, Kazemeynee M, Azizkhan H. Renal stone model system dynamics approach. In: Vennix JAM, Faber J, Scheper WJ, Takkenberg CAT (eds). Proceedings of the 1992 international system dynamics conference; 1992 July 14-17; Utrecht. Boston: System Dynamics Society 1992: 445-454.

Morecroft, JDW. System dynamics: portraying bounded rationality. *Omega* 1983; 11: 131-142.

Morecroft JDW. Rationality in the analysis of behavioral simulation models. *Management Science* 1985; 31: 900-916.

Morecroft JDW. Strategy support models. *Strategic management journal* 1984; 5: 215-229.

Mukherjee AK. A simulation model for management of operations in the pharmacy of a hospital. *Simulation* 1991; 56: 91-103.

Mulgan R, Logan RL. The coronary bypass waiting list: a social evaluation. *New Zealand Medical Journal* 1990; 103: 371-372.

Mullen P. Waiting lists in the post-review NHS. *Health Services Management Research* 1994; 7: 131-145.

Mulligan J. Attitudes towards the NHS and its alternatives 1983-1996. In: *Health care UK 1997/98: the King's Fund annual review of health policy*. Harrison A (ed). London: King's Fund 1998.

Mulrow CD. Rationale for systematic reviews. *BMJ* 1994; 309: 597-599.

Murphy D. Outcomes research: moving through the adolescent years. *Focus on Outcome Analysis* 1995; 4: 3-6.

Naylor CD, Baigre RS, Goldman, *et al.* Revascularisation Panel and Consensus Methods Group. Assessment of priority for coronary revascularisation procedures. *Lancet* 1990; 335: 1070-1073.

Naylor *et al* 1993a. Naylor CN, Levington CM, Wheeler S, *et al.* Queuing for coronary surgery during severe supply-demand mismatch in a Canadian referral centre: a case study of implicit rationing. *Social Science and Medicine* 1993; 37: 6-67.

Naylor *et al* 1993b. Naylor D, Morgan C, Levinton *et al.* Waiting to coronary revascularisation in Toronto: 2 years' experience with a regional referral office. *Canadian Medical Association Journal* 1993; 149: 955-962.

Neelamkavil F. *Computer simulation and modelling*. Chichester: Wiley 1987.

NERA 1993. *Diagnosing deficiencies, prescribing progress. A report on the economics of health care reform.* An independent report by National Economic Research Associates. Commissioned by the Pharmaceutical Partners for Better Health care, December 1993.

New B. Le Grand J. *Rationing in the NHS: principles and pragmatism.* London: King's Fund 1996

Newchurch 1993. Newchurch & Company Limited. *Acute hospitals - a case for treatment.* Newchurch health briefing 1993.

Newton JN, Henderson J, Goldacre MJ. Waiting list dynamics and the impact of earmarked funding. *BMJ* 1995; 311: 783-785.

NHS 1946. House of Commons Debates: Committee stage of the National Health Service Bill. London: HMSO, June 18, 1946: Columns 1561-2

NHS 1974. CJWP(PP)2, September 1974. Treasury, SS 10/01A.

NHS 1983. Department of Health and Social Security. *Care in the community.* London: HMSO 1983.

NHS 1987. Department of Health. *Promoting better health: the Government's programme for improving primary health care.* London: HMSO 1987.

NHS 1989a. Secretaries of State for Health, Wales, Northern Ireland and Scotland. *Working for Patients.* Cm 555. London: HMSO 1989.

NHS 1989b. Department of Health and Welsh Office. *General practice in the NHS: a new contract.* London: DHSS, 1989.

NHS 1991a. Department of Health. *The patient's charter.* London: HMSO 1991

NHS 1991b. Department of Health. *The health of the nation: a consultative document for a health strategy for England.* London: HMSO 1991.

NHS 1991c. NHS Management Executive. *Integrating primary and secondary care.* London: HMSO 1991.

NHS 1992. *Report of the inquiry into London's health service, medical education and research.* Presented to the Secretaries of State for Health and Education by Sir Bernard Tomlinson. October 1992. London: HMSO 1992.

NHS 1993a. Department of Health. *Managing the new NHS.* London: HMSO 1993.

NHS 1993b. Department of Health. *Making London better.* London: HMSO 1993.

NHS 1993c. National Health Service in Scotland Management Executive. *GP contract health promotion package: guidance on implementation.* NHS PCA(M)(1993) 3 Edinburgh: Scottish Office 1993.

NHS 1993d. NHS Management Executive. *Junior doctors: the new deal.* London: NHSME 1993.

NHS 1993e. Department of Health. Hospital doctors: training for the future, the report of the working group on specialist medical training. Misc[93]31. London: HMSO 1993

NHS 1994a. Department of Health. *Coronary heart disease: an epidemiological overview.* London: HMSO 1994.

NHS 1994b. NHS Executive. *Developing NHS purchasing and GP fundholding: towards a primary care-led NHS.* EL(94)79. Leeds: NHS Executive 1994

NHS 1994c. Department of Health. *R&D priorities in relation to the interface between primary and secondary care.* Report to the NHS Central Research and Development Committee, 1994.

NHS 1995. Expert advisory group on cancer to the chief medical officer of England and Wales. *A policy framework for commissioning cancer services: guidance to purchasers and providers of cancer services (the Calman-Hine report).* Department of Health. London: HMSO 1995.

NHS 1996a. Department of Health. *The patient's charter and you.* London: HMSO 1996

NHS 1996b. NHS Executive. *Primary care: the future.* Leeds: NHS Executive 1994.

NHS 1996c. *Primary care: the future – choice and opportunity.* London: HMSO 1996.

NHS 1997a. Phillips C. Department of Health. Personal communication by telephone on 3/11/97 and 5/11/97.

NHS 1997b. Secretary of State for Health. *The new NHS: modern, dependable.* Cm 3807. London: TSO 1997.

NHS 1997c. *Public health common data set 1996.* Volume IV. London: Department of Health 1997.

NHS 1997d. NHS Centre for Reviews and Dissemination, University of York. Management of stable angina. *Effective Health Care* 1997; 3: 1-8.

NHS 1998b. NHS Executive. Research and development in the Department of Health and National Health Service. In: Department of Health. *Research and Development: towards an evidence-base for health services, public health and social care.* Information Pack. Leeds: NHS Executive 1998.

NHS 1998c. NHS Executive. *Moderning health and social services: national priorities guidance 1999/0-2001/2.* Leeds: NHS Executive 1998.

NHS 1999. *Saving lives: our healthier nation.* Presented to Parliament by the Secretary of State for Health by command of Her Majesty, July 1999. Cm 4386. London: TSO 1999.

NHS 2000a. Department of Health. *National service framework for coronary heart disease.* London: Department of Health 2000.

NHS 2000b. Department of Health. *Shaping the future NHS: long term planning for hospitals and related services. Consultation document on the findings of the national beds enquiry.* Leeds: Department of Health 2000.

Nutley S, Smith P. League tables for performance improvement in health care. *Journal of Health Services Research and Policy* 1998; 3: 50-57.

OECD 1994. Organisation for Economic Co-operation and Development. *OECD economic surveys 1993-4: United Kingdom.* Paris: OECD 1994

OED 1995. *Oxford English Dictionary.* 9th edition, 1995.

OHE 1992. Office of Health Economics. *Compendium of health statistics.* 8th edition. London: OHE 1992.

OHE 2000. Office of Health Economics. *Compendium of health statistics.* 12th edition. London: OHE 2000.

O' Cathain, Brazier JE, Milner PC, Fall M. Cost effectiveness of minor surgery in general practice: a prospective comparison with hospital practice. *British Journal of General Practice* 1992; 42: 13-17.

O'Kane PC. A simulation model of a diagnostic radiology department. *European Journal of Operational Research* 1981; 6: 38-45.

OPCS 1991. *Office of Population and Census Study.* London: HMSO 1991.

OPCS 1997. Office of Population Censuses and Surveys. The Government's expenditure plans 1997-8 to 1999-2000, Cm 3612. London: HMSO 1997.

Oliva R 1996. *A dynamic theory of service delivery: implications for managing service quality.* PhD dissertation. Cambridge (MA): MIT

Papaconstantinou HD, Marshall AJ, Burrell CJ. Diagnostic cardiac catheterisation in a hospital without on-site cardiac surgery. *Heart* 1999; 81: 465-469.

Parsonage M, Neuberger H. Discounting and health benefits. *Health Economics* 1992; 1: 71-76.

Patterson D, Treasure T. *Disorders of the cardiovascular system.* London: Edward Arnold 1993

Patton MQ. *Qualitative evaluation and research methods.* London: Sage 1980

Paul R. Recent developments in simulation modelling. *Journal of the Operational Research Society* 1991; 42: 217-226.

Paul R. Outpatient clinics: the CLINSIM simulation package. *OR Insight.* Special issue on simulation in health 1995; 8: 24-27.

Paul R, Balmer D. *Simulation modelling.* Bromley: Chartwell-Bratt 1993.

Peckham S. *Primary and secondary health care: shifting the balance to primary care.* Briefing Paper No. 5. Wessex Research Consortium, 1992.

Peterson LL, Leese B. What will a primary care led NHS mean for GP workload? The problem of the lack of an evidence base. *BMJ* 1997; 314: 1337-1341.

Petrou S, Renton A. The QALY: a guide for the public health physician. *Public Health* 1993; 107: 327-336.

Petticrew M, Turner-Boutle M, Sheldon T. The management of stable angina. *Health Service Journal* 1997; 107:36-37.

Pidd M. *Computer simulation in management science.* 4th edition. Chichester: Wiley; 1998.

Pieper B, Lepczyk M, Caldwell M. Perceptions of the waiting period before coronary artery bypass grafting. *Heart Lung* 1985; 14: 40-44.

Pierskalla WP, Brailer DJ. Applications of operations research in health care delivery. In: Pollock SM, Rothkopf MH, Barnett A (eds). *Handbooks in OR & MS.* Volume 6. Amsterdam: Elsevier Science 1994: 469-505.

Pope C. Dissecting a waiting list. *Health Services Management Research* 1991; 4:112-119.

Pope C. Cutting queues or cutting corners: waiting lists and the 1990 reforms. *BMJ* 1992; 305: 577-579.

Popper KR. *The logic of scientific discovery.* New York Basic Books, 1959.

Posnett J. Is bigger better?: concentration in the provision of secondary care. *BMJ* 1999; 319:1063-1065

Postma ThJBM, Smits MT, Terpstra S, *et al.* Personnel planning in health care: an example in the field of rheumatology. Proceedings of the System Dynamics Conference 1992; 515-524.

Pritsker AAB. Compilations of definitions of simulation. *Simulation* 1979; 33: 61-63.

Quade ES. Pitfalls in formulation and modeling. In: Majone G, Quade ES (eds). *Pitfalls of analysis.* Chichester: Wiley 1980.

Rahn RJ. Aggregation in system dynamics. *System Dynamics Review* 1985; 1: 111-122.

Raiffa H. *Decision analysis: introductory lectures on choices under uncertainty.* Reading (MA): Addison Wesley 1968.

Randers J. Guidelines for model conceptualization. In: Randers J (ed). *Elements of the system dynamics method.* Cambridge (MA): MIT Press 1980.

Rathwell T. Health care systems in the United Kingdom and Canada: can they deliver? In: Lee K (ed). *Health care systems in Canada and the UK.* Keele: Ryburn Publishing 1994.

Rayner, M. *Coronary heart disease statistics* 1993

RCP/RCS 1992. Fourth Report of a Joint Cardiology Committee of the Royal College of Physicians of London and the Royal College of Surgeons of England. Provision of services for the diagnosis and treatment of heart disease. *British Heart Journal* 1992; 67: 106-116.

Reagan-Cirincione P, Schuman S, Richardson GP, *et al.* Decision modeling: tools for strategic thinking. *Interfaces* 1991; 21: 52-65

Rein M. *Social science and public policy.* Harmondsworth: Penguin 1976.

Reinke, WA. *Health planning for effective management.* New York: Oxford University Press 1988.

Richardson GP. Problems with causal-loop diagrams. *System Dynamics Review* 1986; 2; 158-170.

Richardson GP. *Feedback thought in social science and systems theory.* Philadelphia University of Pennsylvania Press 1991.

Richardson GP. Problems for the future of system dynamics. *System Dynamics Review* 1996; 12: 141-157.

Richardson GP, Pugh AL. *Introduction to system dynamics modeling with DYNAMO.* Cambridge (MA): MIT Press 1981.

Richardson GP, Wolstenholme EF, Morecroft JDW (eds). Systems thinkers, systems thinking. *System Dynamics Review* 1994; 10: 2-3.

Richie-Dunham JL, Méndez Galván JF. Evaluating epidemic intervention policies with systems thinking: a case study of dengue fever in Mexico. *System Dynamics Review* 1999; 15: 119-138.

Rink E, Hilton S, Szczepura A *et al.* Impact of introducing near patient testing for standard investigations in general practice. *BMJ* 1993; 307: 775-778.

RITA 1993. Rita Trial Participants. Coronary angioplasty verses coronary artery bypass surgery: the Randomised Intervention Treatment of Angina (RITA) trial. *Lancet* 1993; 341: 573-580.

Rittel HWJ, Webber MM. Dilemmas in a general theory of planning. *Policy Sciences* 1973; 4: 155-169.

Rivett G. *From cradle to the grave: Fifty years of the National Health Service.* London: King's Fund 1998.

Roberts E, May N. Can primary care and community-based models of emergency care substitute for the hospital accident and emergency (A&E) department? *Health Policy* 1998; 44: 191-214.

Roberts N. Teaching dynamic feedback systems thinking: an elementary view. *Management Science* 1978; 24: 836-843.

Roberts C, Dangerfield B. Modelling the epidemiological consequences of HIV infection and AIDS: a contribution from operational research. *Journal of the Operational Research Society* 1990; 41: 273-289.

Roberts SD, Klein RW. Simulation of medical decisions: applications of SLN. *Simulation* 1984; 43: 234-241.

Roberts SD, Maxwell DR, Gross TL. Cost-effective care of end-stage renal disease: a billion dollar question. *Annals of Internal Medicine* 1980; 92: 243-248.

Robinson 1993a. Robinson R. Economic evaluation and health care: what does it mean? *BMJ* 1993; 307: 670-673.

Robinson 1993b. Robinson R. Economic evaluation and health care: costs and cost-minimisation analysis. *BMJ* 1993; 307: 726-728.

Robinson 1993c. Robinson R. Economic evaluation and health care: cost-effectiveness analysis. *BMJ* 1993; 307: 793-795

Robinson 1993d. Robinson R. Economic evaluation and health care: cost-utility analysis. *BMJ* 1993; 307: 859-862.

Robinson 1993e. Robinson R. Economic evaluation and health care: cost-benefit analysis. *BMJ* 1993; 307: 924-926.

Roland M, Coulter A (eds). *Hospital referrals*. Oxford: Oxford University Press 1992.

Roland M, Morris R. Are referrals by general practitioners influenced by the availability of consultants? *BMJ* 1988; 297: 599-600.

Romanin-Jacur G, Facchin P, Optimal planning of a pediatric semi-intensive care unit via simulation. *European Journal of Operational Research* 1987; 29: 192-198.

Rosenhead J. Operational research in health services planning. *European Journal of Operational Research* 1978; 2: 75-85.

Rosenhead J. Old and new paradigms of analysis. In: Rosenhead J (ed). *Rational analysis of a problematic world.* Chichester: Wiley 1989.

Royal Commission. Royal Commission on the National Health Service. *Royal Commission on the National Health Service: Report.* Chair: Merrison A. London: HMSO, 1979.

Royston G, Dost A, Townshend J, Turner H. Using system dynamics to help develop and implement policies and programmes in health care in England. *System Dynamics Review* 1999; 15: 293-314.

Russell-Jones R. The future of dermatology – in hospital or out? *Journal of the Royal College of Physicians of London* 1996; 30: 413-414.

Rutten F, Drummond M. *Making decisions about health technologies: a cost-effectiveness perspective.* University of York Centre for Health Economics 1994.

Sackett DL, Rosenberg WM, Gray JA *et al.* Evidence based medicine: what it is and what it isn't. *BMJ* 1996; 312: 71-72.

Sans S, Kesteloot H, Kromhout D. The burden of cardiovascular diseases mortality in Europe. *European Heart Journal* 1997; 18: 1231-1248.

Savas E. Simulation and cost effectiveness analysis of New York's emergency ambulance. *Management Science* 1969; 15: B608-B627

Scholl, GJ. Benchmarking the system dynamics community. *System Dynamics Review* 1992; 8: 263-266.

Scholl, GJ. Benchmarking the system dynamics community: research results. *System Dynamics Review* 1995; 11: 139-155.

Schomig A, Neumann FJ, Kastrati A, *et al.* A randomised comparison of anti-platelet and anticoagulant therapy after coronary artery stents. *New England Journal of Medicine* 1996; 334: 1084-1089.

Scott A. Primary or secondary care? What can economics contribute to evaluation at the interface? *Journal of Public Health Medicine* 1996; 18: 19-26.

Scott A, Maynard A. *Will the new GP contract lead to cost-effective medical practice?* Discussion paper 82. York: Centre for Health Economics, University of York, 1991.

Scott A, Wordsworth S. The effects of shifts in the balance of care on general practice workload. *Family Practice* 1999; 16: 12-17.

Scott A, Vale L. Increased general practice workload due to a primary care led National Health Service: the need for evidence to support rhetoric. *British Journal of General Practice* 1998; 48: 1085-1088.

Senge PM. *The fifth discipline: the art and practice of the learning organisation.* New York: Doubleday/Currency 1990

Selby JV, Bruce MPH, Fireman MA, *et al.* Variation among hospitals in coronary angiography practices and outcomes after myocardial infarction in a large health maintenance organisation. *New England Journal of Medicine* 1996; 335: 1888-1896.

Selby P, Gillis C, Haward R. Benefits from specialised cancer care. *Lancet* 1996; 348:313-318.

Serruys PW. Rotterdam Thoraxcentre Interventional Cardiology Group. *Handbook of coronary stents.* Serruys PW (ed). London: Martin Dunitz 1996.

Shannon RE. *Systems simulation: the art and science.* Englewood Cliffs (NJ): Prentice Hall 1975.

Shaw T, Cochrane M. NHS Purchasing. In: Ham C, Merry P (eds). *1995/1996 annual NHS handbook.* 10th edition. Tunbridge Wells: JMH Publishing 1995: 178-182.

Shekelle P, Roland M. Nurse-led telephone-advice lines. *Lancet* 1999; 354: 88-89.

Sheldon TA, Faulkener A. Vetting new technologies. *BMJ* 1996; 313:508.

Shubrooks SJ, Nesto RW, Leeman D *et al.* Urgent coronary bypass surgery for failed percutaneous coronary intervention in the stent era: is backup necessary? *American Heart Journal* 2001; 142: 190-196.

Sigwart U. Percutaneous transluminal coronary angioplasty: what next? *British Heart Journal* 1990; 63: 321-322.

Simon, H. Rational decision making in business organizations, *American Economic Review* 1979; 69: 493-513.

Smith J. Acute services. In: Merry P (ed). *NHS Handbook 1999/2000.* 14th edition. Tunbridge Wells: JMH Publishing 1999.

Smith LDR, Spyer G, Dean JW. Audit of cardiac catheterisation in a district general hospital: implications for training. *Heart* 1999; 81: 461-464.

Smith R. Towards a knowledge based health service. *BMJ* 1994; 309: 217-218.

Smith R. Rationing: the debate we have to have. *BMJ* 1995; 310: 686.

Smith R. Reconfiguring acute hospital services. *BMJ* 1999; 319: 797-798.

Smith R. How best to organise acute hospital services? *BMJ* 2001; 323: 245-246.

Smith-Daniels VL, Schweikhart SB, Smith-Daniels DE. Capacity management in health care services: review and future research directions. *Decision Sciences* 1988; 19: 889-919.

Spiby J. Health care technology in the United Kingdom. *Health Policy* 1994; 30: 295-334.

Spurgeon P. Development of clinical care networks. In: Merry P (ed). *NHS Handbook 2001/2002.* 16th edition. East Sussex: JMH Publishing 2001: 191-193.

Starfield B. Is primary care essential? *Lancet* 1994; 334:1129-1133.

Starkley IR.Letter. *Lancet* 1993; 341: 1020.

Stein K, Milne R. The NHS R&D health technology assessment programme. In: Baker MR, Kirk S (eds). *Research and Development for the NHS: evidence, evaluation and effectiveness.* 2nd edition. Oxford: Radcliffe Medical Press 1998.

Sterman JD. Appropriate summary statistics for evaluating the historical fit of system dynamics models. *Dynamica* 1984; 10:51-66.

Sterman JD. Learning in and about complex systems. *System Dynamics Review* 1994; 10; 291-330.

Sterman JD. Business dynamics: systems thinking and modeling for a complex world. Boston: McGraw Hill 2000.

Sterman J, Repenning N, Kofman F. Unanticipated side effects of successful quality programs: exploring the paradox of organizational improvement. *Management Science* 1997; 43: 503-521.

Stevens RS, Potter JM, Hildrick Smith M. Effect on a geriatric service of opening a 25-bed ward on a district general hospital site: an audit. *Journal of the Royal College of Physicians of London* 1990; 24: 107-111.

Stewart JT, Gray HH, Ward DE, *et al.* Major complications of coronary arteriography: the place for cardiac surgery. *British Heart Journal* 1990; 63: 74-77.

Strauch RE. "Squishy" problems and quantitative methods. *Policy Sciences* 1975; 6: 175-184.

Schomig A Neumann FJ, Kastrati A, *et al.* A randomised comparison of anti-platelet and anticoagulant therapy after coronary artery stents. *New England Journal of Medicine* 1996; 334: 1084-1089.

Sowden A, Sheldon T, Alberti G. Shared care in diabetes: better evaluation is needed. *BMJ* 1995; 310: 142-143.

Swanton RH. *Cardiology*. 4th edition. Oxford: Blackwell Science 1998

Swanton RH. Cardiology: new challenges for the millennium. *Hospital Medicine* 1999; 60: 622-623

Sweeney B. The referral system: prevents overmedicalisation and keeps costs down. *BMJ* 1994; 304: 1180-1181.

Tank-Nielsen C. Sensitivity analysis in system dynamics. In: Randers J (ed). *Elements of the system dynamics method.* Cambridge (MA): MIT Press 1980.

Taylor K, Lane D. Simulation applied to health services: opportunities for applying the system dynamics approach *Journal of Health Services Research and Policy* 1998; 3: 226-232.

Townsend J, Piper M, Frank AO. Reduction in hospital readmission stay of elderly patients by a community-based hospital discharge scheme: a randomised controlled trial. *BMJ* 1988; 297: 545-547.

TPET 1996. Total purchasing evaluation team. *Total purchasing: a profile of national pilot projects.* London: King's Fund 1996

TPET 1997. Mays N, Goodwin N, Bevan G, Wyke S on behalf of the Total Purchasing National Evaluation Team. *BMJ* 1997; 315: 652-655.

Treasure T, Anderson J. Coronary artery surgery. *Medicine International* 1993; 21: 397-400.

Tybulewicz AT, Rigby ML, Redington AN. Open-access paediatric echocardiography: changing role and referral patterns to a consultant-led service in a tertiary referral centre. *Heart* 1996; 75: 632-634.

Tunnicliffe Wilson JC. Implementation of computer simulation projects in health care. *Journal of the Operational Research Society* 1981; 32: 825-832.

Udvarhelyi S *et al.* Cost-effectiveness and cost benefit analysis in the medical literature: are the methods being used correctly? *Annals of Internal Medicine* 1992; 116: 238-244.

Unger F. European survey on cardiac interventions, open heart surgery, PTCA, cardiac catheterisation in 1992. Report of the Instititute of Cardiac Survey of the European Academy of Sciences and Arts. *Annals of the European Academy of Sciences and Arts.* Vol 6. Salzburg: Academia Scientiarium et Artium Europea 1993.

Vemuri S. Simulated analysis of patient waiting time in an outpatient pharmacy. American *Journal of Hospital Pharmacy* 1984; 41: 1127-1130.

Vennix JAM. *Mental models and computer models: design and evaluation of a computer-based learning environment for policy-making.* PhD dissertation. Nijmegen: University of Nijmegen 1990.

Vennix JAM. *Group model building: facilitating team learning using system dynamics.* Chichester: Wiley 1996.

Vennix JAM, Gubbels JW. Knowledge elicitation in conceptual model building: a case study in modeling a regional dutch health care system. *European Journal of Operational Research* 1992; 59: 85-101.

Ventana Systems. *VENSIM system manuals.* Ventana Systems Inc, Belmont, MA, USA 1996.

Vetter N. The death of the hospital. University of Wales College Medicine Brotaf Health Authority and Gwent Community Trust, Cardiff Wales 1996.

Waldegrave W. Parliamentary written answer. *House of Commons Official Report* (Hansard). 1991 October 14. 196: col 592.

Waller BF. "Crackers, breakers, stretchers, drillers, scrapers, shavers, burners, welders and melters" - the future treatment of atherosclerotic coronary artery disease? A clinical-morphologic assessment. *Journal of the American College of Cardiology* 1989; 13: 969-987.

Warden J. New cover for NHS negligence claims. *BMJ* 1995; 310: 896.

Warden J. Walk-in health care. *BMJ* 1999; 318: 756.

Warner KE, Luce BR. *Cost-benefit and cost-effectiveness analysis in health care.* Ann Arbor (MI): Health Administration Press 1982.

Warner M. Present needs and future context: forces for change in health care in the United Kingdom. In: Lee K (ed) *Health care systems in Canada and the United Kingdom: can they deliver?* Ryburn Publishing, Keele University Press 1994.

Warner M, Riley C. Closer to home: health care in the 21st century. Birmingham: NAHAT 1994.

Webster C. *The National Health Service: a political history*. Oxford: OUP 1998.

Weintraub WS, Jones EL, King SB *et al.* Changing use of coronary angioplasty and coronary bypass surgery in the treatment of coronary artery disease. *American Journal of Cardiology* 1990; 65: 183-188.

West R. Assessment of evidence verses consensus or prejudice. *Journal of Epidemiology and Community Health* 1992; 321-322.

WHO 1978a. World Health Organisation. *Primary health care: report of the International Conference on Primary Health Care*, Alma-Ata, USSR, 6-12 September. Geneva: World Health Organisation, 1978.

WHO 1978b. World Health Organisation Working Group. *Research on simulation models for health management.* Lisbon, 26-29 September 1978.

WHO 1985. *Targets for health for all: targets in support of the European regional strategy for health for all by the year 2000.* Copenhagen, World Health Organisation, Regional Office for Europe 1985.

Wickham JEA. Future developments. *BMJ* 1994; 308: 193-196.

Williams SV. How many intensive care beds are enough. *Critical Care Medicine* 1983; 412-416.

Weinstein MC, Stason WB. Foundations of cost-effectiveness analysis for health and medical practices. *New England Journal of Medicine.* 1977; 296: 716-721.

Weinstein MC, Coxson PG, Williams LW, *et al.* Forecasting coronary heart disease incidence, mortality and cost: the coronary heart disease policy model. *ALPH* 1987; 77: 1417-1426

Wilkin D. Patterns of referral: explaining variation. In: Roland R, Coulter A (eds) *Hospital referrals*. Oxford: Oxford University Press 1992

Wilt A, Goddin D. Health care case study: simulation staffing needs and work flow in an outpatient diagnostic center. *Industrial Engineering* 1989; 21: 22-26

Wright MB. The application of a surgical bed simulation model. *European Journal of Operational Research* 1987; 32: 26-32.

Wolstenholme EF. Designing and assessing the benefits of control policies for conveyer belt systems in underground control mines. *Dynamica* 1980;6

Wolstenholme EF. *System enquiry: a system dynamics approach.* Chichester: Wiley, 1990

Wolstenholme EF. A case study in community care using systems thinking. *Journal of the Operational Research Society* 1993; 44: 925-934.

Wolstenholme 1999a. Wolstenholme EF. A patient flow perspective of U.K. Health Services: exploring the case for new "intermediate care" initiatives. *System Dynamics Review* 1999; 15: 253-271

Wolstenholme 1999b. Wolstenholme EF. Qualitative vs quantitative modelling: the evolving balance. *Journal of the Operational Research Society 1999; 50:422-428*

Wolstenholme EF, Coyle RG. Modelling discrete events in system dynamics models: a case study. *Dynamica* 1980; 6:21-27.

Worthington D. Hospital waiting list management models. *Journal of the Operational Research Society* 1991; 42: 833-843.

Yates J. *Why are we waiting?* Oxford: Oxford University Press, 1987

Yin 1994a. Yin RK. Evaluation: a singular craft. In: Reichardt C, Rallis S. *New directions in program evaluation*. San Francisco: Jossey-Bass 1994.

Yin 1994b. Yin RK. *Case study research: design and methods*. 2nd edition. California: Sage Publications 1994.

A SYSTEM DYNAMICS MODEL FOR PLANNING AND EVALUATING SHIFTS IN HEALTH SERVICES: THE CASE OF CARDIAC CATHETERISATION PROCEDURES IN THE NHS

VOLUME II

(Appendices)

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The London School of Economics and Political Science

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APPENDICES

APPENDIX A - ABBREVIATIONS

A&E	Accident and Emergency
CC	Cardiac Catheterisation
CHD	Coronary Heart Disease
DES	Discrete Event Simulation
DGH	District General Hospital
EBM	Evidence-Based Medicine
GP	General Practitioner
HA	Health Authority
NHS	National Health Service
OP	Outpatient
QALY	Quality Adjusted Life Year
RCT	Randomised Controlled Trial
SD	System Dynamics

APPENDIX B - GLOSSARIES

B1. Glossary of Health-Related Terms

B2. Glossary of Modelling Terms

These two glossaries are derived from a number of sources. In particular, the glossary of health-related terms is based upon the British Heart Foundation's patient information booklet (BHF 1999). Primary sources of reference for the modelling glossary are Richardson and Pugh (1981) and the STELLA software manuals (High Performance Systems 1997).

B1. Glossary of Health-Related Terms

ANGINA - A choking sensation in the chest, caused by insufficient blood reaching the heart. In most cases, indicates **coronary heart disease**.

ARTERY - A main blood vessel carrying blood from the heart to the rest of the body.

CARDIAC - Pertaining to the heart.

CARDIAC CATHETERISATION - An invasive procedure of passing a **catheter** through a vein or artery towards the heart. Used for the diagnosis and treatment of heart disease.

CATHETER - A long, hollow, flexible tube.

CONGENITAL HEART DISEASE - Structural malformation of the heart or its connecting blood vessels, present at birth. Forms the third largest group of patients who undergo **cardiac catheterisation.**

CORONARY ARTERIES - Arteries which feed blood to the **myocardium**.

CORONARY ANGIOPLASTY - An **invasive** treatment for **coronary heart disease** whereby an attempt is made to unblock a narrowing in a **coronary artery**. This treatment procedure may be carried out during **cardiac catheterisation.**

CORONARY ANGIOGRAPHY - An **invasive** procedure which involves injecting an X-ray opaque liquid through the **coronary artery** to provide an image of the coronary anatomy. Forms part of a **cardiac catheterisation** investigation.

CORONARY BYPASS SURGERY - An **invasive** treatment for **coronary heart disease** whereby a bypass channel is constructed around a narrowing in a **coronary artery**. Involves surgery on the open heart while the circulation is diverted to a heart-lung machine ('open heart' surgery).

CORONARY HEART DISEASE - Also known as coronary artery disease and ischaemic heart disease. A disease process whereby the inner layer of the **coronary arteries** become thickened and deposits of fat are laid down. Forms the vast majority of patients who undergo **cardiac catheterisation.**

DIFFERENTIAL DIAGNOSIS - This term refers to the process of making a correct diagnosis between diseases which present a similar clinical picture.

DISTRICT LEVEL - Secondary health service level within the primary, secondary, tertiary divisions.

ELECTIVE - Non-emergency, waiting list. May be subdivided between routine and urgent.

HEART VALVE DISEASE - Abnormalities of the heart valves. Forms the second largest group of patients who undergo **cardiac catheterisation**.

INCIDENCE - The number of new cases of a disease appearing in a given time period, or the proportion of population experiencing new incidents.

INTERVENTION - Treatment procedure

INVASIVE - Involving penetration of the skin.

INVESTIGATION - Diagnostic procedure

ISCHAEMIA - Inadequate blood supply

MORBIDITY - Illness.

MORTALITY - Death.

MYOCARDIUM - Heart muscle.

MYOCARDIAL INFARCTION - Heart attack.

PREVALENCE - Number or proportion of population affected by a disease.

RESTENOSIS - A stenosis is a constriction as with a **coronary artery** which is narrowed by **coronary heart disease**. Restenosis is the process whereby re-narrowing occurs.

B2. Glossary of Modelling Terms

AUXILIARY - See converter.

BEHAVIOUR - Refers to the evolution over time of a system variable

CAUSAL HYPOTHESIS - Presents an explanation of how the **structure** of a system causes its **behaviour** over time.

CAUSAL-LOOP DIAGRAM - Also known as an influence diagram. A diagram which is used to represent **information feedback** structure. Useful for conceptualising problems and for presenting policy insights in non-technical presentations.

CO-FLOW FORMULATION - Co-flow (co-incident **flow** or **rate**-to-**rate**) formulations are employed to represent a process that runs in parallel with some primary process or to track an attribute associated with a **flow**. The inputs to the co-flowing process are usually the primary flow multiplied by a conversion coefficient so the two flows will behave identically, provided the conversion coefficient is a constant.

CONNECTOR - Used in a **stock and flow diagram** to represent the transmission of information and inputs which are used to regulate the **flows**.

CONSTANT - See converter.

CONVERTER - Used in a **stock and flow diagram** for a variety of purposes to represent information used to calculate a **flow.** Converter is the term used in SD models generated by the *STELLA* software. Encompasses constants (constant converters), table functions (graphical converters) and auxiliaries (non-constant, non-graphical converters).

CLOUD - Used in a **stock and flow diagram** to represent 'sources' and 'sinks' of the material flowing through the **stocks**. Marks the boundary of the **model.**

DELAY - May refer to lags in the flows of materials or lags in perceptions or cognition.

DOMINANT STRUCTURE - Subset of the feedback structure of a SD model which is understood to be principally responsible for the **behaviour** pattern.

FEEDBACK LOOP - See information feedback loop.

FLOW - Used to represent an activity which can fill and/or drain the associated **stock**. A flow can be in one direction (uniflow) or both directions (biflow). The flow regulator contains the algebraic expression which determines the volume of the flow. Also known as a **rate**. Flow is the term used with SD models generated by the *STELLA* software.

GHOST - A replica of a **stock, flow** or **converter**. Can be used to improve the clarity of a stock and flow diagram by breaking and uncrossing links and to prevent the diagram resembling a bowl of spaghetti. Can also be used to collect together parameters into a convenient location.

INFORMATION FEEDBACK LOOP - Arises from a decision, based upon information about some property of the system, resulting in an action, which is intended to influence the value of that property. The result of the action changes the property of the system and thus leads to new information about that property. This may lead to further actions. A closed causal relationship thus propagates through the system as time unfolds.

LEVEL - See stock.

NON-LINEARITY - When one factor is not a simple proportion of another factor (e.g. hospital admission rates may be proportional to the number of available beds unless the number of vacant beds are low when elective admission rates may drop to zero) or when one factor is not independently responsive to several other factors (e.g. hospital admission rates are not independently responsive to the number of available beds and demand as 100% bed occupancy renders the levels of demand irrelevant in determining admission rates). Represented in an SD model by a graphical **converter**.

MODE OF BEHAVIOUR - A dynamic pattern such as exponential growth or oscillation.

MODEL - A simplified representation of something in the 'real world'. A model is constructed for a specific purpose.

POLICY - In the context of SD, this refers to a rule that continuously transforms information into decisions.

RATE - See **flow**.

REFERENCE MODE - A graph of an important variable displaying its **behaviour** over time. Used to define the problem focus in a SD study. Reference modes may describe problematic **behaviour**, more desirable system **behaviour** or observed **behaviour** under an existing **policy.**

SIMULATION - A pragmatic, non-optimising approach which involves the construction and dynamic analysis of a **model**.

STOCK - Used to represent anything which accumulates, both physical and non physical. Collects whatever flows into and out of it. A stock with two **flows** (an inflow and an outflow) can be visualised as the level in a bath tub, the tap controlling the flow of water into to the bath and the plug controlling the flow of water out of the bath. Also known as a **level**. Stock is the term used with SD models generated by the *STELLA* software.

STOCK AND FLOW DIAGRAM - Compared with a **causal-loop diagram**, a stock and flow diagram is more detailed and matches more closely the complete quantitative description of the model.

STRUCTURE - Refers to the integrated network of information linking various flows in the system such as people, resources and money.

SYSTEM BOUNDARY - Encloses the smallest possible number of components necessary for the **behaviour** under investigation.

TABLE FUNCTION - See **converter**.

TIME FRAME - Period of time over which a dynamic problem unfolds.

APPENDIX C - COLLABORATIVE WORK

C1. Site Visits

C2. Interviews and Contacts

C2a. Heartwick Hospital

C2b. Ribsley Hospital

C2c. Veinbridge Hospital

C2d. Purchasers/Commissioners

C2e. Other Relevant Health Practitioner Contacts

C3. Sources and Quality of the Numerical Data

C1. Site Visits

Site	Nature of Visit
Heartwick Hospital	Observation work (20/6/97 and 26/6/97) of CC and coronary angioplasty procedures in the catheter laboratory and nuclear imaging scans (15/7/97) in the nuclear imaging department. Attended a weekly staff meeting (20/6/98) which was devoted to a review of patient care. Spoke to various medical, nursing and technical staff.
Ribsley General	Observational work (24/3/98) of CC mobile unit and ward. Spoke to various medical, nursing and technical staff.
Veinbridge General	Observational work (12/8/97) of CC mobile unit and ward. Spoke to various medical, nursing and technical staff.

C2. Interviews and Contacts

C2a. Heartwick Hospital

Position	Nature of Contact
Consultant Cardiologist	First meeting on 13/6/97 during which feedback was obtained on a preliminary causal hypothesis. Interviewed (1/10/97 and 21/1/98) to discuss general issues about cardiac services and his experiences of district CC services, and to obtain his response to the CC and other hypotheses. Met (11/9/98 and 22/10/98) to present some graphs and obtain feedback on the conceptual model.
Hospital Manager	Interviewed (3/7/98) and spoke by telephone on several occasions to clarify further issues. Discussed both general issues and specific concerns about CC.
Information Dept Officer	Liaised on numerous occasions, mainly between Feb 98 and May 98, with regard to the procurement of hospital data
Information Dept Officer	Met briefly (18/3/98) to clarify some hospital coding queries.
Consultant of Nuclear Medicine	Interviewed on 15/7/97 to discuss nuclear imaging and its relationship with CC.

C2b. Ribsley General Hospital

Position	**Nature of Contact**
Consultant Cardiologist	Interviewed (17/2/98 and 24/3/98) to discuss his experiences of district CC services and to obtain feedback on results of data analysis. Met (13/5/98) to clarify data queries. Met (19/8/98) to obtain his feedback on the conceptual model. Also spoke by telephone on several occasions to discuss queries. Met to present simulation model and illustrative model output and to discuss calibration of simulation model (14/6/99 and 10/8/99).
Hospital Manager	Interviewed (24/3/98) to discuss her experiences of district CC services. Subsequently liaised on several occasions by telephone with regard to the procurement of hospital data. Met (2/8/99) to provide update on project.
Information Manager	Met (2/8/99) to discuss request for OP data. Subsequently spoke on telephone on several occasions to discuss queries.

C2c. Veinbridge General Hospital

Position	**Nature of Contact**
Consultant Cardiologist	Interviewed (6/2/98) to discuss his experiences of district CC services and other issues. Communicated further via letters (May 98) to clarify data queries. Met (1/9/98 and 9/9/98) to clarify data queries, obtain further data and to obtain his feedback on the conceptual model. Met to present simulation model and illustrative model output, and to discuss calibration of simulation model (6/8/99 and 21/8/99).
Hospital Manager	Liaised on several occasions by telephone with regard to the procurement of hospital data.

C2d. Purchasers/Commissioners

HA = Health Authority. HA1, HA2 and HA3 are the local purchasers for Heartwick, Veinbridge and Ribsley Hospitals respectively. HA4 is another purchaser of services from Heartwick Hospital.

Position	**Nature of Contact**
Purchaser, HA1	Telephone conversation (22/7/97) of a general nature.
Purchaser, HA2	Interviewed (18/6/98) to discuss his experiences of district CC services. Interview was tape-recorded.
Purchaser, HA2	Interviewed (18/6/98) to discuss her experiences of district CC services. Interview was tape-recorded.
Purchaser, HA3	Interviewed (17/7/97) to discuss her experiences of district CC services, and to obtain her response to the CC and other causal hypotheses. Interview was tape-recorded.
Purchaser, HA4	Interviewed (18/7/98) to discuss her experiences of district CC services, and to obtain her response to the CC and other causal hypotheses. Tape-recorded interview.
Public Health Consultant, HA4	Interviewed (23/7/97) to discuss her experiences of district CC services, and to obtain her response to the CC and other causal hypotheses. Interview was tape-recorded.

C2e. Other Relevant Health Practitioner Contacts

Hospitals X, Y and Z refer to other hospitals

Position	**Nature of Contact**
Business Manager, Cardiocare	Interviewed (17/8/98) to discuss his experiences of district CC services and to place the experiences of Veinbridge and Ribsley Hospitals in a broader context. Tape-recorded interview.
Operations Manager, Cardiocare	Liaised on several occasions by telephone with regard to the procurement of audit data.
Consultant Cardiologist, Hospital X	Interviewed (11/2/96) to discuss general issues including his experiences of district CC services. Clarified further issues by telephone (7/1/98).
Consultant Cardiologist, Hospital Y	Interviewed (19/10/98) to discuss his use of a scoring system which enables him to systematically identify high risk patients for catheterisation. Also visited his catheter laboratory and spoke informally to several of his colleagues.

Dr Clare Phillips, Specialist Clinical Services, Department of Health	Telephone conversations (3/11/97 and 5/11/97) to obtain a government perspective on several clinical initiatives including the development of district CC services.
Hospital Manager, Hospital Z	Interviewed (16/7/98 and 14/8/97) to discuss her experiences of district CC services, and to obtain her response to the CC and other hypotheses. Tape-recorded interviews.

C3. Sources and Quality of the Numerical Data

Organisation	**Databases**
Heartwick Hospital	Numerical (hospital), written and mental databases
Ribsley General	Numerical (CC waiting list) and mental databases
Veinbridge General	Numerical (CC and hospital) databases, mental database
Cardiocare	Numerical database

The collaborators were very accommodating in providing access to data. However, several problems were encountered concerning the acquisition of useful numerical data. According to the experiences of other modellers, which are documented in the literature, these data problems are not unusual.

Some of the requested data was unavailable as it was not routinely collected, lost or aggregated with other data. Only one of the DGHs held a database on the CC waiting list with dates of patients joining and leaving the waiting list. For the other DGH, such information was contained within the patients' notes which were not accessed. Some data was unreliable. Sometimes the actual levels of hospital activity had been under-recorded. This became apparent when the data was cross-checked against data from other numerical databases or when collaborative feedback was sought. Some data was subsequently disregarded completely. Some of these could be replaced with data from more reliable sources and sources were used to augment existing data which under-recorded activity. Inaccuracies were also revealed in the disaggregation of data which was attributed to inconsistencies in data input. It has been suggested in the literature that waiting list data are unreliable as referral rates adjust to reduce waiting lists and thus 'mask' the true extent of patients who are waiting for hospital services. Therefore, it might be concluded that the analysis of waiting lists and waiting times should be avoided. However, the consideration of these factors is essential, as this demand response is an important feature of interest in the study. There was also fragmentation of data sources and inconsistencies arose when data was cross-checked and aggregated, as these data were collected for different purposes. Minor adjustments were made to overcome these problems.

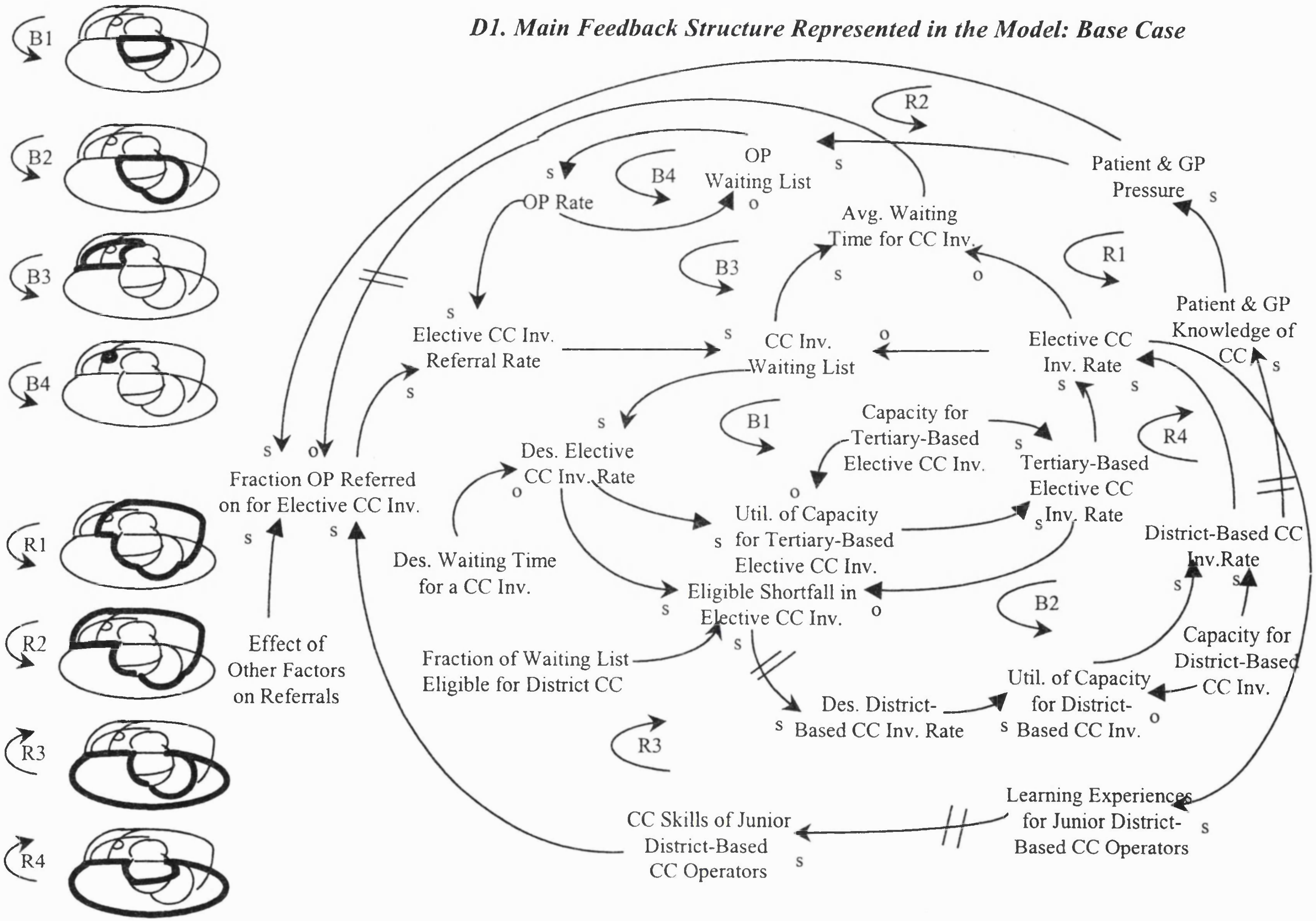
APPENDIX D - CONCEPTUAL MODEL

D1. Main Feedback Structure Represented in the Model: Base Case

D2. Potential Interactions Between Active Feedback Loops

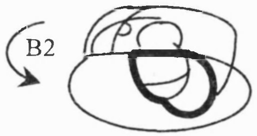
D3. Main Feedback Structure Represented in the Model: With a Structural Change

D1. Main Feedback Structure Represented in the Model: Base Case



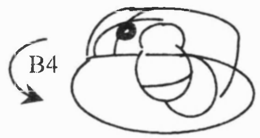
D2. Potential Interactions Between Active Feedback Loops

Adjustments in Tertiary-Based Elective CC Inv. Rate

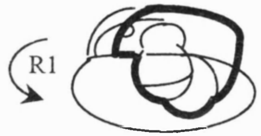


Adjustments in District-Based CC Inv. Rate

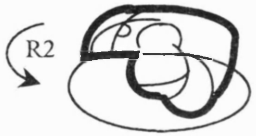
Changes in Waiting Time Effect on Demand for a CC Inv.



Adjustments in OP Rate



Changes in Knowledge Effect on Demand for an OP Appt

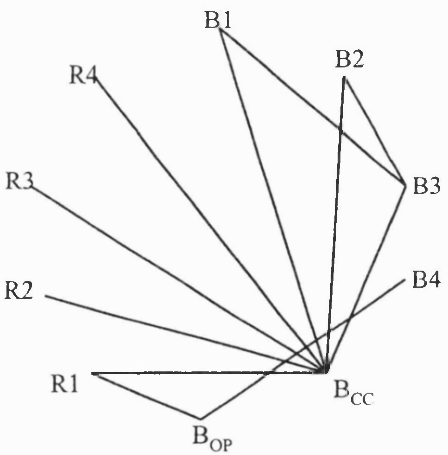


Changes in Knowledge Effect on Demand for a CC Inv.

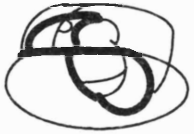
Changes in Gain of District-Based CC Operator Skill at the District Level

Changes in Gain of District-Based CC Operator Skill at the Tertiary Level

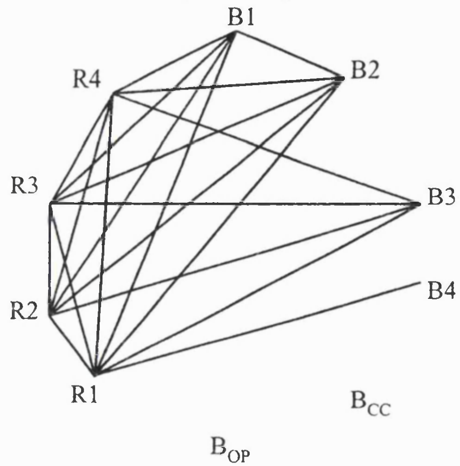
1. Loops Driving Each Other Exogenously



e.g. B2 & B3

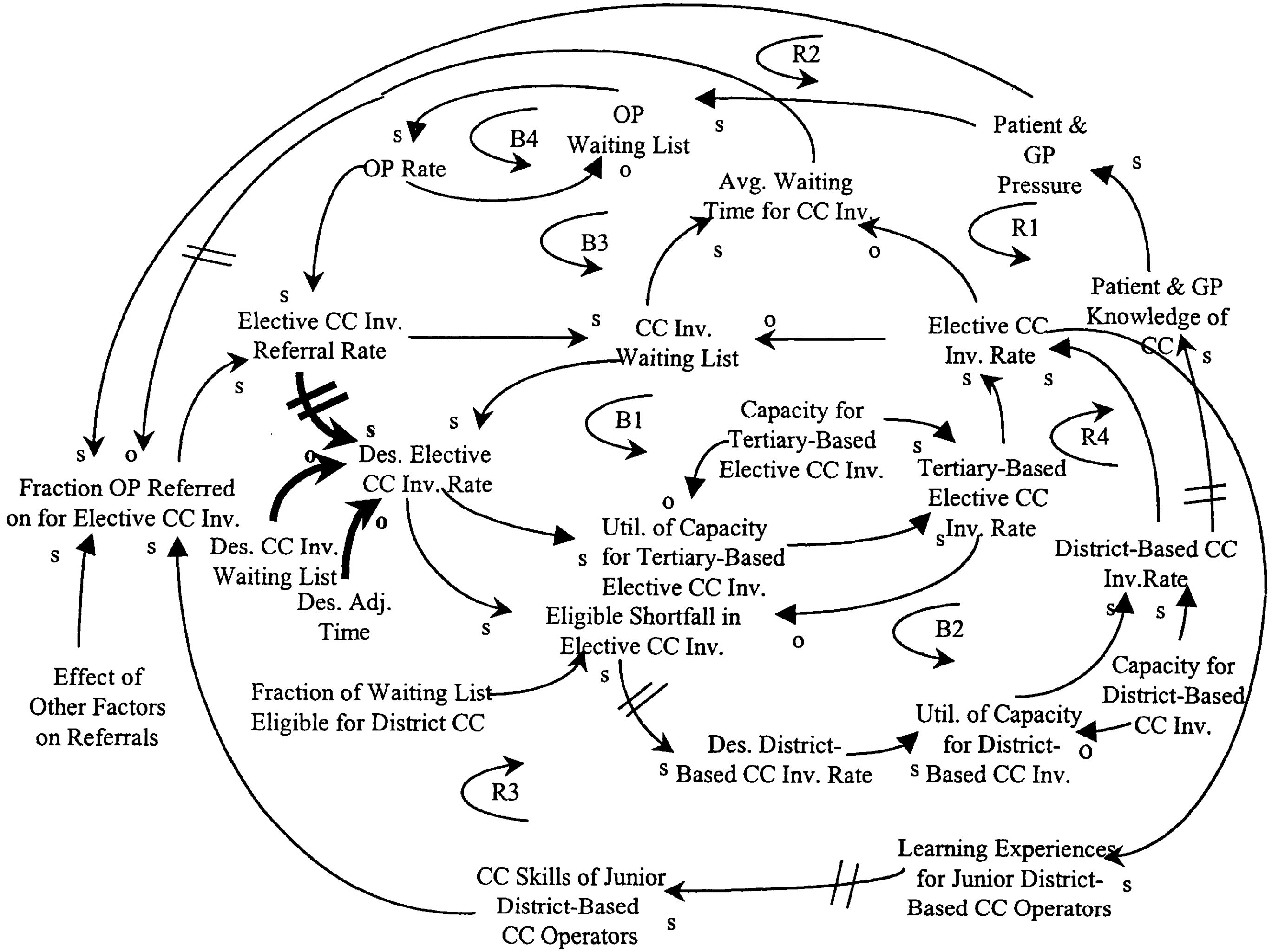


2. Loops Sharing Causal Links



e.g. B3 & R3

D3. Main Feedback Structure Represented in the Model: With a Structural Change



D3 depicts the use of a waiting list goal to drive patient activity rates. As with D1, which portrays the desired waiting time driving activity rates (a base case assumption), both the referrals onto the CC investigation waiting list from inpatients and 'other' removals from the waiting list (those which did not constitute patient activity such as deaths on the waiting list) are excluded for simplicity. When seeking a desired waiting list, the desired elective CC investigation rate is composed of two parts. The first part is the investigation rate required to maintain the existing waiting list size. The investigation rate should at least equal the perceived referral rate in order to ensure that the waiting list does not rise further. The second part represents the adjustment required in order to bring the waiting list down to its desired level. The calculation corresponding to D3 is:

$$\text{Des. Elective CC Inv. Rate} = \text{Average Elective CC Inv. Referral Rate} + \frac{(\text{CC Inv. Waiting List - Des. CC Inv. Waiting List})}{\text{Des. Adj Time}}$$

The calculation corresponding to D1 where a desired waiting time is sought is:

$$\text{Des. Elective CC Inv. Rate} = \frac{\text{CC Inv. Waiting List}}{\text{Des. Waiting Time for a CC Inv.}}$$

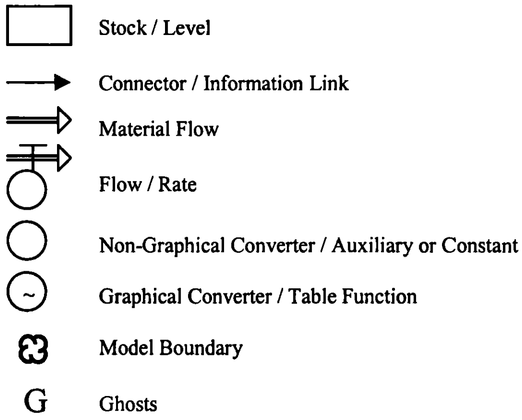
In calculating the desired investigation rate, seeking a desired waiting list used information about the referral rate; this information was not used when seeking a desired waiting time. Information about the current size of the waiting list was also used in a different way in the former compared to the latter. The introduction of the causal link between the average referral rate and desired investigation rate created several further feedback processes (these processes are not highlighted in D3).

The calculations that featured in the simulation model were more complex as they accounted for the inclusion of the inpatient referrals and non-activity removals. The formulation of the model equations also ensured that the desired investigation rate did not exceed the number of patients available i.e. it did not drive the waiting list below zero. The calculations for the desired OP activity rate followed the same principle as those for the desired elective CC investigation rate.

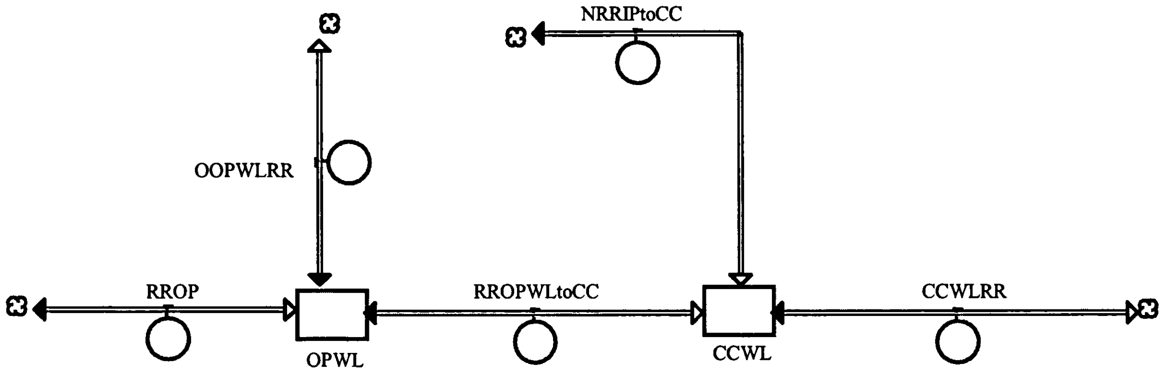
APPENDIX E - SIMULATION MODEL AND CALCULATIONS

E1. Stock and Flow Diagrams

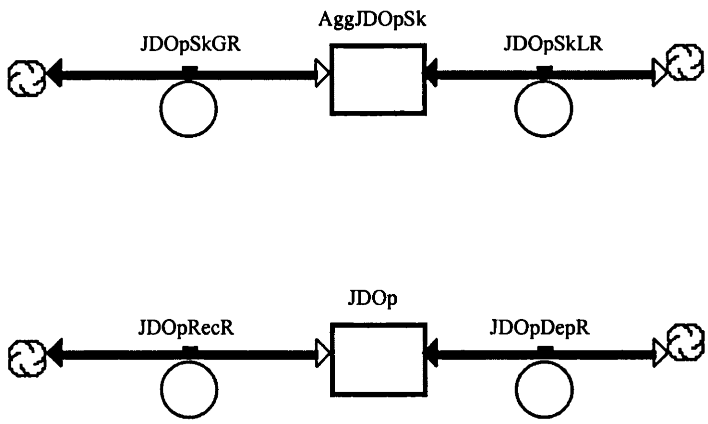
Symbols Used in Stock and Flow Diagrams



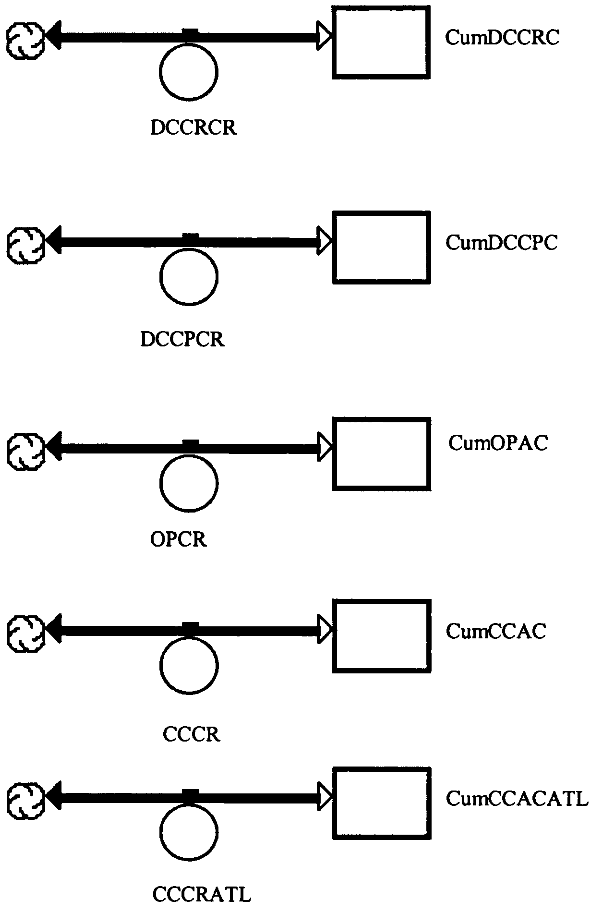
E1a. Key Flows



Key Patient Flows

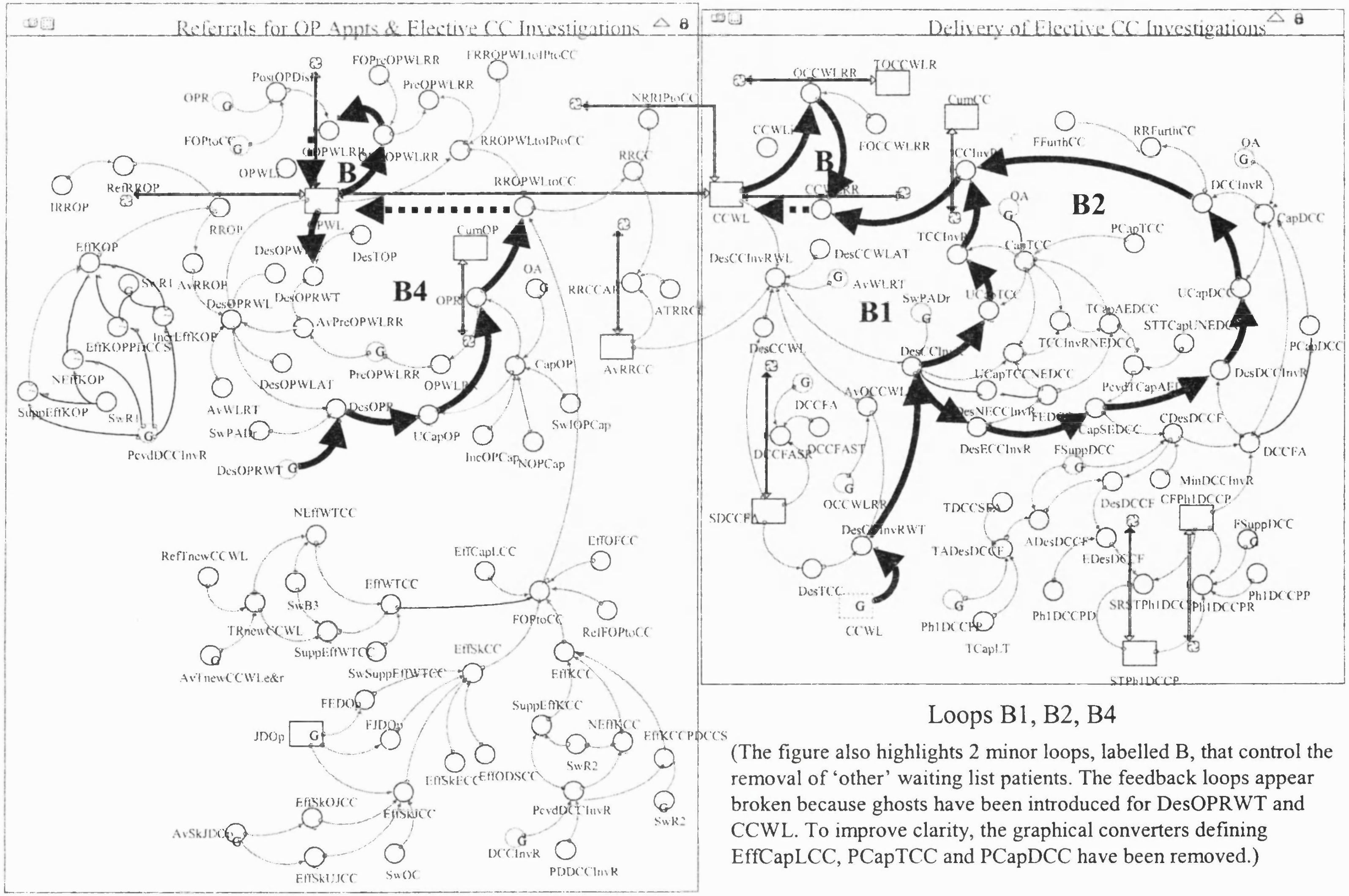


Skills Flows


CumDCCRC
DCCRCR
CumDCCPC
DCCPCR
CumOPAC
OPCR
CumCCAC
CCCR
CumCCACATL
CCCRATL

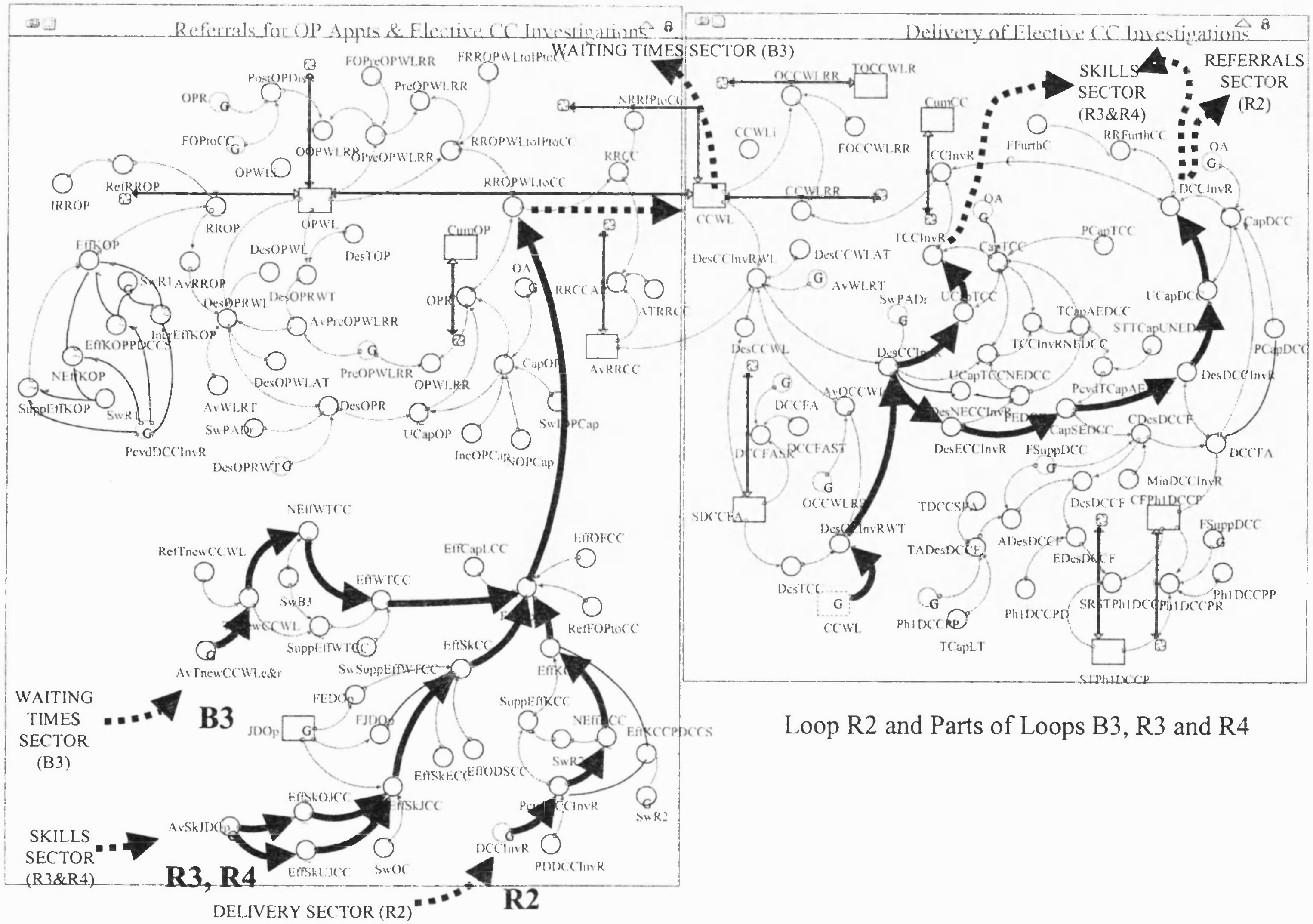
Cost Flows

E1b. Representation of Main Feedback Loops

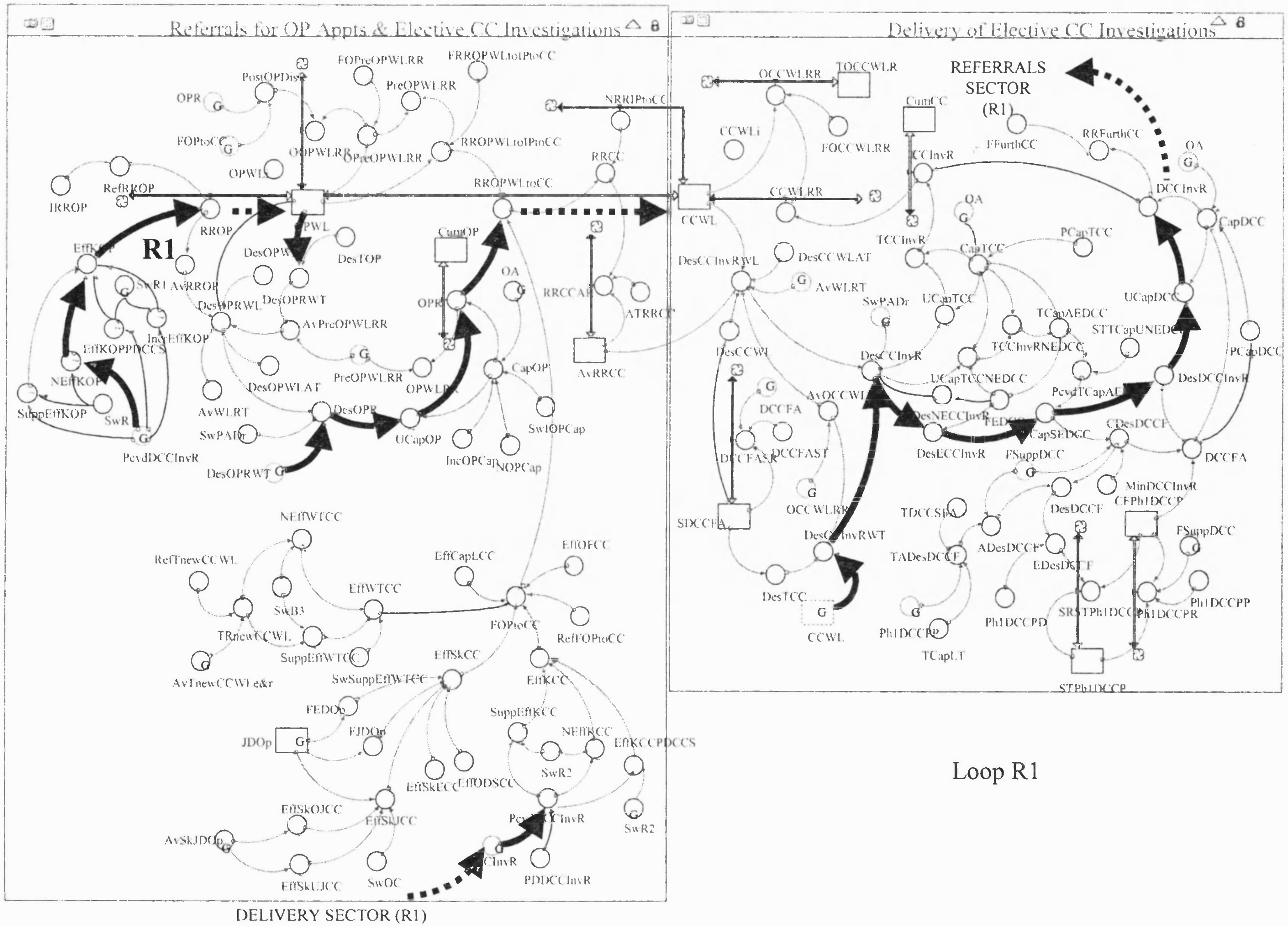


Loops B1, B2, B4

(The figure also highlights 2 minor loops, labelled B, that control the removal of 'other' waiting list patients. The feedback loops appear broken because ghosts have been introduced for DesOPRWT and CCWL. To improve clarity, the graphical converters defining EffCapLCC, PCapTCC and PCapDCC have been removed.)

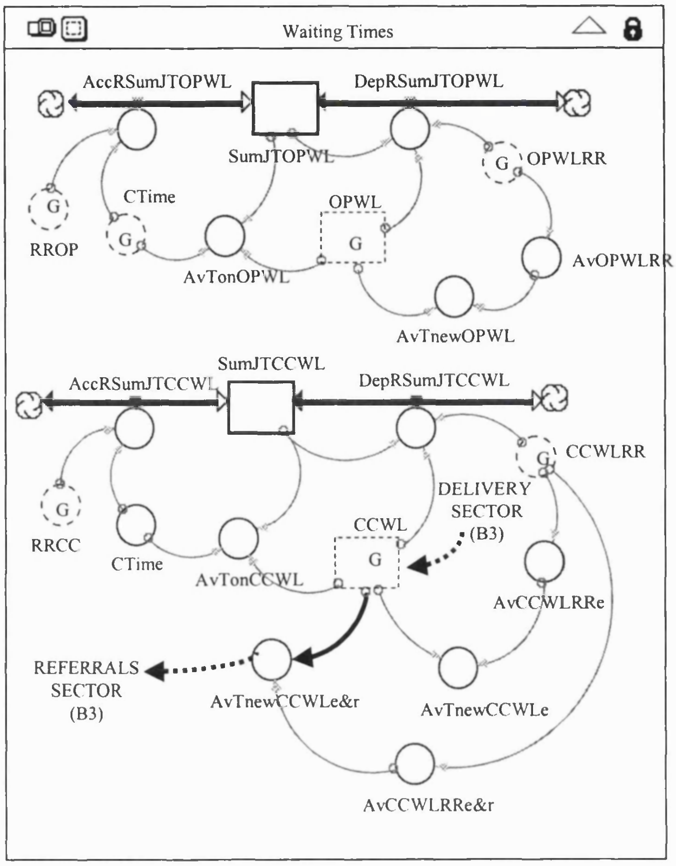


Loop R2 and Parts of Loops B3, R3 and R4

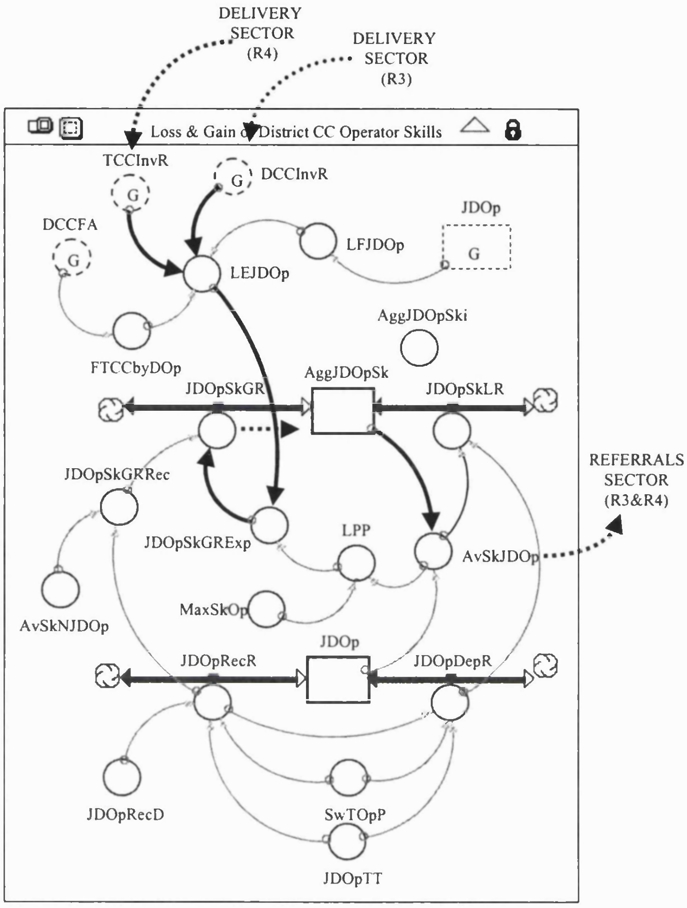

Referrals for OP Appts & Elective CC Investigations
Delivery of Elective CC Investigations
REFERRALS SECTOR (R1)
R1
DELIVERY SECTOR (R1)

Loop R1

Remaining Links of Loop B3



Remaining Links of Loops R3 and R4



E2. Documented Listings of Simulation Model Equations

DT = 0.125

Duration of simulation = 54 months (Ribsley General case), 72 months (Veinbridge General case)

The equations are listed in the following order:

1. Stocks (levels) listed alphabetically, with their corresponding flows (rates)
2. Non-graphical convertors (constants and auxiliaries), listed alphabetically
3. Graphical convertors (table functions), listed alphabetically

E2a. Model Equations Parameterised to the Ribsley General Case

AggJDOpSk(t) = AggJDOpSk(t - dt) + (JDOpSkGR - JDOpSkLR) * dt

INIT AggJDOpSk = AggJDOpSki

DOCUMENT: Aggregate junior district-based CC operator skill [skill units].

It is assumed that in April 1995, the junior operator at that time will have accumulated sufficient skills in CC to have almost saturated the 'skills effect' on referrals for CC investigations. The initial value is based on the following assumptions: historical elective CC investigation activity levels at the tertiary level equal the level at April 1995 (11.75/mth), and junior district operator fraction equal to 0.75.

JDOpSkGR = 1*(JDOpSkGRRec+JDOpSkGRExp)+0*PULSE(1000,10,0)

DOCUMENT: Junior district-based CC operator skills gain rate [skill units/mth].

JDOpSkLR = JDOpDepR*AvSkJDOp+0*PULSE(1000,10)

DOCUMENT: Junior district-based CC operator skills loss rate [skill units/mth].

AvRRCC(t) = AvRRCC(t - dt) + (RRCCAR) * dt

INIT AvRRCC = 18.69

DOCUMENT: Average rate of referrals for an elective CC investigation [pats/mth].

RRCCAR = (RRCC-AvRRCC)/ATRRCC

DOCUMENT: Referral rate for an elective CC investigation averaging rate [pats/mth/mth].

CCWL(t) = CCWL(t - dt) + (RROPWLtoCC + NRRIPtoCC - CCWLRR) * dt

INIT CCWL = CCWLi

DOCUMENT: CC investigation waiting list length [pats].

Initialised at the Apr 95 (t=0) level using real data (with some patients removed) plus an expert estimate of the other waiting list removals (deaths on waiting list etc).

RROPWLtoCC = OPR*FOPtoCC+RROPWLtoIPtoCC

DOCUMENT: Rate of referrals from OP waiting list to an elective CC investigation [pats/mth].

Comprises patients who were referred on after attending an OP appointment and patients who, waiting for an OP appointment, deteriorated and were referred on following a hospital admission.

NRRIPtoCC = 1*5.5*(1-0*Step(1,20))+0*PULSE(1000,10,0)

DOCUMENT: New referral rate from inpatients to an elective CC investigation [pats/mth].

Prior to hospital admission, these patients may have been: asymptomatic; symptomatic but the patient may not have yet sought medical treatment for their symptoms; or, symptomatic and under GP care. This may also include patients who were in hospital receiving non cardiac treatment. "New" refers to patients not already known to the cardiologists. This excludes: (1) those who were on the OP waiting list, deteriorated, stabilised and were then placed on the CC investigation waiting list (these are already accounted for in the referrals from the OP waiting list, RROPWLtoCC) and (2) patients who are already on the CC investigation waiting list but have deteriorated, become hospital admissions and restabilised (as they will remain classified as in need of an elective CC investigation, they are already included on the CC investigation waiting list, CCWL). The value is derived from an expert estimate (6.5 pats/mth) for the total referrals from inpatients i.e. including (1) but excluding (2). It is assumed that (2) will form the minority of the total referrals from inpatients. The validity of the split in the referrals from inpatients is not important, given the purpose of our study.

CCWLRR = CCInvR+OCCWLRR

DOCUMENT: CC investigation waiting list removal rate [pats/mth].

CFPh1DCCP(t) = CFPh1DCCP(t - dt) + (Ph1DCCPR) * dt

INIT CFPh1DCCP = 0

DOCUMENT: Completed fraction of phase 1 district CC service preparation (completed fraction of a basic district site) [-].

A district service can be provided by hiring a mobile catheter laboratory. However, a suitable site has to be prepared for the mobile. "Site" refers to the base upon which the mobile is situated (it has to be perfectly level and able to withstand the considerable weight of the mobile) and the electrical and telecommunication links to connect the mobile to the host hospital. At a later stage, the mobile may be replaced by an integrated catheter laboratory. The mobile would be used whilst the integrated lab was being constructed so the construction of the lab and associated delays would not need to be represented in the model but the associated financial costs would. In the model, the different phases of district service are referred to as Phase 1 (using a mobile) and Phase 2 (using an integrated catheter lab) and the site for the mobile is referred to as a "basic" district site.

Ph1DCCPR = FSuppDCC*(IF ((TIME>=STPh1DCCP) AND (CFPh1DCCP<1)) THEN (1/Ph1DCCPP) ELSE 0)

DOCUMENT: Phase 1 district CC service preparation rate [-/mth].

Having set the preparation of a basic district site and facility to begin, preparation occurs until the site and facility are complete. It relies upon continual financial support for the district service; if financial support were withdrawn, development would be suspended.

CumCC(t) = CumCC(t - dt) + (CCInvR) * dt

INIT CumCC = 0

DOCUMENT: Cumulative elective CC investigations [pats].

CCInvR = DCCInvR+TCCInvR

DOCUMENT: Elective CC investigation rate [pats/mth].

Overall elective CC investigations at tertiary and district levels for patients referred from a given district hospital. For those conducted at the tertiary level, may also involve synchronous treatment.

CumCCAC(t) = CumCCAC(t - dt) + (CCCR) * dt

INIT CumCCAC = 0

DOCUMENT: Cumulative CC activity costs [pounds].

Cumulative costs of CC investigations, for patients from a given district hospital. CC investigations conducted at the tertiary level may also involve synchronous investigation and intervention (treatment) which will be more expensive than a CC intervention. This is one of several several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total CC investigation activity costs generated over time by considering the area under the CC investigation rate curve.

CCCR = AvCTCC*TCCInvR+(AvCDCC+FFurthCC*AvCFurthCC)*DCCInvR

DOCUMENT: CC activity cost rate [pounds/pat].

Refers to costs of CC procedures for patients originally referred for an elective CC investigation from a given district hospital so refers to CC investigations and treatments.

CumCCACATL(t) = CumCCACATL(t - dt) + (CCCRATL) * dt

INIT CumCCACATL = 0

DOCUMENT: Cumulative CC activity costs if all activity were carried out at the tertiary level [pounds].

CCCRATL = (DCCInvR+TCCInvR)*AvCTCC

DOCUMENT: CC activity cost rate if all were carried out at the tertiary level [pounds/pat].

This is what the CC cost rate would be if the total elective activity were conducted at the tertiary level, assuming the same (district+tertiary) capacity could be achieved at the tertiary level.

CumCCWLAdds(t) = CumCCWLAdds(t - dt) + (CCWLAddR) * dt

INIT CumCCWLAdds = 0

DOCUMENT: Cumulative CC waiting list additions [pats].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of referrals for elective CC investigations by considering the area under the CC investigation referral rate curve.

CCWLAddR = NRRIPtoCC+RROPWLtoCC

DOCUMENT: CC waiting list addition rate [pats/mth]

CumCCWLRems(t) = CumCCWLRems(t - dt) + (CCWLRemR) * dt

INIT CumCCWLRems = 0

DOCUMENT: Cumulative CC waiting list removals [pats]

CCWLRemR = CCWLRR

DOCUMENT: CC waiting list removal rate [pats/mth]

CumDCCPC(t) = CumDCCPC(t - dt) + (DCCPCR) * dt

INIT CumDCCPC = 0

DOCUMENT: Cumulative district CC service preparation costs [pounds].

DCCPCR = Ph1DCCPMCR+Ph2DCCPMCR

DOCUMENT: District CC service preparation cost rate [pounds/mth].

Phase 1 refers to the costs incurred to prepare a site for a mobile-based district service. Phase 2 refers to the costs incurred to prepare a site and construct a facility for an integrated cath lab-based district service.

CumDCCRC(t) = CumDCCRC(t - dt) + (DCCRCR) * dt

INIT CumDCCRC = 0

DOCUMENT: Cumulative district CC service running costs [pounds].

DCCRCR = IF(DCCInvR>0) THEN MDCCRCR ELSE 0

DOCUMENT: District CC service running cost rate [pounds/mth].

These costs are not incurred until the district service is up and running.

CumGJDOpSk(t) = CumGJDOpSk(t - dt) + (GRJDOpSk) * dt

INIT CumGJDOpSk = 0

DOCUMENT: Cumulative gain in junior district-based CC operator skills [skill units]

GRJDOpSk = JDOpSkGR

DOCUMENT: Gain rate of junior district-based CC operator skills [skill units/mth]

CumLJDOpSk(t) = CumLJDOpSk(t - dt) + (LRJDOpSk) * dt

INIT CumLJDOpSk = 0

DOCUMENT: Cumulative loss in junior district-based CC operator skills [skill units]

LRJDOpSk = JDOpSkLR

DOCUMENT: Loss rate of junior district-based CC operator skills [skill units/mth]

CumOP(t) = CumOP(t - dt) + (OPR) * dt

INIT CumOP = 0

DOCUMENT: Cumulative OP activity [pats].

OPR = CapOP*UCapOP

DOCUMENT: OP rate [pats/mth].

Desired activity which can be delivered depends upon the capacity available and utilisation of that capacity.

CumOPAC(t) = CumOPAC(t - dt) + (OPCR) * dt

INIT CumOPAC = 0

DOCUMENT: Cumulative OP activity costs [pounds].

Cumulative costs of OP appointments, for patients from a given district hospital. This is one of several several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total OP activity costs generated over time by considering the area under the OP rate curve.

OPCR = AvCOP*OPR

DOCUMENT: OP cost rate [pounds/pat].

CumOPWLAdds(t) = CumOPWLAdds(t - dt) + (OPWLAddR) * dt

INIT CumOPWLAdds = 0

DOCUMENT: Cumulative OP waiting list additions [pats].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of referrals for OP appointments over time by considering the area under the OP referral rate curve.

OPWLAddR = RROP

DOCUMENT: OP waiting list addition rate [pats/mth]

CumOPWLRems(t) = CumOPWLRems(t - dt) + (OPWLRemR) * dt

INIT CumOPWLRems = 0

DOCUMENT: Cumulative OP waiting list removals [pats]

OPWLRemR = OOPWLRR+RROPWLtoCC

DOCUMENT: OP waiting list removal rate [pats/mth]

DECCWL(t) = DECCWL(t - dt) + (GRDECCWL) * dt

INIT DECCWL = 0

DOCUMENT: Duration of excessive CC investigation waiting list [mths]

Total time for which the CC investigation waiting list exceeded its desired value.

GRDECCWL = IF ((CCWL-DesCCWL)>0.5) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive CC investigation waiting list [mths/mth].

DEOPWL(t) = DEOPWL(t - dt) + (GRDEOPWL) * dt

INIT DEOPWL = 0

DOCUMENT: Duration of excessive OP waiting list [mths]

Total time for which the OP waiting list exceeded its desired value.

GRDEOPWL = IF ((OPWL-DesOPWL)>0.5) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive OP waiting list [mths/mth].

DETnewCCWL(t) = DETnewCCWL(t - dt) + (GRDETnewCCWL) * dt

INIT DETnewCCWL = 0

DOCUMENT: Duration of excessive average estimated waiting time for new CC investigation waiting list patients [mths]

Total time for which the average estimated waiting time for new CC investigation waiting list patients exceeded its desired value.

GRDETnewCCWL = IF ((AvTnewCCWLe-DesTCC)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive average estimated waiting time for new CC investigation waiting list patients [mths/mth]

DETnewOPWL(t) = DETnewOPWL(t - dt) + (GRDETnewOPWL) * dt

INIT DETnewOPWL = 0

DOCUMENT: Duration of excessive average estimated waiting time for new OP waiting list patients [mths]

Total time for which the average estimated waiting time for new OP waiting list patients exceeded its desired value.

GRDETnewOPWL = IF ((AvTnewOPWL-DesTOP)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive average estimated waiting time for new OP waiting list patients [mths/mth]

DETonCCWL(t) = DETonCCWL(t - dt) + (GRDETonCCWL) * dt

INIT DETonCCWL = 0

DOCUMENT: Duration of excessive average time spent on CC investigation waiting list [mths]

Total time for which the average time spent on the CC investigation waiting list exceeded its desired value.

GRDETonCCWL = IF ((AvTonCCWL-DesTCC)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive time on CC investigation waiting list [mths/mth]

DETonOPWL(t) = DETonOPWL(t - dt) + (GRDETonOPWL) * dt

INIT DETonOPWL = 0

DOCUMENT: Duration of excessive average time spent on OP waiting list [mths]

Total time for which the average time spent on the OP waiting list exceeded its desired value.

GRDETonOPWL = IF ((AvTonOPWL-DesTOP)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive time on OP waiting list [mths/mth].

DStDCC(t) = DStDCC(t - dt) + (GRDemStDCC) * dt

INIT DStDCC = 0

DOCUMENT: Duration of stimulated demand for CC investigation [mths]

GRDemStDCC = IF ((FOPtoCC/(RefFOPtoCC*EffSkCC)-1)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of stimulated demand for CC investigation [mths/mth].

Demand can only be suppressed by the skills effect.

DStDemOP(t) = DStDemOP(t - dt) + (GRDemStDOP) * dt

INIT DStDemOP = 0

DOCUMENT: Duration of stimulated demand for OP appointment [mths]

GRDemStDOP = IF ((EffKOP-1)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of stimulated demand for OP appointment [mths/mth]

JDOp(t) = JDOp(t - dt) + (JDOpRecR - JDOpDepR) * dt

INIT JDOp = 1

DOCUMENT: Number of junior district-based CC operators [doctors].

JDOpRecR = SwTOpP*PULSE(1,6+JDOpRecD,JDOpTT+JDOpRecD)

DOCUMENT: Junior district-based CC operator recruitment rate [doctors/mth].

There is no need to synchronise the recruitment of district operator trainees with the availability of the district service. The district operator trainees refer to junior cardiologists-in-training who are based at the district hospital. In the absence of a district service, they acquire skills in delivering CC at the tertiary centre.

JDOpDepR = SwTOpP*(PULSE(1,6,999)+DELAY(JDOpRecR,JDOpTT,0))

DOCUMENT: Junior district-based CC operator departure rate [doctors/mth].

When trainee operators complete their training at the district hospital, they move on to another hospital and the trainee vacancy which subsequently arises is subsequently filled with a new novice trainee.

MaxCCWL(t) = MaxCCWL(t - dt) + (SRMaxCCWL) * dt

INIT MaxCCWL = 0

DOCUMENT: Maximum CC investigation waiting list [pats]

SRMaxCCWL = IF (CCWL>MaxCCWL) THEN PULSE(CCWL-MaxCCWL) ELSE 0

DOCUMENT: Set rate of maximum CC investigation waiting list [pats/mth]

MaxOPWL(t) = MaxOPWL(t - dt) + (SRMaxOPWL) * dt

INIT MaxOPWL = 0

DOCUMENT: Maximum OP waiting list [pats]

SRMaxOPWL = IF (OPWL>MaxOPWL) THEN PULSE(OPWL-MaxOPWL) ELSE 0

DOCUMENT: Set rate of Maximum OP waiting list [pats/mth]

MaxRRCC(t) = MaxRRCC(t - dt) + (SRMaxRRCC) * dt

INIT MaxRRCC = 0

DOCUMENT: Maximum referral rate for elective CC investigation [pats/mth]

SRMaxRRCC = IF (RRCC>MaxRRCC) THEN PULSE(RRCC-MaxRRCC) ELSE 0

DOCUMENT: Set rate of maximum referral rate for elective CC investigation set rate [pats/mth/mth]

MaxRROP(t) = MaxRROP(t - dt) + (SRMaxRROP) * dt

INIT MaxRROP = 0

DOCUMENT: Maximum referral rate for OP appointment [pats/mth]

SRMaxRROP = IF (RROP>MaxRROP) THEN PULSE(RROP-MaxRROP) ELSE 0

DOCUMENT: Set rate of maximum referral rate for OP appointment [pats/mth/mth]

MaxTnewCCWL(t) = MaxTnewCCWL(t - dt) + (SRMaxTnewCCWL) * dt

INIT MaxTnewCCWL = 0

DOCUMENT: Maximum average estimated waiting time for new CC investigation waiting list patients [mths]

SRMaxTnewCCWL = IF (AvTnewCCWLe>MaxTnewCCWL) THEN PULSE(AvTnewCCWLe-MaxTnewCCWL) ELSE 0

DOCUMENT: Set rate of maximum average estimated waiting time for new CC investigation waiting list patients [mths/mth]

MaxTnewOPWL(t) = MaxTnewOPWL(t - dt) + (SRMaxTnewOPWL) * dt

INIT MaxTnewOPWL = 0

DOCUMENT: Maximum average estimated waiting time for new OP waiting list patients [mths]

SRMaxTnewOPWL = IF (AvTnewOPWL>MaxTnewOPWL) THEN PULSE(AvTnewOPWL-MaxTnewOPWL) ELSE 0

DOCUMENT: Set rate of maximum average estimated waiting time for new OP waiting list patients [mths/mth]

MaxTonCCWL(t) = MaxTonCCWL(t - dt) + (SRMaxTonCCWL) * dt

INIT MaxTonCCWL = 0

DOCUMENT: Maximum average time spent on CC investigation waiting list [mths]

SRMaxTonCCWL = IF (AvTonCCWL>MaxTonCCWL) THEN PULSE(AvTonCCWL-MaxTonCCWL) ELSE 0

DOCUMENT: Set rate of maximum average time spent on CC investigation waiting list [mths/mth]

MaxTonOPWL(t) = MaxTonOPWL(t - dt) + (SRMaxTonOPWL) * dt

INIT MaxTonOPWL = 0

DOCUMENT: Maximum average time spent on OP waiting list [mths]

SRMaxTonOPWL = IF (AvTonOPWL>MaxTonOPWL) THEN PULSE(AvTonOPWL-MaxTonOPWL) ELSE 0

DOCUMENT: Set rate of maximum average time spent on OP waiting list [mths/mth]

MinCCWL(t) = MinCCWL(t - dt) + (SRMinCCWL) * dt

INIT MinCCWL = 1000

DOCUMENT: Minimum CC investigation waiting list [pats]

SRMinCCWL = IF (CCWL<MinCCWL) THEN PULSE(CCWL-MinCCWL) ELSE 0

DOCUMENT: Set rate of minimum CC investigation waiting list [pats/mth]

MinOPWL(t) = MinOPWL(t - dt) + (SRMinOPWL) * dt

INIT MinOPWL = 1000

DOCUMENT: Minimum OP waiting list [pats]

SRMinOPWL = IF (OPWL<MinOPWL) THEN PULSE(OPWL-MinOPWL) ELSE 0

DOCUMENT: Set rate of minimum OP waiting list set rate [pats/mth]

MinRRCC(t) = MinRRCC(t - dt) + (SRMinRRCC) * dt
INIT MinRRCC = 1000
DOCUMENT: Minimum referral rate for elective CC investigation [pats/mth]
SRMinRRCC = IF (RRCC<MinRRCC) THEN PULSE(RRCC-MinRRCC) ELSE 0
DOCUMENT: Set rate of minimum referral rate for elective CC investigation [pats/mth/mth]

MinRROP(t) = MinRROP(t - dt) + (SRMinRROP) * dt
INIT MinRROP = 1000
DOCUMENT: Minimum referral rate for OP appointment [pats/mth]
SRMinRROP = IF (RROP<MinRROP) THEN PULSE(RROP-MinRROP) ELSE 0
DOCUMENT: Set rate of minimum referral rate for OP appointment [pats/mth/mth]

MinTnewCCWL(t) = MinTnewCCWL(t - dt) + (SRMinTnewCCWL) * dt
INIT MinTnewCCWL = 1000
DOCUMENT: Minimum average estimated waiting time for new CC investigation waiting list patients [mths]
SRMinTnewCCWL = IF (AvTnewCCWLe<MinTnewCCWL) THEN PULSE(AvTnewCCWLe-MinTnewCCWL) ELSE 0
DOCUMENT: Set rate of minimum average estimated waiting time for new CC investigation waiting list patients [mths/mth]

MinTnewOPWL(t) = MinTnewOPWL(t - dt) + (SRMinTnewOPWL) * dt
INIT MinTnewOPWL = 1000
DOCUMENT: Minimum average estimated waiting time for new OP waiting list patients [mths]
SRMinTnewOPWL = IF (AvTnewOPWL<MinTnewOPWL) THEN PULSE(AvTnewOPWL-MinTnewOPWL) ELSE 0
DOCUMENT: Set rate minimum average estimated waiting time for new OP waiting list patients [mths/mth]

MinTonCCWL(t) = MinTonCCWL(t - dt) + (SRMinTonCCWL) * dt
INIT MinTonCCWL = 1000
DOCUMENT: Minimum average time spent on CC investigation waiting list [mths]
SRMinTonCCWL = IF (AvTonCCWL<MinTonCCWL) THEN PULSE(AvTonCCWL-MinTonCCWL) ELSE 0
DOCUMENT: Set rate of minimum average time spent on CC investigation waiting list [mths/mth]

MinTonOPWL(t) = MinTonOPWL(t - dt) + (SRMinTonOPWL) * dt
INIT MinTonOPWL = 1000
DOCUMENT: Minimum average time spent on OP waiting list [mths]

SRMinTonOPWL = IF (AvTonOPWL<MinTonOPWL) THEN PULSE(AvTonOPWL-MinTonOPWL) ELSE 0
DOCUMENT: Set rate of minimum average time spent on OP waiting list [mths/mth]

OPWL(t) = OPWL(t - dt) + (RROP - RROPWLtoCC - OOPWLRR) * dt
INIT OPWL = OPWLi
DOCUMENT: OP waiting list length [pats].
All references to OP refer to cardiology OP.
We assume that there is sufficient capacity for OP services so that the actual OP activity equals the desired OP activity (quoted by the consultant at 80 pats/week), and the avg waiting time list for new patients joining the OP waiting list is maintained (quoted by the consultant at 5 weeks). Taking into account the other OP waiting list removals (as estimated by the consultant), the initial waiting list size is calculated.
RROP = 1*RefRROP*EffKOP+0*PULSE(1000,10,0)
DOCUMENT: Referral rate for an OP appointment [pats/mth].
RROPWLtoCC = OPR*FOPtoCC+RROPWLtoIPtoCC
DOCUMENT: Rate of referrals from OP waiting list to an elective CC investigation [pats/mth].
Comprises patients who were referred on after attending an OP appointment and patients who, waiting for an OP appointment, deteriorated and were referred on following a hospital admission.
OOPWLRR = PostOPDisR+OPreOPWLRR
DOCUMENT: Other OP waiting list removal rate [pats/mth].
Refers to OP waiting list removals "other" than those who were referred on for elective CC investigation. Comprises post OP discharges and pre OP appt removals from the waiting list. The latter collectively refers to waiting list deaths, patients whose condition improved, moved away from the area, condition deteriorated and became emergencies or left NHS to seek private care.

PrSIECCWL(t) = PrSIECCWL(t - dt) + (GRPrSIECCWL) * dt
INIT PrSIECCWL = 0
DOCUMENT: Pressure summary index associated with an excessive CC investigation waiting list [pressure].
This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering the area under the CC investigation waiting list curve and a conversion factor. We assume that the waiting list will only exert pressure on the system if it exceeds its desired length.
GRPrSIECCWL = IF (CCWL>DesCCWL) THEN ((CCWL-DesCCWL)*RPrPP) ELSE 0
DOCUMENT: Gain rate of pressure summary index associated with excessive CC waiting list [pressure/mth]

PrSIEOPWL(t) = PrSIEOPWL(t - dt) + (GRPrSIEOPWL) * dt
INIT PrSIEOPWL = 0
DOCUMENT: Pressure summary index associated with an excessive OP waiting list [pressure].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering the area under the OP waiting list curve and a conversion factor. We assume that the waiting list will only exert pressure on the system if it exceeds its desired length.

GRPrSIEOPWL = IF (OPWL>DesOPWL) THEN ((OPWL-DesOPWL)*RPrPP) ELSE 0

DOCUMENT: Gain rate of pressure summary index associated with excessive OP waiting list [pressure/mth]

PrSIETonCCWL(t) = PrSIETonCCWL(t - dt) + (GRPrSIETonCCWL) * dt

INIT PrSIETonCCWL = 0

DOCUMENT: Pressure summary index associated with an excessive average time spent on the CC investigation waiting list [pressure].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering a conversion factor and the area under the curve for the average time spent on the CC investigation waiting list. We assume that the delay for a CC investigation will only exert pressure on the system if it exceeds its desired level.

GRPrSIETonCCWL = IF (AvTonCCWL>DesTCC) THEN ((AvTonCCWL-DesTCC)*RPrPM) ELSE 0

DOCUMENT: Gain rate of pressure summary index associated with excessive average time spent on CC investigation waiting list [pressure/mth]

PrSIETonOPWL(t) = PrSIETonOPWL(t - dt) + (GRPrSIETonOPWL) * dt

INIT PrSIETonOPWL = 0

DOCUMENT: Pressure summary index associated with an excessive average time spent on the OP waiting list [pressure].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering a conversion factor and the area under the curve for the average time spent on the OP waiting list. We assume that the delay for an OP appointment will only exert pressure on the system if it exceeds its desired level.

GRPrSIETonOPWL = IF (AvTonOPWL>DesTOP) THEN ((AvTonOPWL-DesTOP)*RPrPM) ELSE 0

DOCUMENT: Gain rate of pressure summary index associated with excessive average time spent on OP waiting list [pressure/mth]

SDCCFA(t) = SDCCFA(t - dt) + (DCCFASR) * dt

INIT SDCCFA = 0

DOCUMENT: Smoothed district CC facility availability [-].

The availability of the district facility will determine the values of the goals driving the desired CC investigation rate. As changes in availability will not lead to instantaneous changes in the goals, the availability is smoothed.

DCCFASR = (DCCFA-SDCCFA)/DCCFAST

DOCUMENT: Smoothing rate of district CC facility availability [-/mth].

STPh1DCCP(t) = STPh1DCCP(t - dt) + (SRSTPPh1DCC) * dt

INIT STPh1DCCP = 1000

DOCUMENT: Start time of phase 1 district CC service preparation [mths].

The default value of 1000 indicates that preparation of the district site will never take place.

SRSTPPh1DCC = IF ((CFPh1DCCP = 0) AND (EDesDCCF>=1) AND (STPh1DCCP=1000)) THEN PULSE(TIME-1000) ELSE 0

DOCUMENT: Start rate of start time of preparation of phase 1 district CC service [mths/mth].

District site preparation is initialised in instances where preparation has not yet taken place and there exists an expressed desire for a district facility (either an anticipated or current desire or both).

The formulation of the start time as a level ensures that the preparation of a new site can only be initialised once. This is because the model is only designed to represent a single district hospital so there can only be a single district site.

SumJTCCWL(t) = SumJTCCWL(t - dt) + (AccRSumJTCCWL - DepRSumJTCCWL) * dt

INIT SumJTCCWL = 3044.8

DOCUMENT: Sum of join times for patients on the CC investigation waiting list [pat.mths].

Used to calculate the average time spent on the waiting list for CC investigations, for patients from Ribsley General. Initialised so that this average waiting time is 2.4 months to correspond with the real system.

AccRSumJTCCWL = RRCC*CTime

DOCUMENT: Accumulation rate of sum of join times of patients on the CC investigation waiting list [pats].

Used to calculate the average time spent on the waiting list for CC investigations, for patients from a given district hospital.

DepRSumJTCCWL = IF(CCWL<>0) THEN (CCWLRR*SumJTCCWL/CCWL) ELSE 0

DOCUMENT: Depletion rate of sum of join times of patients on the CC investigation waiting list [pats].

Used to calculate the average time spent on the waiting list for CC investigations, for patients from a given district hospital.

SumJTOPWL(t) = SumJTOPWL(t - dt) + (AccRSumJTOPWL - DepRSumJTOPWL) * dt

INIT SumJTOPWL = 15198.79

DOCUMENT: Sum of join times for patients on the OP waiting list [pat.mths].

Used to calculate the average time spent on the waiting list for an OP appointment for patients from Ribsley General. Initialised so that this average waiting time is equal to the desired waiting time of 1.1538 months (5 weeks) to correspond with the description that the system was stable and the desired waiting time was maintained.

AccRSumJTOPWL = RROP*CTime

DOCUMENT: Accumulation rate of sum of join times of patients on the OP waiting list [pats].

Used to calculate the average time spent on the waiting list for an OP appointment for patients from a given district hospital.

DepRSumJTOPWL = IF(OPWL<>0) THEN (OPWLRR*SumJTOPWL/OPWL) ELSE 0

DOCUMENT: Depletion rate of sum of join times of patients on the OP waiting list [pats].

Used to calculate the average time spent on the waiting list for an OP appointment for patients from a given district hospital.

TOCCWLR(t) = TOCCWLR(t - dt) + (OCCWLRR) * dt

INIT TOCCWLR = 0

DOCUMENT: Total other CC investigation waiting list removals [pats].

Used for validation purposes only. To check the total number of other waiting list removals (deaths on waiting list etc) from the CC waiting list against the actual data during the period Apr95 to Apr 98 (t=0 to t=36). Will only be precise if driving model with historical activity data.

OCCWLRR = CCWL*FOCCWLRR

DOCUMENT: Other CC investigation waiting list removal rate [pats/mth].

These are removals from the waiting list "other" than those that constitute patient (elective CC investigation) activity because they represent patients who died on the waiting list, left the list because: their condition improved; they moved to another area; deteriorated and became emergency CC cases; or, choose to seek private care.

ACumDCCRC = IF(CumDCCRC<CumDCCRCAL) THEN 1 ELSE 0

DOCUMENT: Affordability of cumulative district CC service running costs [-].

Support is not given to district service if the cumulative running costs exceed a certain level.

ADesDCCF = IF((FSuppDCC=1) AND (TIME>=TADesDCCF)) THEN 1 ELSE 0

DOCUMENT: Anticipated desire for a district CC facility [-].

A desire for a district service may be anticipated, given the knowledge of the planned withdrawal of tertiary capacity in the future and financial support for a district service.

AggJDOpSki = 1*73.95

DOCUMENT: Initial aggregate junior district-based CC operator skill [skill units].

AMDCCRCR = IF (MDCCRCR<=MDCCRCRAL) THEN 1 ELSE 0

DOCUMENT: Affordability of monthly district CC facility running cost rate [-].

Support is not given to district service if the monthly running costs exceed a certain level.

APh1DCCPC = IF (Ph1DCCPC<=Ph1DCCPCAL) THEN 1 ELSE 0

DOCUMENT: Affordability of phase 1 district CC service preparation costs [-].

Support is not given to district service if the phase 1 preparation costs exceed a certain level.

APh2DCCPC = IF (Ph2DCCPC<=Ph2DCCPCAL) THEN 1 ELSE 0

DOCUMENT: Affordability of phase 2 district CC service preparation costs [-].

Support is not given to phase 2 of a district service if the phase 2 preparation costs exceed a certain level.

ATRRCC = 3

DOCUMENT: Averaging time of referral rate for an elective CC investigation [mths].

An expert estimate.

AvCCWLRRe = SMTH1(CCWLRR,1)

DOCUMENT: Average CC investigation waiting list removal rate, used to represent the Evaluation of pressure on the system [pats/mth].

The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of one month is assumed to represent the average delay to evaluate changes in pressure on the system.

AvCCWLRRe&r = SMTH1(CCWLRR,3)

DOCUMENT: Average CC investigation waiting list removal rate, used to represent the Evaluation of pressure on the system and the Response to that pressure [pats/mth].

The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of 3 months is assumed to represent the average delay to evaluate pressure on the system and respond to that pressure e.g. by changing referral rate or desired activity.

AvCDCC = 521

DOCUMENT: Average cost of a district-based CC investigation [pounds/pat].

Only costs at March 1997 are known.

AvCFurthCC = AvCTCCT/(1+DR)^(AvTFurthCC/12)

DOCUMENT: Average cost per further CC procedure [pounds/pat].

A weighted average. Patients who underwent investigation at the district level which showed that they required treatment will have to undergo a 2nd CC procedure at a later date. The cost, therefore, needs to be discounted. We assume that the price does not change during the discounted period. Otherwise, another adjustment would need to be made to AvCTCCT. We assume that 1/3 of patients require the 2nd CC procedure to be carried out on an inpatient basis (an expert's lower estimate) and 50% will involve the use of coronary stents.

AvCOP = 100

DOCUMENT: Average cost per OP appointment [pounds/pat].

Actual costs were not available so this is an approximation.

AvCTCC = AvCTCCI*(1-FFurthCC)+FFurthCC*AvCTCCT

DOCUMENT: Average cost per tertiary-based CC procedure [pounds/pat].

A weighted average. Only costs in March 1997 are available. Considers the patients who require investigation only and those who also require treatment. For the latter group, if they undergo CC investigation at the tertiary level can have their treatment procedure carried out at the same time. Otherwise, they need to undergo a further CC procedure (investigation at the district level and treatment at the tertiary level).

AvCTCCI = 525

DOCUMENT: Average cost per tertiary-based CC investigation [pounds/pat].

This relates to patients directly referred for a CC from the given district hospital. We assume that 1/3 of patients require the CC procedure to be carried out on an inpatient basis (an expert's lower estimate). Only cost in March 1997 is known.

AvCTCCT = 1361

DOCUMENT: Average cost per (tertiary-based) CC treatment (or synchronous investigation and treatment) [pounds/pat].

A weighted average. We assume that 1/3 of patients require the CC procedure to be carried out on an inpatient basis (an expert's lower estimate) and 50% of interventional CC will involve the use of coronary stents. Higher estimates of the proportion with stents will result in a higher average cost per tertiary procedure. We assume that the cost of synchronous investigation and treatment will equal the cost of a treatment procedure only. Only costs for March 1997 are known.

AvOCCWLRR = SMTH1(OCCWLRR,3)

DOCUMENT: Average other CC investigation waiting list removal rate [pats/mth].

This waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of 3 months is assumed to model the evaluation of pressure on the system and response to that pressure e.g. a change in referrals or desired activity.

AvOPWLRR = SMTH1(OPWLRR,1)

DOCUMENT: Average OP waiting list removal rate [pats/mth].

The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of one month is assumed to represent the average delay to evaluate changes in pressure on the system.

AvPreOPWLRR = SMTH1(PreOPWLRR,3)

DOCUMENT: Average pre-appointment OP waiting list removal rate [pats/mth].

The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of 3 months is assumed to model the evaluation of pressure on the system and response to that pressure e.g. a change in referrals or desired activity.

AvRROP = SMTH1(RROP,3)

DOCUMENT: Average rate of referrals for cardiology OP appointment [pats/mth].

The averaging period is an expert estimate.

AvSkJDOp = IF (JDOp=0) THEN 0 ELSE (AggJDOpSk/JDOp)

DOCUMENT: Average CC operator skill per junior district-based operator [skill units/doctor].

The use of the IF statement prevents a division by zero forcing the simulation to stop.

AvSkNJDOp = 0

DOCUMENT: Average skill per new junior district-based CC operator [skill units/doctor].

Assume that trainee CC operators arrive at Ribsley district hospital as complete novices.

AvTFurthCC = 4.5

DOCUMENT: Average waiting time for further CC procedure (following a district-based CC investigation) [mths].

Used for illustrative purposes only. Based upon simplifying assumptions.

AvTnewCCWLe = IF (AvCCWLRRe = 0) THEN 999 ELSE (CCWL/AvCCWLRRe)

DOCUMENT: Average estimated waiting time for new CC investigation waiting list patients, used to represent the Evaluation of pressure on the system [mths].

This estimate is based upon size of waiting list and average waiting list removal rate at time of entry onto the waiting list. This is used to evaluate changes in pressure on the system. A zero average removal rate would suggest an infinite waiting time as activity would be suspended. To accommodate this extreme case and enable the simulation to proceed, a very large waiting time has been specified.

AvTnewCCWLe&r = IF (AvCCWLRRe&r = 0) THEN 999 ELSE (CCWL/AvCCWLRRe&r)

DOCUMENT: Average estimated waiting time for new CC investigation waiting list patients, used to represent the Evaluation of pressure on the system and the Response to that pressure [mths].

This estimate is based upon size of waiting list and average waiting list removal rate at time of entry onto the waiting list. This is used to calculate the effect of changes in the WT on referrals for CC investigations. Changes in the waiting list removal rate do not lead to instantaneous changes in referrals for CC investigations, but changes are smoothed over a 3 month period. A zero smoothed removal rate would suggest an infinite waiting time as activity would be suspended. To accommodate this extreme case and enable the simulation to proceed, a very large waiting time has been specified.

AvTnewOPWL = IF (AvOPWLRR = 0) THEN 999 ELSE (OPWL/AvOPWLRR)

DOCUMENT: Average estimated waiting time for new OP waiting list patients [mths].

This estimate is based upon the average waiting time for new patients joining the OP waiting list, based upon size of waiting list and average waiting list removal rate at time of entry onto the waiting list. This is used to evaluate changes in pressure on the system. A zero average removal rate would suggest an infinite waiting time as activity would be suspended. To accommodate this extreme case and enable the simulation to proceed, a very large waiting time has been specified.

AvTonCCWL = IF (CCWL<>0) THEN (CTime-(SumJTCCWL/CCWL))
ELSE 0
DOCUMENT: Average time spent on the CC investigation waiting list [mths].
The formulation avoids, in cases where there are no patients on the waiting list, a division by zero, and forces a value of zero which is consistent with reality.

AvTonOPWL = IF (OPWL<>0) THEN (CTime-(SumJTOPWL/OPWL))
ELSE 0
DOCUMENT: Average time spent on the OP waiting list [mths].
The formulation avoids, in cases where there are no patients on the waiting list, a division by zero, and forces a value of zero which is consistent with reality.

AvWLRT = 0.5
DOCUMENT: Average waiting list removal time [mths].
This represents the average time it would take to arrange an investigation of a patient waiting on the CC investigation waiting list.

CapDCC = IF (OA=1) THEN (PCapDCC*DCCFA) ELSE 0
DOCUMENT: Capacity for district-based CC [pats/mth].
By definition, these are elective investigations.

CapOP = IF (OA=1) THEN ((1-SwIOPCap)*NOPCap+SwIOPCap*IncOPCap) ELSE 0
DOCUMENT: Capacity for OP appointments [pats/mth].
Specified by the consultant. Altered during policy analysis.

CapSEDCC = IF (DesECCInvR<PcvdTCapAEDCC) THEN 0 ELSE (DesECCInvR-PcvdTCapAEDCC)
DOCUMENT: Capacity shortfall (at tertiary level) with respect to patients who are eligible to undergo district-based CC investigation [pats/mth].
The capacity shortfall at the tertiary level is the activity level that desired minus the maximum activity that it is able to do (i.e. capacity). However, that is not what we are considering in the context of a shift to the district level. We are only interested in the shortfall that is eligible to be shifted to the district level - only that which constitutes low risk investigations. By definition, these will be elective cases. Furthermore, high risk elective cases (not eligible to be investigated at the district level) will take precedence over the low risk cases in using the available capacity at the tertiary level. Therefore, eligible capacity shortfall
= desired eligible activity - tertiary capacity that could be devoted to eligible patients
= desired eligible activity - (tertiary capacity - avg activity at tertiary level devoted to non eligible patients).

CapTCC = IF (OA=1) THEN PCapTCC ELSE 0
DOCUMENT: Capacity for elective tertiary-based CC investigations [pats/mth].

CCWLi = 88
DOCUMENT: Initial CC investigation waiting list length [pats]
Calculated using real data excluding other waiting list removals plus an estimate for other waiting list removals.

CDesDCCF = IF((CapSEDCC>=MinDCCInvR) AND (FSuppDCC=1)) THEN 1 ELSE 0
DOCUMENT: Current desire for district CC facility [-].
A desire for a district service is expressed if there exists sufficient demand to sustain the service and financial support.

CTime = 37+TIME
DOCUMENT: Current time [mths].
The adjustment of 37 refers to the initialisation period to set average time on waiting lists to the real values.

CumC = CumCCAC+CumOPAC+CumDCCPC+CumDCCRC
DOCUMENT: Cumulative costs [pounds].
Comprises patient activity costs, district service preparation and running costs.

CumCAL = 10000000
DOCUMENT: Cumulative costs affordability limit [pounds].
The use of a very large number represents unconstrained patient activity.

CumDCCRCAL = Step(500,TDCCSFA)+Step(200,34)+0*Step(150,46)+0*Step(150,58)+0*Step(150,70)
DOCUMENT: Cumulative district CC service running costs affordability limit [pounds].
This amount is equivalent to 10 month's worth of running costs initially and then, at a later stage, is increased by an amount equivalent to 4 further month's worth of running costs. We assume that the lack of affordability forces the suspension of the district service at t=24 (end March 1997) and t=38 (end May 1998). Financial constraints may be imposed to prevent the second district service as part of the policy analysis. Also as part of the policy analysis, the period of the second district service may be extended or further temporary injections of funding may be made.

DCCFA = IF((CFPh1DCCP>=0.95) AND (CDesDCCF=1) AND (PCapDCC>0)) THEN 1 ELSE 0
DOCUMENT: District CC facility availability [-].
For a district site to be available, a desire for a district facility has to prevail, the district site has to be at a sufficient level of completion and staff have to be available.

DCCFAST = 1
DOCUMENT: District CC facility availability smoothing time [mths].

The availability of the district facility influences the value of the goals driving the desired CC investigation rate. As changes in availability will not lead to instantaneous changes in the goals, the availability is smoothed.

DCCInvR = CapDCC*UCapDCC

DOCUMENT: District-based CC investigation rate [pats/mth].

Desired activity which can be delivered depends upon the capacity available and utilisation of that capacity. Only low risk CC investigations can be conducted at the district level. This forms the majority of elective investigations. All CC investigations at the district level are carried out by district CC operators.

DesCCInvR = SwPADr*DesCCInvRWL+(1-SwPADr)*DesCCInvRWT

DOCUMENT: Desired elective CC investigation rate [pats/mth].

The goal driving the desired level of activity may be a desired waiting time for new patients joining the waiting list (a WT policy - the base case) or a desired waiting list size (a WL policy - a policy analysis case).

DesCCInvRWL=MAX(MIN(AvRRCC+(CCWL-DesCCWL)/DesCCWLAT-AvOCCWLRR,
CCWL/AvWLRT+AvRRCC),0)

DOCUMENT: Desired elective CC investigation rate driven by the waiting list goal [pats/mth].

In seeking a waiting list goal (desired waiting list length), the desired activity rate will be composed of: (1) the average number of patients joining the waiting list (in order to maintain the waiting list at its existing level); plus (2) any additional adjustment required to meet the desired waiting list size, and, minus (3) any other removals from the waiting list (otherwise, more activity may be carried out than is necessary). However, there are two situations which place bounds on the actual values that the desired activity can take. The first situation is where there are insufficient patients available to meet the calculated desired activity rate - the actual activity rate will be derived from the existing waiting list and new patients joining the waiting list. This is formulated using the MIN( ) function. The second situation is when the calculated desired activity rate works out as being negative - the actual desired activity rate will be zero. This is represented by the use of the MAX( ) function.

DesCCInvRWT = IF(DesTCC=0) THEN 999 ELSE ((CCWL/DesTCC)-AvOCCWLRR)

DOCUMENT: Desired elective CC investigation rate driven by the waiting time goal [pats/mth].

In calculating the activity rate desired to meet the waiting time goal, it is necessary to account for other waiting list removals (which will reduce the required activity rate). Otherwise, more activity may be carried out than is necessary. A desired waiting time of zero would call for an infinitely large activity rate. For the model to accommodate this extreme case and enable the simulation to proceed (i.e. avoid a division by zero), an IF statement is used involving the assignment of a very large number to the desired activity rate.

DesCCWL = IF (SDCCFA>0.5) THEN 30 ELSE 60

DOCUMENT: Desired CC investigation waiting list length [pats].

The desired waiting list is 60 patients (quoted by the consultant) but we assume that, as the district service can provide additional capacity, the desired waiting list is reduced to 30 patients when the district service is present. A desired waiting list of 56 is specified as part of the policy analysis.

DesCCWLAT = 2
DOCUMENT: Desired CC investigation waiting list adjustment time [mths].
A value of 2 was quoted by the consultant. Varied to 2.7 as part of the policy analysis.

DesDCCF = ADesDCCF+CDesDCCF
DOCUMENT: Desire for a district CC facility [-].
A desire for a district facility may be anticipated given the knowledge that a tertiary facility is going to be closed in the future which would result in a significant loss of capacity.

DesDCCInvR = CapSEDCC*DCCFA
DOCUMENT: Desired district-based CC investigation rate [pats/mth].
For a shortfall in activity to represent desired district activity, a suitable facility has to be in place at the district hospital.

DesECCInvR = DesCCInvR*FEDCC
DOCUMENT: Desired eligible CC investigation rate [pats/mth].
This refers to patients who are eligible to undergo CC investigation at the district level - low risk elective investigations.

DesNECCInvR = DesCCInvR*(1-FEDCC)
DOCUMENT: Desired non-eligible CC investigation rate [pats/mth].
This refers to patients who are not eligible to undergo CC investigation at the district level - high risk elective investigations.

DesOPR = SwPADr*DesOPRWL+(1-SwPADr)*DesOPRWT
DOCUMENT: Desired OP rate [pats/mth].
The goal driving the desired level of activity may be a desired waiting time for new patients joining the waiting list (a WT policy - the base case) or a desired waiting list size (a WL policy - a policy analysis case).

DesOPRWL=MAX(MIN(AvRROP+(OPWL-DesOPWL)/DesOPWLAT-AvPreOPWLRR,
OPWL/AvWLRT+AvRROP),0)
DOCUMENT: Desired OP rate driven by the waiting list goal [pats/mth].
In seeking a waiting list goal (desired waiting list length), the desired activity rate will be composed of: (1) the average number of patients joining the waiting list (in order to maintain the waiting list at its existing level); plus (2) any additional adjustment required to meet the desired waiting list size, and, minus (3) any other removals from the waiting list (otherwise, more activity may be carried out than is necessary).

However, there are two situations which place bounds on the actual values that the desired activity can take. The first situation is where there are insufficient patients available to meet the calculated desired activity rate - the actual activity rate will be derived from the existing waiting list and new patients joining the waiting list. This is formulated using the MIN( ) function. The second situation is when the calculated desired activity rate works out as being negative - the actual desired activity rate will be zero. This is represented by the use of the MAX( ) function.

DesOPRWT = IF(DesTOP=0) THEN 999 ELSE ((OPWL/DesTOP)-AvPreOPWLRR)
DOCUMENT: Desired OP rate driven by the waiting time goal [pats/mth].
In calculating the activity rate desired to meet the waiting time goal, it is necessary to account for other waiting list removals (which will reduce the required activity rate). Otherwise, more activity may be carried out than is necessary. A desired waiting time of zero would call for an infinitely large activity rate. For the model to accommodate this extreme case and enable the simulation to proceed (i.e. avoid a division by zero), an IF statement is used involving the assignment of a very large number to the desired activity rate.

DesOPWL = 424
DOCUMENT: Desired OP waiting list length [pats].
Set to equal the initial OP waiting list size, taking into account an estimate for the other waiting list removals (deaths on the waiting list, moved away from the area etc).

DesOPWLAT = 2
DOCUMENT: Desired OP waiting list adjustment time [mths].
A value of 2 was quoted by the consultant. Varied to 2.7 as part of the policy analysis.

DesTCC = IF (SDCCFA>0.5) THEN 1.5 ELSE 3
DOCUMENT: Desired waiting time for a CC investigation [mths].
The WT goal is 3 months (quoted by the consultant), but we assume that as the district service can provide additional capacity, the WT goal is halved when the district service is present.

DesTOP = 1.1538
DOCUMENT: Desired waiting time for an OP appointment [mths].
A goal of 5 weeks was specified by the consultant. This has been converted to months.

DR = 0.03
DOCUMENT: Discount rate [-].
Costs which occur in the future are discounted. Set at 0.03 per annum for illustrative purposes.

EDesDCCF = DELAY(DesDCCF,Ph1DCCPD)
DOCUMENT: Expressed desire for a district CC facility [-].

EffCapLCC=1*EffCapLCCB+0*EffCapLCCN+0*EffCapLCCS+0*EffCapLCCPI+0*EffCapLCCFDS +0*EffCapLCCW+0*EffCapLCCSPRDS

DOCUMENT: Effect of significant capacity loss on referrals for elective CC investigation [-].

We assume that a significant loss of capacity will result in a reduction in referrals as a 'knee jerk' reaction. The timing of this effect will depend on the timing of the capacity losses. The '0"s act as switches for the sensitivity and policy analysis.

EffCDSuppDCC = IF (AvCDCC<=AvCTCCI) THEN 1 ELSE 0

DOCUMENT: Effect of CC investigation cost differential on support for district-based CC service [-].

Support is not given to district service if the cost of district CC investigations is more than the cost of CC investigation at the tertiary level.

EffKCC = 1*NEffKCC+0*EffKCCPDCCS+0*SuppEffKCC

DOCUMENT: Effect of knowledge of CC on referrals for elective CC investigation [-].

The knowledge effect on referrals for CC investigations may be altered as part of the sensitivity analysis or policy analysis.

EffKOP = 1*NEffKOP+0*EffKOPPDCCS+0*SuppEffKOP+0*IncrEffKOP

DOCUMENT: Effect of knowledge of CC on referrals for an OP appointment [-].

The knowledge effect on demand for OP appointments may be altered as part of the sensitivity analysis or policy analysis.

EffODSCC = 1/6

DOCUMENT: Effect of other district-based screeners on referrals for elective CC investigation [-].

Refers to doctors who screen patients for CC investigations but are non CC operators. At Ribsley General, non CC operators refer 0.5 to 1 patients in 80 (0.75/80) whilst expert operators refer 4 to 5 patients in 80 (4.5/80). Therefore, non CC operators refer 1/6 of the number of patients referred by expert operators. These are expert estimates.

EffOFCC = 1

DOCUMENT: Effect of other factors on referrals for elective CC investigation [-].

A example of another factor which might influence the referral threashold is the introduction of a permanent district service which, given the ability to increase capacity, might encourage the referral threshold to drop so that more 'grey area' cases would be investigated by CC. Given that district services at Ribsley General were only temporary, this is set to the default value of 1 (no effect).

EffSkCC = EffSkECC*FEDOp+EffSkJCC*FJDOp+(1-FEDOp-FJDOp)*EffODSCC

DOCUMENT: Effect of CC operator skills on referrals for elective CC investigation [-].

The skills effect is a weighted average considering the skills multipliers and proportions of patient decisions made by expert CC operators, junior CC operators and other screening doctors at the district hospital.

EffSkECC = 1

DOCUMENT: Effect of CC operator skills of expert district-based operators on referrals for elective CC investigation [-].

As the reference referral factor is based upon an assumption of fully skilled CC operators, it is consistent that the skills effect for expert district operators should take a value of 1.

EffSkJCC = IF(JDOp=0) THEN 0 ELSE (SwOC*EffSkOJCC+(1-SwOC)*EffSkUJCC)

DOCUMENT: Effect of CC operator skills of junior district-based operators on referrals for elective CC investigation [-].

The effect of CC skills of junior district CC operators on their referral rates for CC investigations will depend on whether they are naturally overconfident or underconfident. It is assumed that overconfidence will result in a period of over-referrals whilst underconfidence will lead to under-referrals. This refers to aggregate behaviour. The system being considered involves a single district hospital and the reference to overconfidence or underconfidence is determined by the culture at that hospital. This effect only applies in cases where there are junior operators.

EffWTCC = 1*NEffWTCC+0*SuppEffWTCC

DOCUMENT: Effect of waiting time for CC investigation on referrals for elective CC investigation [-].

This waiting time effect may be suppressed as part of the policy analysis, representing the affect of the implementation of a clinical guideline.

FEDCC = 0.9

DOCUMENT: Fraction of CC investigation waiting list that are eligible for district-based investigation [-].

Assumes that the majority of elective patients could be investigated at the district level. An expert estimate.

FEDOp = IF (JDOp=0) THEN 0.53 ELSE 0.4

DOCUMENT: Fraction CC investigation recommendations made by expert district CC operators [-].

This refers to final decisions made. In the absence of juniors, final decisions would not be on a 50:50 split between the expert and others. At Ribsley General, with juniors, initial assessments are on a 20:20:60 split between the expert, juniors and others respectively. We assume that if there were no juniors, their workload (20% of the total workload) would be split evenly between the expert and others. Therefore, initial assessments would be on a 30:70 split between the expert and others. The expert then reviews 1/3 of the patients initially assessed by others (1/3 x 70% of the total workload = 23% of the total workload) so final decisions would be on a (30+23):(70-23) i.e. 53:47 split between the expert and others.

FFurthCC = 0.1

DOCUMENT: Fraction of patients referred for further CC (following a district-based CC investigation) [-].

An average, based upon patient activity data. Since synchronous investigations and interventions (treatment) procedures cannot be carried out at the district level, the fraction of patients who require a CC-based treatment have to be referred on the tertiary level for a second CC procedure.

FJDOp = IF (JDOp=0) THEN 0 ELSE 0.2

DOCUMENT: Fraction CC investigation recommendations made by expert district CC operators [-].

This refers to final decisions made. An expert estimate. The fraction decided by junior district operators would be zero if there were no junior district operators present.

FOCCWLRR = 0.025

DOCUMENT: Fractional other CC investigation waiting list removal rate [-/mth].

These are removals from the waiting list "other" than those that constitute patient (elective CC investigation) activity. An expert estimate.

FOPreOPWLRR = 0.048

DOCUMENT: Fractional other pre-appointment OP waiting list removal rate [-/mth].

This refers to OP waiting list removals "other" than those on the waiting list who deteriorated, were admitted into hospital, stabilised and were sent home and placed on the CC investigation waiting list. Based on an expert estimate.

FOPtoCC=RefFOPtoCC*EffSkCC*(IF(EffCapLCC<1) THEN EffCapLCC ELSE (EffCapLCC*EffKCC*EffWTCC*EffOFCC))

DOCUMENT: Fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].

The use of the IF( ) function reflects the assumption that the 'knee jerk' reaction to the capacity losses will dominate over the effects of WT, knowledge of CC and other factors on referrals for elective CC investigations.

FRROPWLtoIPtoCC = 0.002*(1-0*Step(1,20))

DOCUMENT: Fractional rate of referrals from the OP waiting list via inpatients to an elective CC investigation [-/mth].

Based on an expert estimate.

FSuppDCC = IF ((ACumDCCRC=1) AND (AMDCCRCR=1) AND (APh1DCCPC=1) AND (EffCDSuppDCC=1) AND (OA=1)) THEN 1 ELSE 0

DOCUMENT: Financial support for a district CC service [-].

The district service relies upon the running costs and site preparation costs being affordable, the district procedural cost being attractive compared to a CC investigation carried out at the tertiary level, and there being sufficient funds to continue delivering services. Both the cumulative and monthly running costs are considered. This is because whilst a given monthly running cost might be considered reasonable to warrant the introduction of a district service, this may not necessary imply that a permanent service can be afforded. There may only be sufficient funding available to pay the running costs for a limited period. A value of "1" will indicate 'affordable' whilst a value of "0" will indicate 'not affordable'.

FSuppPh2DCC = IF ((APh2DCCPC=1) AND (FSuppDCC=1)) THEN 1 ELSE 0

DOCUMENT: Financial support for a phase 2 district CC service [-].

Refers to support for an integrated catheter laboratory.

FTCCbyDOp = IF (DCCFA<>0) THEN 0 ELSE 0.95

DOCUMENT: Fraction of tertiary-based elective CC investigations carried out by a district-based CC operator [-].

An expert estimate. Refers to patients referred from the given district hospital of interest and to district-based CC operators from that hospital. District cardiologists with CC operator skills are allocated sessions at the tertiary centre to investigate their patients. The fraction is not 1 because allowances are made for absences due to sickness and holidays. District cardiologists who are CC operators and only carry out CC investigations will not have sessions at the tertiary centre for elective CC investigations if there is a district service in place at their (district) hospital. District cardiologists who also do interventional CC work (treatments) and have CC facilities in place at their hospital will retain sessions for elective CC investigations on their high risk patients at the tertiary centre. The consultant at Ribsley General only does investigations.

IncOPCap = 390

DOCUMENT: Increased OP capacity [pats/mth]

Used as part of the policy analysis.

IRROP = 0

DOCUMENT: Increase in referral rate for OP appointment [-]

Expressed as a percentage. Used for conducting sensitivity analysis.

JDOpRecD = 0

DOCUMENT: Junior district-based CC operator recruitment delay [mths].

The delay in filling the trainee CC operator vacancy, following the departure of the junior operator after completion of his/her training period.

JDOpSkGRExp = LEJDOp*LPP

DOCUMENT: Junior district-based CC operator skills gain rate via experience [skill units/mth].

Assumes that all trainees work under supervision so trainees and trainers don't operate on separate patients.

JDOpSkGRRec = AvSkNJDOp*JDOpRecR

DOCUMENT: Junior district-based CC operator skills gain rate via recruitment [skill units/mth].

A new trainee recruit may have come via from another district hospital with some exposure to CC investigations and therefore not arrive as a complete novice. Therefore, some CC skills may be gained via recruitment.

JDOpTT = 12

DOCUMENT: Junior district-based CC operator training time [mths].

Quoted by the consultant.

LEJDOp = (DCCInvR+TCCInvR*FTCCbyDOp)*LFJDOp

DOCUMENT: Learning experiences for junior district-based CC operators [pats/mth].

The pool of patients from which junior district CC operators gain skills is a fraction of the patients from the district hospital that are investigated at the district level and a fraction of the elective patients investigated at the tertiary level.

LFJDOp = IF (JDOp=0) THEN 0 ELSE 0.75

DOCUMENT: (Patient activity) learning fraction of junior district-based CC operators [-].

This is the fraction of investigations from which the junior operator learns. It will exceed the fraction for which the junior actually conducts the investigation because the junior operator will learn from discussions with the consultant, audit etc. Increased to 0.9 as part of the policy analysis, to represent a change in policy.

MaxSkOp = 100

DOCUMENT: Maximum CC skills per CC operator [skill units/doctor].

MBCheckPats = OPWLi+CCWLi+CumOPWLAdds+CumCCWLAdds-CumOPWLRems-CumCCWLRems -1*Max(OPWL,0)-1*Max(CCWL,0)-0*OPWL-0*CCWL

DOCUMENT: Mass balance check on patients [pats]

MBCheckSk = AggJDOpSki+CumGJDOpSk-CumLJDOpSk-Max(AggJDOpSk,0)

DOCUMENT: Mass balance check on skills of junior district-based CC operators [skill units]

MDCCRCR = 50

DOCUMENT: Monthly district CC facility running cost rate [pounds/mth].

An approximation.

MDCCRCRAL = Step(100,TDCCSFA)

DOCUMENT: Monthly district CC facility running cost rate affordability limit [pounds/mth].

An expert estimate since data is not available.

MinDCCInvR = 4

DOCUMENT: Minimum district-based elective CC investigation rate [pats/mth].

The minimum observed activity level using a single session in a mobile catheter laboratory.

NOPCap = 1105/3

DOCUMENT: Normal OP capacity [pats/mth].

Quoted as 85 patients/week.

OA = IF (CumC<=CumCAL) THEN 1 ELSE 0

DOCUMENT: Overall affordability [-].

If the total overall costs exceed a certain level, support for the district service will be withdrawn and all elective patient activity will be suspended.

OPreOPWLRR = OPWL*FOPreOPWLRR

DOCUMENT: Other pre-appointment OP waiting list removal rate [pats/mth].

This refers to OP waiting list removals "other" than those on the waiting list who deteriorated, were admitted into hospital, stabilised and were sent home and placed on the CC investigation waiting list. Instead, these are removals from the waiting list that do not constitute OP activity because they represent patients who died on the waiting list or left the list because: their condition improved; they moved to another area; deteriorated and became emergency referrals for CC investigation; deteriorated, became hospital admissions, stabilised and then were simply sent home (i.e. were not referred on for an elective or emergency CC investigation); or, choose to seek private care.

OPWLi = 424

DOCUMENT: Initial OP waiting list length [pats].

Calculation based upon the available data and the description that the system was stable.

OPWLRR = OPR+PreOPWLRR

DOCUMENT: OP waiting list removal rate [pats/mth].

PCapDCC=1*PCapDCCB+0*PCapDCCSPRDS+0*PCapDCCPermDS+0*PCapDCCFDS +0*PCapDCCET+0*PCapDCCW

DOCUMENT: Potential capacity for elective district-based CC investigations [pats/mth].

This is the elective district-based CC investigation capacity that would be available if the district service were affordable.

PCapTCC=1*PCapTCCB+0*PCapTCCSPRDS+0*PCapTCCPermDS+0*PCapTCCFDS +0*PCapTCCET+0*PCapTCCW+0*PCapTCCSDS+0*PCapTCCNDS

DOCUMENT: Potential capacity for tertiary-based elective CC investigations [pats/mth].

This is the elective tertiary-based CC investigation capacity that would be available if it were affordable. Capacity data is specified using an approximation of historical activity data (smoothed), extracting the behaviour of interest. Increased as part of the policy analysis.

PcvdDCCInvR = SMTH3(DCCInvR,PDDCCInvR)

DOCUMENT: Perceived district-based CC investigation rate [pats/mth].

A 3rd order delay is chosen rather than a 1st order delay because a sudden increase in CC Inv activity at the district level would not be perceived immediately. These are perceptions by those outside the district hospital (GPs and patients) of something occurring within the district hospital. GPs will learn about the availability of the district service via written communication with the district hospital (referral letters) and patients will gain knowledge through 'word of mouth'. Because the district service was only temporary at Ribsley General, it was not marketed (unlike the case of the permanent service at Veinbridge) so the perception delay would be longer.

PcvdTCapAEDCC = SMTH1(TCapAEDCC,STTCapUNEDCC)
DOCUMENT: Perceived tertiary-based elective CC investigation capacity available for those eligible to undergo district-based CC [pats/mth].
The capacity available for eligible patients needs to be averaged since it is derived from an instantaneous rate which is, therefore, unobservable.

PDDCCInvR = 6
DOCUMENT: Perception delay of district-based CC investigation rate (by GPs and patients) [mths].
An expert estimate.

Ph1DCCPC = 30000
DOCUMENT: Phase 1 district CC service preparation costs [pounds].
An expert estimate since data not available.

Ph1DCCPCAL = Step(35000,TDCCSFA)
DOCUMENT: Phase 1 district CC service preparation costs affordability limit [pounds].
An expert estimate.

Ph1DCCPD = 1
DOCUMENT: Phase 1 district CC service preparation delay [mths].
An expert estimate. This refers to the delay to respond to the need for a district facility.

Ph1DCCPMCR = (IF (Ph1DCCPR>0) THEN (Ph1DCCPC/Ph1DCCPP) ELSE 0)
DOCUMENT: Phase 1 district CC service preparation monthly cost rate [pounds/mth].
Monthly costs incurred to prepare a site for phase 1 (i.e. mobile cath lab-based) district service. It is assumed that the total costs are spread evenly over the site preparation period.

Ph1DCCPP = 3
DOCUMENT: Phase 1 district CC service preparation period [mths].
An approximation.

Ph2DCCPC = 1000000
DOCUMENT: Phase 2 district CC service preparation costs [pounds].

Ph2DCCPCAL = 0
DOCUMENT: Phase 2 district CC service preparation costs affordablity limit [pounds].

The construction of an integrated cath lab at Ribsley General is prevented due to financial constraints.

Ph2DCCPD = 999

DOCUMENT: Phase 2 district CC service preparation delay [mths].

A very large number is specified to indicate that the district service at Risbley General will never enter phase 2.

Ph2DCCPMCR=FSuppPh2DCC*(IF(CumDCCPC<(Ph1DCCPC+Ph2DCCPC))THEN STEP(Ph2DCCPC/Ph2DCCPP, (STPh1DCCP+Ph2DCCPD)) ELSE 0)

DOCUMENT: Phase 2 district CC service preparation monthly cost rate [pounds/mth].

This refers to the costs incurred to construct an integrated catheter laboratory. It is assumed that the total costs are spread evenly over the site and facility preparation period.

Ph2DCCPP = 6

DOCUMENT: Phase 2 district CC service preparation period [mths].

This is the time it would take to construct an integrated lab if funding were available.

PostOPDisR = OPR*(1-FOPtoCC)

DOCUMENT: Post-OP appointment discharge rate [pats/mth].

These are patients which are not referred on for an elective CC investigation.

PreOPWLRR = RROPWLtoIPtoCC+OPreOPWLRR

DOCUMENT: Pre-appointment OP waiting list removal rate [pats/mth].

These are all the removals from the waiting list that do not constitute patient (outpatient) activity. They represent patients who died on the waiting list, left the list because: their condition improved; they moved to another area; deteriorated and became emergency referrals for CC investigation; deteriorated, became hospital admissions, stabilised and were then sent home (i.e. didn't result in being referred for elective or emergency CC investigation; deteriorated, became hospital admissions, stabilised and were placed on the CC investigation waiting list; or, choose to seek private care.

RefFOPtoCC = 0.05625

DOCUMENT: Reference fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].

This is the referral fraction for which there was no district service, normal capacity levels, all district screeners are fully skilled and there is no stimulation nor suppression of demand due to the waiting time or patient/GP pressure effects. This would correspond with a situation for which GPs' and patients' knowledge of CC relies totally on that derived from tertiary activity and the waiting time is at a level so that it neither stimulates nor suppresses demand. An expert estimate (between 4 and 5 patients in 80 or 4.5/80) at Ribsley General. The remaining patients are discharged back to their GP following their OP appointment. Some will be subsequently followed up. The follow-up process is not being modelled and this will form a recommendation for further development of the model.

RefRROP = 367.87*(1+Step(IRROP,48))

DOCUMENT: Reference rate of referrals for an OP appointment [pats/mth].

Represents new and follow-up patients. This is the OP referral rate for which the effect of patient and GP knowledge of CC is 1 i.e. knowledge is based upon tertiary activity only. Initially set at a level such that the OP waiting list additions and removals balance (as reported by the consultant). Later increased by 5% as part of the policy analysis.

RefTnewCCWL = 3

DOCUMENT: Reference waiting time for new CC investigation waiting list patients [mths].

Used to calculate 'WT effect' on referrals for CC. Represents the waiting time for which referrals will neither be suppressed not stimulated; waiting times greater than this reference value will suppress demand and waiting times lower than this reference value will stimulate demand. 6 months was quoted by the expert but this produced behaviour which was inconsistent with the real world system. Therefore, the value was adjusted.

RPrPM = 1

DOCUMENT: Rate of pressure gain per month (spent on the waiting list) [pressure/mth/mth]

We arbitrarily specifiy that each month spent on the waiting list exerts one unit of pressure each month. As the purpose is to compare pressure associated with different simulation runs, its value is irrelevant.

RPrPP = 1

DOCUMENT: Rate of pressure gain per patient (on the waiting list) [pressure/patient/mth]

We arbitrarily specifiy that a patient exerts one unit of pressure on the system for each month spent on the waiting list. As the purpose is to compare pressure associated with different simulation runs, the value of this parameter is irrelevant.

RRCC = RROPWLtoCC+NRRIPtoCC

DOCUMENT: Referral rate for an elective CC investigation [pats/mth].

Considers referrals from both the outpatient and inpatient route.

RRFurthCC = DCCInvR*FFurthCC

DOCUMENT: Rate of referral (from a district-based CC investigation) to a further CC (treatment) procedure [pats/mth].

As only CC investigations can be carried out at the district level, patients who also require interventional CC (treatment) have to be referred to the tertiary level for a 2nd procedure. When necessary, synchronous diagnostic and treatments are carried out on patients investigated at the tertiary level so none of these patients require a 2nd procedure.

RROPWLtoIPtoCC = OPWL*FRROPWLtoIPtoCC

DOCUMENT: Rate of referrals from the OP waiting list via inpatients to an elective CC investigation [pats/mth].

This refers to patients on the OP waiting list who deteriorated, were admitted into hospital, stabilised and then placed on the CC investigation waiting list. Therefore, they were referred for an elective CC investigation after admission as an inpatient as opposed to after assessment as an outpatient.

STTCapUNEDCC = 3+1*(-Step(2.75,13)+Step(2.75,15)-Step(2.75,34)+Step(2.75,35))

DOCUMENT: Smoothing time of tertiary-based elective CC investigation capacity use by patients not eligible to undergo a district-based CC [mths].

An expert estimate. We assume that response time is shorter when the tertiary capacity shortfall is anticipated.

SwB3 = 1

DOCUMENT: Switch for feedback loop B3 [-].

0 = Off; 1 = On. Refers to the waiting time effect on referrals for elective CC investigations.

SwIOPCap = 0

DOCUMENT: Switch for increase in OP capacity [-]

0 = normal OP capacity level; 1 = increased OP capacity level. Used as part of the policy analysis.

SwOC = 0

DOCUMENT: Switch for overconfidence in referral behaviour (of junior district-based CC operators) [-].

0 = Off (underconfidence); 1 = On (overconfidence). "Underconfidence" is the tendency of junior cardiologists, as they embark upon their CC training, to hesitate and under-refer patients. As they gain CC skills, they gain confidence and this is reflected by them wanting to refer more patients on for CC investigations. This behaviour pattern would be expected in a hospital in which the referral behaviour was conservative, typically led by a consultant cardiologist who only carried out CC investigations. Overconfident referral behaviour among juniors would be expected in a hospital in which the referral behaviour was more 'aggressive', typically led by a consultant cardiologist who also carried out CC treatments. We assume underconfidence at Ribsley General.

SwPADr = 0

DOCUMENT: Switch for patient activity driver [-].

1 = Seeks a desired waiting list length; 0 = Seeks a desired average waiting time. The desired activity rate is driven by a desired waiting time for new patients joining the waiting list or a desired waiting list size. The desired activity rate is currently driven by a waiting time goal. This reflects the policy currently used by the consultant. Used for the policy analysis.

SwR1 = 1

DOCUMENT: Switch for feedback loop R1 [-].

0 = Off; 1 = On. Refers to the knowledge effect on referrals for cardiology outpatient appointments.

SwR2 = 1

DOCUMENT: Switch for feedback loop R1 [-].

0 = Off; 1 = On. Refers to the knowledge effect on referrals for CC investigations.

SwTOpP = 1

DOCUMENT: Switch for trainee district CC operator programme [-].

0 = Off (No trainee operator programme); 1 = On (Use of a trainee operator programme). Used as part of the policy analysis.

TADesDCCF = IF (TCapLT=999) THEN 999 ELSE (TCapLT-Ph1DCCPP)

DOCUMENT: Time of anticipated desire for district CC facility [mths].

999 is the default value indicating no anticipated desire for district facility.

TCapAEDCC = IF(FEDCC=0) THEN 0 ELSE (CapTCC-TCCInvRNEDCC)

DOCUMENT: Tertiary-based elective CC investigation capacity available for those eligible to undergo district-based CC [pats/mth].

This is the fraction of tertiary capacity which is not being used by non eligible patients (who have first priority on the use of tertiary resources). It is assumed that, if no cases were eligible to be shifted to the district level, the capacity that would be available for these patients would be allocated elsewhere.

TCapLT = 13

DOCUMENT: Tertiary capacity loss time [mths].

A value is 999 would indicate no anticipated desire. Changes from default if a loss in tertiary capacity is anticipated. Currently specifies simulation time corresponding to May 96.

TCCInvR = CapTCC*UCapTCC

DOCUMENT: Tertiary-based elective CC investigation rate [pats/mth].

This represents patients referred from the district hospital of interest for an elective CC investigation. Elective CC investigations on patients referred by GPs directly to the tertiary centre, elective CC investigations on patients referred from district hospitals which do not have consultants with CC skills, emergency CC investigations and CC interventions (treatments) lie outside the boundary of the model. The elective CC investigation rate at the tertiary level will depend upon the capacity available and its utilisation. The level of capacity utilisation will be driven by the desired activity rate. All CC investigations can be safely conducted at the tertiary level whereas only low risk elective investigations can be safely delivered at the district level.

TCCInvRNEDCC = CapTCC*UCapTCCNEDCC

DOCUMENT: Tertiary-based elective CC investigation rate of those not eligible to undergo district-based CC [pats/mth].

TDCCSFA = IF (TADesDCCF=999) THEN 999 ELSE TADesDCCF

DOCUMENT: Time district CC service first affordable [mths].

A value of 999 indicates the case where a district service is never affordable. In the case of Ribsley General, it was the situation that led to the anticipated desire (planned temporary closure of tertiary facilities) that led to the district service being affordable. If the closure of tertiary facilities had not occurred, it is assumed that the district service would have never been affordable.

TRnewCCWL = IF(RefTnewCCWL=0) THEN 999 ELSE (AvTnewCCWLe&r/RefTnewCCWL)

DOCUMENT: Waiting time ratio for new CC investigation waiting list patients [-].

The use of the IF statement ensures that a division by zero will not cause the simulation to stop. However, in reality the reference WT for new CC waiting list patients would never be zero since we are dealing with elective patients.

EffCapLCCB = GRAPH(TIME)

(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 0.25), (26.0, 0.5), (27.0, 0.75), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 1.00), (38.0, 1.00), (39.0, 0.25), (40.0, 0.5), (41.0, 0.75), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00)

DOCUMENT: Effect of significant capacity loss on referrals for an elective CC investigation corresponding to the base case scenario [-].

A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The first capacity loss relates to the delay in introducing the district service to compensate for the loss of tertiary capacity. The second and third capacity losses relate to the significant drops in capacity following the withdrawal of the district service. It is assumed that the effect diminishes over a period of three months.

EffCapLCCFDS = GRAPH(TIME)

(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 0.25), (26.0, 0.5), (27.0, 0.75), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 1.00), (38.0, 1.00), (39.0, 0.25), (40.0, 0.5), (41.0, 0.75), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 0.25), (51.0, 0.5), (52.0, 0.75), (53.0, 1.00), (54.0, 1.00)

DOCUMENT: Effect of significant capacity loss on referrals for the case with further district sessions [-].

A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The first capacity loss relates to the delay in introducing the district service to compensate for the loss of tertiary capacity. The second, third, fourth and fifth capacity losses relate to the significant drops in capacity following the withdrawal of the district service. It is assumed that the effect diminishes over a period of three months.

EffCapLCCN = GRAPH(TIME)

(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00), (26.0, 1.00), (27.0, 1.00), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 0.25), (38.0, 0.5), (39.0, 0.75), (40.0, 1.00), (41.0, 1.00), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00)

DOCUMENT: Effect of significant capacity loss on referrals for the case with no district service [-].

Used as part of the sensitivity analysis. A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The first and second capacity losses relate to the loss of tertiary capacity. It is assumed that the effect dimishes over a period of three months.

EffCapLCCPI = GRAPH(TIME)

(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00), (26.0, 1.00), (27.0, 1.00), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 1.00), (38.0, 1.00), (39.0, 1.00), (40.0, 1.00), (41.0, 1.00), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00)

DOCUMENT: Effect of significant capacity loss on referrals for the case with permanent increases in capacity [-].

Used as part of the policy analysis. A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The capacity loss relates to the delay in introducing the district service to compensate for the loss of tertiary capacity. It is assumed that the effect diminishes over a period of three months.

EffCapLCCS = GRAPH(TIME)

(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 0.25), (26.0, 0.5), (27.0, 0.75), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 0.25), (38.0, 0.5), (39.0, 0.75), (40.0, 1.00), (41.0, 1.00), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00)

DOCUMENT: Effect of significant capacity loss on referrals for the case with a single district service [-].
Used as part of the policy analysis. A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The first capacity loss relates to the delay in introducing the district service to compensate for the loss of tertiary capacity. The second capacity loss relates to the significant drop in capacity following the withdrawal of the district service. The third capacity loss relates to the second temporary closure of tertiary facilities. It is assumed that the effect diminishes over a period of three months.

EffCapLCCSPRDS = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00), (26.0, 1.00), (27.0, 1.00), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 1.00), (38.0, 1.00), (39.0, 0.25), (40.0, 0.5), (41.0, 0.75), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00)
DOCUMENT: Effect of significant capacity loss on referrals for the case with a semi permanent reduced district service [-].
Used as part of the policy analysis. A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The first capacity loss relates to the loss of tertiary capacity and the second capacity loss relates to the loss of the district service. It is assumed that the effect diminishes over a period of three months.

EffCapLCCW = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 0.25), (26.0, 0.5), (27.0, 0.75), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 0.25), (34.0, 0.5), (35.0, 0.75), (36.0, 1.00), (37.0, 1.00), (38.0, 1.00), (39.0, 0.25), (40.0, 0.5), (41.0, 0.75), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00)
DOCUMENT: Effect of significant capacity loss on referrals for the case with a winter crisis [-].
This crisis involves a further temporary loss of elective capacity without a replacement district service. A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The first capacity loss relates to the delay in introducing the district service to compensate for the loss of tertiary capacity. The second and fourth capacity losses relate to the significant drops in capacity following the withdrawal of the district service. The third capacity loss relates to the further temporary loss of (tertiary) elective capacity, representing a winter crisis. It is assumed that the effect diminishes over a period of three months.

EffKCCPDCCS = GRAPH(IF (SwR2=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.02), (10.0, 1.09), (12.5, 1.13), (15.0, 1.15), (17.5, 1.15), (20.0, 1.15)

DOCUMENT: Effect of knowledge of CC on referrals for an elective CC investigation with a permanent district CC service [-].

Relates to GP and patient knowledge of CC. It is assumed that a permanent district service would stimulate more demand than a temporary service as greater efforts would be devoted to promoting the service and greater interest would be generated. Furthermore, a permanent district service at Ribsley General would be assumed to generate less demand than a permanent district service at Veinbridge General, assuming the same patient and GP behaviour. This follows because increased pressure to refer would have a greater effect on the typically more 'aggressive' cardiologists at Veinbridge General; the effects of knowledge on referrals represents the effect of pressure to refer, generated by increased knowledge, and the response to that pressure. If the loop is switched off or the district service is not present, the input is zero forcing the effect to equal 1. We assume that pressure can only be exerted to refer whilst the district service is present.

EffKOPPDCCS = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.01), (10.0, 1.05), (12.5, 1.15), (15.0, 1.20), (17.5, 1.20), (20.0, 1.20)

DOCUMENT: Effect of knowledge of CC on referrals for an OP appointment with a permanent district CC service [-].

Represents GP and patient knowledge effect. If the loop is switched off the input is zero forcing effect to equal 1. It is assumed that a permanent district service would stimulate more demand than a temporary service as greater efforts would be devoted to promoting the service and greater interest would be generated. Furthermore, a permanent district service at Ribsley General would be assumed to generate less demand than a permanent district service at Veinbridge General, assuming the same patient and GP behaviour. This follows because increased pressure to refer would have a greater effect on the typically more 'aggressive' cardiologists at Veinbridge General; the effects of knowledge on referrals represents the effect of pressure to refer, generated by increased knowledge, and the response to that pressure.

EffSkOJCC = GRAPH(AvSkJDOp)

(0.00, 0.167), (10.0, 0.167), (20.0, 0.167), (30.0, 0.167), (40.0, 0.285), (50.0, 0.8), (60.0, 1.21), (70.0, 1.21), (80.0, 1.00), (90.0, 1.00), (100, 1.00)

DOCUMENT: Effect of CC operator skills of overconfident junior district-based operators on referrals for elective CC investigation [-].

Graph was constructed using expert estimates.

EffSkUJCC = GRAPH(AvSkJDOp)

(0.00, 0.167), (10.0, 0.167), (20.0, 0.167), (30.0, 0.167), (40.0, 0.167), (50.0, 0.167), (60.0, 0.36), (70.0, 0.862), (80.0, 1.00), (90.0, 1.00), (100, 1.00)

DOCUMENT: Effect of CC operator skills of underconfident junior district-based operators on referrals for elective CC investigation [-].

Graph was constructed using expert estimates. This reflects the base case assumption for Ribsley General.

IncrEffKOP = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.00), (10.0, 1.00), (12.5, 1.01), (15.0, 1.04), (17.5, 1.05), (20.0, 1.05)

DOCUMENT: Increased effect of knowledge of CC on referrals for a cardiology OP appointment [-].

Represents GP and patient knowledge effect. Used during the sensitivity analysis.

LPP = GRAPH(AvSkJDOp/MaxSkOp)

(0.00, 2.00), (0.1, 2.00), (0.2, 2.00), (0.3, 2.00), (0.4, 2.00), (0.5, 2.00), (0.6, 1.72), (0.7, 0.46), (0.8, 0.12), (0.9, 0.04), (1, 0.00)

DOCUMENT: Learning per patient [skill units/patient].

Constructed using expert estimates.

NEffKCC = GRAPH(IF (SwR2=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.02), (10.0, 1.04), (12.5, 1.09), (15.0, 1.10), (17.5, 1.10), (20.0, 1.10)

DOCUMENT: Normal effect of knowledge of CC on referrals for an elective CC investigation [-].

Relates to GP and patient knowledge of CC. For Ribsley General, the normal effect is that generated by a temporary district service. If the loop is switched off or district service is not present, input is zero forcing effect to equal 1. We assume that pressure can only be exerted to refer whilst the district service is present. This graph was presented to the consultant who thought that it seemed quite reasonable. Variations were explored via the sensitivity analysis.

NEffKOP = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.00), (10.0, 1.00), (12.5, 1.01), (15.0, 1.02), (17.5, 1.02), (20.0, 1.02)

DOCUMENT: Normal effect of knowledge of CC on referrals for an OP appointment [-].

Represents GP and patient knowledge effect. For Ribsley General, the normal effect is that generated by a temporary district service. If the loop is switched off, the input is zero forcing the effect to equal 1. We assume that as the district service was temporary, it would not be heavily marketed and generally low interest in CC would be generated so the effect of the district service on referrals for an OP appt, would be low. The consultant stated that he could not comment on the validity of the graph. Variations were explored via the sensitivity analysis.

NEffWTCC = GRAPH(IF(SwB3=0) THEN 1 ELSE TRnewCCWL)

(0.00, 1.10), (0.2, 1.10), (0.4, 1.10), (0.6, 1.09), (0.8, 1.06), (1.00, 1.00), (1.20, 0.97), (1.40, 0.96), (1.60, 0.95), (1.80, 0.95)

DOCUMENT: Normal effect of waiting time for CC investigation on referrals for elective CC investigation [-].

Assumes that a low WT will stimulate demand but long WT will suppress demand. If the loop is switched off, the input is zero forcing the effect to equal 1. Based on expert estimates.

PCapDCCB = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 8.00), (15.0, 23.0), (16.0, 23.0), (17.0, 23.0), (18.0, 23.0), (19.0, 23.0), (20.0, 23.0), (21.0, 23.0), (22.0, 23.0), (23.0, 23.0), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 19.6), (35.0, 19.6), (36.0, 19.6), (37.0, 19.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00)

DOCUMENT: Potential capacity for elective district-based CC investigations corresponding to the base case scenario [pats/mth].

This uses an approximation of the historical activity data (the district service was affordable) and capacities are implied from the comment by the consultant that the system often operated at full capacity. The historical data (smoothed) were divided between four different situations and, for each situation, averages were taken to derive four different capacity levels. Corresponding to increasing levels of capacity, these situations were: (1) no district service, (2) district service in first month of operation, (3) district service with normal capacity levels e.g. providing a replacement service during a moderate closure of tertiary facilities, and (4) district service with elevated capacity levels e.g. providing a replacement service during a major closure of tertiary facilities or to support a major shift to district level.

PCapDCCET = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 8.00), (15.0, 18.1), (16.0, 18.1), (17.0, 18.1), (18.0, 18.1), (19.0, 18.1), (20.0, 18.1), (21.0, 18.1), (22.0, 18.1), (23.0, 18.1), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 12.6), (37.0, 12.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00)

DOCUMENT: Potential capacity for elective district-based CC investigations with an expanded tertiary-based service [pats/mth].

This represents a resource neutral policy for April 1995 to May 1998 only. The capacity from July 1996 onwards is level, set the average base case level for the period July 1996 to May 1998 (allowances are made for the low first month of the district service). We assume that capacity increases were planned at the tertiary level and the district service is only used to provide cover for the tertiary facility closures. Used as part of the policy analysis.

PCapDCCFDS = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 8.00), (15.0, 23.0), (16.0, 23.0), (17.0, 23.0), (18.0, 23.0), (19.0, 23.0), (20.0, 23.0), (21.0, 23.0), (22.0, 23.0), (23.0, 23.0), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 19.6), (35.0, 19.6), (36.0, 19.6), (37.0, 19.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 19.6), (47.0, 19.6), (48.0, 19.6), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00)

DOCUMENT: Potential capacity for elective district-based CC investigations with further district sessions [pats/mth].

This involves additional district sessions in February to April 1999, 2000 and 2001.

PCapDCCPermDS = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 8.00), (15.0, 18.1), (16.0, 18.1), (17.0, 18.1), (18.0, 18.1), (19.0, 18.1), (20.0, 18.1), (21.0, 18.1), (22.0, 18.1), (23.0, 18.1), (24.0, 12.6), (25.0, 12.6), (26.0, 12.6), (27.0, 12.6), (28.0, 12.6), (29.0, 12.6), (30.0, 12.6), (31.0, 12.6), (32.0, 12.6), (33.0, 12.6), (34.0, 12.6), (35.0, 12.6), (36.0, 12.6), (37.0, 12.6), (38.0, 12.6), (39.0, 12.6), (40.0, 12.6), (41.0, 12.6), (42.0, 12.6), (43.0, 12.6), (44.0, 12.6), (45.0, 12.6), (46.0, 12.6), (47.0, 12.6), (48.0, 12.6), (49.0, 12.6), (50.0, 12.6), (51.0, 12.6), (52.0, 12.6), (53.0, 12.6), (54.0, 12.6)

DOCUMENT: Potential capacity for elective district-based CC investigations with a permanent district service [pats/mth].

This represents a resource neutral policy for April 1995 to May 1998 only. However, unlike the base case, the district service is not withdrawn and the capacity from July 1996 onwards is level, set the average base case level for the period July 1996 to May 1998 (allowances are made for the low first month of the district service). Used as part of the policy analysis.

PCapDCCSPRDS = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 8.00), (15.0, 18.1), (16.0, 18.1), (17.0, 18.1), (18.0, 18.1), (19.0, 18.1), (20.0, 18.1), (21.0, 18.1), (22.0, 18.1), (23.0, 18.1), (24.0, 12.6), (25.0, 12.6), (26.0, 12.6), (27.0, 12.6), (28.0, 12.6), (29.0, 12.6), (30.0, 12.6), (31.0, 12.6), (32.0, 12.6), (33.0, 12.6), (34.0, 12.6), (35.0, 12.6), (36.0, 12.6), (37.0, 12.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00)

DOCUMENT: Potential capacity for elective district-based CC investigations with a semi-permanent reduced district service [pats/mth].

This represents a resource neutral policy in that the total capacity that was provided for Ribsley General patients between April 1995 and April 2001 is unchanged. However, unlike the base case, the district service is not withdrawn until June 1998 and the capacity from July 1996 to May 1998 is level (allowances are made for the low first month of the district service), set to the average base case level for this period. Used as part of the policy analysis.

PCapDCCW = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 8.00), (15.0, 23.0), (16.0, 23.0), (17.0, 23.0), (18.0, 23.0), (19.0, 23.0), (20.0, 23.0), (21.0, 23.0), (22.0, 23.0), (23.0, 23.0), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 19.6), (36.0, 19.6), (37.0, 19.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00)

DOCUMENT: Potential capacity for elective district-based CC investigations with a winter crisis [pats/mth].

Assumes loss of capacity due to a winter crisis over 3 months where resources are diverted from elective investigations to emergency and treatment cases.

PCapTCCB = GRAPH(TIME)

(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 11.8), (25.0, 11.8), (26.0, 11.8), (27.0, 11.8), (28.0, 11.8), (29.0, 11.8), (30.0, 11.8), (31.0, 11.8), (32.0, 11.8), (33.0, 11.8), (34.0, 6.50), (35.0, 6.50), (36.0, 6.50), (37.0, 6.50), (38.0, 11.8), (39.0, 11.8), (40.0, 11.8), (41.0, 11.8), (42.0, 11.8), (43.0, 11.8), (44.0, 11.8), (45.0, 11.8), (46.0, 11.8), (47.0, 11.8), (48.0, 11.8), (49.0, 11.8), (50.0, 11.8), (51.0, 11.8), (52.0, 11.8), (53.0, 11.8), (54.0, 11.8)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations corresponding to the base case scenario [pats/mth].

This is the tertiary elective CC capacity that would be available if it were affordable. It uses an approximation of the historical activity data and capacities are implied from the comment by the consultant that the system often operated at full capacity. The historical data (smoothed) were divided between five different situations and, for each situation, averages were taken to derive five different capacity levels. Corresponding to increasing levels of capacity, these situations were: (1) with a major reduction in capacity e.g. during a major closure of tertiary facilities, (2) with a moderate reduction in capacity e.g. during a moderate closure of tertiary facilities, (3) during the first month of a major closure of tertiary facilties, (4) normal capacity levels (5) elevated capacity levels.

PCapTCCET = GRAPH(TIME)

(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 19.1), (25.0, 19.1), (26.0, 19.1), (27.0, 19.1), (28.0, 19.1), (29.0, 19.1), (30.0, 19.1), (31.0, 19.1), (32.0, 19.1), (33.0, 19.1), (34.0, 19.1), (35.0, 19.1), (36.0, 6.50), (37.0, 6.50), (38.0, 19.1), (39.0, 19.1), (40.0, 19.1), (41.0, 19.1), (42.0, 19.1), (43.0, 19.1), (44.0, 19.1), (45.0, 19.1), (46.0, 19.1), (47.0, 19.1), (48.0, 19.1), (49.0, 19.1), (50.0, 19.1), (51.0, 19.1), (52.0, 19.1), (53.0, 19.1), (54.0, 19.1)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with an expanded tertiary-based service [pats/mth].

This represents a resource neutral policy for April 1995 to May 1998 only. The capacity from July 1996 onwards is level, set the average base case level for the period July 1996 to May 1998 (allowances are made for the low first month of the district service). We assume that capacity increases were planned at the tertiary level and the district service is only used to provide cover for the tertiary facility closures. Used as part of the policy analysis.

PCapTCCFDS = GRAPH(TIME)

(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 11.8), (25.0, 11.8), (26.0, 11.8), (27.0, 11.8), (28.0, 11.8), (29.0, 11.8), (30.0, 11.8), (31.0, 11.8), (32.0, 11.8), (33.0, 11.8), (34.0, 6.50), (35.0, 6.50), (36.0, 6.50), (37.0, 6.50), (38.0, 11.8), (39.0, 11.8), (40.0, 11.8), (41.0, 11.8), (42.0, 11.8), (43.0, 11.8), (44.0, 11.8), (45.0, 11.8), (46.0, 6.50), (47.0, 6.50), (48.0, 6.50), (49.0, 11.8), (50.0, 11.8), (51.0, 11.8), (52.0, 11.8), (53.0, 11.8), (54.0, 11.8)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with further district sessions [pats/mth].

This involves additional district sessions in February to April in 1999, 2000 and 2001.

PCapTCCNDS = GRAPH(TIME)

(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 11.8), (25.0, 11.8), (26.0, 11.8), (27.0, 11.8), (28.0, 11.8), (29.0, 11.8), (30.0, 11.8), (31.0, 11.8), (32.0, 11.8), (33.0, 11.8), (34.0, 11.8), (35.0, 11.8), (36.0, 6.50), (37.0, 6.50), (38.0, 11.8), (39.0, 11.8), (40.0, 11.8), (41.0, 11.8), (42.0, 11.8), (43.0, 11.8), (44.0, 11.8), (45.0, 11.8), (46.0, 11.8), (47.0, 11.8), (48.0, 11.8), (49.0, 11.8), (50.0, 11.8), (51.0, 11.8), (52.0, 11.8), (53.0, 11.8), (54.0, 11.8)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with no district service [pats/mth].

PCapTCCPermDS = GRAPH(TIME)

(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 6.50), (25.0, 6.50), (26.0, 6.50), (27.0, 6.50), (28.0, 6.50), (29.0, 6.50), (30.0, 6.50), (31.0, 6.50), (32.0, 6.50), (33.0, 6.50), (34.0, 6.50), (35.0, 6.50), (36.0, 6.50), (37.0, 6.50), (38.0, 6.50), (39.0, 6.50), (40.0, 6.50), (41.0, 6.50), (42.0, 6.50), (43.0, 6.50), (44.0, 6.50), (45.0, 6.50), (46.0, 6.50), (47.0, 6.50), (48.0, 6.50), (49.0, 6.50), (50.0, 6.50), (51.0, 6.50), (52.0, 6.50), (53.0, 6.50), (54.0, 6.50)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with a permanent district service [pats/mth].

This represents a resource neutral policy for April 1995 to May 1998 only. However, unlike the base case, the district service is not withdrawn and the capacity from July 1996 onwards is level, set the average base case level for the period July 1996 to May 1998 (allowances are made for the low first month of the district service). Used as part of the policy analysis.

PCapTCCSDS = GRAPH(TIME)
(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 11.8), (25.0, 11.8), (26.0, 11.8), (27.0, 11.8), (28.0, 11.8), (29.0, 11.8), (30.0, 11.8), (31.0, 11.8), (32.0, 11.8), (33.0, 11.8), (34.0, 11.8), (35.0, 11.8), (36.0, 6.50), (37.0, 6.50), (38.0, 11.8), (39.0, 11.8), (40.0, 11.8), (41.0, 11.8), (42.0, 11.8), (43.0, 11.8), (44.0, 11.8), (45.0, 11.8), (46.0, 11.8), (47.0, 11.8), (48.0, 11.8), (49.0, 11.8), (50.0, 11.8), (51.0, 11.8), (52.0, 11.8), (53.0, 11.8), (54.0, 11.8)
DOCUMENT: Potential capacity for elective tertiary-based CC investigations with single district service [pats/mth].

PCapTCCSPRDS = GRAPH(TIME)
(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 6.50), (25.0, 6.50), (26.0, 6.50), (27.0, 6.50), (28.0, 6.50), (29.0, 6.50), (30.0, 6.50), (31.0, 6.50), (32.0, 6.50), (33.0, 6.50), (34.0, 6.50), (35.0, 6.50), (36.0, 6.50), (37.0, 6.50), (38.0, 11.8), (39.0, 11.8), (40.0, 11.8), (41.0, 11.8), (42.0, 11.8), (43.0, 11.8), (44.0, 11.8), (45.0, 11.8), (46.0, 11.8), (47.0, 11.8), (48.0, 11.8), (49.0, 11.8), (50.0, 11.8), (51.0, 11.8), (52.0, 11.8), (53.0, 11.8), (54.0, 11.8)
DOCUMENT: Potential capacity for elective tertiary-based CC investigations with a semi-permanent reduced district service [pats/mth].
This represents a resource neutral policy in that the total capacity that was provided for Ribsley General patients between April 1995 and April 2001 is unchanged. However, unlike the base case, the district service is not withdrawn until June 1998 and the capacity from July 1996 to May 1998 is level (allowances are made for the low first month of the district service), set to the average base case level for this period. Used as part of the policy analysis.

PCapTCCW = GRAPH(TIME)
(0.00, 11.8), (1.00, 11.8), (2.00, 11.8), (3.00, 11.8), (4.00, 11.8), (5.00, 11.8), (6.00, 21.6), (7.00, 21.6), (8.00, 21.6), (9.00, 21.6), (10.0, 21.6), (11.0, 21.6), (12.0, 21.6), (13.0, 10.8), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 11.8), (25.0, 11.8), (26.0, 11.8), (27.0, 11.8), (28.0, 11.8), (29.0, 11.8), (30.0, 11.8), (31.0, 11.8), (32.0, 3.00), (33.0, 3.00), (34.0, 3.00), (35.0, 6.50), (36.0, 6.50), (37.0, 6.50), (38.0, 11.8), (39.0, 11.8), (40.0, 11.8), (41.0, 11.8), (42.0, 11.8), (43.0, 11.8), (44.0, 11.8), (45.0, 11.8), (46.0, 11.8), (47.0, 11.8), (48.0, 11.8), (49.0, 11.8), (50.0, 11.8), (51.0, 11.8), (52.0, 11.8), (53.0, 11.8), (54.0, 11.8)
DOCUMENT: Potential capacity for elective tertiary-based CC investigations with a winter crisis [pats/mth].

Assumes loss of capacity due to a winter crisis over 3 months where resources are diverted from elective investigations to emergency and treatment cases.

SuppEffKCC = GRAPH(IF (SwR2=0) THEN 0 ELSE PcvdDCCInvR)
(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.01), (10.0, 1.02), (12.5, 1.04), (15.0, 1.05), (17.5, 1.05), (20.0, 1.05)
DOCUMENT: Suppressed effect of knowledge of CC on referrals for elective CC investigation [-].
Assumes that the use of a guideline could suppress some of the stimulated demand. Used as part of the policy analysis.

SuppEffKOP = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)
(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.00), (10.0, 1.00), (12.5, 1.00), (15.0, 1.01), (17.5, 1.01), (20.0, 1.01)
DOCUMENT: Suppressed effect of knowledge of CC on referrals for OP appointments [-].
Assumes that the use of a guideline could suppress some of the stimulated demand. Used as part of the policy analysis.

SuppEffWTCC = GRAPH(IF(SwB3=0) THEN 1 ELSE TRnewCCWL)
(0.00, 1.05), (0.2, 1.05), (0.4, 1.05), (0.6, 1.04), (0.8, 1.01), (1.00, 1.00), (1.20, 0.97), (1.40, 0.96), (1.60, 0.95), (1.80, 0.95)
DOCUMENT: Suppressed effect of waiting time for CC investigation on referrals for elective CC investigation [-].
Assumes that the use of a guideline could suppress some of the stimulated demand. Used as part of the policy analysis.

UCapDCC = GRAPH(IF (CapDCC=0) THEN 0 ELSE (DesDCCInvR/CapDCC))
(0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1, 0.97), (1.10, 1.00), (1.20, 1.00)
DOCUMENT: Utilisation of capacity for district-based CC [-].
By definition, this refers to elective CC investigations.
If exactly the full capacity was desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

UCapOP = GRAPH(IF (CapOP=0) THEN 0 ELSE (DesOPR/CapOP))
(0.00, 0.00), (0.05, 0.05), (0.1, 0.1), (0.15, 0.15), (0.2, 0.2), (0.25, 0.25), (0.3, 0.3), (0.35, 0.35), (0.4, 0.4), (0.45, 0.45), (0.5, 0.5), (0.55, 0.55), (0.6, 0.6), (0.65, 0.65), (0.7, 0.7), (0.75, 0.75), (0.8, 0.8), (0.85, 0.85), (0.9, 0.9), (0.95, 0.95), (1.00, 0.97), (1.05, 1.00), (1.10, 1.00)
DOCUMENT: Utilisation of capacity for OP appointments [-].
If exactly the full capacity was desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

UCapTCC = GRAPH(IF(CapTCC=0) THEN 0 ELSE DesCCInvR/CapTCC)
(0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1, 0.97), (1.10, 1.00), (1.20, 1.00)
DOCUMENT: Utilisation of capacity for elective tertiary-based CC investigations [-].
If full capacity is desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

UCapTCCNEDCC = GRAPH(IF(CapTCC=0) THEN 0 ELSE DesCCInvR*(1-FEDCC)/CapTCC)
(0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1, 0.97), (1.10, 1.00), (1.20, 1.00)
DOCUMENT: Utilisation of capacity for tertiary-based elective CC investigation by those not eligible to undergo a district-based investigation [-].
If full capacity is desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

E2b. Model Equations Parameterised to the Veinbridge General Case

AggJDOpSk(t) = AggJDOpSk(t - dt) + (JDOpSkGR - JDOpSkLR) * dt
INIT AggJDOpSk = AggJDOpSki
DOCUMENT: Aggregate junior district-based CC operator skill [skill units].
It is assumed that in April 1995, the junior operator at that time will have accumulated sufficient skills in CC to have almost saturated the 'skills effect' on referrals for CC investigations. The initial value is based on the following assumptions: historical elective CC investigation activity levels at the tertiary level equal the level at April 1995 (11.75/mth), and junior district operator fraction equal to 0.75.
JDOpSkGR = 1*(JDOpSkGRRec+JDOpSkGRExp)+0*PULSE(1000,10,0)
DOCUMENT: Junior district-based CC operator skills gain rate [skill units/mth].
JDOpSkLR = JDOpDepR*AvSkJDOp+0*PULSE(1000,10)
DOCUMENT: Junior district-based CC operator skills loss rate [skill units/mth].

AvRRCC(t) = AvRRCC(t - dt) + (RRCCAR) * dt
INIT AvRRCC = 35.64
DOCUMENT: Average rate of referrals for elective CC investigation [pats/mth].
RRCCAR = (RRCC-AvRRCC)/ATRRCC
DOCUMENT: Referral rate for an elective CC investigation averaging rate [pats/mth/mth].

CCWL(t) = CCWL(t - dt) + (RROPWLtoCC + NRRIPtoCC - CCWLRR) * dt
INIT CCWL = CCWLi
DOCUMENT: CC investigation waiting list length [pats].
Initialised at the Apr 95 (t=0) level using real data (with some patients removed) plus an expert estimate of the other waiting list removals (deaths on waiting list etc).
RROPWLtoCC = OPR*FOPtoCC+RROPWLtoIPtoCC

DOCUMENT: Rate of referrals from OP waiting list to an elective CC investigation [pats/mth].

Comprises patients who were referred on after attending an OP appointment and patients who, waiting for an OP appointment, deteriorated and were referred on following a hospital admission.

NRRIPtoCC = 1*5.5*(1-0*Step(1,20))+0*PULSE(1000,10,0)

DOCUMENT: New referral rate from inpatients to an elective CC investigation [pats/mth].

Prior to hospital admission, these patients may have been: asymptomatic; symptomatic but the patient may not have yet sought medical treatment for their symptoms; or, symptomatic and under GP care. This may also include patients who were in hospital receiving non cardiac treatment. "New" refers to patients not already known to the cardiologists. This excludes: (1) those who were on the OP waiting list, deteriorated, stabilised and were then placed on the CC investigation waiting list (these are already accounted for in the referrals from the OP waiting list, RROPWLtoCC) and (2) patients who are already on the CC investigation waiting list but have deteriorated, become hospital admissions and restabilised (as they will remain classified as in need of an elective CC investigation, they are already included on the CC investigation waiting list, CCWL). The value is derived from an expert estimate (6.5 pats/mth) for the total referrals from inpatients i.e. including (1) but excluding (2). It is assumed that (2) will form the minority of the total referrals from inpatients. The validity of the split in the referrals from inpatients is not important, given the purpose of our study.

CCWLRR = CCInvR+OCCWLRR

DOCUMENT: CC investigation waiting list removal rate [pats/mth].

CFPh1DCCP(t) = CFPh1DCCP(t - dt) + (Ph1DCCPR) * dt

INIT CFPh1DCCP = 0

DOCUMENT: Completed fraction of phase 1 district CC service preparation (completed fraction of a basic district site) [-].

A district service can be provided by hiring a mobile catheter laboratory. However, a suitable site has to be prepared for the mobile. "Site" refers to the base upon which the mobile is situated (it has to be perfectly level and able to withstand the considerable weight of the mobile) and the electrical and telecommunication links to connect the mobile to the host hospital. At a later stage, the mobile may be replaced by an integrated catheter laboratory. The mobile would be used whilst the integrated lab was being constructed so the construction of the lab and associated delays would not need to be represented in the model but the associated financial costs would. In the model, the different phases of district service are referred to as Phase 1 (using a mobile) and Phase 2 (using an integrated catheter lab) and the site for the mobile is referred to as a "basic" district site.

Ph1DCCPR = FSuppDCC*(IF ((TIME>=STPh1DCCP) AND (CFPh1DCCP<1)) THEN (1/Ph1DCCPP) ELSE 0)

DOCUMENT: Phase 1 district CC service preparation rate [-/mth].

Having set the preparation of a basic district site and facility to begin, preparation occurs until the site and facility are complete. It relies upon continual financial support for the district service; if financial support were withdrawn, development would be suspended.

CumCC(t) = CumCC(t - dt) + (CCInvR) * dt

INIT CumCC = 0

DOCUMENT: Cumulative elective CC investigations [pats].

CCInvR = DCCInvR+TCCInvR

DOCUMENT: Elective CC investigation rate [pats/mth].

Overall elective CC investigations at tertiary and district levels for patients referred from a given district hospital. For those conducted at the tertiary level, may also involve synchronous treatment.

CumCCAC(t) = CumCCAC(t - dt) + (CCCR) * dt

INIT CumCCAC = 0

DOCUMENT: Cumulative CC activity costs [pounds].

Cumulative costs of CC investigations, for patients from a given district hospital. CC investigations conducted at the tertiary level may also involve synchronous investigation and intervention (treatment) which will be more expensive than a CC intervention. This is one of several several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total CC investigation activity costs generated over time by considering the area under the CC investigation rate curve.

CCCR = AvCTCC*TCCInvR+(AvCDCC+FFurthCC*AvCFurthCC)*DCCInvR

DOCUMENT: CC activity cost rate [pounds/pat].

Refers to costs of CC procedures for patients originally referred for an elective CC investigation from a given district hospital so refers to CC investigations and treatments.

CumCCACATL(t) = CumCCACATL(t - dt) + (CCCRATL) * dt

INIT CumCCACATL = 0

DOCUMENT: Cumulative CC activity costs if all activity were carried out at the tertiary level [pounds].

CCCRATL = (DCCInvR+TCCInvR)*AvCTCC

DOCUMENT: CC activity cost rate if all were carried out at the tertiary level [pounds/pat].

This is what the CC cost rate would be if the total elective activity were conducted at the tertiary level, assuming the same (district+tertiary) capacity could be achieved at the tertiary level.

CumCCWLAdds(t) = CumCCWLAdds(t - dt) + (CCWLAddR) * dt

INIT CumCCWLAdds = 0

DOCUMENT: Cumulative CC waiting list additions [pats].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of referrals for elective CC investigations by considering the area under the CC investigation referral rate curve.

CCWLAddR = NRRIPtoCC+RROPWLtoCC

DOCUMENT: CC waiting list addition rate [pats/mth]

CumCCWLRems(t) = CumCCWLRems(t - dt) + (CCWLRemR) * dt

INIT CumCCWLRems = 0

DOCUMENT: Cumulative CC waiting list removals [pats]

CCWLRemR = CCWLRR

DOCUMENT: CC waiting list removal rate [pats/mth]

CumDCCPC(t) = CumDCCPC(t - dt) + (DCCPCR) * dt

INIT CumDCCPC = 0

DOCUMENT: Cumulative district CC service preparation costs [pounds].

DCCPCR = Ph1DCCPMCR+Ph2DCCPMCR

DOCUMENT: District CC service preparation cost rate [pounds/mth].

Phase 1 refers to the costs incurred to prepare a site for a mobile-based district service. Phase 2 refers to the costs incurred to prepare a site and construct a facility for an integrated cath lab-based district service.

CumDCCRC(t) = CumDCCRC(t - dt) + (DCCRCR) * dt

INIT CumDCCRC = 0

DOCUMENT: Cumulative district CC service running costs [pounds].

DCCRCR = IF(DCCInvR>0) THEN MDCCRCR ELSE 0

DOCUMENT: District CC service running cost rate [pounds/mth].

These costs are not incurred until the district service is up and running.

CumGJDOpSk(t) = CumGJDOpSk(t - dt) + (GRJDOpSk) * dt

INIT CumGJDOpSk = 0

DOCUMENT: Cumulative gain in junior district-based CC operator skills [skill units]

GRJDOpSk = JDOpSkGR

DOCUMENT: Gain rate of junior district-based CC operator skills [skill units/mth]

CumLJDOpSk(t) = CumLJDOpSk(t - dt) + (LRJDOpSk) * dt

INIT CumLJDOpSk = 0

DOCUMENT: Cumulative loss in junior district-based CC operator skills [skill units]

LRJDOpSk = JDOpSkLR

DOCUMENT: Loss rate of junior district-based CC operator skills [skill units/mth]

CumOP(t) = CumOP(t - dt) + (OPR) * dt

INIT CumOP = 0

DOCUMENT: Cumulative OP activity [pats].

OPR = CapOP*UCapOP

DOCUMENT: OP rate [pats/mth].

Desired activity which can be delivered depends upon the capacity available and utilisation of that capacity.

CumOPAC(t) = CumOPAC(t - dt) + (OPCR) * dt

INIT CumOPAC = 0

DOCUMENT: Cumulative OP activity costs [pounds].

Cumulative costs of OP appointments, for patients from a given district hospital. This is one of several several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total OP activity costs generated over time by considering the area under the OP rate curve.

OPCR = AvCOP*OPR

DOCUMENT: OP cost rate [pounds/pat].

CumOPWLAdds(t) = CumOPWLAdds(t - dt) + (OPWLAddsR) * dt

INIT CumOPWLAdds = 0

DOCUMENT: Cumulative OP waiting list additions [pats].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of referrals for OP appointments over time by considering the area under the OP referral rate curve.

OPWLAddsR = RROP

DOCUMENT: OP waiting list addition rate [pats/mth]

CumOPWLRems(t) = CumOPWLRems(t - dt) + (OPWLRemR) * dt

INIT CumOPWLRems = 0

DOCUMENT: Cumulative OP waiting list removals [pats]

OPWLRemR = OOPWLRR+RROPWLtoCC

DOCUMENT: OP waiting list removal rate [pats/mth]

DECCWL(t) = DECCWL(t - dt) + (GRDECCWL) * dt

INIT DECCWL = 0

DOCUMENT: Duration of excessive CC investigation waiting list [mths]

Total time for which the CC investigation waiting list exceeded its desired value.

GRDECCWL = IF ((CCWL-DesCCWL)>0.5) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive CC investigation waiting list [mths/mth].

DEOPWL(t) = DEOPWL(t - dt) + (GRDEOPWL) * dt

INIT DEOPWL = 0

DOCUMENT: Duration of excessive OP waiting list [mths]

Total time for which the OP waiting list exceeded its desired value.

GRDEOPWL = IF ((OPWL-DesOPWL)>0.5) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive OP waiting list [mths/mth].

DETnewCCWL(t) = DETnewCCWL(t - dt) + (GRDETnewCCWL) * dt

INIT DETnewCCWL = 0

DOCUMENT: Duration of excessive average estimated waiting time for new CC investigation waiting list patients [mths]

Total time for which the average estimated waiting time for new CC investigation waiting list patients exceeded its desired value.

GRDETnewCCWL = IF ((AvTnewCCWLe-DesTCC)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive estimated average waiting time for new CC investigation waiting list patients [mths/mth]

DETnewOPWL(t) = DETnewOPWL(t - dt) + (GRDETnewOPWL) * dt

INIT DETnewOPWL = 0

DOCUMENT: Duration of excessive average estimated waiting time for new OP waiting list patients [mths]

Total time for which the average estimated waiting time for new OP waiting list patients exceeded its desired value.

GRDETnewOPWL = IF ((AvTnewOPWL-DesTOP)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive average estimated waiting time for new OP waiting list patients [mths/mth]

DETonCCWL(t) = DETonCCWL(t - dt) + (GRDETonCCWL) * dt

INIT DETonCCWL = 0

DOCUMENT: Duration of excessive average time spent on waiting list for a CC investigation [mths]

Total time for which the average time spent on the CC investigation waiting list exceeded its desired value.

GRDETonCCWL = IF ((AvTonCCWL-DesTCC)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive average time spent on CC investigation waiting list [mths/mth]

DETonOPWL(t) = DETonOPWL(t - dt) + (GRDETonOPWL) * dt

INIT DETonOPWL = 0

DOCUMENT: Duration of excessive average time spent on the OP waiting list [mths]

Total time for which the average time on the OP waiting list exceeded its desired value.

GRDETonOPWL = IF ((AvTonOPWL-DesTOP)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of excessive average time spent on OP waiting list [mths/mth].

DStDemCC(t) = DStDemCC(t - dt) + (GRDStDemCC) * dt

INIT DStDemCC = 0

DOCUMENT: Duration of stimulated demand for CC investigation [mths]

GRDStDemCC = IF ((FOPtoCC/(RefFOPtoCC*EffSkCC)-1)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of stimulated demand for CC investigation [mths/mth].

Demand can only be suppressed by the skills effect.

DStDemOP(t) = DStDemOP(t - dt) + (GRDStDemOP) * dt

INIT DStDemOP = 0

DOCUMENT: Duration of stimulated demand for OP appointment [mths]

GRDStDemOP = IF ((EffKOP-1)>0.001) THEN 1 ELSE 0

DOCUMENT: Gain rate of duration of stimulated demand for OP appointment [mths/mth]

JDOp(t) = JDOp(t - dt) + (JDOpRecR - JDOpDepR) * dt

INIT JDOp = 1

DOCUMENT: Number of junior district-based CC operators [doctors].

JDOpRecR = SwTOpP*PULSE(1,6+JDOpRecD,JDOpTT+JDOpRecD)

DOCUMENT: Junior district-based CC operator recruitment rate [doctors/mth].

There is no need to synchronise the recruitment of district operator trainees with the availability of the district service. The district operator trainees refer to junior cardiologists-in-training who are based at the district hospital. In the absence of a district service, they acquire skills in delivering CC at the tertiary centre.

JDOpDepR = SwTOpP*(PULSE(1,6,999)+DELAY(JDOpRecR,JDOpTT,0))

DOCUMENT: Junior district-based CC operator departure rate [doctors/mth].

When trainee operators complete their training at the district hospital, they move on to another hospital and the trainee vacancy which subsequently arises is subsequently filled with a new novice trainee.

MaxCCWL(t) = MaxCCWL(t - dt) + (SRMaxCCWL) * dt

INIT MaxCCWL = 0

DOCUMENT: Maximum CC investigation waiting list [pats]

SRMaxCCWL = IF (CCWL>MaxCCWL) THEN PULSE(CCWL-MaxCCWL) ELSE 0

DOCUMENT: Set rate of maximum CC investigation waiting list [pats/mth]

MaxOPWL(t) = MaxOPWL(t - dt) + (SRMaxOPWL) * dt

INIT MaxOPWL = 0

DOCUMENT: Maximum OP waiting list [pats]

SRMaxOPWL = IF (OPWL>MaxOPWL) THEN PULSE(OPWL-MaxOPWL) ELSE 0

DOCUMENT: Set rate of maximum OP waiting list [pats/mth]

MaxRRCC(t) = MaxRRCC(t - dt) + (SRMaxRRCC) * dt

INIT MaxRRCC = 0

DOCUMENT: Maximum referral rate for elective CC investigation [pats/mth]

SRMaxRRCC = IF (RRCC>MaxRRCC) THEN PULSE(RRCC-MaxRRCC) ELSE 0

DOCUMENT: Set rate of maximum referral rate for elective CC investigation [pats/mth/mth]

MaxRROP(t) = MaxRROP(t - dt) + (SRMaxRROP) * dt

INIT MaxRROP = 0

DOCUMENT: Maximum referral rate for OP appointment [pats/mth]

SRMaxRROP = IF (RROP>MaxRROP) THEN PULSE(RROP-MaxRROP) ELSE 0

DOCUMENT: Set rate of maximum referral rate for OP appointment [pats/mth/mth]

MaxTnewCCWL(t) = MaxTnewCCWL(t - dt) + (SRMaxTnewCCWL) * dt

INIT MaxTnewCCWL = 0

DOCUMENT: Maximum average estimated waiting time for new CC investigation waiting list patients [mths]

SRMaxTnewCCWL = IF (AvTnewCCWLe>MaxTnewCCWL) THEN PULSE(AvTnewCCWLe-MaxTnewCCWL) ELSE 0

DOCUMENT: Set rate of maximum average estimated waiting time for new CC investigation waiting list patients [mths/mth]

MaxTnewOPWL(t) = MaxTnewOPWL(t - dt) + (SRMaxTnewOPWL) * dt

INIT MaxTnewOPWL = 0

DOCUMENT: Maximum average estimated waiting time for new OP waiting list patients [mths]

SRMaxTnewOPWL = IF (AvTnewOPWL>MaxTnewOPWL) THEN PULSE(AvTnewOPWL-MaxTnewOPWL) ELSE 0

DOCUMENT: Set rate of maximum average estimated waiting time for new OP waiting list patients [mths/mth]

MaxTonCCWL(t) = MaxTonCCWL(t - dt) + (SRMaxTonCCWL) * dt

INIT MaxTonCCWL = 0

DOCUMENT: Maximum average time spent on CC investigation waiting list [mths]

SRMaxTonCCWL = IF (AvTonCCWL>MaxTonCCWL) THEN PULSE(AvTonCCWL-MaxTonCCWL) ELSE 0

DOCUMENT: Set rate of maximum average time on CC investigation waiting list [mths/mth]

MaxTonOPWL(t) = MaxTonOPWL(t - dt) + (SRMaxTonOPWL) * dt

INIT MaxTonOPWL = 0

DOCUMENT: Maximum average time spent on OP waiting list [mths]

SRMaxTonOPWL = IF (AvTonOPWL>MaxTonOPWL) THEN PULSE(AvTonOPWL-MaxTonOPWL) ELSE 0

DOCUMENT: Set rate of maximum average time spent on the OP waiting list [mths/mth]

MinCCWL(t) = MinCCWL(t - dt) + (SRMinCCWL) * dt

INIT MinCCWL = 1000

DOCUMENT: Minimum CC investigation waiting list [pats]

SRMinCCWL = IF (CCWL<MinCCWL) THEN PULSE(CCWL-MinCCWL) ELSE 0

DOCUMENT: Set rate of minimum CC investigation waiting list [pats/mth]

MinOPWL(t) = MinOPWL(t - dt) + (SRMinOPWL) * dt
INIT MinOPWL = 1000
DOCUMENT: Minimum OP waiting list [pats]
SRMinOPWL = IF (OPWL<MinOPWL) THEN PULSE(OPWL-MinOPWL) ELSE 0
DOCUMENT: Set rate of minimum OP waiting list [pats/mth]

MinRRCC(t) = MinRRCC(t - dt) + (SRMinRRCC) * dt
INIT MinRRCC = 1000
DOCUMENT: Minimum referral rate for elective CC investigation [pats/mth]
SRMinRRCC = IF (RRCC<MinRRCC) THEN PULSE(RRCC-MinRRCC) ELSE 0
DOCUMENT: Set rate of minimum referral rate for an elective CC investigation [pats/mth/mth]

MinRROP(t) = MinRROP(t - dt) + (SRMinRROP) * dt
INIT MinRROP = 1000
DOCUMENT: Minimum referral rate for OP appointment [pats/mth]
SRMinRROP = IF (RROP<MinRROP) THEN PULSE(RROP-MinRROP) ELSE 0
DOCUMENT: Set rate of minimum referral rate for an OP appointment [pats/mth/mth]

MinTnewCCWL(t) = MinTnewCCWL(t - dt) + (SRMinTnewCCWL) * dt
INIT MinTnewCCWL = 1000
DOCUMENT: Minimum average estimated waiting time for new CC investigation waiting list patients [mths]
SRMinTnewCCWL = IF (AvTnewCCWLe<MinTnewCCWL) THEN PULSE(AvTnewCCWLe-MinTnewCCWL) ELSE 0
DOCUMENT: Set rate of minimum average estimated waiting time for new CC investigation waiting list patients [mths/mth]

MinTnewOPWL(t) = MinTnewOPWL(t - dt) + (SRMinTnewOPWL) * dt
INIT MinTnewOPWL = 1000
DOCUMENT: Minimum average estimated waiting time for new OP waiting list patients [mths]
SRMinTnewOPWL = IF (AvTnewOPWL<MinTnewOPWL) THEN PULSE(AvTnewOPWL-MinTnewOPWL) ELSE 0
DOCUMENT: Set rate of minimum average estimated waiting time for new OP waiting list patients [mths/mth]

MinTonCCWL(t) = MinTonCCWL(t - dt) + (SRMinTonCCWL) * dt
INIT MinTonCCWL = 1000
DOCUMENT: Minimum average time spent on CC investigation waiting list [mths]
SRMinTonCCWL = IF (AvTonCCWL<MinTonCCWL) THEN PULSE(AvTonCCWL-MinTonCCWL) ELSE 0
DOCUMENT: Set rate of minimum average time spent on CC investigation waiting list [mths/mth]

MinTonOPWL(t) = MinTonOPWL(t - dt) + (SRMinTonOPWL) * dt

INIT MinTonOPWL = 1000

DOCUMENT: Minimum average time spent on OP waiting list [mths]

SRMinTonOPWL = IF (AvTonOPWL<MinTonOPWL) THEN PULSE(AvTonOPWL-MinTonOPWL) ELSE 0

DOCUMENT: Set rate of minimum average time spent on the OP waiting list [mths/mth]

OPWL(t) = OPWL(t - dt) + (RROP - RROPWLtoCC - OOPWLRR) * dt

INIT OPWL = OPWLi

DOCUMENT: OP waiting list length [pats].

All references to OP refer to cardiology OP.

RROP = 1*RefRROP*EffKOP+0*PULSE(1000,10,0)

DOCUMENT: Referral rate for an OP appointment [pats/mth].

RROPWLtoCC = OPR*FOPtoCC+RROPWLtoIPtoCC

DOCUMENT: Rate of referrals from OP waiting list to an elective CC investigation [pats/mth].

Comprises patients who were referred on after attending an OP appointment and patients who, waiting for an OP appointment, deteriorated and were referred on following a hospital admission.

OOPWLRR = PostOPDisR+OPreOPWLRR

DOCUMENT: Other OP waiting list removal rate [pats/mth].

Refers to OP waiting list removals "other" than those who were referred on for elective CC investigation. Comprises post OP discharges and pre OP appt removals from the waiting list. The latter collectively refers to waiting list deaths, patients whose condition improved, moved away from the area, condition deteriorated and became emergencies or left NHS to seek private care.

PrSIECCWL(t) = PrSIECCWL(t - dt) + (GRPrSIECCWL) * dt

INIT PrSIECCWL = 0

DOCUMENT: Pressure summary index associated with an excessive CC investigation waiting list length [pressure].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering the area under the CC investigation waiting list curve and a conversion factor. We assume that the waiting list will only exert pressure on the system if it exceeds its desired length.

GRPrSIECCWL = IF (CCWL>DesCCWL) THEN ((CCWL-DesCCWL)*RPrPP) ELSE 0

DOCUMENT: Gain rate of pressure summary index associated with an excessive CC investigation waiting list length [pressure/mth].

PrSIEOPWL(t) = PrSIEOPWL(t - dt) + (GRPrSIEOPWL) * dt

INIT PrSIEOPWL = 0

DOCUMENT: Pressure summary index associated with an excessive OP waiting list length [pressure].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering the area under the OP waiting list curve and a conversion factor. We assume that the waiting list will only exert pressure on the system if it exceeds its desired length.

GRPrSIEOPWL = IF (OPWL>DesOPWL) THEN ((OPWL-DesOPWL)*RPrPP) ELSE 0

DOCUMENT: Gain rate of pressure summary index associated with an excessive OP waiting list length [pressure/mth].

PrSIETonCCWL(t) = PrSIETonCCWL(t - dt) + (GRPrSIETonCCWL) * dt

INIT PrSIETonCCWL = 0

DOCUMENT: Pressure summary index associated with an excessive average time spent on the CC investigation waiting list [pressure].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering a conversion factor and the area under the curve for the average time spent on the CC investigation waiting list. We assume that the delay for a CC investigation will only exert pressure on the system if it exceeds its desired level.

GRPrSIETonCCWL = IF (AvTonCCWL>DesTCC) THEN ((AvTonCCWL-DesTCC)*RPrPM) ELSE 0

DOCUMENT: Gain rate of pressure summary index associated with an excessive average time spent on the OP waiting list [pressure/mth].

PrSIETonOPWL(t) = PrSIETonOPWL(t - dt) + (GRPrSIETonOPWL) * dt

INIT PrSIETonOPWL = 0

DOCUMENT: Pressure summary index associated with an excessive average time spent on the OP waiting list [pressure].

This is one of several stocks in the model that are used to summarise and compare the graphical output of different simulation runs. They measure different aspects of pressure exerted on the system over time and are based upon the area under the relevant curve. For this index, we count the total number of 'pressure.months' by considering a conversion factor and the area under the curve for the average time spent on the OP waiting list. We assume that the delay for an OP appointment will only exert pressure on the system if it exceeds its desired level.

GRPrSIETonOPWL = IF (AvTonOPWL>DesTOP) THEN ((AvTonOPWL-DesTOP)*RPrPM) ELSE 0

DOCUMENT: Gain rate of pressure summary index associated with an excessive average time spent on the CC investigation waiting list [pressure/mth].

SDCCFA(t) = SDCCFA(t - dt) + (SRDCCFA) * dt

INIT SDCCFA = 0

DOCUMENT: Smoothed district CC facility availability [-].

The availability of the district facility will determine the values of the goals driving the desired CC investigation rate. As changes in availability will not lead to instantaneous changes in the goals, the availability is smoothed.

SRDCCFA = (DCCFA-SDCCFA)/DCCFAST

DOCUMENT: Smoothing rate of district CC facility availability [-/mth].

STPh1DCCP(t) = STPh1DCCP(t - dt) + (STSRPh1DCCP) * dt

INIT STPh1DCCP = 1000

DOCUMENT: Start time of phase 1 district CC service preparation [mths].

The default value of 1000 indicates that preparation of the district site will never take place.

STSRPh1DCCP = IF ((CFPh1DCCP = 0) AND (EDesDCCF>=1) AND (STPh1DCCP=1000)) THEN PULSE(TIME-1000) ELSE 0

DOCUMENT: Start time of set rate of phase 1 district CC service preparation [mths/mth].

District site preparation is initialised in instances where preparation has not yet taken place and there exists an expressed desire for a district facility (either an anticipated or current desire or both).

The formulation of the start time as a level ensures that the preparation of a new site can only be initialised once. This is because the model is only designed to represent a single district hospital so there can only be a single district site.

SumJTCCWL(t) = SumJTCCWL(t - dt) + (AccRCCWLJT - DepRCCWLJT) * dt

INIT SumJTCCWL = 6592

DOCUMENT: Sum of join times for patients on the CC investigation waiting list [pat.mths].

Used to calculate the average time spent on the waiting list for CC investigations, for patients from Veinbridge General. Initialised so that the average time spent on the waiting list equals the desired waiting time which is consistent with the descriptions that the system was stable prior to the introduction of the district service.

AccRCCWLJT = RRCC*CTime

DOCUMENT: Accumulation rate of join times of patients on the CC investigation waiting list [pats].

Used to calculate the average time spent on the waiting list for CC investigations, for patients from a given district hospital.

DepRCCWLJT = IF(CCWL<>0) THEN (CCWLRR*SumJTCCWL/CCWL) ELSE 0

DOCUMENT: Depletion rate of join times of patients on the CC investigation waiting list [pats].

Used to calculate the average time spent on the waiting list for CC investigations, for patients from a given district hospital.

SumJTOPWL(t) = SumJTOPWL(t - dt) + (AccROPWLJT - DepROPWLJT) * dt

INIT SumJTOPWL = 18277.99

DOCUMENT: Sum of join times for patients on the OP waiting list [pat.mths].

Used to calculate the average time spent on the waiting list for an OP appointment for patients from Veinbridge General. Initialised so that the average time spent on the waiting list equals the desired waiting time which is consistent with the descriptions that the system was stable prior to the introduction of the district service.

AccROPWLJT = RROP*CTime

DOCUMENT: Accumulation rate of join times of patients on the OP waiting list [pats].

Used to calculate the average time spent on the waiting list for an OP appointment for patients from a given district hospital.

DepROPWLJT = IF(OPWL<>0) THEN (OPWLRR*SumJTOPWL/OPWL) ELSE 0

DOCUMENT: Depletion rate of join times of patients on the OP waiting list [pats].

Used to calculate the average time spent on the waiting list for an OP appointment for patients from a given district hospital.

TOCCWLR(t) = TOCCWLR(t - dt) + (OCCWLRR) * dt

INIT TOCCWLR = 0

DOCUMENT: Total other CC investigation waiting list removals [pats].

Used for validation purposes only. To check the total number of other waiting list removals (deaths on waiting list etc) from the CC waiting list against the actual data during the period Apr95 to Apr 98 (t=0 to t=36).

OCCWLRR = CCWL*FOCCWLRR

DOCUMENT: Other CC investigation waiting list removal rate [pats/mth].

These are removals from the waiting list "other" than those that constitute patient (elective CC investigation) activity because they represent patients who died on the waiting list, left the list because: their condition improved; they moved to another area; deteriorated and became emergency CC cases; or, choose to seek private care.

ACumDCCRC = IF(CumDCCRC<CumDCCRCAL) THEN 1 ELSE 0

DOCUMENT: Affordability of cumulative district CC service running costs [-].

Support is not given to district service if the cumulative running costs exceed a certain level.

ADesDCCF = IF((FSuppDCC=1) AND (TIME>=TADesDCCF)) THEN 1 ELSE 0

DOCUMENT: Anticipated desire for a district CC facility [-].

A desire for a district service may be anticipated, given the knowledge of the planned withdrawal of tertiary capacity in the future and financial support for a district service.

AggJDOpSki = 80

DOCUMENT: Initial aggregate junior district-based CC operator skill [skill units].

We assume that as the level of tertiary activity is higher for Veinbridge patients, we would expect a quicker rate of gain of experience and skills. Therefore, we assume that at t=0 (Apr 95) the existing trainee at Veinbridge would have gained sufficient skills to have reached saturation point i.e. skills to have reached at least 80 units.

AMDCCRCR = IF (MDCCRCR<=MDCCRCRAL) THEN 1 ELSE 0
DOCUMENT: Affordability of monthly district CC facility running cost rate [-].
Support is not given to district service if the monthly running costs exceed a certain level.

APh1DCCPC = IF (Ph1DCCPC<=Ph1DCCPCAL) THEN 1 ELSE 0
DOCUMENT: Affordability of phase 1 district CC service preparation costs [-].
Support is not given to district service if the phase 1 preparation costs exceed a certain level.

APh2DCCPC = IF (Ph2DCCPC<=Ph2DCCPCAL) THEN 1 ELSE 0
DOCUMENT: Affordability of phase 2 district CC service preparation costs [-].
Support is not given to phase 2 of a district service if the phase 2 preparation costs exceed a certain level.

ATRRCC = 3
DOCUMENT: Averaging time of referral rate for an elective CC investigation [mths].
An expert estimate.

AvCCWLRRe = SMTH1(CCWLRR,1)
DOCUMENT: Average CC investigation waiting list removal rate, used to represent the Evaluation of pressure on the system [pats/mth].
The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of one month is assumed to represent the average delay to evaluate changes in pressure on the system.

AvCCWLRRe&r = SMTH1(CCWLRR,3)
DOCUMENT: Average CC investigation waiting list removal rate, used to represent the Evaluation of pressure on the system and the Response to that pressure [pats/mth].
The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. A averaging period of 3 months is assumed to represent the average delay to evaluate pressure on the system and respond to that pressure e.g. by changing referral rate or desired activity.

AvCDCC = 525
DOCUMENT: Average cost of a district-based CC investigation [pounds/pat].
Only costs at March 1997 are known. Told that prices were consistent with those of Heartwick Hospital. Calculated as a weighted average of costs of day case and inpatient procedures and assumes 1/3 requires procedure as an inpatient.

AvCFurthCC = AvCTCCT/(1+DR)^(AvTFurthCC/12)
DOCUMENT: Average cost per further CC procedure [pounds/pat].
A weighted average. Patients who underwent investigation at the district level which showed that they required treatment will have to undergo a 2nd CC procedure at a later date. The cost, therefore, needs to be discounted. We assume that the price does not change during the discounted period. Otherwise, another

adjustment would need to be made to AvCTCCT. We assume that 1/3 of patients require the 2nd CC procedure to be carried out on an inpatient basis (an expert's lower estimate) and 50% will involve the use of coronary stents.

AvCOP = 100
DOCUMENT: Average cost per OP appointment [pounds/pat].
Actual costs were not available so this is an approximation.

AvCTCC = AvCTCCI*(1-FFurthCC)+FFurthCC*AvCTCCT
DOCUMENT: Average cost per tertiary-based CC procedure [pounds/pat].
A weighted average. Only costs in March 1997 are available. Considers the patients who require investigation only and those who also require treatment. For the latter group, if they undergo CC investigation at the tertiary level can have their treatment procedure carried out at the same time. Otherwise, they need to undergo a further CC procedure (investigation at the district level and treatment at the tertiary level).

AvCTCCI = 525
DOCUMENT: Average cost per tertiary-based CC investigation [pounds/pat].
This relates to patients directly referred for a CC from the given district hospital. Told that cost was equal to that of a district-based investigation. We assume that 1/3 of patients require the CC procedure to be carried out on an inpatient basis (an expert's lower estimate). Only cost in March 1997 is known.

AvCTCCT = 1361
DOCUMENT: Average cost per (tertiary-based) CC treatment (or synchronous investigation and treatment) [pounds/pat].
A weighted average. We assume that 1/3 of patients require the CC procedure to be carried out on an inpatient basis (an expert's lower estimate) and 50% of interventional CC will involve the use of coronary stents. Higher estimates of the proportion with stents will result in a higher average cost per tertiary procedure. We assume that the cost of synchronous investigation and treatment will equal the cost of a treatment procedure only. Only costs for March 1997 are known.

AvOCCWLRR = SMTH1(OCCWLRR,3)
DOCUMENT: Average other CC investigation waiting list removal rate [pats/mth].
This waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of 3 months is assumed to model the evaluation of pressure on the system and response to that pressure e.g. a change in referrals or desired activity.

AvOPWLRR = SMTH1(OPWLRR,1)
DOCUMENT: Average OP waiting list removal rate [pats/mth].

The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of one month is assumed to represent the average delay to evaluate changes in pressure on the system.

AvPreOPWLRR = SMTH1(PreOPWLRR,3)

DOCUMENT: Average pre-appointment OP waiting list removal rate [pats/mth].

The waiting list removal rate needs to be averaged because it is an instantaneous rate and as such is unobservable. An averaging period of 3 months is assumed to model the evaluation of pressure on the system and response to that pressure e.g. a change in referrals or desired activity.

AvRROP = SMTH1(RROP,3)

DOCUMENT: Average rate of referrals for OP appointment [pats/mth].

The averaging period is an expert estimate.

AvSkJDOp = IF (JDOp=0) THEN 0 ELSE (AggJDOpSk/JDOp)

DOCUMENT: Average skill per junior district-based operator [skill units/doctor].

The use of the IF statement prevents a division by zero forcing the simulation to stop.

AvSkNJDOp = 0

DOCUMENT: Average skill per new junior district-based CC operator [skill units/doctor].

Assume that trainee CC operators arrive at Ribsley district hospital as complete novices.

AvTFurthCC = 4.5

DOCUMENT: Average waiting time for further CC procedure (following a district-based CC investigation) [mths].

Used for illustrative purposes only. Based upon simplifying assumptions.

AvTnewCCWLe = IF (AvCCWLRRe = 0) THEN 999 ELSE (CCWL/AvCCWLRRe)

DOCUMENT: Average estimated waiting time for new CC investigation waiting list patients, used to represent the Evaluation of pressure on the system [mths].

This estimate is based upon size of waiting list and average waiting list removal rate at time of entry onto the waiting list. This is used to evaluate changes in pressure on the system. A zero average removal rate would suggest an infinite waiting time as activity would be suspended. To accommodate this extreme case and enable the simulation to proceed, a very large waiting time has been specified.

AvTnewCCWLe&r = IF (AvCCWLRRe&r = 0) THEN 999 ELSE (CCWL/AvCCWLRRe&r)

DOCUMENT: Average estimated waiting time for new CC investigation waiting list patients, used to represent the Evaluation of pressure on the system and the Response to that pressure [mths].

This estimate is based upon size of waiting list and average waiting list removal rate at time of entry onto the waiting list. This is used to calculate the effect of changes in the WT on referrals for CC investigations. Changes in the waiting list removal rate do not lead to instantaneous changes in referrals for CC investigations, but changes are smoothed over a 3 month period. A zero smoothed removal rate would suggest an infinite waiting time as activity would be suspended. To accommodate this extreme case and enable the simulation to proceed, a very large waiting time has been specified.

AvTnewOPWL = IF (AvOPWLRR = 0) THEN 999 ELSE (OPWL/AvOPWLRR)
DOCUMENT: Average estimated waiting time for new OP waiting list patients [mths].
This estimate is based upon the average waiting time for new patients joining the OP waiting list, based upon size of waiting list and average waiting list removal rate at time of entry onto the waiting list. This is used to evaluate changes in pressure on the system. A zero average removal rate would suggest an infinite waiting time as activity would be suspended. To accommodate this extreme case and enable the simulation to proceed, a very large waiting time has been specified.

AvTonCCWL = IF (CCWL<>0) THEN (CTime-(SumJTCCWL/CCWL))
ELSE 0
DOCUMENT: Average time spent on the CC investigation waiting list [mths].
The formulation avoids, in cases where there are no patients on the waiting list, a division by zero, and forces a value of zero which is consistent with reality.

AvTonOPWL = IF (OPWL<>0) THEN (CTime-(SumJTOPWL/OPWL))
ELSE 0
DOCUMENT: Average time spent on the OP waiting list [mths].
The formulation avoids, in cases where there are no patients on the waiting list, a division by zero, and forces a value of zero which is consistent with reality.

AvWLRT = 0.5
DOCUMENT: Average waiting list removal time [mths].
This represents the average time it would take to arrange an investigation of a patient waiting on the CC investigation waiting list.

CapDCC = IF (OA=1) THEN (PCapDCC*DCCFA) ELSE 0
DOCUMENT: Capacity for district-based CC [pats/mth].
By definition, these are elective investigations.

CapOP = IF (OA=1) THEN ((1-SwIOPCap)*NOPCap+SwIOPCap*IncOPCap) ELSE 0
DOCUMENT: Capacity for OP appointments [pats/mth].
Specified by the consultant. Altered during policy analysis.

CapSEDCC = IF (DesECCInvR<PcvdTCapAEDCC) THEN 0 ELSE (DesECCInvR-PcvdTCapAEDCC)
DOCUMENT: Capacity shortfall (at tertiary level) with respect to patients who are eligible to undergo district-based CC investigation [pats/mth].

The capacity shortfall at the tertiary level is the activity level that desired minus the maximum activity that it is able to do (i.e. capacity). However, that is not what we are considering in the context of a shift to the district level. We are only interested in the shortfall that is eligible to be shifted to the district level - only that which constitutes low risk investigations. By definition, these will be elective cases. Furthermore, high risk elective cases (not eligible to be investigated at the district level) will take precedence over the low risk cases in using the available capacity at the tertiary level. Therefore, eligible capacity shortfall
= desired eligible activity - tertiary capacity that could be devoted to eligible patients
= desired eligible activity - (tertiary capacity - avg activity at tertiary level devoted to non eligible patients).

CapTCC = IF (OA=1) THEN PCapTCC ELSE 0
DOCUMENT: Capacity for elective tertiary-based CC investigations [pats/mth].

CCWLi = 128
DOCUMENT: Initial CC investigation waiting list length [pats]

CDesDCCF = IF((CapSEDCC>=MinDCCInvR) AND (FSuppDCC=1)) THEN 1 ELSE 0
DOCUMENT: Current desire for district CC facility [-].
A desire for a district service is expressed if there exists sufficient demand to sustain the service and financial support.

CTime = 55+TIME
DOCUMENT: Current time [mths].
The adjustment of 55 refers to the initialisation period to set average time on waiting lists to the average time estimated for new patients joining the waiting lists.

CumC = CumCCAC+CumOPAC+CumDCCPC+CumDCCRC
DOCUMENT: Cumulative costs [pounds].
Comprises patient activity costs, district service preparation and running costs.

CumCAL = 10000000
DOCUMENT: Cumulative costs affordability limit [pounds].
The use of a very large number represents unconstrained patient activity.

CumDCCRCAL =
1*Step(1000000,TDCCFA)+0*(Step(550,TDCCFA)+Step(100,36))+0*(Step(150,46)+Step(150,58)+Step(150,70))
DOCUMENT: Cumulative district CC service running costs affordability limit [pounds].
This amount is equivalent to 10 month's worth of running costs initially and then, at a later stage, is increased by an amount equivalent to 4 further month's worth of running costs. We assume that the lack of affordability forces the suspension of the district service at t=24 (end March 1997) and t=38 (end May 1998). Financial constraints may be imposed to prevent the second district service as part of the policy

analysis. Also as part of the policy analysis, the period of the second district service may be extended or further temporary injections of funding may be made.

DCCFA = IF((CFPh1DCCP>=0.95) AND (CDesDCCF=1) AND (PCapDCC>0)) THEN 1 ELSE 0

DOCUMENT: District CC facility availability [-].

For a district site to be available, a desire for a district facility has to prevail, the district site has to be at a sufficient level of completion and staff have to be available.

DCCFAST = 1

DOCUMENT: District CC facility availability smoothing time [mths].

The availability of the district facility influences the value of the goals driving the desired CC investigation rate. As changes in availability will not lead to instantaneous changes in the goals, the availability is smoothed.

DCCInvR = CapDCC*UCapDCC

DOCUMENT: District-based CC investigation rate [pats/mth].

Desired activity which can be delivered depends upon the capacity available and utilisation of that capacity. Only low risk CC investigations can be conducted at the district level. This forms the majority of elective investigations. All CC investigations at the district level are carried out by district CC operators.

DesCCInvR = SwPADr*DesCCInvRWL+(1-SwPADr)*DesCCInvRWT

DOCUMENT: Desired elective CC investigation rate [pats/mth].

The goal driving the desired level of activity may be a desired waiting time for new patients joining the waiting list (a WT policy - the base case) or a desired waiting list size (a WL policy - a policy analysis case).

DesCCInvRWL=MAX(MIN(AvRRCC+(CCWL-DesCCWL)/DesCCWLAT-AvOCCWLRR,
CCWL/AvWLRT+AvRRCC),0)

DOCUMENT: Desired elective CC investigation rate driven by the waiting list goal [pats/mth].

In seeking a waiting list goal (desired waiting list length), the desired activity rate will be composed of: (1) the average number of patients joining the waiting list (in order to maintain the waiting list at its existing level); plus (2) any additional adjustment required to meet the desired waiting list size, and, minus (3) any other removals from the waiting list (otherwise, more activity may be carried out than is necessary). However, there are two situations which place bounds on the actual values that the desired activity can take. The first situation is where there are insufficient patients available to meet the calculated desired activity rate - the actual activity rate will be derived from the existing waiting list and new patients joining the waiting list. This is formulated using the MIN( ) function. The second situation is when the calculated desired activity rate works out as being negative - the actual desired activity rate will be zero. This is represented by the use of the MAX( ) function.

DesCCInvRWT = IF(DesTCC=0) THEN 999 ELSE ((CCWL/DesTCC)-AvOCCWLRR)

DOCUMENT: Desired elective CC investigation rate driven by the waiting time goal [pats/mth].

In calculating the activity rate desired to meet the waiting time goal, it is necessary to account for other waiting list removals (which will reduce the required activity rate). Otherwise, more activity may be carried out than is necessary. A desired waiting time of zero would call for an infinitely large activity rate. For the model to accommodate this extreme case and enable the simulation to proceed (i.e. avoid a division by zero), an IF statement is used involving the assignment of a very large number to the desired activity rate.

DesCCWL = IF (SDCCFA>0.5) THEN 128 ELSE 128

DOCUMENT: Desired CC investigation waiting list length [pats].

DesCCWLAT = 2

DOCUMENT: Desired CC investigation waiting list adjustment time [mths].

A value of 2 was quoted by the consultant. Varied to 3 as part of the policy analysis.

DesDCCF = ADesDCCF+CDesDCCF

DOCUMENT: Desire for a district CC facility [-].

A desire for a district facility may be anticipated given the knowledge that a tertiary facility is going to be closed in the future which would result in a significant loss of capacity.

DesDCCInvR = CapSEDCC*DCCFA

DOCUMENT: Desired district-based CC investigation rate [pats/mth].

For a shortfall in activity to represent desired district activity, a suitable facility has to be in place at the district hospital.

DesECCInvR = DesCCInvR*FEDCC

DOCUMENT: Desired eligible CC investigation rate [pats/mth].

This refers to patients who are eligible to undergo CC investigation at the district level - low risk elective investigations.

DesNECCInvR = DesCCInvR*(1-FEDCC)

DOCUMENT: Desired non-eligible CC investigation rate [pats/mth].

This refers to patients who are not eligible to undergo CC investigation at the district level - high risk elective investigations.

DesOPR = SwPADr*DesOPRWL+(1-SwPADr)*DesOPRWT

DOCUMENT: Desired OP rate [pats/mth].

The goal driving the desired level of activity may be a desired waiting time for new patients joining the waiting list (a WT policy - the base case) or a desired waiting list size (a WL policy - a policy analysis case).

DesOPRWL=MAX(MIN(AvRROP+(OPWL-DesOPWL)/DesOPWLAT-AvPreOPWLRR, OPWL/AvWLRT+AvRROP),0)

DOCUMENT: Desired OP rate driven by the waiting list goal [pats/mth].

In seeking a waiting list goal (desired waiting list length), the desired activity rate will be composed of: (1) the average number of patients joining the waiting list (in order to maintain the waiting list at its existing level); plus (2) any additional adjustment required to meet the desired waiting list size, and, minus (3) any other removals from the waiting list (otherwise, more activity may be carried out than is necessary). However, there are two situations which place bounds on the actual values that the desired activity can take. The first situation is where there are insufficient patients available to meet the calculated desired activity rate - the actual activity rate will be derived from the existing waiting list and new patients joining the waiting list.This is formulated using the MIN( ) function. The second situation is when the calculated desired activity rate works out as being negative - the actual desired activity rate will be zero. This is represented by the use of the MAX( ) function.

DesOPRWT = IF(DesTOP=0) THEN 999 ELSE ((OPWL/DesTOP)-AvPreOPWLRR)

DOCUMENT: Desired OP rate driven by the waiting time goal [pats/mth].

In calculating the activity rate desired to meet the waiting time goal, it is necessary to account for other waiting list removals (which will reduce the required activity rate). Otherwise, more activity may be carried out than is necessary. A desired waiting time of zero would call for an infinitely large activity rate. For the model to accommodate this extreme case and enable the simulation to proceed (i.e. avoid a division by zero), an IF statement is used involving the assignment of a very large number to the desired activity rate.

DesOPWL = 338

DOCUMENT: Desired OP waiting list length [pats].

Set to equal the initial OP waiting list size which is consistent with the description that the system was stable, there was sufficient capacity to meet demand and the desired waiting times were maintained.

DesOPWLAT = 2

DOCUMENT: Desired OP waiting list adjustment time [mths].

A value of 2 was quoted by the consultant. Varied to 3 as part of the policy analysis.

DesTCC = IF (SDCCFA>0.5) THEN 3.5 ELSE 3.5

DOCUMENT: Desired waiting time for a CC investigation [mths].

The WT goal is 3.5 months (quoted by the consultant).

DesTOP = 0.9231

DOCUMENT: Desired waiting time for an OP appointment [mths].

A goal of 4 weeks was specified by the consultant. This has been converted to months.

DR = 0.03

DOCUMENT: Discount rate [-].

Costs which occur in the future are discounted. Set at 0.03 per annum for illustrative purposes.

EDesDCCF = DELAY(DesDCCF,Ph1DCCPD)

DOCUMENT: Expressed desire for a district CC facility [-].

EffCapLCC = 1*EffCapLCCB+0*EffCapLCCN+0*EffCapLCCW

DOCUMENT: Effect of significant capacity loss on referrals for elective CC investigation [-].

We assume that a significant loss of capacity will result in a reduction in referrals as a 'knee jerk' reaction. The timing of this effect will depend on the timing of the capacity losses. The '0"s act as switches for the sensitivity and policy analysis.

EffCapLCCB = 1

DOCUMENT: Effect of significant capacity loss on referrals for elective CC investigation corresponding to the base case scenario [-].

A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. The base case involves no significant capacity losses.

EffCDSuppDCC = IF (AvCDCC<=AvCTCCI) THEN 1 ELSE 0

DOCUMENT: Effect of CC investigation cost differential on support for district-based CC service [-].

Support is not given to district service if the cost of district CC investigations is more than the cost of CC investigation at the tertiary level.

EffKCC = 1*NEffKCC+0*EffKCCTDCCS+0*SuppEffKCC

DOCUMENT: Effect of knowledge of CC on referrals for elective CC investigation [-].

The knowledge effect on referrals for CC investigations may be altered as part of the sensitivity analysis or policy analysis.

EffKOP = 1*NEffKOP+0*EffKOPTDCCS+0*SuppEffKOP+0*IncrEffKOP

DOCUMENT: Effect of knowledge of CC on referrals for an OP appointment [-].

The knowledge effect on demand for OP appointments may be altered as part of the sensitivity analysis or policy analysis.

EffODSCC = 1/6

DOCUMENT: Effect of other district-based screeners on referrals for elective CC investigation [-].

Refers to doctors who screen patients for CC investigations but are non CC operators. We assume that the referral behaviour at Veinbridge is more aggressive than that at Ribsley General so that the referrals of non CC operators will be higher. We use the same multiplier.

EffSkCC = EffSkECC*FEDOp+EffSkJCC*FJDOp+(1-FEDOp-FJDOp)*EffODSCC

DOCUMENT: Effect of CC operator skills on referrals for elective CC investigation [-].

The skills effect is a weighted average considering the skills multipliers and proportions of patient decisions made by expert CC operators, junior CC operators and other screening doctors at the district hospital.

EffSkECC = 1

DOCUMENT: Effect of CC operator skills of expert district-based operators on referrals for elective CC investigation [-].

As the reference referral factor is based upon an assumption of fully skilled CC operators, it is consistent that the skills effect for expert district operators should take a value of 1.

EffSkJCC = IF(JDOp=0) THEN 0 ELSE (SwOC*EffSkOJCC+(1-SwOC)*EffSkUJCC)

DOCUMENT: Effect of CC operator skills of junior district-based operators on referrals for elective CC investigation [-].

The effect of CC skills of junior district CC operators on their referral rates for CC investigations will depend on whether they are naturally overconfident or underconfident. It is assumed that overconfidence will result ina period of over-referrals whilst underconfidence will lead to under-referrals. This refers to aggregate behaviour. The system being considered involves a single district hospital and the reference to overconfidence or underconfidence is determined by the culture at that hospital. This effect only applies in cases where there are junior operators.

EffWTCC = 1*NEffWTCC+0*SuppEffWTCC

DOCUMENT: Effect of waiting time for CC investigation on referrals for elective CC investigation [-].

This waiting time effect may be suppressed as part of the policy analysis, representing the affect of the implementation of a clinical guideline.

FEDOp = IF (JDOp=0) THEN 1 ELSE 1

DOCUMENT: Fraction CC investigation recommendations made by expert district CC operators [-].

This refers to final decisions made. The consultant stated that the expert CC operator makes final decisions on all patients.

FFurthCC = 0.17

DOCUMENT: Fraction of patients referred for further CC (following a district-based CC investigation) [-].

An average, based upon patient activity data. Since synchronous investigations and interventions (treatment) procedures cannot be carried out at the district level, the fraction of patients who require a CC-based treatment have to be referred on the tertiary level for a second CC procedure.

FJDOp = IF (JDOp=0) THEN 0 ELSE 0

DOCUMENT: Fraction CC investigation recommendations made by expert district CC operators [-].

This refers to final decisions made. An expert estimate. The fraction decided by junior district operators would be zero if there were no junior district operators present.

FOCCWLRR = 0.0078

DOCUMENT: Fractional other CC investigation waiting list removal rate [-/mth].

These are removals from the waiting list "other" than those that constitute patient (elective CC investigation) activity. Based upon an expert estimate.

FOPreOPWLRR = 0.022

DOCUMENT: Fractional other pre-appointment OP waiting list removal rate [-/mth].

This refers to OP waiting list removals "other" than those on the waiting list who deteriorated, were admitted into hospital, stabilised and were sent home and placed on the CC investigation waiting list. Based on an expert estimate.

FOPtoCC=RefFOPtoCC*EffSkCC*(IF(EffCapLCC<1) THEN EffCapLCC ELSE (EffCapLCC*EffKCC *EffWTCC*EffOFCC))

DOCUMENT: Fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].

The use of the IF( ) function reflects the assumption that the 'knee jerk' reaction to the capacity losses will dominate over the effects of WT, knowledge of CC and other factors on referrals for elective CC investigations.

FRROPWLtoIPtoCC = 0.003

DOCUMENT: Fractional rate of referrals from the OP waiting list via inpatients to an elective CC investigation [-/mth].

Based on an expert estimate.

FSuppDCC=IF ((ACumDCCRC=1) AND (AMDCCRCR=1) AND (APh1DCCPC=1) AND (EffCDSuppDCC=1) AND (OA=1)) THEN 1 ELSE 0

DOCUMENT: Financial support for a district CC service [-].

The district service relies upon the running costs and site preparation costs being affordable, the district procedural cost being attractive compared to a CC investigation carried out at the tertiary level, and there being sufficient funds to continue delivering services. Both the cumulative and monthly running costs are considered. This is because whilst a given monthly running cost might be considered reasonable to warrant the introduction of a district service, this may not necessary imply that a permanent service can be afforded. There may only be sufficient funding available to pay the running costs for a limited period. A value of "1" will indicate 'affordable' whilst a value of "0" will indicate 'not affordable'.

FSuppPh2DCC = IF ((APh2DCCPC=1) AND (FSuppDCC=1)) THEN 1 ELSE 0

DOCUMENT: Financial support for a phase 2 district CC service [-].

Refers to support for an integrated catheter laboratory.

FTCCbyDO = IF (DCCFA<>0) THEN 0.95 ELSE 0.95

DOCUMENT: Fraction of tertiary-based elective CC investigations carried out by a district-based CC operator [-].

An expert estimate. Refers to patients referred from the given district hospital of interest and to district-based CC operators from that hospital. District cardiologists with CC operator skills are allocated sessions at the tertiary centre to investigate their patients. The fraction is not 1 because allowances are made for absences due to sickness and holidays. District cardiologists who are CC operators and only carry out CC investigations will not have sessions at the tertiary centre for elective CC investigations if there is a district service in place at their (district) hospital. District cardiologists who also do interventional CC work (treatments) and have CC facilities in place at their hospital will retain sessions for elective CC investigations on their high risk patients at the tertiary centre. The consultant at Veinbridge General does investigations and interventional work.

IncOPCap = 462.91

DOCUMENT: Increased OP capacity [pats/mth]

10% increase. Used as part of the policy analysis.

IRROP = 0

DOCUMENT: Increase in referral rate for OP appointment [-]

Expressed as a percentage. Used for conducting sensitivity analysis.

JDOpRecD = 0

DOCUMENT: Junior district-based CC operator recruitment delay [mths].

The delay in filling the trainee CC operator vacancy, following the departure of the junior operator after completion of his/her training period.

JDOpSkGRExp = LEJDOp*LPP

DOCUMENT: Junior district-based CC operator skills gain rate via experience [skill units/mth].

Assumes that all trainees work under supervision so trainees and trainers don't operate on separate patients.

JDOpSkGRRec = AvSkNJDOp*JDOpRecR

DOCUMENT: Junior district-based CC operator skills gain rate via recruitment [skill units/mth].

A new trainee recruit may have come via from another district hospital with some exposure to CC investigations and therefore not arrive as a complete novice. Therefore, some CC skills may be gained via recruitment.

JDOpTT = 24

DOCUMENT: Junior district-based CC operator training time [mths].

Quoted by the consultant.

LEJDOp = (DCCInvR+TCCInvR*FTCCbyDO)*LFJDOp

DOCUMENT: Learning experiences for junior district-based CC operators [pats/mth].

The pool of patients from which junior district CC operators gain skills is a fraction of the patients from the district hospital which are investigated at the district level and a fraction of the elective patients investigated at the tertiary level.

LFJDOp = IF (JDOp=0) THEN 0 ELSE 0.75

DOCUMENT: (Patient activity) learning fraction of junior district-based CC operators [-].

This is the fraction of investigations from which the junior operator learns. It will exceed the fraction for which the junior actually conducts the investigation because the junior operator will learn from discussions with the consultant, audit etc. Increased to 0.9 as part of the policy analysis, to represent a change in policy.

MaxSkOp = 100

DOCUMENT: Maximum CC skills per CC operator [skill units/doctor].

MBCheckPats=OPWLi+CCWLi+CumOPWLAdds+CumCCWLAdds-CumOPWLRems-CumCCWLRems-1*Max(OPWL,0)-1*Max(CCWL,0)-0*OPWL-0*CCWL

DOCUMENT: Mass balance check on patients [pats]

MBCheckSk = AggJDOpSki+CumGJDOpSk-CumLJDOpSk-Max(AggJDOpSk,0)

DOCUMENT: Mass balance check on skills of junior district-based CC operators [skill units]

MDCCRCR = 50

DOCUMENT: Monthly district CC facility running cost rate [pounds/mth].

An approximation.

MDCCRCRAL = Step(100,TDCCFA)

DOCUMENT: Monthly district CC facility running cost rate affordability limit [pounds/mth].

An expert estimate since data is not available.

MinDCCInvR = 9

DOCUMENT: Minimum district-based elective CC investigation rate [pats/mth].

The minimum observed activity level using a single session in a mobile catheter laboratory.

NOPCap = 420.83

DOCUMENT: Normal OP capacity [pats/mth].

Calculated from an expert estimate for the OP capacity utilisation of 85% and an estimate for the average OP rate prior to the introduction of the district service. The OP activity data was unreliable. Consequently, this parameter was estimated from the descriptions of the system (system was stable, sufficient capacity to meet demand, desired waiting times were maintained) and the assumption that Veinbridge cardiologists referred 50% more patients on for a CC investigation than cardiologists at Ribsley.

OA = IF (CumC<=CumCAL) THEN 1 ELSE 0

DOCUMENT: Overall affordability [-].

If the total overall costs exceed a certain level, support for the district service will be withdrawn and all elective patient activity will be suspended.

OPreOPWLRR = OPWL*FOPreOPWLRR

DOCUMENT: Other pre-appointment OP waiting list removal rate [pats/mth].

This refers to OP waiting list removals "other" than those on the waiting list who deteriorated, were admitted into hospital, stabilised and were sent home and placed on the CC investigation waiting list. Instead, these are removals from the waiting list that do not constitute OP activity because they represent patients who died on the waiting list or left the list because: their condition improved; they moved to another area; deteriorated and became emergency referrals for CC investigation; deteriorated, became hospital admissions, stabilised and then were simply sent home (i.e. were not referred on for an elective or emergency CC investigation); or, choose to seek private care.

OPWLi = 338

DOCUMENT: Initial OP waiting list length [pats].

There was no hard data on the OP waiting list so this parameter was estimated from the descriptions of the system (system was stable, sufficient capacity to meet demand, desired waiting times were maintained) and the assumption that Veinbridge cardiologists referred 50% more patients on for a CC investigation than cardiologists at Ribsley.

OPWLRR = OPR+PreOPWLRR

DOCUMENT: OP waiting list removal rate [pats/mth].

PCapDCC=1*PCapDCCB+0*PCapDCCET+0*PCapDCCPDS+0*PCapDCCTDS+0*PCapDCCNSDem+0 *PCapDCCW

DOCUMENT: Potential capacity for elective district-based CC investigations [pats/mth].

This is the elective district-based CC investigation capacity that would be available if the district service were affordable.

PCapTCC=1*PCapTCCB+0*PCapTCCET+0*PCapTCCNDS+0*PCapTCCTDS+0*PCapTCCPDS+0*PCa pTCCNSDem+0*PCapTCCW

DOCUMENT: Potential capacity for tertiary-based elective CC investigations [pats/mth].

This is the elective tertiary-based CC investigation capacity that would be available if it were affordable. Capacity data is specified using an approximation of historical activity data (smoothed), extracting the behaviour of interest. Increased as part of the policy analysis.

PcvdDCCInvR = SMTH3(DCCInvR,PDDCCInvR)

DOCUMENT: Perceived district-based CC investigation rate [pats/mth].

A 3rd order delay is chosen rather than a 1st order delay because a sudden increase in CC Inv activity at the district level would not be perceived immediately. These are perceptions by those outside the district hospital (GPs and patients) of something occurring within the district hospital. GPs will learn about the availability of the district service via written communication with the district hospital (referral letters) and patients will gain knowledge through 'word of mouth'. Because the district service was only temporary at Ribsley General, it was not marketed (unlike the case of the permanent service at Veinbridge) so the perception delay would be longer.

PcvdTCapAEDCC = 0*TCapAEDCC+1*SMTH1(TCapAEDCC,STTCapUNEDCC)

DOCUMENT: Perceived tertiary-based elective CC investigation capacity available for those eligible to undergo district-based CC [pats/mth].

The capacity available for eligible patients needs to be averaged since it is derived from an instantaneous rate which is, therefore, unobservable.

PDDCCInvR = 6

DOCUMENT: Perception delay of district-based CC investigation rate (by GPs and patients) [mths].

An expert estimate.

Ph1DCCPC = 6500

DOCUMENT: Phase 1 district CC service preparation costs [pounds].

An expert estimate since data not available.

Ph1DCCPCAL = Step(6500,TDCCFA)

DOCUMENT: Phase 1 district CC service preparation costs affordability limit [pounds].

An expert estimate.

Ph1DCCPD = 0

DOCUMENT: Phase 1 district CC service preparation delay [mths].

An expert estimate. This refers to the delay to respond to the need for a district facility. In constrast with Ribsley General, at Veinbridge the support for a district service was such that there was no delay in responding to the knowledge of an anticipated loss of tertiary capacity.

Ph1DCCPMCR = (IF (Ph1DCCPR>0) THEN (Ph1DCCPC/Ph1DCCPP) ELSE 0)

DOCUMENT: Phase 1 district CC service preparation monthly cost rate [pounds/mth].

Monthly costs incurred to prepare a site for phase 1 (i.e. mobile cath lab-based) district service. It is assumed that the total costs are spread evenly over the site preparation period.

Ph1DCCPP = 2

DOCUMENT: Phase 1 district CC service preparation period [mths].

An approximation.

Ph2DCCPC = 1000000

DOCUMENT: Phase 2 district CC service preparation costs [pounds].

Ph2DCCPCAL = 1000000

DOCUMENT: Phase 2 district CC service preparation costs affordablity limit [pounds].

An integrated cath lab is constructed at Veinbridge General.

Ph2DCCPD = 17

DOCUMENT: Phase 2 district CC service preparation delay [mths].

This delay is measured from the beginning of phase 1 preparation. A very large number would indicate that the district service will never enter phase 2.

Ph2DCCPMCR=FSuppPh2DCC*(IF(CumDCCPC<(Ph1DCCPC+Ph2DCCPC))THEN STEP(Ph2DCCPC/Ph2DCCPP, (STPh1DCCP+Ph2DCCPD)) ELSE 0)

DOCUMENT: Phase 2 district CC service preparation monthly cost rate [pounds/mth].

This refers to the costs incurred to construct an integrated catheter laboratory. It is assumed that the total costs are spread evenly over the site and facility preparation period.

Ph2DCCPP = 6

DOCUMENT: Phase 2 district CC service preparation period [mths].

This is the time it would take to construct an integrated lab if funding were available.

PostOPDisR = OPR*(1-FOPtoCC)

DOCUMENT: Post-OP appointment discharge rate [pats/mth].

These are patients which are not referred on for an elective CC investigation.

PreOPWLRR = RROPWLtoIPtoCC+OPreOPWLRR

DOCUMENT: Pre-appointment OP waiting list removal rate [pats/mth].

These are all the removals from the waiting list that do not constitute patient (outpatient) activity. They represent patients who died on the waiting list, left the list because: their condition improved; they moved to another area; deteriorated and became emergency referrals for CC investigation; deteriorated, became hospital admissions, stabilised and were then sent home (i.e. didn't result in being referred for elective or emergency CC investigation; deteriorated, became hospital admissions, stabilised and were placed on the CC investigation waiting list; or, choose to seek private care.

RefFOPtoCC = 0.05625*1.5

DOCUMENT: Reference fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].

This is the referral fraction for which there was no district service, normal capacity levels, all district screeners are fully skilled and there is no stimulation nor suppression of demand due to the waiting time or patient/GP pressure effects. This would correspond with a situation for which GPs' and patients' knowledge of CC relies totally on that derived from tertiary activity and the waiting time is at a level so that it neither stimulates nor suppresses demand. The remaining patients are discharged back to their GP following their OP appointment. Some will be subsequently followed up. The follow-up process is not being modelled and this will form a recommendation for further development of the model.

The expert estimate was unreliable as applying it would produce behaviour (continual growth in the CC waiting list and waiting times) that was inconsistent with that described prior to the introduction of district services (sufficient capacity to meet demand). Instead, the value used was based on the assumption that Veinbridge General cardiologists would refer 50% more than those at Ribsley General. The actual value chosen is not important as our focus is on the mode of behaviour of the system. This assumed value is used to derive values of several other variables in the model.

RefRROP = 366.16*(1+Step(IRROP,48))
DOCUMENT: Reference rate of referrals for an OP appointment [pats/mth].
Represents new and follow-up patients. This is the OP referral rate for which the effect of patient and GP knowledge of CC is 1 i.e. knowledge is based upon tertiary activity only. Initially set at a level such that the OP waiting list additions and removals balance (as reported by the consultant). Later increased as part of the policy analysis.

Calculation of this value is based on the assumption that Veinbridge cardiologists refer 50% more patients on for a CC investigation than cardiologists at Ribsley.

RefTnewCCWL = 3.5
DOCUMENT: Reference waiting time for new CC investigation waiting list patients [mths].
Used to calculate 'WT effect' on referrals for CC. Represents the waiting time for which referrals will neither be suppressed not stimulated; waiting times greater than this reference value will suppress demand and waiting times lower than this reference value will stimulate demand. Set to desired waiting time.

RPrPM = 1
DOCUMENT: Rate of pressure per month (spent on the waiting list) [pressure/mth/mth]
We arbitrarily specifiy that each month spent on the waiting list exerts one unit of pressure per month. As the purpose is to compare pressure associated with different simulation runs, its value is irrelevant.

RPrPP = 1
DOCUMENT: Rate of pressure gain per patient (on the waiting list) [pressure/patient/mth]
We arbitrarily specifiy that a patient exerts one unit of pressure on the system for each month spent on the waiting list. As the purpose is to compare pressure associated with different simulation runs, the value of this parameter is irrelevant.

RRCC = RROPWLtoCC+NRRIPtoCC
DOCUMENT: Referral rate for an elective CC investigation [pats/mth].

Considers referrals from both the outpatient and inpatient route.

RRFurthCC = DCCInvR*FFurthCC

DOCUMENT: Rate of referral (from a district-based CC investigation) to a further CC (treatment) procedure [pats/mth].

As only CC investigations can be carried out at the district level, patients who also require interventional CC (treatment) have to be referred to the tertiary level for a 2nd procedure. When necessary, synchronous diagnostic and treatments are carried out on patients investigated at the tertiary level so none of these patients require a 2nd procedure.

RROPWLtoIPtoCC = OPWL*FRROPWLtoIPtoCC

DOCUMENT: Rate of referrals from the OP waiting list via inpatients to an elective CC investigation [pats/mth].

This refers to patients on the OP waiting list who deteriorated, were admitted into hospital, stabilised and then placed on the CC investigation waiting list. Therefore, they were referred for an elective CC investigation after admission as an inpatient as opposed to after assessment as an outpatient.

STTCapUNEDCC = 3-Step(2.75,13)+Step(2.75,14)-0*(Step(2.75,36)-Step(2.75,37))-0*(Step(2.75,46)-Step(2.75,47)+Step(2.75,58)-Step(2.75,59)+Step(2.75,70)-Step(2.75,71))

DOCUMENT: Smoothing time of tertiary-based elective CC investigation capacity use by patients not eligible to undergo a district-based CC [mths].

Although there were no capacity shortfalls for Veinbridge General patients, we would assume that the response time would have been shorter if a capacity shortfall was anticipated.

SwB3 = 1

DOCUMENT: Switch for feedback loop B3 [-].

0 = Off; 1 = On. Refers to the waiting time effect on referrals for elective CC investigations.

SwIOPCap = 0

DOCUMENT: Switch for increase in OP capacity [-]

0 = normal OP capacity level; 1 = increased OP capacity level. Used as part of the policy analysis.

SwOC = 1

DOCUMENT: Switch for overconfidence in referral behaviour (of junior district-based CC operators) [-].

0 = Off (underconfidence); 1 = On (overconfidence). "Underconfidence" is the tendency of junior cardiologists, as they embark on their CC training, to hesitate and under-refer patients. As they gain CC skills, they gain confidence and this is reflected by them wanting to refer more patients on for CC investigations. This behaviour pattern would be expected in a hospital in which the referral behaviour was conservative, typically led by a consultant cardiologist who only carried out CC investigations. Overconfident referral behaviour among juniors would be expected in a hospital in which the referral

behaviour was more 'aggressive', typically led by a consultant cardiologist who also carried out CC treatments. We assume overconfidence at Veinbridge General.

SwPADr = 0
DOCUMENT: Switch for patient activity driver [-].
1 = Seeks a desired waiting list length; 0 = Seeks a desired average waiting time. The desired activity rate is driven by a desired waiting time for new patients joining the waiting list or a desired waiting list size. The desired activity rate is currently driven by a waiting time goal. This reflects the policy currently used by the consultant. Used for the policy analysis.

SwR1 = 1
DOCUMENT: Switch for feedback loop R1 [-].
0 = Off; 1 = On. Refers to the knowledge effect on referrals for cardiology outpatient appointments.

SwR2 = 1
DOCUMENT: Switch for feedback loop R1 [-].
0 = Off; 1 = On. Refers to the knowledge effect on referrals for CC investigations.

SwTOpP = 1
DOCUMENT: Switch for trainee district CC operator programme [-].
0 = Off (No trainee operator programme); 1 = On (Use of a trainee operator programme). Used as part of the policy analysis.

TADesDCCF = IF (TCapLT=999) THEN 999 ELSE (TCapLT-Ph1DCCPP)
DOCUMENT: Time of anticipated desire for district CC facility [mths].
999 is the default value indicating no anticipated desire for district facility.

TCapAEDCC = IF(FEDCC=0) THEN 0 ELSE (CapTCC-TCCInvRNEDCC)
DOCUMENT: Tertiary-based elective CC investigation capacity available for those eligible to undergo district-based CC [pats/mth].
This is the fraction of tertiary capacity which is not being used by non eligible patients (who have first priority on the use of tertiary resources). It is assumed that, if no cases were eligible to be shifted to the district level, the capacity that would be available for these patients would be allocated elsewhere.

TCapLT = 13
DOCUMENT: Tertiary capacity loss time [mths].
A value is 999 would indicate no anticipated desire. Changes from default if a loss in tertiary capacity is anticipated. Currently specifies simulation time corresponding to May 96.

TCCInvR = CapTCC*UCapTCC
DOCUMENT: Tertiary-based elective CC investigation rate [pats/mth].

This represents patients referred from the district hospital of interest for an elective CC investigation. Elective CC investigations on patients referred by GPs directly to the tertiary centre, elective CC investigations on patients referred from district hospitals which do not have consultants with CC skills, emergency CC investigations and CC interventions (treatments) lie outside the boundary of the model. The elective CC investigation rate at the tertiary level will depend upon the capacity available and its utilisation. The level of capacity utilisation will be driven by the desired activity rate. All CC investigations can be safely conducted at the tertiary level whereas only low risk elective investigations can be safely delivered at the district level.

TCCInvRNEDCC = CapTCC*UCapTCCNEDCC
DOCUMENT: Tertiary-based elective CC investigation rate of those not eligible to undergo district-based CC [pats/mth].

TDCCFA = IF (TADesDCCF=999) THEN 999 ELSE TADesDCCF
DOCUMENT: Time district CC service first affordable [mths].
A value of 999 indicates the case where a district service is never affordable. In the case of Ribsley General, it was the situation that led to the anticipated desire (planned temporary closure of tertiary facilities) that led to the district service being affordable. If the closure of tertiary facilities had not occurred, it is assumed that the district service would have never been affordable.

TRnewCCWL = IF(RefTnewCCWL=0) THEN 999 ELSE (AvTnewCCWLe&r/RefTnewCCWL)
DOCUMENT: Waiting time ratio for new CC investigation waiting list patients [-].
The use of the IF statement ensures that a division by zero will not cause the simulation to stop. However, in reality the reference WT for new CC waiting list patients would never be zero since we are dealing with elective patients.

EffCapLCCN = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 0.25), (15.0, 0.5), (16.0, 0.75), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00), (26.0, 1.00), (27.0, 1.00), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 1.00), (34.0, 1.00), (35.0, 1.00), (36.0, 1.00), (37.0, 0.25), (38.0, 0.5), (39.0, 0.75), (40.0, 1.00), (41.0, 1.00), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00), (55.0, 1.00), (56.0, 1.00), (57.0, 1.00), (58.0, 1.00), (59.0, 1.00), (60.0, 1.00), (61.0, 1.00), (62.0, 1.00), (63.0, 1.00), (64.0, 1.00), (65.0, 1.00), (66.0, 1.00), (67.0, 1.00), (68.0, 1.00), (69.0, 1.00), (70.0, 1.00), (71.0, 1.00), (72.0, 1.00)
DOCUMENT: Effect of significant capacity loss on referrals for the case with no district service [-].
Used as part of the sensitivity analysis. A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. Both capacity

losses relate to losses of tertiary capacity. It is assumed that the effect dimishes over a period of three months.

EffCapLCCW = GRAPH(TIME)

(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00), (26.0, 1.00), (27.0, 1.00), (28.0, 1.00), (29.0, 1.00), (30.0, 1.00), (31.0, 1.00), (32.0, 1.00), (33.0, 0.25), (34.0, 0.5), (35.0, 0.75), (36.0, 1.00), (37.0, 1.00), (38.0, 1.00), (39.0, 1.00), (40.0, 1.00), (41.0, 1.00), (42.0, 1.00), (43.0, 1.00), (44.0, 1.00), (45.0, 1.00), (46.0, 1.00), (47.0, 1.00), (48.0, 1.00), (49.0, 1.00), (50.0, 1.00), (51.0, 1.00), (52.0, 1.00), (53.0, 1.00), (54.0, 1.00), (55.0, 1.00), (56.0, 1.00), (57.0, 1.00), (58.0, 1.00), (59.0, 1.00), (60.0, 1.00), (61.0, 1.00), (62.0, 1.00), (63.0, 1.00), (64.0, 1.00), (65.0, 1.00), (66.0, 1.00), (67.0, 1.00), (68.0, 1.00), (69.0, 1.00), (70.0, 1.00), (71.0, 1.00), (72.0, 1.00)

DOCUMENT: Effect of significant capacity loss on referrals for the case with a winter crisis [-].

This crisis involves a temporary loss of elective capacity at both the district and tertiary levels. A value of 1 indicates a zero effect. It is assumed that a significant drop in capacity will cause referrals to be temporarily suppressed as a 'knee jerk' reaction. There is only a single knee jerk reaction as the capacity losses due to the closures of tertiary facilities are compensated for by the use of the district service. It is assumed that the effect diminishes over a period of three months.

EffKCCTDCCS = GRAPH(IF (SwR2=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.02), (10.0, 1.09), (12.5, 1.13), (15.0, 1.15), (17.5, 1.15), (20.0, 1.15)

DOCUMENT: Effect of knowledge of CC on referrals for an elective CC investigation with a temporary district service [-].

Relates to GP and patient knowledge of CC. It is assumed that a temporary district service would stimulate less demand than a permanent service as less effort would be devoted to promoting the service and less interest would be generated. Furthermore, a temporary district service at Veinbridge General would be assumed to generate more demand than a temporary district service at Ribsley General, assuming the same patient and GP behaviour. This follows because increased pressure to refer would have a greater effect on the typically more 'aggressive' cardiologists at Veinbridge General; the effects of knowledge on referrals represents the effect of pressure to refer, generated by increased knowledge, and the response to that pressure. If the loop is switched off or the district service is not present, the input is zero forcing the effect to equal 1. We assume that pressure can only be exerted to refer whilst the district service is present.

EffKOPTDCCS = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.00), (10.0, 1.00), (12.5, 1.02), (15.0, 1.05), (17.5, 1.05), (20.0, 1.05)

DOCUMENT: Effect of knowledge of CC on referrals for an OP appointment with a temporary district CC service [-].

Represents GP and patient knowledge effect. If loop switched off the input is zero forcing effect to equal 1. It is assumed that a temporary district service would stimulate less demand than a permanent service as less effort would be devoted to promoting the service and less interest would be generated. Furthermore, a temporary district service at Veinbridge General would be assumed to generate more demand than a temporary district service at Ribsley General, assuming the same patient and GP behaviour. This follows because increased pressure to refer would have a greater effect on the typically more 'aggressive' cardiologists at Veinbridge General; the effects of knowledge on referrals represents the effect of pressure to refer, generated by increased knowledge, and the response to that pressure.

EffOFCC = GRAPH(TIME)

(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.18), (15.0, 1.20), (16.0, 1.20), (17.0, 1.20), (18.0, 1.20), (19.0, 1.20), (20.0, 1.20), (21.0, 1.20), (22.0, 1.20), (23.0, 1.20), (24.0, 1.20), (25.0, 1.20), (26.0, 1.20), (27.0, 1.20), (28.0, 1.20), (29.0, 1.20), (30.0, 1.20), (31.0, 1.20), (32.0, 1.20), (33.0, 1.20), (34.0, 1.20), (35.0, 1.36), (36.0, 1.40), (37.0, 1.40), (38.0, 1.40), (39.0, 1.40), (40.0, 1.40), (41.0, 1.40), (42.0, 1.40), (43.0, 1.40), (44.0, 1.40), (45.0, 1.40), (46.0, 1.40), (47.0, 1.40), (48.0, 1.40), (49.0, 1.40), (50.0, 1.40), (51.0, 1.40), (52.0, 1.40), (53.0, 1.40), (54.0, 1.40), (55.0, 1.40), (56.0, 1.40), (57.0, 1.40), (58.0, 1.40), (59.0, 1.40), (60.0, 1.40), (61.0, 1.40), (62.0, 1.40), (63.0, 1.40), (64.0, 1.40), (65.0, 1.40), (66.0, 1.40), (67.0, 1.40), (68.0, 1.40), (69.0, 1.40), (70.0, 1.40), (71.0, 1.40), (72.0, 1.40)

DOCUMENT: Effect of other factors on referrals for elective CC investigation [-].

A example of another factor which might influence the referral threshold is the introduction of a permanent district service which, given the ability to increase capacity, might encourage the referral threshold to drop so that more 'grey area' cases would be investigated by CC. The values were derived from sensitivity analysis to produce the utilisation of district-based CC capacity of approximately 54% representing adequate district-based CC capacity to meet demand (See PCapDCCB).

EffSkOJCC = GRAPH(AvSkJDOp)

(0.00, 0.167), (10.0, 0.167), (20.0, 0.167), (30.0, 0.167), (40.0, 0.285), (50.0, 0.8), (60.0, 1.21), (70.0, 1.21), (80.0, 1.00), (90.0, 1.00), (100, 1.00)

DOCUMENT: Effect of CC operator skills of overconfident junior district-based operators on referrals for elective CC investigation [-].

Graph was constructed using expert estimates.

EffSkUJCC = GRAPH(AvSkJDOp)

(0.00, 0.167), (10.0, 0.167), (20.0, 0.167), (30.0, 0.167), (40.0, 0.167), (50.0, 0.167), (60.0, 0.36), (70.0, 0.862), (80.0, 1.00), (90.0, 1.00), (100, 1.00)

DOCUMENT: Effect of CC operator skills of underconfident junior district-based operators on referrals for elective CC investigation [-].

Graph was constructed using expert estimates. This reflects the base case assumption for Ribsley General.

FEDCC = GRAPH(TIME)

(0.00, 0.9), (1.00, 0.9), (2.00, 0.9), (3.00, 0.9), (4.00, 0.9), (5.00, 0.9), (6.00, 0.9), (7.00, 0.9), (8.00, 0.9), (9.00, 0.9), (10.0, 0.9), (11.0, 0.9), (12.0, 0.9), (13.0, 0.9), (14.0, 0.9), (15.0, 0.9), (16.0, 0.9), (17.0, 0.9), (18.0, 0.9), (19.0, 0.9), (20.0, 0.9), (21.0, 0.9), (22.0, 0.9), (23.0, 0.9), (24.0, 0.9), (25.0, 0.9), (26.0, 0.9), (27.0, 0.9), (28.0, 0.9), (29.0, 0.9), (30.0, 0.9), (31.0, 0.9), (32.0, 0.9), (33.0, 0.9), (34.0, 0.909), (35.0, 0.924), (36.0, 0.943), (37.0, 0.95), (38.0, 0.95), (39.0, 0.95), (40.0, 0.95), (41.0, 0.95), (42.0, 0.95), (43.0, 0.95), (44.0, 0.95), (45.0, 0.95), (46.0, 0.95), (47.0, 0.95), (48.0, 0.95), (49.0, 0.95), (50.0, 0.95), (51.0, 0.95), (52.0, 0.95), (53.0, 0.95), (54.0, 0.95), (55.0, 0.95), (56.0, 0.95), (57.0, 0.95), (58.0, 0.95), (59.0, 0.95), (60.0, 0.95), (61.0, 0.95), (62.0, 0.95), (63.0, 0.95), (64.0, 0.95), (65.0, 0.95), (66.0, 0.95), (67.0, 0.95), (68.0, 0.95), (69.0, 0.95), (70.0, 0.95), (71.0, 0.95), (72.0, 0.95)

DOCUMENT: Fraction of CC investigation waiting list that are eligible for district-based investigation [-]. Assumes that the majority of elective patients could be investigated at the district level. This is altered with the development with the integrated cath lab at Veinbridge to reflect the reported change in policy by shifting slightly higher risk investigations to the district level.

IncrEffKOP = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.01), (10.0, 1.05), (12.5, 1.15), (15.0, 1.38), (17.5, 1.40), (20.0, 1.40)

DOCUMENT: Increased effect of knowledge of CC on referrals for a cardiology OP appointment [-]. Represents GP and patient knowledge effect. Used during the sensitivity analysis.

LPP = GRAPH(AvSkJDOp/MaxSkOp)

(0.00, 2.00), (0.1, 2.00), (0.2, 2.00), (0.3, 2.00), (0.4, 2.00), (0.5, 2.00), (0.6, 1.72), (0.7, 0.46), (0.8, 0.12), (0.9, 0.04), (1, 0.00)

DOCUMENT: Learning per patient [skill units/patient].
Constructed using expert estimates.

NEffKCC = GRAPH(IF (SwR2=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.02), (10.0, 1.09), (12.5, 1.14), (15.0, 1.19), (17.5, 1.20), (20.0, 1.20)

DOCUMENT: Normal effect of knowledge of CC on referrals for an elective CC investigation [-].
Relates to GP and patient knowledge of CC. For Veinbridge General, the normal effect is that generated by a permanent district service. If the loop is switched off or district service is not present, input is zero forcing effect to equal 1. We assume that pressure can only be exerted to refer whilst the district service is present. This graph was presented to the consultant who thought that it seemed quite reasonable. Variations were explored via the sensitivity analysis.

NEffKOP = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.01), (10.0, 1.05), (12.5, 1.15), (15.0, 1.20), (17.5, 1.20), (20.0, 1.20)

DOCUMENT: Normal effect of knowledge of CC on referrals for an OP appointment [-].

Represents GP and patient knowledge effect. For Veinbridge General, the normal effect is that generated by a permanent district service. If the loop is switched off, the input is zero forcing the effect to equal 1. We assume that as the district service was permanent, it would be heavily marketed and generally strong interest in CC would be generated so the effect of the district service on referrals for an OP appt, would be high. The consultant stated that he could not comment on the validity of the graph. Variations were explored via the sensitivity analysis.

NEffWTCC = GRAPH(IF(SwB3=0) THEN 1 ELSE TRnewCCWL)
(0.00, 1.00), (0.2, 1.00), (0.4, 1.00), (0.6, 1.00), (0.8, 1.00), (1.00, 1.00), (1.20, 1.00), (1.40, 1.00), (1.60, 1.00), (1.80, 1.00)
DOCUMENT: Normal effect of waiting time for CC investigation on referrals for elective CC investigation [-].
The consultant stated that referrals were never influenced by waiting times. A value represents a zero effect.

PCapDCCB = GRAPH(TIME)
(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 43.5), (14.0, 87.0), (15.0, 87.0), (16.0, 87.0), (17.0, 87.0), (18.0, 87.0), (19.0, 87.0), (20.0, 87.0), (21.0, 87.0), (22.0, 87.0), (23.0, 87.0), (24.0, 87.0), (25.0, 87.0), (26.0, 87.0), (27.0, 87.0), (28.0, 87.0), (29.0, 87.0), (30.0, 87.0), (31.0, 87.0), (32.0, 87.0), (33.0, 87.0), (34.0, 96.8), (35.0, 104), (36.0, 104), (37.0, 104), (38.0, 104), (39.0, 104), (40.0, 104), (41.0, 104), (42.0, 104), (43.0, 104), (44.0, 104), (45.0, 104), (46.0, 104), (47.0, 104), (48.0, 104), (49.0, 104), (50.0, 104), (51.0, 104), (52.0, 104), (53.0, 104), (54.0, 104), (55.0, 104), (56.0, 104), (57.0, 104), (58.0, 104), (59.0, 104), (60.0, 104), (61.0, 104), (62.0, 104), (63.0, 104), (64.0, 104), (65.0, 104), (66.0, 104), (67.0, 104), (68.0, 104), (69.0, 104), (70.0, 104), (71.0, 104), (72.0, 104)
DOCUMENT: Potential capacity for elective district-based CC investigations corresponding to the base case scenario [pats/mth].
This is the elective district-based CC investigation capacity that would be available if the district service were affordable. The consultant quoted activity of 20 pats/week = 87 pats/mth and with integrated laboratory, activity increased to 24 pats/week=104 pats/mth and he said that the capacity would expand to support this. Suggests high capacity utilisation but data does not support this (perhaps his figures included private patients). For example, if the capacity was 87 pats/mth, the maximum activity (May 96 to Dec 97) =75 would imply 86% utilisation but average activity (Jun 96 to Dec 97) = 47.11 implies only 54% utilisation. Activity (May 96) = 18. If we assume 1/2 capacity = 43.5, this implies only 41% utilisation. However, we were told that there was adequate capacity to meet demand for the district CC service (unlike the OP service which was under pressure) so provided that the model reflects the district CC capacity constraint not being reached, we can assume that model provides an adequate representation of the real world in the base case (behaviourally, albeit not numerically). Caution will be required in considering the potential effects of further increases in demand for the district CC service and reductions in the district CC capacity. For these situations, the discrepancy between the real capacity and capacity specified in the model might be significant.

We specify capacities for four different situations. Corresponding to increasing levels of capacity, these situations were: (1) no district service (0 pats/mth), (2) district service in first month of operation (43.5 pats/mth), (3) district service with normal capacity levels e.g. providing a replacement service during a major closure of tertiary facilities (87 pats/mth), (4) district service with integrated facility (104 pats/mth).

PCapDCCET = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 43.5), (14.0, 87.0), (15.0, 87.0), (16.0, 87.0), (17.0, 87.0), (18.0, 87.0), (19.0, 87.0), (20.0, 87.0), (21.0, 87.0), (22.0, 87.0), (23.0, 87.0), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 76.6), (37.0, 76.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00), (55.0, 0.00), (56.0, 0.00), (57.0, 0.00), (58.0, 0.00), (59.0, 0.00), (60.0, 0.00), (61.0, 0.00), (62.0, 0.00), (63.0, 0.00), (64.0, 0.00), (65.0, 0.00), (66.0, 0.00), (67.0, 0.00), (68.0, 0.00), (69.0, 0.00), (70.0, 0.00), (71.0, 0.00), (72.0, 0.00)

DOCUMENT: Potential capacity for elective district-based CC investigations with an expanded tertiary-based service [pats/mth].

This is the elective district-based CC investigation capacity that would be available if the district service were affordable. An expanded tertiary service is assumed with the district service used to cover tertiary facility closures only. Used for policy analysis.

PCapDCCNSDem = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 43.5), (14.0, 87.0), (15.0, 87.0), (16.0, 87.0), (17.0, 87.0), (18.0, 87.0), (19.0, 87.0), (20.0, 87.0), (21.0, 87.0), (22.0, 87.0), (23.0, 87.0), (24.0, 87.0), (25.0, 87.0), (26.0, 87.0), (27.0, 87.0), (28.0, 87.0), (29.0, 87.0), (30.0, 87.0), (31.0, 87.0), (32.0, 87.0), (33.0, 87.0), (34.0, 87.0), (35.0, 87.0), (36.0, 87.0), (37.0, 87.0), (38.0, 87.0), (39.0, 87.0), (40.0, 87.0), (41.0, 87.0), (42.0, 87.0), (43.0, 87.0), (44.0, 87.0), (45.0, 87.0), (46.0, 87.0), (47.0, 87.0), (48.0, 87.0), (49.0, 87.0), (50.0, 87.0), (51.0, 87.0), (52.0, 87.0), (53.0, 87.0), (54.0, 87.0), (55.0, 87.0), (56.0, 87.0), (57.0, 87.0), (58.0, 87.0), (59.0, 87.0), (60.0, 87.0), (61.0, 87.0), (62.0, 87.0), (63.0, 87.0), (64.0, 87.0), (65.0, 87.0), (66.0, 87.0), (67.0, 87.0), (68.0, 87.0), (69.0, 87.0), (70.0, 87.0), (71.0, 87.0), (72.0, 87.0)

DOCUMENT: Potential capacity for elective district-based CC investigations with no simulated demand (due to other factors) [pats/mth].

PCapDCCPDS = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 43.5), (14.0, 87.0), (15.0, 87.0), (16.0, 87.0), (17.0, 87.0), (18.0, 87.0), (19.0, 87.0), (20.0, 87.0), (21.0, 87.0), (22.0, 87.0), (23.0, 87.0), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 76.6), (37.0, 76.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 76.6), (47.0, 76.6), (48.0, 76.6), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00), (55.0, 0.00), (56.0, 0.00), (57.0, 0.00), (58.0, 76.6), (59.0, 76.6), (60.0, 76.6), (61.0, 0.00), (62.0, 0.00), (63.0, 0.00), (64.0, 0.00), (65.0, 0.00), (66.0, 0.00), (67.0, 0.00), (68.0, 0.00), (69.0, 0.00), (70.0, 76.6), (71.0, 76.6), (72.0, 76.6)

DOCUMENT: Potential capacity for elective district-based CC investigations with a periodic district service [pats/mth].

This is the elective district-based CC investigation capacity that would be available if the district service were affordable. District service used to cover tertiary facility closures and provides several further temporary sessions. Used for policy analysis.

PCapDCCTDS = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 43.5), (14.0, 87.0), (15.0, 87.0), (16.0, 87.0), (17.0, 87.0), (18.0, 87.0), (19.0, 87.0), (20.0, 87.0), (21.0, 87.0), (22.0, 87.0), (23.0, 87.0), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 76.6), (37.0, 76.6), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00), (55.0, 0.00), (56.0, 0.00), (57.0, 0.00), (58.0, 0.00), (59.0, 0.00), (60.0, 0.00), (61.0, 0.00), (62.0, 0.00), (63.0, 0.00), (64.0, 0.00), (65.0, 0.00), (66.0, 0.00), (67.0, 0.00), (68.0, 0.00), (69.0, 0.00), (70.0, 0.00), (71.0, 0.00), (72.0, 0.00)

DOCUMENT: Potential capacity for elective district-based CC investigations with a temporary district service [pats/mth].

This is the elective district-based CC investigation capacity that would be available if the district service were affordable. District service covers tertiary facility closures only. Used for policy analysis.

PCapDCCW = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 43.5), (14.0, 87.0), (15.0, 87.0), (16.0, 87.0), (17.0, 87.0), (18.0, 87.0), (19.0, 87.0), (20.0, 87.0), (21.0, 87.0), (22.0, 87.0), (23.0, 87.0), (24.0, 87.0), (25.0, 87.0), (26.0, 87.0), (27.0, 87.0), (28.0, 87.0), (29.0, 87.0), (30.0, 87.0), (31.0, 87.0), (32.0, 22.0), (33.0, 22.0), (34.0, 22.0), (35.0, 96.8), (36.0, 104), (37.0, 104), (38.0, 104), (39.0, 104), (40.0, 104), (41.0, 104), (42.0, 104), (43.0, 104), (44.0, 104), (45.0, 104), (46.0, 104), (47.0, 104), (48.0, 104), (49.0, 104), (50.0, 104), (51.0, 104), (52.0, 104), (53.0, 104), (54.0, 104), (55.0, 104), (56.0, 104), (57.0, 104), (58.0, 104), (59.0, 104), (60.0, 104), (61.0, 104), (62.0, 104), (63.0, 104), (64.0, 104), (65.0, 104), (66.0, 104), (67.0, 104), (68.0, 104), (69.0, 104), (70.0, 104), (71.0, 104), (72.0, 104)

DOCUMENT: Potential capacity for elective district-based CC investigations with a winter crisis [pats/mth].

Assumes loss of capacity due to a winter crisis over 3 months where resources are diverted from elective investigations to emergency and treatment cases.

PCapTCCB = GRAPH(TIME)

(0.00, 39.7), (1.00, 39.7), (2.00, 39.7), (3.00, 39.7), (4.00, 39.7), (5.00, 39.7), (6.00, 39.7), (7.00, 39.7), (8.00, 39.7), (9.00, 39.7), (10.0, 39.7), (11.0, 39.7), (12.0, 39.7), (13.0, 17.7), (14.0, 9.42), (15.0, 9.42), (16.0, 9.42), (17.0, 9.42), (18.0, 9.42), (19.0, 9.42), (20.0, 9.42), (21.0, 9.42), (22.0, 9.42), (23.0, 9.42), (24.0, 9.42), (25.0, 9.42), (26.0, 9.42), (27.0, 9.42), (28.0, 9.42), (29.0, 9.42), (30.0, 9.42), (31.0, 9.42), (32.0, 9.42), (33.0, 9.42), (34.0, 7.00), (35.0, 4.70), (36.0, 4.71), (37.0, 4.71), (38.0, 4.71), (39.0, 4.71), (40.0, 4.71), (41.0, 4.71), (42.0, 4.71), (43.0, 4.71), (44.0, 4.71), (45.0, 4.71), (46.0, 4.71), (47.0, 4.71), (48.0, 4.71), (49.0, 4.71), (50.0, 4.71), (51.0, 4.71), (52.0, 4.71), (53.0, 4.71), (54.0, 4.71), (55.0, 4.71), (56.0, 4.71), (57.0, 4.71), (58.0, 4.71), (59.0, 4.71), (60.0, 4.71), (61.0, 4.71), (62.0, 4.71), (63.0, 4.71), (64.0, 4.71), (65.0, 4.71), (66.0, 4.71), (67.0, 4.71), (68.0, 4.71), (69.0, 4.71), (70.0, 4.71), (71.0, 4.71), (72.0, 4.71)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations corresponding to the base case scenario [pats/mth].

This is the tertiary elective CC capacity that would be available if it were affordable. It uses an approximation of the historical activity data and capacities are implied from the comments by the consultant about the utilisation of capacity. The historical data were divided between three different situations and, for each situation, averages were taken to derive three different capacity levels. Corresponding to decreasing levels of capacity, these situations were: (1) normal capacity levels, (2) during the first month of a major closure of tertiary facilities, (3) during a major closure of tertiary facilities or involving a major shift in workload to the district level. Two further capacity levels represented a further shift in workload to the district level (of higher risk patients). The consultant at Veinbridge stated that prior to the introduction fo the district service, the tertiary service operated at 90% utilisation. We assume that following the introduction of the district service, cases would be shifted to the district level so that the tertiary service would operate at 100% utilisation.

PCapTCCET = GRAPH(TIME)

(0.00, 39.7), (1.00, 39.7), (2.00, 39.7), (3.00, 39.7), (4.00, 39.7), (5.00, 39.7), (6.00, 39.7), (7.00, 39.7), (8.00, 39.7), (9.00, 39.7), (10.0, 39.7), (11.0, 39.7), (12.0, 39.7), (13.0, 17.7), (14.0, 9.42), (15.0, 9.42), (16.0, 9.42), (17.0, 9.42), (18.0, 9.42), (19.0, 9.42), (20.0, 9.42), (21.0, 9.42), (22.0, 9.42), (23.0, 9.42), (24.0, 59.5), (25.0, 59.5), (26.0, 59.5), (27.0, 59.5), (28.0, 59.5), (29.0, 59.5), (30.0, 59.5), (31.0, 59.5), (32.0, 59.5), (33.0, 59.5), (34.0, 59.5), (35.0, 59.5), (36.0, 19.8), (37.0, 19.8), (38.0, 59.5), (39.0, 59.5), (40.0, 59.5), (41.0, 59.5), (42.0, 59.5), (43.0, 59.5), (44.0, 59.5), (45.0, 59.5), (46.0, 59.5), (47.0, 59.5), (48.0, 59.5), (49.0, 59.5), (50.0, 59.5), (51.0, 59.5), (52.0, 59.5), (53.0, 59.5), (54.0, 59.5), (55.0, 59.5), (56.0, 59.5), (57.0, 59.5), (58.0, 59.5), (59.0, 59.5), (60.0, 59.5), (61.0, 59.5), (62.0, 59.5), (63.0, 59.5), (64.0, 59.5), (65.0, 59.5), (66.0, 59.5), (67.0, 59.5), (68.0, 59.5), (69.0, 59.5), (70.0, 59.5), (71.0, 59.5), (72.0, 59.5)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with an expanded tertiary-based service [pats/mth].

This is the tertiary elective CC capacity that would be available if it were affordable. An expanded tertiary-based service is assumed with the district service used to cover tertiary facility closures only. The tertiary-based capacity is increased by 50%. This produces capacity levels which are lower than those assumed at the district level for the base case scenario. However, larger increases at the tertiary level were assumed to be unrealistic and besides, the base case assumptions are slightly suspect. For the 1998 tertiary facility closure it is assumed that 1/2 the capacity is lost. Used for policy analysis.

PCapTCCNDS = GRAPH(TIME)
(0.00, 39.7), (1.00, 39.7), (2.00, 39.7), (3.00, 39.7), (4.00, 39.7), (5.00, 39.7), (6.00, 39.7), (7.00, 39.7), (8.00, 39.7), (9.00, 39.7), (10.0, 39.7), (11.0, 39.7), (12.0, 39.7), (13.0, 17.7), (14.0, 9.42), (15.0, 9.42), (16.0, 9.42), (17.0, 9.42), (18.0, 9.42), (19.0, 9.42), (20.0, 9.42), (21.0, 9.42), (22.0, 9.42), (23.0, 9.42), (24.0, 39.7), (25.0, 39.7), (26.0, 39.7), (27.0, 39.7), (28.0, 39.7), (29.0, 39.7), (30.0, 39.7), (31.0, 39.7), (32.0, 39.7), (33.0, 39.7), (34.0, 39.7), (35.0, 39.7), (36.0, 19.8), (37.0, 19.8), (38.0, 39.7), (39.0, 39.7), (40.0, 39.7), (41.0, 39.7), (42.0, 39.7), (43.0, 39.7), (44.0, 39.7), (45.0, 39.7), (46.0, 39.7), (47.0, 39.7), (48.0, 39.7), (49.0, 39.7), (50.0, 39.7), (51.0, 39.7), (52.0, 39.7), (53.0, 39.7), (54.0, 39.7), (55.0, 39.7), (56.0, 39.7), (57.0, 39.7), (58.0, 39.7), (59.0, 39.7), (60.0, 39.7), (61.0, 39.7), (62.0, 39.7), (63.0, 39.7), (64.0, 39.7), (65.0, 39.7), (66.0, 39.7), (67.0, 39.7), (68.0, 39.7), (69.0, 39.7), (70.0, 39.7), (71.0, 39.7), (72.0, 39.7)
DOCUMENT: Potential capacity for elective tertiary-based CC investigations with no district service [pats/mth].
This is the tertiary elective CC capacity that would be available if it were affordable.

PCapTCCNSDem = GRAPH(TIME)
(0.00, 39.7), (1.00, 39.7), (2.00, 39.7), (3.00, 39.7), (4.00, 39.7), (5.00, 39.7), (6.00, 39.7), (7.00, 39.7), (8.00, 39.7), (9.00, 39.7), (10.0, 39.7), (11.0, 39.7), (12.0, 39.7), (13.0, 17.7), (14.0, 9.42), (15.0, 9.42), (16.0, 9.42), (17.0, 9.42), (18.0, 9.42), (19.0, 9.42), (20.0, 9.42), (21.0, 9.42), (22.0, 9.42), (23.0, 9.42), (24.0, 9.42), (25.0, 9.42), (26.0, 9.42), (27.0, 9.42), (28.0, 9.42), (29.0, 9.42), (30.0, 9.42), (31.0, 9.42), (32.0, 9.42), (33.0, 9.42), (34.0, 9.42), (35.0, 9.42), (36.0, 9.42), (37.0, 9.42), (38.0, 9.42), (39.0, 9.42), (40.0, 9.42), (41.0, 9.42), (42.0, 9.42), (43.0, 9.42), (44.0, 9.42), (45.0, 9.42), (46.0, 9.42), (47.0, 9.42), (48.0, 9.42), (49.0, 9.42), (50.0, 9.42), (51.0, 9.42), (52.0, 9.42), (53.0, 9.42), (54.0, 9.42), (55.0, 9.42), (56.0, 9.42), (57.0, 9.42), (58.0, 9.42), (59.0, 9.42), (60.0, 9.42), (61.0, 9.42), (62.0, 9.42), (63.0, 9.42), (64.0, 9.42), (65.0, 9.42), (66.0, 9.42), (67.0, 9.42), (68.0, 9.42), (69.0, 9.42), (70.0, 9.42), (71.0, 9.42), (72.0, 9.42)
DOCUMENT: Potential capacity for elective tertiary-based CC investigations with no stimulated demand (due to other factors) [pats/mth].

PCapTCCPDS = GRAPH(TIME)
(0.00, 39.7), (1.00, 39.7), (2.00, 39.7), (3.00, 39.7), (4.00, 39.7), (5.00, 39.7), (6.00, 39.7), (7.00, 39.7), (8.00, 39.7), (9.00, 39.7), (10.0, 39.7), (11.0, 39.7), (12.0, 39.7), (13.0, 17.7), (14.0, 9.42), (15.0, 9.42), (16.0, 9.42), (17.0, 9.42), (18.0, 9.42), (19.0, 9.42), (20.0, 9.42), (21.0, 9.42), (22.0, 9.42), (23.0, 9.42), (24.0, 39.7), (25.0, 39.7), (26.0, 39.7), (27.0, 39.7), (28.0, 39.7), (29.0, 39.7), (30.0, 39.7), (31.0, 39.7),

(32.0, 39.7), (33.0, 39.7), (34.0, 39.7), (35.0, 39.7), (36.0, 19.8), (37.0, 19.8), (38.0, 39.7), (39.0, 39.7), (40.0, 39.7), (41.0, 39.7), (42.0, 39.7), (43.0, 39.7), (44.0, 39.7), (45.0, 39.7), (46.0, 19.8), (47.0, 19.8), (48.0, 19.8), (49.0, 39.7), (50.0, 39.7), (51.0, 39.7), (52.0, 39.7), (53.0, 39.7), (54.0, 39.7), (55.0, 39.7), (56.0, 39.7), (57.0, 39.7), (58.0, 19.8), (59.0, 19.8), (60.0, 19.8), (61.0, 39.7), (62.0, 39.7), (63.0, 39.7), (64.0, 39.7), (65.0, 39.7), (66.0, 39.7), (67.0, 39.7), (68.0, 39.7), (69.0, 39.7), (70.0, 19.8), (71.0, 19.8), (72.0, 19.8)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with a periodic district service [pats/mth].

This is the elective tertiary CC capacity that would be available if it were affordable.

PCapTCCTDS = GRAPH(TIME)

(0.00, 39.7), (1.00, 39.7), (2.00, 39.7), (3.00, 39.7), (4.00, 39.7), (5.00, 39.7), (6.00, 39.7), (7.00, 39.7), (8.00, 39.7), (9.00, 39.7), (10.0, 39.7), (11.0, 39.7), (12.0, 39.7), (13.0, 17.7), (14.0, 9.42), (15.0, 9.42), (16.0, 9.42), (17.0, 9.42), (18.0, 9.42), (19.0, 9.42), (20.0, 9.42), (21.0, 9.42), (22.0, 9.42), (23.0, 9.42), (24.0, 39.7), (25.0, 39.7), (26.0, 39.7), (27.0, 39.7), (28.0, 39.7), (29.0, 39.7), (30.0, 39.7), (31.0, 39.7), (32.0, 39.7), (33.0, 39.7), (34.0, 39.7), (35.0, 39.7), (36.0, 19.8), (37.0, 19.8), (38.0, 39.7), (39.0, 39.7), (40.0, 39.7), (41.0, 39.7), (42.0, 39.7), (43.0, 39.7), (44.0, 39.7), (45.0, 39.7), (46.0, 39.7), (47.0, 39.7), (48.0, 39.7), (49.0, 39.7), (50.0, 39.7), (51.0, 39.7), (52.0, 39.7), (53.0, 39.7), (54.0, 39.7), (55.0, 39.7), (56.0, 39.7), (57.0, 39.7), (58.0, 39.7), (59.0, 39.7), (60.0, 39.7), (61.0, 39.7), (62.0, 39.7), (63.0, 39.7), (64.0, 39.7), (65.0, 39.7), (66.0, 39.7), (67.0, 39.7), (68.0, 39.7), (69.0, 39.7), (70.0, 39.7), (71.0, 39.7), (72.0, 39.7)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with a temporary district service [pats/mth].

This is the elective tertiary CC capacity that would be available if it were affordable. Used for policy analysis.

PCapTCCW = GRAPH(TIME)

(0.00, 39.7), (1.00, 39.7), (2.00, 39.7), (3.00, 39.7), (4.00, 39.7), (5.00, 39.7), (6.00, 39.7), (7.00, 39.7), (8.00, 39.7), (9.00, 39.7), (10.0, 39.7), (11.0, 39.7), (12.0, 39.7), (13.0, 17.7), (14.0, 9.42), (15.0, 9.42), (16.0, 9.42), (17.0, 9.42), (18.0, 9.42), (19.0, 9.42), (20.0, 9.42), (21.0, 9.42), (22.0, 9.42), (23.0, 9.42), (24.0, 9.42), (25.0, 9.42), (26.0, 9.42), (27.0, 9.42), (28.0, 9.42), (29.0, 9.42), (30.0, 9.42), (31.0, 9.42), (32.0, 4.71), (33.0, 4.71), (34.0, 4.71), (35.0, 4.71), (36.0, 4.71), (37.0, 4.71), (38.0, 4.71), (39.0, 4.71), (40.0, 4.71), (41.0, 4.71), (42.0, 4.71), (43.0, 4.71), (44.0, 4.71), (45.0, 4.71), (46.0, 4.71), (47.0, 4.71), (48.0, 4.71), (49.0, 4.71), (50.0, 4.71), (51.0, 4.71), (52.0, 4.71), (53.0, 4.71), (54.0, 4.71), (55.0, 4.71), (56.0, 4.71), (57.0, 4.71), (58.0, 4.71), (59.0, 4.71), (60.0, 4.71), (61.0, 4.71), (62.0, 4.71), (63.0, 4.71), (64.0, 4.71), (65.0, 4.71), (66.0, 4.71), (67.0, 4.71), (68.0, 4.71), (69.0, 4.71), (70.0, 4.71), (71.0, 4.71), (72.0, 4.71)

DOCUMENT: Potential capacity for elective tertiary-based CC investigations with a winter crisis [pats/mth].

Assumes loss of capacity due to a winter crisis over 3 months where resources are diverted from elective investigations to emergency and treatment cases.

SuppEffKCC = GRAPH(IF (SwR2=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.01), (10.0, 1.03), (12.5, 1.09), (15.0, 1.11), (17.5, 1.10), (20.0, 1.10)

DOCUMENT: Suppressed effect of knowledge of CC on referrals for elective CC investigation [-].

Assumes that the use of a guideline could suppress some of the stimulated demand. Used as part of the policy analysis.

SuppEffKOP = GRAPH(IF (SwR1=0) THEN 0 ELSE PcvdDCCInvR)

(0.00, 1.00), (2.50, 1.00), (5.00, 1.00), (7.50, 1.01), (10.0, 1.04), (12.5, 1.09), (15.0, 1.10), (17.5, 1.10), (20.0, 1.10)

DOCUMENT: Suppressed effect of knowledge of CC on referrals for an OP appointment [-].

Assumes that the use of a guideline could suppress some of the stimulated demand. Used as part of the policy analysis.

SuppEffWTCC = GRAPH(IF(SwB3=0) THEN 1 ELSE TRnewCCWL)

(0.00, 1.00), (0.2, 1.00), (0.4, 1.00), (0.6, 1.00), (0.8, 1.00), (1.00, 1.00), (1.20, 1.00), (1.40, 1.00), (1.60, 1.00), (1.80, 1.00)

DOCUMENT: Suppressed effect of waiting time for CC investigation on referrals for elective CC investigation [-].

There is a zero waiting time effect at Veinbridge General.

UCapDCC = GRAPH(IF (CapDCC=0) THEN 0 ELSE (DesDCCInvR/CapDCC))

(0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1, 0.97), (1.10, 1.00), (1.20, 1.00)

DOCUMENT: Utilisation of capacity for district-based CC [-].

By definition, this refers to elective CC investigations.

If exactly the full capacity was desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

UCapOP = GRAPH(IF (CapOP=0) THEN 0 ELSE (DesOPR/CapOP))

(0.00, 0.00), (0.05, 0.05), (0.1, 0.1), (0.15, 0.15), (0.2, 0.2), (0.25, 0.25), (0.3, 0.3), (0.35, 0.35), (0.4, 0.4), (0.45, 0.45), (0.5, 0.5), (0.55, 0.55), (0.6, 0.6), (0.65, 0.65), (0.7, 0.7), (0.75, 0.75), (0.8, 0.8), (0.85, 0.85), (0.9, 0.9), (0.95, 0.95), (1.00, 0.97), (1.05, 1.00), (1.10, 1.00)

DOCUMENT: Utilisation of capacity for OP appointments [-].

If exactly the full capacity was desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

UCapTCC = GRAPH(IF(CapTCC=0) THEN 0 ELSE DesCCInvR/CapTCC)

(0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1, 0.97), (1.10, 1.00), (1.20, 1.00)

DOCUMENT: Utilisation of capacity for elective tertiary-based CC investigations [-].
If full capacity is desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

UCapTCCNEDCC = GRAPH(IF(CapTCC=0) THEN 0 ELSE DesCCInvR*(1-FEDCC)/CapTCC)
(0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1, 0.97), (1.10, 1.00), (1.20, 1.00)
DOCUMENT: Utilisation of capacity for tertiary-based elective CC investigation by those not eligible to undergo a district-based investigation [-].
If full capacity is desired, it is assumed that it would not be available due to practical difficulties. The use of the IF statement ensures that a division by zero does not cause the simulation to stop.

E3. Alphabetical Listings of Simulation Model Variable Names

The variables are listed in the following order:

1. Stocks (levels) with their corresponding in-flows and out-flows (rates), listed alphabetically by stock
2. Non-graphical convertors (constants and auxiliaries), listed alphabetically
3. Graphical convertors (table functions), listed alphabetically

E3a. Stocks (52)

AggJDOpSk	Aggregate junior district-based CC operator skill [skill units].
AvRRCC	Average rate of referrals for elective CC investigation [pats/mth].
CCWL	CC investigation waiting list length [pats].
CFPh1DCCP	Completed fraction of phase 1 district service preparation (completed fraction of a basic district site) [-].
CumCC	Cumulative elective CC investigations [pats].
CumCCAC	Cumulative CC activity costs [pounds].
CumCCACATL	Cumulative CC activity costs if all activity were carried out at the tertiary level [pounds].
CumCCWLAdds	Cumulative CC waiting list additions [pats].
CumCCWLRems	Cumulative CC waiting list removals [pats]
CumDCCPC	Cumulative district CC service preparation costs [pounds].
CumDCCRC	Cumulative district CC service running costs [pounds].
CumGJDOpSk	Cumulative gain in junior district-based CC operator skills [skill units]
CumLJDOpSk	Cumulative loss in junior district-based CC operator skills [skill units]
CumOP	Cumulative OP activity [pats].
CumOPAC	Cumulative OP activity costs [pounds].
CumOPWLAdds	Cumulative OP waiting list additions [pats].

CumOPWLRems	Cumulative OP waiting list removals [pats]
DECCWL	Duration of excessive CC investigation waiting list [mths]
DEOPWL	Duration of excessive OP waiting list [mths]
DETnewCCWL	Duration of excessive average estimated waiting time estimated for new CC investigation waiting list patients [mths]
DETnewOPWL	Duration of excessive average estimated waiting time estimated for new OP waiting list patients [mths]
DETonCCWL	Duration of excessive time on waiting list for CC investigation [mths]
DETonOPWL	Duration of excessive time on OP waiting list [mths]
DstDemCC	Duration of stimulated demand for CC investigation [mths]
DstDemOP	Duration of stimulated demand for OP appointment [mths]
JDOp	Number of junior district-based CC operators [doctors].
MaxCCWL	Maximum CC investigation waiting list [pats]
MaxOPWL	Maximum OP waiting list [pats]
MaxRRCC	Maximum referral rate for elective CC investigation [pats/mth]
MaxRROP	Maximum referral rate for OP appointment [pats/mth]
MaxTnewCCWL	Maximum average estimated waiting time for new CC investigation waiting list patients [mths]
MaxTnewOPWL	Maximum average estimated waiting time for new OP waiting list patients [mths]
MaxTonCCWL	Maximum average waiting time on CC waiting list [mths]
MaxTonOPWL	Maximum average waiting time on OP waiting list [mths]
MinCCWL	Minimum CC investigation waiting list [pats]
MinOPWL	Minimum OP waiting list [pats]
MinRRCC	Minimum referral rate for elective CC investigation [pats/mth]
MinRROP	Minimum referral rate for OP appointment [pats/mth]
MinTnewCCWL	Minimum average estimated waiting time for new CC investigation waiting list patients [mths]
MinTnewOPWL	Minimum average estimated waiting time for new OP waiting list patients [mths]
MinTonCCWL	Minimum average waiting time on CC investigation waiting list [mths]
MinTonOPWL	Minimum average waiting time on OP waiting list [mths]
OPWL	OP waiting list length [pats].
PrSIECCWL	Pressure summary index associated with an excessive CC investigation waiting list [pressure].
PrSIEOPWL	Pressure summary index associated with an excessive OP waiting list [pressure].
PrSIETonCCWL	Pressure summary index associated with an excessive average time spent on the CC investigation waiting list [pressure].
PrSIETonOPWL	Pressure summary index associated with an excessive average time spent on the OP waiting list [pressure].
SDCCFA	Smoothed district CC facility availability [-].
STPh1DCCP	Start time of phase 1 district CC service preparation [mths].
SumJTCCWL	Sum of join times for patients on CC investigation waiting list [pat.mths].

SumJTOPWL	Sum of join times for patients on cardiology OP waiting list [pat.mths].
TOCCWLR	Total rate of other CC investigation waiting list removals [pats].

E3b. Flows (59)

AccRSumCCWLJT	Accumulation rate of join time of patients on the CC investigation waiting list [pats].
AccRSumOPWLJT	Accumulation rate of join time of patients on the OP waiting list [pats].
CCCR	CC activity cost rate [pounds/pat].
CCCRATL	CC activity cost rate if all were carried out at the tertiary level [pounds/pat].
CCInvR	Elective CC investigation rate [pats/mth].
CCWLAddR	CC waiting list addition rate [pats/mth]
CCWLRemR	CC waiting list removal rate [pats/mth]
CCWLRR	CC investigation waiting list removal rate [pats/mth].
DCCFASR	District CC investigation facility availability smoothing rate [-/mth].
DCCPCR	District CC service preparation cost rate [pounds/mth].
DCCRCR	District CC service running cost rate [pounds/mth].
DepRSumCCWLJT	Depletion rate of join time of patients on the CC investigation waiting list [pats].
DepRSumOPWLJT	Depletion rate of join time of patients on the OP waiting list [pats].
GRDECCWL	Gain rate of duration of excessive CC investigation waiting list [mths/mth].
GRDEOPWL	Gain rate of duration of excessive OP waiting list [mths/mth].
GRDETnewCCWL	Gain rate of duration of excessive estimated average waiting time for new CC investigation waiting list patients [mths/mth]
GRDETnewOPWL	Gain rate of duration of excessive estimated average waiting time for new OP waiting list patients [mths/mth]
GRDETonCCWL	Gain rate of duration of excessive time on CC investigation waiting list [mths/mth]
GRDETonOPWL	Gain rate of duration of excessive time on OP waiting list [mths/mth].
GRDStDemCC	Gain rate of duration of stimulated demand for CC investigation [mths/mth].
GRDStDemOP	Gain rate of duration of stimulated demand for OP appointment [mths/mth]
GRJDOpSk	Gain rate of junior district-based CC operator skills [skill units/mth]
GRPrSIECCWL	Gain rate of pressure summary index associated with an excessive CC investigation waiting list [pressure/mth]
GRPrSIEOPWL	Gain rate of pressure summary index associated with an excessive OP waiting list [pressure/mth]
GRPSIETonCCWL	Gain rate of pressure summary index associated with an excessive average time spent on CC investigation waiting list [pressure/mth]
GRPSIETonOPWL	Gain rate of pressure summary index associated with an excessive average time spent on OP waiting list [pressure/mth].
JDOpDepR	Junior district-based CC operator departure rate [doctors/mth].
JDOpRecR	Junior district-based CC operator recruitment rate [doctors/mth].

JDOpSkGR	Junior district-based CC operator skills gain rate [skill units/mth].
JDOpSkLR	Junior district-based CC operator skills loss rate [skill units/mth].
LRJDOpSk	Loss rate of junior district-based CC operator skills [skill units/mth]
NRRIPtoCC	New referral rate from inpatients to an elective CC investigation [pats/mth].
OCCWLRR	Other CC investigation waiting list removal rate [pats/mth].
OOPWLRR	Other OP waiting list removal rate [pats/mth].
OPCR	OP cost rate [pounds/pat].
OPR	OP rate [pats/mth].
OPWLAddR	OP waiting list addition rate [pats/mth]
OPWLRemR	OP waiting list removal rate [pats/mth]
Ph1DCCPR	Phase 1 district CC service preparation rate [-/mth].
RRCCAR	Referral rate for an elective CC investigation averaging rate [pats/mth/mth].
RROP	Referral rate for an OP appointment [pats/mth].
RROPWLtoCC	Rate of referrals from OP waiting list to an elective CC investigation [pats/mth].
SRMaxCCWL	Set rate of maximum CC investigation waiting list set rate [pats/mth]
SRMaxOPWL	Set rate of maximum OP waiting list set rate [pats/mth]
SRMaxRRCC	Set rate of maximum referral rate for elective CC investigation set rate [pats/mth/mth]
SRMaxRROP	Set rate of maximum referral rate for OP appointment set rate [pats/mth/mth]
SRMaxTnewCCWL	Set rate of maximum average estimated time for new CC investigation waiting list patients [mths/mth]
SRMaxTnewOPWL	Set rate of maximum average estimated time for new OP waiting list patients [mths/mth]
SRMaxTonCCWL	Set rate of maximum average time spent on CC waiting list [mths/mth]
SRMaxTonOPWL	Set rate of maximum average time spent on OP waiting list [mths/mth]
SRMinCCWL	Set rate of minimum CC investigation waiting list [pats/mth]
SRMinOPWL	Set rate of minimum OP waiting list [pats/mth]
SRMinRRCC	Set rate of minimum referral rate for elective CC investigation [pats/mth/mth]
SRMinRROP	Set rate of minimum referral rate for OP appointment [pats/mth/mth]
SRMinTnewCCWL	Set rate of minimum average estimated time for new CC investigation waiting list patients [mths/mth]
SRMinTnewOPWL	Set rate of minimum average estimated time for new OP waiting list patients [mths/mth]
SRMinTonCCWL	Set rate of minimum average time spent on OP waiting list [mths/mth]
SRMinTonOPWL	Set rate of minimum average time spent on OP waiting list [mths/mth]
SRSTPh1DCCP	Set rate of start time of phase 1 district CC service preparation [mths/mth].

E3c. Non-Graphical Converters (139)

ACumDCCRC	Affordability of cumulative district CC service running costs [-].

ADesDCCF	Anticipated desire for a district CC facility [-].
AggJDOpSki	Initial aggregate junior district-based CC operator skill [skill units].
AMDCCRCR	Affordability of monthly district CC facility running cost rate [-].
APh1DCCPC	Affordability of phase 1 district CC service preparation costs [-].
APh2DCCPC	Affordability of phase 2 district CC service preparation costs [-].
ATRRCC	Averaging time of referral rate for an elective CC investigation [mths].
AvCCWLRRe	Average CC investigation waiting list removal rate, used to represent the Evaluation of pressure on the system [pats/mth].
AvCCWLRRe&r	Average CC investigation waiting list removal rate, used to represent the Evaluation of pressure on the system and the Response to that pressure [pats/mth].
AvCDCC	Average cost of a district-based CC investigation [pounds/pat].
AvCFurthCC	Average cost per further CC procedure [pounds/pat].
AvCOP	Average cost per OP appointment [pounds/pat].
AvCTCC	Average cost per tertiary-based CC procedure [pounds/pat].
AvCTCCI	Average cost per tertiary-based CC investigation [pounds/pat].
AvCTCCT	Average cost per (tertiary-based) CC treatment (or synchronous investigation and treatment) [pounds/pat].
AvOCCWLRR	Average other CC investigation waiting list removal rate [pats/mth].
AvOPWLRR	Average OP waiting list removal rate [pats/mth].
AvPreOPWLRR	Average pre-appointment OP waiting list removal rate [pats/mth].
AvRROP	Average rate of referrals for OP appointment [pats/mth].
AvSkJDOp	Average CC operator skill per junior district-based operator [skill units/doctor].
AvSkNJDOp	Average CC operator skill per new junior district-based CC operator [skill units/doctor].
AvTFurthCC	Average waiting time for further CC procedure (following a district-based CC investigation) [mths].
AvTnewCCWLe	Average estimated waiting time for new CC investigation waiting list patients, used to represent the Evaluation of pressure on the system [mths].
AvTnewCCWLe&r	Average estimated waiting time for new CC investigation waiting list patients, used to represent the Evaluation of pressure on the system and the Response to that pressure [mths].
AvTnewOPWL	Average estimated waiting time for new OP waiting list patients [mths].
AvTonCCWL	Average time spent on the CC investigation waiting list [mths].
AvTonOPWL	Average time spent on the OP waiting list [mths].
AvWLRT	Average waiting list removal time [mths].
CapDCC	Capacity for district-based CC [pats/mth].
CapOP	Capacity for OP appointments [pats/mth].
CapSEDCC	Capacity shortfall at tertiary level with respect to patients who are eligible to undergo district-based CC investigation [pats/mth].

CapTCC	Capacity for elective tertiary-based CC investigations [pats/mth].
CCWLi	Initial CC investigation waiting list length pats]
CDesDF	Current desire for district facility [-].
CTime	Current time [mths].
CumC	Cumulative costs [pounds].
CumCAL	Cumulative costs affordability limit [pounds].
CumDCCRCAL	Cumulative district CC service running costs affordability limit [pounds].
DCCInvR	District-based CC investigation rate [pats/mth].
DesCCInvR	Desired elective CC investigation rate [pats/mth].
DesCCInvRWL	Desired elective CC investigation rate driven by a waiting list goal [pats/mth].
DesCCInvRWT	Desired elective CC investigation rate driven by a waiting time goal [pats/mth].
DesCCWL	Desired CC investigation waiting list length [pats].
DesCCWLAT	Desired CC investigation waiting list adjustment time [mths].
DesDCCInvR	Desired district-based CC investigation rate [pats/mth].
DesDCCF	Desire for a district CC facility [-].
DesECCInvR	Desired eligible CC investigation rate [pats/mth].
DesNECCInvR	Desired non-eligible CC investigation rate [pats/mth].
DesOPR	Desired OP rate [pats/mth].
DesOPRWL	Desired OP rate driven by a waiting list goal [pats/mth].
DesOPRWT	Desired OP rate driven by a waiting time goal [pats/mth].
DesOPWL	Desired OP waiting list length [pats].
DesOPWLAT	Desired OP waiting list adjustment time [mths].
DesTCC	Desired waiting time for a CC investigation [mths].
DesTOP	Desired waiting time for an OP appointment [mths].
DCCFA	District CC facility availability [-].
DCCFAST	District CC facility availability smoothing time [mths].
DR	Discount rate [-].
EDesDCCF	Expressed desire for a district CC facility [-].
EffCapLCC	Effect of significant capacity loss on referrals for elective CC investigation [-].
EffCDSuppDCC	Effect of CC investigation cost differential on support for district-based CC service [-].
EffKCC	Effect of knowledge of CC on referrals for elective CC investigation [-].
EffKOP	Effect of knowledge of CC on referrals for an OP appointment [-].
EffODSCC	Effect of other district-based screeners on referrals for elective CC investigation [-].
EffOFCC	Effect of other factors on referrals for elective CC investigation [-].
EffSkCC	Effect of CC operator skills on referrals for elective CC investigation [-].
EffSkECC	Effect of CC operator skills of expert district-based operators on referrals for elective CC investigation [-].

EffSkJCC	Effect of CC operator skills of junior district-based operators on referrals for elective CC investigation [-].
EffWTCC	Effect of waiting time for CC investigation on referrals for elective CC investigation [-].
FEDCC	Fraction of CC investigation waiting list that are eligible for district-based investigation [-].
FEDOp	Fraction CC investigation recommendations made by expert district CC operators [-].
FFurthCC	Fraction of patients referred for further CC (following a district-based CC investigation) [-].
FJDOp	Fraction CC investigation recommendations made by expert district CC operators [-].
FOCCWLRR	Fractional other CC investigation waiting list removal rate [-/mth].
FOPreOPWLRR	Fractional other pre-appointment OP waiting list removal rate [-/mth].
FOPtoCC	Fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].
FRROPWLtoIPtoCC	Fractional rate of referrals from the OP waiting list via inpatients to an elective CC investigation [-/mth].
FSuppDCC	Financial support for a district CC service [-].
FSuppPh2DCC	Financial support for a phase 2 district CC service
FTCCbyDO	Fraction of tertiary-based elective CC investigations carried out by a district-based CC operator [-].
IncOPCap	Increased OP capacity [pats/mth]
IRROP	Increase in referral rate for OP appointment [-]
JDOpRecD	Junior district-based CC operator recruitment delay [mths].
JDOpSkGRExp	Junior district-based CC operator skills gain rate via experience [skill units/mth].
JDOpSkGRRec	Junior district-based CC operator skills gain rate via recruitment [skill units/mth].
JDOpTT	Junior district-based CC operator training time [mths].
LEJDOp	Learning experiences for junior district-based CC operators [pats/mth].
LFJDOp	(Patient activity) learning fraction of junior district-based CC operators [-].
MBCheckPats	Mass balance check on patients [pats]
MBCheckSk	Mass balance check on skills of junior district-based CC operators [skill units]
MaxSkOp	Maximum CC skills per CC operator [skill units/doctor].
MinDCCInvR	Minimum district-based elective CC investigation rate [pats/mth].
MDCCRCR	Monthly district CC facility running cost rate [pounds/mth].
MDCCRCRAL	Monthly district CC facility running cost rate affordability limit [pounds/mth].
NOPCap	Normal OP capacity [pats/mth].
OA	Overall affordability [-].
OPreOPWLRR	Other pre-appointment OP waiting list removal rate [pats/mth].
OPWLi	Initial OP waiting list length [pats]
OPWLRR	OP waiting list removal rate [pats/mth].

PCapDCC	Potential capacity for elective district-based CC investigations [pats/mth].
PCapTCC	Potential capacity for tertiary-based elective CC investigations [pats/mth].
PcvdDCCInvR	Perceived district-based CC investigation rate [pats/mth].
PcvdTCapAEDCC	Perceived tertiary-based elective CC investigation capacity available
PDDCCInvD	Perception delay of district-based CC investigation rate (by GPs and patients) [mths].
Ph1DCCPC	Phase 1 district CC service preparation costs [pounds].
Ph1DCCPCAL	Phase 1 district CC service preparation costs affordability limit [pounds].
Ph1DCCPD	Phase 1 district CC service preparation delay [mths].
Ph1DCCPMCR	Phase 1 district CC service preparation monthly cost rate [pounds/mth].
Ph1DCCPP	Phase 1 district CC service preparation period [mths].
Ph2DCCPC	Phase 2 district CC service preparation costs [pounds].
Ph2DCCPCAL	Phase 2 district CC service preparation costs affordablity limit [pounds].
Ph2DCCPD	Phase 2 district CC service preparation delay [mths].
Ph2DCCPMCR	Phase 2 district CC service preparation monthly cost rate [pounds/mth].
Ph2DCCPP	Phase 2 district CC service preparation period [mths].
PostOPDisR	Post-OP appointment discharge rate [pats/mth].
PreOPWLRR	Pre-appointment OP waiting list removal rate [pats/mth].
RefFOPtoCC	Reference fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].
RefRROP	Reference rate of referrals for an OP appointment [pats/mth].
RefTnewCCWL	Reference waiting time for new CC investigation waiting list patients [mths].
RPrPM	Rate of pressure gain per month (spent on the waiting list) [pressure/mth/mth]
RPrPP	Rate of pressure gain per patient (on the waiting list)[pressure/patient/mth]
RRCC	Referral rate for an elective CC investigation [pats/mth].
RRFurthCC	Rate of referral (from a district-based CC investigation) to a further CC (treatment) procedure [pats/mth].
RROPWLtoIPtoCC	Rate of referrals from the OP waiting list via inpatients to an elective CC investigation [pats/mth].
STTCapUNEDCC	Smoothing time of tertiary-based elective CC investigation capacity
SwB3	Switch for feedback loop B3 [-].
SwIOPCap	Switch for increase in OP capacity [-]
SwOC	Switch for overconfidence in referral behaviour of junior district-based CC operators [-].
SwPADr	Switch for patient activity driver [-].
SwR1	Switch for feedback loop R1 [-].
SwR2	Switch for feedback loop R1 [-].
SwTOP	Switch for trainee district CC operator programme [-].
TADesDF	Time of anticipated desire for district CC facility [mths].
TCapAEDCC	Tertiary-based elective CC investigation capacity available for those eligible to undergo district-based CC [pats/mth].

TCapLT	Tertiary capacity loss time [mths].
TCCInvR	Tertiary-based elective CC investigation rate [pats/mth].
TCCInvRNEDCC	Tertiary-based elective CC investigation rate of those not eligible to undergo district-based CC [pats/mth].
TDCCSFA	Time district CC service first affordable [mths].
TRnewCCWL	Waiting time ratio for new CC investigation waiting list patients [-].

E3d. Graphical Converters (44)

EffCapLCCB	Effect of significant capacity loss on referrals for elective CC investigation corresponding to the base case scenario [-].
EffCapLCCFDS	Effect of significant capacity loss on referrals for elective CC investigation for the case with further district sessions [-].
EffCapLCCN	Effect of significant capacity loss on referrals for the case with no district service [-].
EffCapLCCPI	Effect of significant capacity loss on referrals for the case with permanent increases in capacity [-].
EffCapLCCSPRDS	Effect of significant capacity loss on referrals for the case with a semi-permanent reduced district service [-].
EffCapLCCS	Effect of significant capacity loss on referrals for the case with a single district service [-].
EffCapLCCW	Effect of significant capacity loss on referrals for elective CC investigation for the case with a winter crisis [-].
EffKCCPDCCS	Effect of knowledge of CC on referrals for an elective CC investigation with a permanent district service [-].
EffKCCTDCCS	Effect of knowledge of CC on referrals for an elective CC investigation with a temporary district service [-].
EffKOPPDCCS	Effect of knowledge of CC on referrals for an OP appointment with a permanent district service [-].
EffKOPTDCCS	Effect of knowledge of CC on referrals for an OP appointment with a temporary district service [-].
EffSkOJCC	Effect of CC operator skills of overconfident junior district-based operators on referrals for elective CC investigation [-].
EffSkUJCC	Effect of CC operator skills of underconfident junior district-based operators on referrals for elective CC investigation [-].
LPP	Learning per patient [skill units/patient].
NEffKCC	Normal effect of knowledge of CC on referrals for an elective CC investigation [-].
NEffKOP	Normal effect of knowledge of CC on referrals for an OP appointment [-].
NEffWTCC	Normal effect of waiting time for CC investigation on referrals for elective CC investigation [-].

PCapDCCB	Potential capacity for elective district-based CC investigations corresponding to the base case scenario [pats/mth].
PCapDCCET	Potential capacity for elective district-based CC investigations with an expanded tertiary-based service [pats/mth].
PCapDCCFDS	Potential capacity for elective district-based CC investigations with further district sessions [pats/mth].
PCapDCCNSDem	Potential capacity for elective district-based CC investigations with no stimulated demand (due to other factors) [pats/mth].
PCapDCCPermDS	Potential capacity for elective district-based CC investigations with a permanent district service [pats/mth].
PCapDCCPDS	Potential capacity for elective district-based CC investigations with a periodic district service [pats/mth].
PCapDCCSPRDS	Potential capacity for elective district-based CC investigations with a semi-permanent reduced district service [pats/mth].
PCapDCCTDS	Potential capacity for elective district-based CC investigations with a temporary district service [pats/mth].
PCapDCCW	Potential capacity for elective district-based CC investigations with a winter crisis [pats/mth].
PCapTCCB	Potential capacity for elective tertiary-based CC investigations corresponding to the base case scenario [pats/mth].
PCapTCCET	Potential capacity for elective tertiary-based CC investigations with an expanded tertiary-based service [pats/mth].
PCapTCCFDS	Potential capacity for elective tertiary-based CC investigations with further district sessions [pats/mth].
PCapTCCNDS	Potential capacity for elective tertiary-based CC investigations with no district service [pats/mth].
PCapTCCNSDem	Potential capacity for elective tertiary-based CC investigations with no stimulated demand (due to other factors) [pats/mth].
PCapTCCPDS	Potential capacity for elective tertiary-based CC investigations with a periodic district service [pats/mth].
PCapTCCPermDS	Potential capacity for elective tertiary-based CC investigations with a permanent district service [pats/mth].
PCapTCCSDS	Potential capacity for elective tertiary-based CC investigations with single district service [pats/mth].
PCapTCCSPRDS	Potential capacity for elective tertiary-based CC investigations with a semi-permanent reduced district service [pats/mth].
PCapTCCTDS	Potential capacity for elective district-based CC investigations with a temporary district service [pats/mth].
PCapTCCW	Potential capacity for elective tertiary-based CC investigations with a winter crisis [pats/mth].

SuppEffKCC	Suppressed effect of knowledge of CC on referrals for elective CC investigation [-].
SuppEffKOP	Suppressed effect of knowledge of CC on referrals for OP appointments [-].
SuppEffWTCC	Suppressed effect of waiting time for CC investigation on referrals for elective CC investigation [-].
UCapDCC	Utilisation of capacity for district-based CC [-].
UCapOP	Utilisation of capacity for OP appointments [-].
UCapTCC	Utilisation of capacity for elective tertiary-based CC investigations [-].
UCapTCCNEDCC	Utilisation of capacity for tertiary-based elective CC investigation by those not eligible to undergo a district-based investigation [-].

E4. Efficiency Calculations

E4a. Calculations of Cost/Case

With a district service (investigated at the district level):

Cost/Case = Wtd cost of investigation at district level and cost of treatment procedure at tertiary level (discounted)

= 1*AvCDCC + (FFurthCC*AvCTCCT)/(1+DR)^AvTFurthCC

Without a district service (investigated at the tertiary level):

Cost/Case = Wtd cost of investigation only and synchronous investigation and treatment

= FFurthCC*AvCTCCI+(1-FFurthCC)*AvCTCCT

where:

AvCDCC	Avg cost of a district-based CC investigation [pounds]
AvCTCCI	Avg cost per tertiary-based CC investigation [pounds]
AvCTCCT	Avg cost per (tertiary-based) CC treatment (or synchronous investigation and treatment) [pounds]
AvTFurthCC	Avg waiting time for further CC procedure (following a district-based CC) [mths]
DR	Discount rate [-]
FFurthCC	Fraction of patients referred for further CC (following a district-based investigation) [-]

E4b. Average Costs for the Ribsley General Case

Uses March 1997 figures only. No other data was available.

Consider only patients eligible for district-based inv. as the cost/case of those not eligible is the same with or without a district service

AvCDCC	Avg cost of a district-based CC investigation [pounds]	=	£521	
AvCTCCI	Avg cost per tertiary-based CC investigation [pounds]	=	£450	(Day case)
			£675	(Inpatient)
=>Wtd Avg Cost		=	£525	(1/3 require inpatient procedure)
			£563	(1/2 require inpatient procedure)
			£600	(2/3 require inpatient procedure)
AvCTCCT	Avg cost per (tertiary-based) CC treatment (or synchronous investigation and treatmer	=	£450	(Day case)
			£1,890	(Inpatient, no stent)
			£4,476	(Inpatient, with stent)
		=	£3,183	(Wtd inpatient, 1/2 with stents)
			£3,442	(Wtd inpatient, 3/5 with stents)
=>Wtd Avg Cost		=	£1,361	(1/3 require inpatients, 1/2 with stents)
			£1,447	(1/3 require inpatients, 3/5 with stents)
			£1,817	(1/2 require inpatients, 1/2 with stents)

			£1,946	(1/2 require inpatients, 3/5 with stents)
			£2,272	(2/3 require inpatients, 1/2 with stents)
			£2,444	(2/3 require inpatients, 3/5 with stents)

E4c. Average Costs for the Veinbridge General Case

Uses March 1997 figures only. No other data was available.

Consider only patients eligible for district-based inv. as the cost/case of those not eligible is the same with or without a district service

AvCDCC	Avg cost of a district-based CC investigation [pounds]	=	£525	
AvCTCCI	Avg cost per tertiary-based CC investigation [pounds]	=	£450	(Day case)
			£675	(Inpatient)
=>Wtd Avg Cost		=	£525	(1/3 require inpatient procedure)
			£563	(1/2 require inpatient procedure)
			£600	(2/3 require inpatient procedure)
AvCTCCT	Avg cost per (tertiary-based) CC treatment (or synchronous investigation and treatmer	=	£450	(Day case)
			£1,890	(Inpatient, no stent)
			£4,476	(Inpatient, with stent)
		=	£3,183	(Wtd inpatient, 1/2 with stents)

		£3,442	(Wtd inpatient, 3/5 with stents)
=>Wtd Avg Cost	=	£1,361	(1/3 require inpatients, 1/2 with stents)
		£1,447	(1/3 require inpatients, 3/5 with stents)
		£1,817	(1/2 require inpatients, 1/2 with stents)
		£1,946	(1/2 require inpatients, 3/5 with stents)
		£2,272	(2/3 require inpatients, 1/2 with stents)
		£2,444	(2/3 require inpatients, 3/5 with stents)

N.B. Stent fraction for the base case calculations is 50%. Range 30%-60% was reported by Petticrew et al (1997). It was assumed that the interventionalists at Veinbridge General and Heartwick Hospital would be at the more 'aggressive' end of this range.

E4d. Efficiency Calculations for Ribsley General Case

								Wtd Cost/Case		
Inpatient	Stent		(p.a)					With	No	
Fraction	Fraction	FFurthCC	DR	AvTFurthCC	AvCDCC	AvCTCCI	AvCTCCT	District Service	District Service	Cost Diff
1/3	1/2	0.10	3%	1	£521	£525	£1,361	£656.77	£608.60	£48.17
1/2	1/2	0.10	3%	1	£521	£563	£1,817	£702.20	£687.90	£14.30
2/3	1/2	0.10	3%	1	£521	£600	£2,272	£747.64	£767.20	-£19.56
1/3	3/5	0.10	3%	1	£521	£525	£1,447	£665.36	£617.22	£48.14
1/2	3/5	0.10	3%	1	£521	£563	£1,946	£715.10	£700.83	£14.27
2/3	3/5	0.10	3%	1	£521	£600	£2,444	£764.84	£784.44	-£19.60
1/3	1/2	0.10	6%	1	£521	£525	£1,361	£656.44	£608.60	£47.84
1/2	1/2	0.10	6%	1	£521	£563	£1,817	£701.77	£687.90	£13.87
2/3	1/2	0.10	6%	1	£521	£600	£2,272	£747.10	£767.20	-£20.10
1/3	3/5	0.10	6%	1	£521	£525	£1,447	£665.02	£617.22	£47.80
1/2	3/5	0.10	6%	1	£521	£563	£1,946	£714.64	£700.83	£13.81
2/3	3/5	0.10	6%	1	£521	£600	£2,444	£764.26	£784.44	-£20.18
1/3	1/2	0.10	3%	3	£521	£525	£1,361	£656.10	£608.60	£47.50
1/2	1/2	0.10	3%	3	£521	£563	£1,817	£701.31	£687.90	£13.41
2/3	1/2	0.10	3%	3	£521	£600	£2,272	£746.53	£767.20	-£20.67
1/3	3/5	0.10	3%	3	£521	£525	£1,447	£664.65	£617.22	£47.43
1/2	3/5	0.10	3%	3	£521	£563	£1,946	£714.15	£700.83	£13.32

2/3	3/5	0.10	3%	3	£521	£600	£2,444	£763.64	£784.44	-£20.80
1/3	1/2	0.10	6%	3	£521	£525	£1,361	£655.13	£608.60	£46.53
1/2	1/2	0.10	6%	3	£521	£563	£1,817	£700.02	£687.90	£12.12
2/3	1/2	0.10	6%	3	£521	£600	£2,272	£744.91	£767.20	-£22.29
1/3	3/5	0.10	6%	3	£521	£525	£1,447	£663.63	£617.22	£46.41
1/2	3/5	0.10	6%	3	£521	£563	£1,946	£712.77	£700.83	£11.94
2/3	3/5	0.10	6%	3	£521	£600	£2,444	£761.90	£784.44	-£22.54
1/3	1/2	0.10	3%	4.5	£521	£525	£1,361	£655.60	£608.60	£47.00
1/2	1/2	0.10	3%	4.5	£521	£563	£1,817	£700.65	£687.90	£12.75
2/3	1/2	0.10	3%	4.5	£521	£600	£2,272	£745.70	£767.20	-£21.50
1/3	3/5	0.10	3%	4.5	£521	£525	£1,447	£664.12	£617.22	£46.90
1/2	3/5	0.10	3%	4.5	£521	£563	£1,946	£713.44	£700.83	£12.61
2/3	3/5	0.10	3%	4.5	£521	£600	£2,444	£762.75	£784.44	-£21.69
1/3	1/2	0.10	6%	4.5	£521	£525	£1,361	£654.16	£608.60	£45.56
1/2	1/2	0.10	6%	4.5	£521	£563	£1,817	£698.72	£687.90	£10.82
2/3	1/2	0.10	6%	4.5	£521	£600	£2,272	£743.29	£767.20	-£23.91
1/3	3/5	0.10	6%	4.5	£521	£525	£1,447	£662.59	£617.22	£45.37
1/2	3/5	0.10	6%	4.5	£521	£563	£1,946	£711.37	£700.83	£10.54
2/3	3/5	0.10	6%	4.5	£521	£600	£2,444	£760.16	£784.44	-£24.28
1/3	1/2	0.10	3%	6	£521	£525	£1,361	£655.10	£608.60	£46.50
1/2	1/2	0.10	3%	6	£521	£563	£1,817	£699.99	£687.90	£12.09

2/3	1/2	0.10	3%	6	£521	£600	£2,272	£744.87	£767.20	-£22.33
1/3	3/5	0.10	3%	6	£521	£525	£1,447	£663.60	£617.22	£46.38
1/2	3/5	0.10	3%	6	£521	£563	£1,946	£712.73	£700.83	£11.90
2/3	3/5	0.10	3%	6	£521	£600	£2,444	£761.85	£784.44	-£22.59
1/3	1/2	0.10	6%	6	£521	£525	£1,361	£653.19	£608.60	£44.59
1/2	1/2	0.10	6%	6	£521	£563	£1,817	£697.43	£687.90	£9.53
2/3	1/2	0.10	6%	6	£521	£600	£2,272	£741.68	£767.20	-£25.52
1/3	3/5	0.10	6%	6	£521	£525	£1,447	£661.56	£617.22	£44.34
1/2	3/5	0.10	6%	6	£521	£563	£1,946	£709.99	£700.83	£9.16
2/3	3/5	0.10	6%	6	£521	£600	£2,444	£758.42	£784.44	-£26.02

Boxed figures refer to base case assumptions. Calculations indicate that district service only efficient if the inpatient percentage is high.

E4e. Efficiency Calculations for Veinbridge General Case

								Wtd Cost/Patient		
Inpatient	Stent		(p.a)					With	No	
Fraction	Fraction	FFurthCC	DR	AvTFurthCC	AvCDCC	AvCTCCI	AvCTCCT	District Service	District Service	Cost Diff
1/3	1/2	0.17	3%	1	£525	£525	£1,361	£755.80	£667.12	£88.68
1/2	1/2	0.17	3%	1	£525	£563	£1,817	£833.05	£775.68	£57.37
2/3	1/2	0.17	3%	1	£525	£600	£2,272	£910.29	£884.24	£26.05
1/3	3/5	0.17	3%	1	£525	£525	£1,447	£770.42	£681.77	£88.64
1/2	3/5	0.17	3%	1	£525	£563	£1,946	£854.97	£797.66	£57.31

2/3	3/5	0.17	3%	1	£525	£600	£2,444	£939.53	£913.55	£25.98
1/3	1/2	0.17	6%	1	£525	£525	£1,361	£755.25	£667.12	£88.13
1/2	1/2	0.17	6%	1	£525	£563	£1,817	£832.31	£775.68	£56.63
2/3	1/2	0.17	6%	1	£525	£600	£2,272	£909.37	£884.24	£25.13
1/3	3/5	0.17	6%	1	£525	£525	£1,447	£769.83	£681.77	£88.06
1/2	3/5	0.17	6%	1	£525	£563	£1,946	£854.18	£797.66	£56.52
2/3	3/5	0.17	6%	1	£525	£600	£2,444	£938.54	£913.55	£24.99
1/3	1/2	0.17	3%	3	£525	£525	£1,361	£754.67	£667.12	£87.55
1/2	1/2	0.17	3%	3	£525	£563	£1,817	£831.53	£775.68	£55.85
2/3	1/2	0.17	3%	3	£525	£600	£2,272	£908.40	£884.24	£24.16
1/3	3/5	0.17	3%	3	£525	£525	£1,447	£769.21	£681.77	£87.44
1/2	3/5	0.17	3%	3	£525	£563	£1,946	£853.35	£797.66	£55.69
2/3	3/5	0.17	3%	3	£525	£600	£2,444	£937.49	£913.55	£23.94
1/3	1/2	0.17	6%	3	£525	£525	£1,361	£753.02	£667.12	£85.90
1/2	1/2	0.17	6%	3	£525	£563	£1,817	£829.34	£775.68	£53.66
2/3	1/2	0.17	6%	3	£525	£600	£2,272	£905.65	£884.24	£21.41
1/3	3/5	0.17	6%	3	£525	£525	£1,447	£767.47	£681.77	£85.69
1/2	3/5	0.17	6%	3	£525	£563	£1,946	£851.00	£797.66	£53.34
2/3	3/5	0.17	6%	3	£525	£600	£2,444	£934.54	£913.55	£20.99
1/3	1/2	0.17	3%	4.5	£525	£525	£1,361	£753.82	£667.12	£86.70
1/2	1/2	0.17	3%	4.5	£525	£563	£1,817	£830.40	£775.68	£54.72

2/3	1/2	0.17	3%	4.5	£525	£600	£2,272	£906.98	£884.24	£22.74
1/3	3/5	0.17	3%	4.5	£525	£525	£1,447	£768.31	£681.77	£86.54
1/2	3/5	0.17	3%	4.5	£525	£563	£1,946	£852.14	£797.66	£54.48
2/3	3/5	0.17	3%	4.5	£525	£600	£2,444	£935.97	£913.55	£22.42
1/3	1/2	0.17	6%	4.5	£525	£525	£1,361	£751.37	£667.12	£84.25
1/2	1/2	0.17	6%	4.5	£525	£563	£1,817	£827.13	£775.68	£51.45
2/3	1/2	0.17	6%	4.5	£525	£600	£2,272	£902.89	£884.24	£18.65
1/3	3/5	0.17	6%	4.5	£525	£525	£1,447	£765.71	£681.77	£83.93
1/2	3/5	0.17	6%	4.5	£525	£563	£1,946	£848.64	£797.66	£50.98
2/3	3/5	0.17	6%	4.5	£525	£600	£2,444	£931.57	£913.55	£18.02
1/3	1/2	0.17	3%	6	£525	£525	£1,361	£752.98	£667.12	£85.86
1/2	1/2	0.17	3%	6	£525	£563	£1,817	£829.27	£775.68	£53.59
2/3	1/2	0.17	3%	6	£525	£600	£2,272	£905.57	£884.24	£21.33
1/3	3/5	0.17	3%	6	£525	£525	£1,447	£767.41	£681.77	£85.64
1/2	3/5	0.17	3%	6	£525	£563	£1,946	£850.93	£797.66	£53.27
2/3	3/5	0.17	3%	6	£525	£600	£2,444	£934.45	£913.55	£20.90
1/3	1/2	0.17	6%	6	£525	£525	£1,361	£749.73	£667.12	£82.61
1/2	1/2	0.17	6%	6	£525	£563	£1,817	£824.94	£775.68	£49.26
2/3	1/2	0.17	6%	6	£525	£600	£2,272	£900.15	£884.24	£15.91
1/3	3/5	0.17	6%	6	£525	£525	£1,447	£763.96	£681.77	£82.19
1/2	3/5	0.17	6%	6	£525	£563	£1,946	£846.29	£797.66	£48.63

2/3	3/5	0.17	6%	6	£525	£600	£2,444	£928.62	£913.55	£15.07

Boxed figures refer to base case assumptions. Calculations indicate that district service not efficient

Inpatient Fraction	Stent Fraction	FFurthCC	(p.a) DR	AvTFurthCC	AvCDCC	AvCTCCI	AvCTCCT	With District Service	No District Service	Cost Diff
1/3	1/2	0.11	3%	1	£525	£525	£1,361	£674.34	£616.96	£57.38
1/2	1/2	0.11	3%	1	£525	£563	£1,817	£724.32	£700.44	£23.88
2/3	1/2	0.11	3%	1	£525	£600	£2,272	£774.31	£783.92	-£9.61
1/3	3/5	0.11	3%	1	£525	£525	£1,447	£683.80	£626.44	£57.36
1/2	3/5	0.11	3%	1	£525	£563	£1,946	£738.51	£714.66	£23.85
2/3	3/5	0.11	3%	1	£525	£600	£2,444	£793.22	£802.88	-£9.66
1/3	1/2	0.11	6%	1	£525	£525	£1,361	£673.98	£616.96	£57.02
1/2	1/2	0.11	6%	1	£525	£563	£1,817	£723.85	£700.44	£23.41
2/3	1/2	0.11	6%	1	£525	£600	£2,272	£773.71	£783.92	-£10.21
1/3	3/5	0.11	6%	1	£525	£525	£1,447	£683.42	£626.44	£56.98
1/2	3/5	0.11	6%	1	£525	£563	£1,946	£738.00	£714.66	£23.34
2/3	3/5	0.11	6%	1	£525	£600	£2,444	£792.58	£802.88	-£10.30
1/3	1/2	0.11	3%	3	£525	£525	£1,361	£673.61	£616.96	£56.65
1/2	1/2	0.11	3%	3	£525	£563	£1,817	£723.34	£700.44	£22.90
2/3	1/2	0.11	3%	3	£525	£600	£2,272	£773.08	£783.92	-£10.84
1/3	3/5	0.11	3%	3	£525	£525	£1,447	£683.02	£626.44	£56.58

1/2	3/5	0.11	3%	3	£525	£563	£1,946	£737.46	£714.66	£22.80
2/3	3/5	0.11	3%	3	£525	£600	£2,444	£791.90	£802.88	-£10.98
1/3	1/2	0.11	6%	3	£525	£525	£1,361	£672.54	£616.96	£55.58
1/2	1/2	0.11	6%	3	£525	£563	£1,817	£721.93	£700.44	£21.49
2/3	1/2	0.11	6%	3	£525	£600	£2,272	£771.31	£783.92	-£12.61
1/3	3/5	0.11	6%	3	£525	£525	£1,447	£681.89	£626.44	£55.45
1/2	3/5	0.11	6%	3	£525	£563	£1,946	£735.94	£714.66	£21.28
2/3	3/5	0.11	6%	3	£525	£600	£2,444	£790.00	£802.88	-£12.89
1/3	1/2	0.11	3%	4.5	£525	£525	£1,361	£673.06	£616.96	£56.10
1/2	1/2	0.11	3%	4.5	£525	£563	£1,817	£722.61	£700.44	£22.17
2/3	1/2	0.11	3%	4.5	£525	£600	£2,272	£772.17	£783.92	-£11.75
1/3	3/5	0.11	3%	4.5	£525	£525	£1,447	£682.44	£626.44	£56.00
1/2	3/5	0.11	3%	4.5	£525	£563	£1,946	£736.68	£714.66	£22.02
2/3	3/5	0.11	3%	4.5	£525	£600	£2,444	£790.92	£802.88	-£11.96
1/3	1/2	0.11	6%	4.5	£525	£525	£1,361	£671.47	£616.96	£54.51
1/2	1/2	0.11	6%	4.5	£525	£563	£1,817	£720.50	£700.44	£20.06
2/3	1/2	0.11	6%	4.5	£525	£600	£2,272	£769.52	£783.92	-£14.40
1/3	3/5	0.11	6%	4.5	£525	£525	£1,447	£680.75	£626.44	£54.31
1/2	3/5	0.11	6%	4.5	£525	£563	£1,946	£734.41	£714.66	£19.75
2/3	3/5	0.11	6%	4.5	£525	£600	£2,444	£788.07	£802.88	-£14.81
1/3	1/2	0.11	3%	6	£525	£525	£1,361	£672.51	£616.96	£55.55

1/2	1/2	0.11	3%	6	£525	£563	£1,817	£721.88	£700.44	£21.44
2/3	1/2	0.11	3%	6	£525	£600	£2,272	£771.25	£783.92	-£12.67
1/3	3/5	0.11	3%	6	£525	£525	£1,447	£681.86	£626.44	£55.41
1/2	3/5	0.11	3%	6	£525	£563	£1,946	£735.90	£714.66	£21.23
2/3	3/5	0.11	3%	6	£525	£600	£2,444	£789.94	£802.88	-£12.94
1/3	1/2	0.11	6%	6	£525	£525	£1,361	£670.41	£616.96	£53.45
1/2	1/2	0.11	6%	6	£525	£563	£1,817	£719.08	£700.44	£18.64
2/3	1/2	0.11	6%	6	£525	£600	£2,272	£767.74	£783.92	-£16.18
1/3	3/5	0.11	6%	6	£525	£525	£1,447	£679.62	£626.44	£53.18
1/2	3/5	0.11	6%	6	£525	£563	£1,946	£732.89	£714.66	£18.23
2/3	3/5	0.11	6%	6	£525	£600	£2,444	£786.16	£802.88	-£16.72

District service only efficient if the inpatient percentage is high

E5. Model-Based Experiments

E5a. List of Experiments

1. Ribsley General Experiments

1a. Base Case Analysis

Preliminary Experiments		**Exp**
Simulating the Base Case Behaviour	Base Case	R0
Basic Causes of the Base Case Behaviour	No Training Programme	R1
	Training Programme Withdrawn	R2
	No Waiting Time Effect nor Knowledge Effects on Referrals	R3
	No Knowledge Effects on Referrals	R4
	No Waiting Time Effect on Referrals	R5
	No Effect of Significant Capacity Loss on Referrals	R6
Sensitivity Analysis		
Limiting the Availability of District Services	No District Service	R7
	Single District Service	R8
Limiting the Availability of Elective Capacity	A Winter Crisis	R9
Maintaining a Constant CC Inv Waiting Time Goal		R10
Altering the Waiting Time Effect on Demand	Decreased Waiting Time Response Time	R11

	Increased Waiting Time Response Time	R12
Altering the Knowledge Effects on Demand	Decreased GP and Patient Perception Delay	R13
	Increased GP and Patient Perception Delay	R14
	Increased Knowledge Effect on Demand for an OP Appt	R15
Altering the Skills Effect on Demand	Decreased Learning Fraction	R16
	Increased Learning Fraction	R17
	Overconfident Referral Behaviour	R18
	Delayed Recruitment	R19
Increase in Exog Demand for an OP Appt	1% Increase	R20a
	4% Increase	R20b
	7% Increase	R20c

1b. Policy Analysis

Parameter Changes

Altering the Capacity for Elective CC Investigations	Semi-Permanent Reduced District Service With Existing Guidelines	R21
	Semi-Permanent Reduced District Service With Modest New Guidelines	R22
	Semi-Permanent Reduced District Service With Strict New Guidelines	R23
	Permanent District Service with Existing Guidelines	R24
	Permanent District Service with Modest New Guidelines	R25
	Permanent District Service with Strict New Guidelines	R26

	Expanded Tertiary Service with Existing Guidelines	R27
	Expanded Tertiary Service with Modest New Guidelines	R28
	Expanded Tertiary Service with Strict New Guidelines	R29
	Further District Sessions (a Periodic District Service) with Existing Guidelines	R30
	Further District Sessions (a Periodic District Service) with Modest New Guidelines	R31
	Further District Sessions (a Periodic District Service) with Strict New Guidelines	R32
Using Demand Management Strategies	Decreased GP and Patient Perception Delay	R13
	Increased GP and Patient Perception Delay	R14
	Use of Modest New Guidelines	R33
	Use of Strict New Guidelines	R34
Altering the CC Operator Skills Base	Increased Learning Fraction	R17
Increasing the OP Capacity	Base Case Assumptions About Demand	R35a
	1% Increase in Exog Demand for an OP Appt	R35b
	2% Increase in Exog Demand for an OP Appt	R35c
	6% Increase in Exog Demand for an OP Appt	R35d
	7% Increase in Exog Demand for an OP Appt	R35e
	12% Increase in Exog Demand for an OP Appt	R35f
	13% Increase in Exog Demand for an OP Appt	R35g
Structural Changes: Seeking Different Activity Targets		
Base Case Assumptions About Supply and Demand	Base Case Parameters for Goals and Adj Times, Seeking a Desired Waiting Time	R0
	Base Case Parameters for Goals and Adj Times, Seeking a Desired Waiting List	R36

	Consistent Parameters for Goals and Adj Times, Seeking a Desired Waiting Time	R37
	Consistent Parameters for Goals and Adj Times, Seeking a Desired Waiting List	R38
Use of New Referral Guidelines	Use of Modest New Guidelines, Consistent Params, Seeking a Desired Waiting List	R39
	Use of Strict New Guidelines, Consistent Params, Seeking a Desired Waiting List	R40
Altering (OP) Demand With Sufficient Capacity Available	0.5% Incr, Consistent Parameters, Seeking a Desired Waiting Time	R41
	0.5% Incr, Consistent Parameters, Seeking a Desired Waiting List	R42
	0.5% Decr, Consistent Parameters, Seeking a Desired Waiting Time	R43
	0.5% Decr, Consistent Parameters, Seeking a Desired Waiting List	R44
Altering (OP) Demand With Insufficient Capacity Available	4% Incr, Consistent Parameters, Seeking a Desired Waiting Time	R45
	4% Incr, Consistent Parameters, Seeking a Desired Waiting List	R46
	7% Incr, Consistent Parameters, Seeking a Desired Waiting Time	R47
	7% Incr, Consistent Parameters, Seeking a Desired Waiting List	R48
A Winter Crisis	Consistent Parameters, Seeking a Desired Waiting Time	R49
	Consistent Parameters, Seeking a Desired Waiting List	R50
No Waiting Time, Skills or Knowledge Effects on Demand,	No Capacity Constraints, Consistent Parameters, Seeking a Desired Waiting Time	R51
No Waiting Time, Skills or Knowledge Effects on Demand,	No Capacity Constraints, Consistent Parameters, Seeking a Desired Waiting List	R52

2. Veinbridge General Experiments

2a. Base Case Analysis

Preliminary Experiments		**Exp**
Simulating the Base Case Behaviour	Base Case	V0
Basic Causes of the Base Case Behaviour	No Knowledge Effects on Referrals	V1
	No Knowledge Effects on Referrals for an OP Appt	V2
	No Knowledge Effects on Referrals for a CC Investigation	V3
Sensitivity Analysis		
Limiting the Availability of District Services	No District Service	V4
	Temporary District Service	V5
	Expanded Tertiary Service	V6
	Periodic District Service	V7
Limiting the Availability of Elective Capacity	A Winter Crisis	V8
Adjusting the CC Investigation Waiting Time Goal		V9
Altering the Knowledge Effects on Demand	Decreased GP and Patient Perception Delay	V10
	Increased GP and Patient Perception Delay	V11
	Increased Knowledge Effect on Demand for an OP Appt	V12
Introducing a Skills Effect on Demand		V13

2b. Policy Analysis

Parameter Changes		
Using Demand Management Strategies	Decreased GP and Patient Perception Delay	V10
	Increased GP and Patient Perception Delay	V11
	Use of Modest New Guidelines	V14
	Use of Strict New Guidelines	V15
Increasing the OP Capacity		V16
Structural Changes: Seeking Different Activity Targets		
Base Case Assumptions About Supply and Demand	Seeking a Desired Waiting Time	V0
	Seeking a Desired Waiting List	V17
Increased OP Capacity	Seeking a Desired Waiting Time	V16
	Seeking a Desired Waiting List	V18
Use of New Referral Guidelines	Use of Modest New Guidelines, Seeking a Desired Waiting Time	V14
	Use of Modest New Guidelines, Seeking a Desired Waiting List	V19
	Use of Strict New Guidelines, Seeking a Desired Waiting Time	V15
	Use of Strict New Guidelines, Seeking a Desired Waiting List	V20
A Winter Crisis	Seeking a Desired Waiting Time	V8
	Seeking a Desired Waiting List	V21

E5b. Parameter Changes for Experiments

Changes for R1-R52 refer to changes to model listing in Appendix E2a

Changes for V1-V21 refer to changes to model listing in Appendix E2b

Exp	Parameter Changes
R0	No changes (Base Case for Ribsley General)
R1	AggJDOpSk(0)=0; JDOp(0)=0; SwTOP=0
R2	SwTOP=0
R3	SwB3=0; SwR1=0; SwR2=0
R4	SwR1=0; SwR2=0
R5	SwB3=0
R6	EffCapLCC=1
R7	Ph1DCCPCAL=0; Ph2DCCPCAL=0; EffCapLCC=EffCapLCCN; PCapTCC=PCapTCCNDS; STTCapUNEDCC=3-Step(2.75,13) +Step(2.75,14)-Step(2.75,36)+Step(2.75,37)
R8	CumDCCRCAL=Step(500,TDCCSFA); EffCapLCC=EffCapLCCS; PCapTCC=PCapTCCSDS; STTCapUNEDCC=3-Step(2.75,13) +Step(2.75,15)-Step(2.75,36) +Step(2.75,37)
R9	PCapTCC=PCapTCCW; PCapDCC=PCapDCCW; EffCapLCC = EffCapLCCW
R10	DesTCC= IF (SDCCFA>0.5) THEN 3 ELSE 3; DesCCWL=IF (SDCCFA>0.5) THEN 60 ELSE 60
R11	Alter averaging time in AvCCWLRRe&r to 1.5
R12	Alter averaging time in AvCCWLRRe&r to 6
R13	PDDCCInvD=3
R14	PDDCCInvD=9
R15	EffKOP=IncrEffKOP
R16	LFJDOp=0.6
R17	LFJDOp=0.9
R18	SwOC=1
R19	JDOpRecD=1
R20	IRROP=0.01,0.04,0.07; Extend simulation time to 120 months.
R21	CumDCCRCAL=Step(1200,TDCCSFA); PCapDCC=PCapDCCSPRDS; PCapTCC= PCapTCCSPRDS; EffCapLCC=EffCapLCCSPRDS; STTCapUNEDCC=3-Step(2.75,13)+Step(2.75,15)
R22	As for R21 and also EffWTCC=SuppEffWTCC; EffKCC=SuppEffKCC; EffKOP=SuppEffKOP
R23	As for R21 and also EffWTCC=SuppEffWTCC (and alter function so that no stimulated demand i.e function doesn't exceed 1); SwR1=0; SwR2=0

R24 CumDCCRCAL=Step(1000000, TDCCSFA); PCapDCC=PCapDCCPermDS; PCapTCC=PCapTCCPermDS; EffKCC=EffKCCPDCCS; EffKOP=EffKOPPDCCS; EffCapLCC=EffCapLCCPI; DesTCC= IF (SDCCFA>0.5) THEN 3 ELSE 3; DesCCWL=IF (SDCCFA>0.5) THEN 60 ELSE 60; STTCapUNEDCC=3-Step(2.75,13)+Step(2.75,15)

R25 As for R24 and also EffWTCC=SuppEffWTCC; EffKCC=SuppEffKCC; EffKOP=SuppEffKOP

R26 As for R24 and also EffWTCC=SuppEffWTCC (and alter function so that no stimulated demand i.e function doesn't exceed 1); SwR1=0; SwR2=0

R27 CumDCCRCAL=Step(500,TDCCSFA)+Step(100,36); PCapTCC=PCapTCCET; PCapDCC=PCapDCCET; EffCapLCC=EffCapLCCPI; DesCCWL=IF(SDCCFA>0.5) THEN 60 ELSE 60; DesTCC= IF(SDCCFA>0.5) THEN 3 ELSE 3; STTCapUNEDCC=3-Step(2.75,13) +Step(2.75,15)-Step(2.75,36)+Step(2.75,37)

R28 As for R27 and also EffWTCC=SuppEffWTCC; EffKCC=SuppEffKCC; EffKOP=SuppEffKOP

R29 As for R27 and also EffWTCC=SuppEffWTCC (and alter function so that no stimulated demand i.e function doesn't exceed 1); SwR1=0; SwR2=0

R30 PCapTCC=PCapTCCFDS; PCapDCC=PCapDCCFDS; EffCapLCC=EffCapLCCFDS; CumDCCRCAL=Step(500,TDSFA) +Step(200,34) +Step(150,46); STTCapUNEDCC=3-Step(2.75,13) +Step(2.75,15)-Step(2.75,34)+Step(2.75,35)

R31 As for R30 and also EffWTCC=SuppEffWTCC; EffKCC=SuppEffKCC; EffKOP=SuppEffKOP

R32 As for R30 and also EffWTCC=SuppEffWTCC (and alter function so that no stimulated demand i.e function doesn't exceed 1); SwR1=0; SwR2=0

R33 EffWTCC=SuppEffWTCC; EffKCC=SuppEffKCC; EffKOP=SuppEffKOP

R34 EffWTCC=SuppEffWTCC (and alter function so that no stimulated demand i.e function doesn't exceed 1); SwR1=0; SwR2=0

R35 SwIOPCap=1; IRROP=0,0.01,0.02,0.06,0.07,0.12,0.13; Extend simulation time to 120 months.

R36 SwPADr=1

R37 DesOPWLAT=3; DesCCWLAT=3; DesCCWL=IF (SDCCFA>0.5) THEN 28 ELSE 56

R38 As for R37 and also SwPADr=1

R39 As for R37 and also SwPADr=1; EffWTCC=SuppEffWTCC; EffKCC=SuppEffKCC; EffKOP=SuppEffKOP

R40 As for R37 and also SwPADr=1; EffWTCC=SuppEffWTCC (and alter function so that no stimulated demand i.e function doesn't exceed 1); SwR1=0; SwR2=0

R41 DesOPWLAT=3; DesCCWLAT=3; DesCCWL=IF (SDCCFA>0.5) THEN 28 ELSE 56; IRROP=0.005. Extend simulation time to 120 months.

R42 As for R41 and also SwPADr=1

R43 DesOPWLAT=3; DesCCWLAT=3; DesCCWL=IF (SDCCFA>0.5) THEN 28 ELSE 56; IRROP= -0.005. Extend simulation time to 120 months.

R44 As for R43 and also SwPADr=1

R45 DesOPWLAT=3; DesCCWLAT=3; DesCCWL=IF (SDCCFA>0.5) THEN 28 ELSE 56; IRROP=0.04. Extend simulation time to 120 months.

R46 As for R45 and also SwPADr=1

R47 DesOPWLAT=3; DesCCWLAT=3; DesCCWL=IF (SDCCFA>0.5) THEN 28 ELSE 56; IRROP=0.07. Extend simulation time to 120 months.

R48 As for R47 and also SwPADr=1

R49 DesOPWLAT=3; DesCCWLAT=3; DesCCWL=IF (SDCCFA>0.5) THEN 28 ELSE 56; PCapTCC=PCapTCCW; PCapDCC=PCapDCCW; EffCapLCC=EffCapLCCW

R50 As for R49 and also SwPADr=1

R51 EffWTCC=0.95; EffSkCC=0.667; EffKCC=1; EffCapLCC=1; CCWLAT=3; OPWLAT=3; DesCCWL=56; PCapTCC=100 (unconstrained)

R52 As for R51 and SwPADr=1

Exp	Parameter Changes
V0	No changes (Base Case for Veinbridge General)
V1	SwR1=0; SwR2=0
V2	SwR1=0
V3	SwR2=0
V4	CumDCCRCAL=0; Ph1DCCPCAL=0; Ph2DCCPCAL=0; EffOFCC=1; EffCapLCC=EffCapLCCN; PCapTCC=PCapTCCNDS; FEDCC=0.9; STTCapUNEDCC=3-Step(2.75,13)+Step(2.75,14)-Step(2.75,36)+Step(2.75,37)
V5	CumDCCRCAL=Step(550,TDCCSFA)+Step(100,36); Ph2DCCPCAL=0; EffOFCC=1 for t=0…13, 1.18 for t=14, 1.2 for t=15…24, 1.18 for t=25, 1 for t=26…72; EffKOP=EffKOPTDCCS; EffKCC=EffKCCTDCCS; PCapTCC=PCapTCCTDS; PCapDCC=PCapDCCTDS; STTCapUNEDCC=3-Step(2.75,13)+Step(2.75,14)-Step(2.75,36) +Step(2.75,37); FEDCC=0.9
V6	CumDCCRCAL=Step(550,TDCCSFA)+Step(100,36); Ph2DCCPCAL=0; PCapTCC=PCapTCCET; PCapDCC=PCapDCCET; EffKOP=EffKOPTDCCS; EffKCC=EffKCCTDCCS; STTCapUNEDCC=3-Step(2.75,13)+Step(2.75,14)-Step(2.75,36)+Step(2.75,37); FEDCC=0.9; EffOFCC=1 for t=0…13, 1.18 for t=14, 1.2 for t=15…24, 1.48 at t=25, 1.6 for t=26…72
V7	CumDCCRCAL=Step(550, TDCCSFA) +Step(100,36) +Step(150,46) +Step(150,58) +Step(150,70); Ph2DCCPCAL=0; PCapTCC=PCapTCCPDS; PCapDCC=PCapDCCPDS; EffKOP=EffKOPTDCCS; EffKCC=EffKCCTDCCS; FEDCC=0.9; STTCapUNEDCC=3-Step(2.75,13)+Step(2.75,14)-Step(2.75,36)+Step(2.75,37) -Step(2.75,46)+Step(2.75,47) -Step(2.75,58)+Step(2.75,59) -Step(2.75,70) +Step(2.75,71); EffOFCC=1 for t=0…13, 1.18 for t=14, 1.2 for t=15…24, 1.18 for t=25, 1 for t=26…72;
V8	PCapTCC=PCapTCCW; PCapDCC=PCapDCCW; EffOFCC= 1 for t=0…13, 1.18 for t=14, 1.2 for t=15…35, 1.36 for t=36, 1.4 for t=37…72; EffCapLCC=EffCapLCCW
V9	DesTCC= IF (SDCCFA>0.5) THEN 1.75 ELSE 3.5; DesCCWL=IF (SDCCFA>0.5) THEN 64 ELSE 128
V10	PDDCCInvD=3
V11	PDDCCInvD=9
V12	EffKOP=IncrEffKOP

V13 FEDOp= IF (JDOp=0) THEN 1 ELSE 0.333; FJDOp=IF(JDOp=0) THEN 0 ELSE 0.333; OPWLi=468; FRROPWLtoIPtoCC=0.002; FOPreOPWLRR=0.023; RefRROP=506.98; NOPCap=582.69; SumJTOPWL(0)=25307.99

V14 EffKOP=SuppEffKOP; EffKCC=SuppEffKCC; EffOFCC=1 for t=13, 1.08 for t=14, 1.1 for t=15…34, 1.16 for t=35, 1.2 for t=36

V15 SwR1=0; SwR2=0; EffOFCC=1; PCapTCC=PCapTCCNSDem; PCapDCC=PCapDCCNSDem

V16 SwIOPCap=1

V17 SwPADr=1

V18 SwPADr=1; SwIOPCap=1

V19 As for V14 and also SwPADr=1

V20 As for V15 and also SwPADr=1

V21 As for V8 and also SwPADr=1

E5c. List of Performance Measures

Waiting Lists:

PrSIEOPWL	Pressure summary index associated with an excessive OP waiting list [pressure]
MaxOPWL	Maximum OP waiting list [pats]
MinOPWL	Minimum OP waiting list [pats]
DEOPWL	Duration of excessive OP waiting list [mths]
PrSIECCWL	Pressure summary index associated with an excessive CC investigation waiting list [pressure]
MaxCCWL	Maximum CC investigation waiting list [pats]
MinCCWL	Minimum CC investigation waiting list [pats]
DECCWL	Duration of excessive CC investigation waiting list [mths]

Waiting Times:

PrSIETonOPWL	Pressure summary index associated with an excessive average time spent on the OP waiting list [pressure]
MaxTonOPWL	Maximum average waiting time on OP waiting list [mths]
MinTonOPWL	Minimum average waiting time on OP waiting list [mths]
DETonOPWL	Duration of excessive time on OP waiting list [mths]
MaxTnewOPWL	Maximum average estimated waiting time for new OP waiting list patients [mths]
MinTnewOPWL	Minimum average estimated waiting time for new OP waiting list patients [mths]
DETnewOPWL	Duration of excessive average estimated waiting time estimated for new OP waiting list patients [mths]
PrSIETonCCWL	Pressure summary index associated with an excessive average time spent on the CC investigation waiting list [pressure]
MaxTonCCWL	Maximum average waiting time on CC waiting list [mths]
MinTonCCWL	Minimum average waiting time on CC investigation waiting list [mths]
DETonCCWL	Duration of excessive time on waiting list for CC investigation [mths]

MaxTnewCCWL	Maximum average estimated waiting time for new CC investigation waiting list patients [mths]
MinTnewCCWL	Minimum average estimated waiting time for new CC investigation waiting list patients [mths]
DETnewCCWL	Duration of excessive average estimated waiting time estimated for new CC investigation waiting list patients [mths]

Resource Use:

CumOP	Cumulative OP activity [pats]
CumOPAC	Cumulative OP activity costs [pounds]
CumCC	Cumulative elective CC investigations [pats]
CumCCAC	Cumulative CC activity costs [pounds]
CumCCACATL	Cumulative CC activity costs if all activity were carried out at the tertiary level [pounds]
CumC	Cumulative costs [pounds]

Referrals:

CumOPWLAdds	Cumulative OP waiting list additions [pats]
MaxRROP	Maximum referral rate for OP appointment [pats/mth]
MinRROP	Minimum referral rate for OP appointment [pats/mth]
DstDemOP	Duration of stimulated demand for OP appointment [mths]
CumCCWLAdds	Cumulative CC waiting list additions [pats]
MaxRRCC	Maximum referral rate for elective CC investigation [pats/mth]
MinRRCC	Minimum referral rate for elective CC investigation [pats/mth]
DstDemCC	Duration of stimulated demand for CC investigation [mths]

E5d. Consistency Calculations for Structural Change Experiments

1. Consistency Calculations for the Ribsley General Case

1a. To Produce Consistency Between the Waiting List and Waiting Time Goals

Assume no capacity constraints, equilibrium and the demand multipliers fixed at their starting values.

CCWLRR = CCInvR + OCCWLRR

No capacity constraints ⇒ CCInvR = DesCCInvR

⇒ CCWLRR = DesCCInvR + OCCWLRR..(1)

DesCCInvR = SwPADr*DesCCInvRWL + (1-SwPADr)*DesCCInvRWT

Seeking a desired waiting time⇒ SwPADr=0 ⇒ DesCCInvR = DesCCInvRWT

= IF (DesTCC=0) THEN 999 ELSE ((CCWL/DesTCC)-AvOCCWLRR)

Assuming DesTCC≠0 ⇒ DesCCInvR = (CCWL/DesTCC)-AvOCCWLRR

Equilibrium ⇒ CCWL= DesCCWL

and AvOCCWLRR=OCCWLRR

⇒DesCCInvR=(DesCCWL/DesTCC)-OCCWLRR... (2)

(1) & (2) ⇒CCWLRR=DesCCWL/DesTCC..(3)

Equilibrium⇒ CCWLRR = RRCC

= RROPWLtoCC+NRRIPtoCC

= OPR*FOPtoCC+RROPWLtoIPtoCC+NRRIPtoCC

= OPR*RefFOPtoCC*EffSkCC*MIN(EffCapLCC,EffKCC*EffWTCC*EffOFCC) + OPWL*FRROPWLtoIPtoCC + NRRIPtoCC..........(4)

No capacity constraints⇒OPR=DesOPR

Seeking a desired waiting time $\Rightarrow$ SwPADr=0 $\Rightarrow$ DesOPR = DesOPRWT

= IF (DesTOP=0) THEN 999 ELSE ((OPWL/DesTOP)-AvPreOPWLRR

DesTOP$\neq$0 $\Rightarrow$ DesOPR = (OPWL/DesTOP)-AvPreOPWLRR

Equilibrium $\Rightarrow$ AvPreOPWLRR=PreOPWLRR

$\Rightarrow$DesOPR =(OPWL/DesTOP)-PreOPWLRR

=(OPWL/DesTOP)-(RROPWLtoIPtoCC+OPreOPWLRR)

=(OPWL/DesTOP)-(OPWL*FRROPWLtoIPtoCC+OPWL*FOPreOPWLRR)......(5)

(3)-(5)$\Rightarrow$DesCCWL/DesTCC=[(OPWL/DesTOP)-(OPWL*FRROPWLtoIPtoCC+OPWL*FOPreOPWLRR)]* RefFOPtoCC*EffSkCC*

MIN(EffCapLCC,EffKCC*EffWTCC*EffOFCC) + OPWL*FRROPWLtoIPtoCC + NRRIPtoCC......(6)

$\Rightarrow$DesCCWL=DesTCC*{[(OPWL/DesTOP)-(OPWL*FRROPWLtoIPtoCC+OPWL*FOPreOPWLRR)]* RefFOPtoCC*EffSkCC*

MIN(EffCapLCC,EffKCC*EffWTCC*EffOFCC) + OPWL*FRROPWLtoIPtoCC + NRRIPtoCC}

Therefore, a waiting list goal of DesTCC*{see above} is consistent with a waiting time goal of DesTCC

Inputting the figures for the case of Ribsley General,

DesCCWL = 3*{[(424/1.15)-(424*0.002+424*0.048)]*0.05625*0.667*MIN(1,1*0.95*1)+424*0.002+5.5}

= 3*{12.38+0.85+5.5}

= 3*18.73

= 56 patients

1b. To Produce Consistency in the Paths to These Consistent Goals.

From CCWL(0) (where CCWL$\neq$DesCCWL), consider DesCCInvRWT=DesCCInvRWL

DesCCInvRWT = IF (DesTCC=0) THEN 999 ELSE ((CCWL/DesTCC)-AvOCCWLRR)

DesCCInvRWL = MAX(MIN(AvRRCC+(CCWL-DesCCWL)/DesCCWLAT-AvOCCWLRR,CCWL/AvWLRT+AvRRCC),0)

Assuming DesTCC≠0, there are sufficient patients on the CC investigation waiting list and the desired waiting list does not force the desired investigation rate to become negative,

⇒(CCWL/DesTCC)-AvOCCWLRR = AvRRCC+(CCWL-DesCCWL)/DesCCWLAT-AvOCCWLRR

⇒CCWL/DesTCC=AvRRCC+(CCWL-DesCCWL)/DesCCWLAT}...(7)

Equilibrium ⇒ AvRRCC=RRCC

From (4) and (5), RRCC = [(OPWL/DesTOP)-(OPWL*FRROPWLtoIPtoCC+OPWL*FOPreOPWLRR)]* RefFOPtoCC*EffSkCC*
MIN(EffCapLCC,EffKCC*EffWTCC*EffOFCC) + OPWL*FRROPWLtoIPtoCC + NRRIPtoCC

⇒ CCWL/DesTCC = [(OPWL/DesTOP)-(OPWL*FRROPWLtoIPtoCC+OPWL*FOPreOPWLRR)]* RefFOPtoCC*EffSkCC*
MIN(EffCapLCC,EffKCC*EffWTCC*EffOFCC) + OPWL*FRROPWLtoIPtoCC + NRRIPtoCC + (CCWL-DesCCWL)/DesCCWLAT

⇒ (CCWL-DesCCWL)/DesCCWLAT={CCWL/DesTCC-[(OPWL/DesTOP)-(OPWL*FRROPWLtoIPtoCC+OPWL*FOPreOPWLRR)]* RefFOPtoCC*EffSkCC*
MIN(EffCapLCC,EffKCC*EffWTCC*EffOFCC) - OPWL*FRROPWLtoIPtoCC - NRRIPtoCC}

⇒ DesCCWLAT=(CCWL-DesCCWL)/{CCWL/DesTCC-[(OPWL/DesTOP)-(OPWL*FRROPWLtoIPtoCC+OPWL*FOPreOPWLRR)]* RefFOPtoCC*EffSkCC*
MIN(EffCapLCC,EffKCC*EffWTCC*EffOFCC) - OPWL*FRROPWLtoIPtoCC - NRRIPtoCC

Therefore, when the CC investigation referral rate is constant, a waiting list adjustment time of (CCWL-DesCCWL)/{see above} will produce the same desired activity rate when seeking a waiting list or waiting time goal.

Inputting the figures for the case of Ribsley General,

DesCCWLAT = (88-56)/(88/3-18.73) = 3 months

2. Consistency Calculations for the Veinbridge General Case

2a. To Produce Consistency Between the Waiting List and Waiting Time Goals

For the case of Veinbridge General, the assumptions of no capacity constraints and equilibrium for CC investigations were in fact the base case assumptions, unlike the case of Ribsley General.

CCWL(0) was constructed from the above assumptions and the given information about CCInvR
As for the Ribsley calculations,
DesCCInvR=(DesCCWL/DesTCC)-OCCWLRR ....(2)
$\Rightarrow$ DesCCWL=DesTCC*(DesCCInvR+OCCWLRR)
Equilibrium $\Rightarrow$ CCInvR=DesCCInvR
and CCWL=DesCCWL
$\Rightarrow$CCWL=DesTCC*(CCInvR+OCCWLRR)
Inputting the figures for the case of Veinbridge General,
$\Rightarrow$CCWL(0) =3.5*(35.7+1) =128 = DesCCWL

Therefore in calibrating the model to the Veinbridge General case, a waiting list goal of 128 patients was already consistent with a waiting time goal of 3.5 months. Therefore, there was no need to re-parameterise for the structural change experiments.

2b. To Produce Consistency in the Paths to These Consistent Goals.

As for the Ribsley calculations,
CCWL/DesTCC=AvRRCC+(CCWL-
DesCCWL)/DesCCWLAT}..(7)

As CCWL=DesCCWL, this equation will hold for all values of DesCCWLAT. Therefore, there was no need to re-parameterise for the structural change experiments.

where:

AvOCCWLRR	Average other CC investigation waiting list removal rate [pats/mth].
AvPreOPWLRR	Average pre-appointment OP waiting list removal rate [pats/mth].
AvRRCC	Average rate of referrals for elective CC investigation [pats/mth].
AvWLRT	Average waiting list removal time [mths].
CapOP	Capacity for OP appointments [pats/mth].
CCInvR	Elective CC investigation rate [pats/mth].
CCWL	CC investigation waiting list length [pats].
CCWLRR	CC investigation waiting list removal rate [pats/mth].
DesCCInvR	Desired elective CC investigation rate [pats/mth].
DesCCInvRWL	Desired elective CC investigation rate driven by a waiting list goal [pats/mth].
DesCCInvRWT	Desired elective CC investigation rate driven by a waiting time goal [pats/mth].
DesCCWL	Desired CC investigation waiting list length [pats].
DesCCWLAT	Desired CC investigation waiting list adjustment time [mths].
DesOPR	Desired OP rate [pats/mth].
DesOPRWL	Desired OP rate driven by a waiting list goal [pats/mth].
DesOPRWT	Desired OP rate driven by a waiting time goal [pats/mth].
DesTCC	Desired waiting time for a CC investigation [mths].
DesTOP	Desired waiting time for a OP appointment [mths].
EffCapLCC	Effect of significant capacity loss on referrals for elective CC investigation [-].
EffKCC	Effect of knowledge of CC on referrals for elective CC investigation [-].
EffKOP	Effect of knowledge of CC on referrals for a OP appointment [-].

EffOFCC	Effect of other factors on referrals for elective CC investigation [-].
EffSkCC	Effect of CC operator skills on referrals for elective CC investigation [-].
EffWTCC	Effect of waiting time for CC investigation on referrals for elective CC investigation [-].
FOPreOPWLRR	Fractional other pre-appointment OP waiting list removal rate [-/mth].
FOPtoCC	Fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].
FRROPWLtoIPtoCC	Fractional rate of referrals from the OP waiting list via inpatients to an elective CC investigation [-/mth].
NRRIPtoCC	New referral rate from inpatients to an elective CC investigation [pats/mth].
OCCWLRR	Other CC investigation waiting list removal rate [pats/mth].
OPR	OP rate [pats/mth].
OPreOPWLRR	Other pre-appointment OP waiting list removal rate [pats/mth].
OPWL	OP waiting list length [pats].
PreOPWLRR	Pre-appointment OP waiting list removal rate [pats/mth].
RefFOPtoCC	Reference fraction of patients assessed at an OP appointment who are referred on for an elective CC investigation [-].
RRCC	Referral rate for an elective CC investigation [pats/mth].
RROPWLtoCC	Rate of referrals from OP waiting list to an elective CC investigation [pats/mth].
RROPWLtoIPtoCC	Rate of referrals from the OP waiting list via inpatients to an elective CC investigation [pats/mth].
SwPADr	Switch for patient activity driver [-].
UCapOP	Utilisation of capacity for OP appointments [-].

E5e. Results of Experiments

* indicates division by zero

For R1-R36 - % changes from R0 (base case)

For R38-R40 - % changes from R37

For R42 - % changes from R41

For R44 - % changes from R43

For R46 - % changes from R45

For R48 - % changes from R47

For R50 - % changes from R49

For R52 - % changes from R51

For R20 and R35b-R35g - results are not listed in the table because timescale was extended from 54 months to 120 months, and therefore, comparisons with the base case and other experiments are meaningless.

For V1-V20 - % changes from V0 (base case)

For V21 - % changes from V8

1. Results of Experiments for the Ribsley General Case

Performance Measure	**R0**	**R1**		**R2**		**R3**		**R4**		**R5**	
PrSIEOPWL [pressure]	154.75	150.43	-2.8%	161.47	4.3%	23.62	-84.7%	23.62	-84.7%	153.52	-0.8%
MaxOPWL [pats]	442	442	0.0%	442	0.0%	424	-4.0%	424	-4.0%	442	0.0%
MinOPWL [pats]	424	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%
DEOPWL [mths]	20.88	20.63	-1.2%	22.00	5.4%	0	-100.0%	0	-100.0%	20.75	-0.6%
PrSIECCWL [pressure]	890.61	815.98	-8.4%	1,240.19	39.3%	947.95	6.4%	845.16	-5.1%	995.46	11.8%
MaxCCWL [pats]	114	108	-4.9%	114	0.0%	118	3.2%	114	0.0%	118	3.2%
MinCCWL [pats]	35	33	-4.5%	37	6.7%	31	-10.6%	33	-6.0%	34	-4.0%
DECCWL [mths]	40.63	40.63	0.0%	44.5	9.5%	39	-4.0%	38.75	-4.6%	40.88	0.6%
PrSIETonOPWL [pressure]	0.15	0.14	-6.7%	0.16	6.7%	0	-100.0%	0	-100.0%	0.15	0.0%
MaxTonOPWL [mths]	1.18	1.18	0.0%	1.18	0.0%	1.15	-2.5%	1.15	-2.5%	1.18	0.0%
MinTonOPWL [mths]	1.15	1.15	0.0%	1.14	-0.9%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETonOPWL [mths]	12.63	12.38	-2.0%	13.13	4.0%	0	-100.0%	0	-100.0%	12.63	0.0%
MaxTnewOPWL [mths]	1.17	1.17	0.0%	1.18	0.9%	1.15	-1.7%	1.15	-1.7%	1.17	0.0%
MinTnewOPWL [mths]	1.15	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETnewOPWL [mths]	9.88	9.75	-1.3%	10.25	3.7%	0	-100.0%	0	-100.0%	9.75	-1.3%
PrSIETonCCWL [pressure]	50.13	47.27	-5.7%	60.7	21.1%	51.23	2.2%	48.45	-3.4%	52.92	5.6%
MaxTonCCWL [mths]	5.12	4.97	-2.9%	5.16	0.8%	5.14	0.4%	5.12	0.0%	5.14	0.4%
MinTonCCWL [mths]	1.69	1.68	-0.6%	1.88	11.2%	1.8	6.5%	1.72	1.8%	1.77	4.7%
DETonCCWL [mths]	41.5	39	-6.0%	45.38	9.3%	38.75	-6.6%	39.25	-5.4%	41.88	0.9%
MaxTnewCCWL [mths]	7.87	7.54	-4.2%	7.87	0.0%	8.07	2.5%	7.87	0.0%	8.07	2.5%
MinTnewCCWL [mths]	1.5	1.46	-2.7%	1.58	5.3%	1.43	-4.7%	1.44	-4.0%	1.51	0.7%
DETnewCCWL [mths]	50.25	49.25	-2.0%	51.63	2.7%	48.5	-3.5%	48.75	-3.0%	50.25	0.0%
CumOP [pats]	18,784	18,782	0.0%	18,787	0.0%	18,719	-0.3%	18,719	-0.3%	18,783	0.0%
CumOPAC [pounds]	1,878,361	1,878,179	0.0%	1,878,650	0.0%	1,871,855	-0.3%	1,871,855	-0.3%	1,878,306	0.0%
CumCC [pats]	848	841	-0.8%	862	1.6%	840	-0.9%	841	-0.8%	847	-0.1%
CumCCAC [pounds]	529,150	524,557	-0.9%	537,922	1.7%	524,149	-0.9%	524,762	-0.8%	528,371	-0.1%
CumCCACATL [pounds]	516,193	511,808	-0.8%	524,378	1.6%	511,455	-0.9%	512,048	-0.8%	515,451	-0.1%
CumC [pounds]	2,439,461	2,434,687	-0.2%	2,448,522	0.4%	2,427,954	-0.5%	2,428,567	-0.4%	2,438,627	0.0%
CumOPWLAdds [pats]	19,937	19,935	0.0%	19,940	0.0%	19,865	-0.4%	19,865	-0.4%	19,936	0.0%
MaxRROP [pats/mth]	377.07	377.07	0.0%	377.07	0.0%	367.87	-2.4%	367.87	-2.4%	377.07	0.0%
MinRROP [pats/mth]	367.87	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%
DStDemOP [mths]	9.63	9.5	-1.3%	9.88	2.6%	0	-100.0%	0	-100.0%	9.5	-1.3%
CumCCWLAdds [pats]	947	934	-1.4%	987	4.2%	943	-0.4%	936	-1.1%	953	0.7%
Max RRCC [pats/mth]	22.31	20.93	-6.2%	22.32	0.0%	19.35	-13.3%	20.58	-7.8%	20.95	-6.1%
MinRRCC [pats/mth]	9.6	9.31	-3.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%
DStDemCC [mths]	11.75	12	2.1%	10.88	-7.4%	0	-100.0%	9.63	-18.0%	12.75	8.5%

Performance Measure	R6		R7		R8		R9		R10		R11	
PrSIEOPWL [pressure]	162.64	5.1%	23.62	-84.7%	154.75	0.0%	154.75	0.0%	87.43	-43.5%	155.08	0.2%
MaxOPWL [pats]	442	0.0%	424	-4.0%	442	0.0%	442	0.0%	437	-1.2%	442	0.0%
MinOPWL [pats]	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%
DEOPWL [mths]	23.38	12.0%	0	-100.0%	20.88	0.0%	20.88	0.0%	17.25	-17.4%	20.88	0.0%
PrSIECCWL [pressure]	1,561.71	75.4%	5,152.86	478.6%	1,496.73	68.1%	1,029.13	15.6%	1,029.14	15.6%	895.12	0.5%
MaxCCWL [pats]	121	6.0%	206	80.8%	135	18.0%	114	0.0%	114	0.0%	114	0.0%
MinCCWL [pats]	38	8.8%	72	106.4%	35	0.0%	35	0.0%	57	62.4%	35	0.5%
DECCWL [mths]	52.13	28.3%	54	32.9%	48.13	18.5%	44.5	9.5%	49.13	20.9%	40.63	0.0%
PrSIETonOPWL [pressure]	0.16	6.7%	0	-100.0%	0.15	0.0%	0.15	0.0%	0.06	-60.0%	0.15	0.0%
MaxTonOPWL [mths]	1.18	0.0%	1.15	-2.5%	1.18	0.0%	1.18	0.0%	1.17	-0.8%	1.18	0.0%
MinTonOPWL [mths]	1.14	-0.9%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETonOPWL [mths]	13.13	4.0%	0	-100.0%	12.63	0.0%	12.63	0.0%	8.38	-33.7%	12.63	0.0%
MaxTnewOPWL [mths]	1.18	0.9%	1.15	-1.7%	1.17	0.0%	1.17	0.0%	1.17	0.0%	1.17	0.0%
MinTnewOPWL [mths]	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETnewOPWL [mths]	10.25	3.7%	0	-100.0%	9.88	0.0%	9.88	0.0%	7.25	-26.6%	9.88	0.0%
PrSIETonCCWL [pressure]	76.11	51.8%	260.44	419.5%	80.22	60.0%	64.36	28.4%	68.58	36.8%	50.31	0.4%
MaxTonCCWL [mths]	5.51	7.6%	11.16	118.0%	6.33	23.6%	5.12	0.0%	5.14	0.4%	5.12	0.0%
MinTonCCWL [mths]	1.98	17.2%	2.4	42.0%	1.69	0.0%	1.69	0.0%	2.4	42.0%	1.7	0.6%
DETonCCWL [mths]	47.88	15.4%	52.63	26.8%	45.63	10.0%	45.63	10.0%	52.63	26.8%	41.88	0.9%
MaxTnewCCWL [mths]	8.24	4.7%	34.51	338.5%	9.4	19.4%	15.97	102.9%	7.87	0.0%	7.87	0.0%
MinTnewCCWL [mths]	1.59	6.0%	3.1	106.7%	1.5	0.0%	1.5	0.0%	2.87	91.3%	1.51	0.7%
DETnewCCWL [mths]	53.5	6.5%	54	7.5%	51.88	3.2%	51.63	2.7%	51.88	3.2%	50.38	0.3%
CumOP [pats]	18,787	0.0%	18,719	-0.3%	18,784	0.0%	18,784	0.0%	18,756	-0.1%	18,784	0.0%
CumOPAC [pounds]	1,878,711	0.0%	1,871,855	-0.3%	1,878,361	0.0%	1,878,361	0.0%	1,875,557	-0.1%	1,878,375	0.0%
CumCC [pats]	864	1.9%	584	-31.1%	785	-7.4%	813	-4.2%	797	-6.1%	849	0.1%
CumCCAC [pounds]	539,773	2.0%	355,499	-32.8%	487,375	-7.9%	506,789	-4.2%	495,346	-6.4%	529,510	0.1%
CumCCACATL [pounds]	526,104	1.9%	355,499	-31.1%	477,876	-7.4%	494,523	-4.2%	484,863	-6.1%	516,532	0.1%
CumC [pounds]	2,450,434	0.4%	2,227,355	-8.7%	2,397,486	-1.7%	2,417,049	-0.9%	2,402,853	-1.5%	2,439,834	0.0%
CumOPWLAdds [pats]	19,941	0.0%	19,865	-0.4%	19,937	0.0%	19,937	0.0%	19,905	-0.2%	19,937	0.0%
MaxRROP [pats/mth]	377.07	0.0%	367.87	-2.4%	377.07	0.0%	377.07	0.0%	376.52	-0.1%	377.07	0.0%
MinRROP [pats/mth]	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%
DStDemOP [mths]	10	3.8%	0	-100.0%	9.63	0.0%	9.63	0.0%	7.75	-19.5%	9.63	0.0%
CumCCWLAdds [pats]	1007	6.4%	912	-3.6%	941	-0.6%	925	-2.3%	928	-2.0%	947	0.1%
Max RRCC [pats/mth]	22.32	0.0%	19.23	-13.8%	22.31	0.0%	22.31	0.0%	20.57	-7.8%	22.31	0.0%
MinRRCC [pats/mth]	15.61	62.6%	9.53	-0.7%	9.53	-0.7%	8.79	-8.4%	9.6	0.0%	9.6	0.0%
DStDemCC [mths]	16.13	37.3%	0	-100.0%	8.75	-25.5%	9.25	-21.3%	5.88	-50.0%	11.5	-2.1%

Performance Measure	**R12**		**R13**		**R14**		**R15**		**R16**		**R17**	
PrSIEOPWL [pressure]	154.26	-0.3%	203.19	31.3%	107.97	-30.2%	255.86	65.3%	152.43	-1.5%	156.15	0.9%
MaxOPWL [pats]	442	0.0%	443	0.1%	439	-0.8%	459	3.9%	442	0.0%	442	0.0%
MinOPWL [pats]	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%
DEOPWL [mths]	20.75	-0.6%	32.13	53.9%	18.63	-10.8%	22.75	9.0%	20.63	-1.2%	20.88	0.0%
PrSIECCWL [pressure]	892.46	0.2%	891.09	0.1%	897.17	0.7%	899.63	1.0%	830.28	-6.8%	936.47	5.1%
MaxCCWL [pats]	114	0.0%	114	0.0%	114	0.0%	114	0.0%	114	-0.1%	114	0.1%
MinCCWL [pats]	35	-0.7%	36	2.4%	34	-3.7%	35	0.0%	33	-4.8%	36	1.9%
DECCWL [mths]	41	0.9%	40	-1.6%	40.88	0.6%	41.13	1.2%	39.88	-1.8%	41.25	1.5%
PrSIETonOPWL [pressure]	0.15	0.0%	0.2	33.3%	0.09	-40.0%	0.29	93.3%	0.15	0.0%	0.15	0.0%
MaxTonOPWL [mths]	1.18	0.0%	1.18	0.0%	1.17	-0.8%	1.2	1.7%	1.18	0.0%	1.18	0.0%
MinTonOPWL [mths]	1.15	0.0%	1.14	-0.9%	1.15	0.0%	1.14	-0.9%	1.15	0.0%	1.15	0.0%
DETonOPWL [mths]	12.63	0.0%	19.63	55.4%	9.88	-21.8%	13.75	8.9%	12.5	-1.0%	12.75	1.0%
MaxTnewOPWL [mths]	1.17	0.0%	1.18	0.9%	1.17	0.0%	1.2	2.6%	1.17	0.0%	1.17	0.0%
MinTnewOPWL [mths]	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETnewOPWL [mths]	9.88	0.0%	13.75	39.2%	8.38	-15.2%	10.5	6.3%	9.75	-1.3%	10	1.2%
PrSIETonCCWL [pressure]	50.23	0.2%	49.84	-0.6%	50.62	1.0%	50.6	0.9%	48.88	-2.5%	51.28	2.3%
MaxTonCCWL [mths]	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.17	1.0%	5.08	-0.8%
MinTonCCWL [mths]	1.69	0.0%	1.72	1.8%	1.69	0.0%	1.69	0.0%	1.67	-1.2%	1.71	1.2%
DETonCCWL [mths]	41.75	0.6%	40.63	-2.1%	42.38	2.1%	42.38	2.1%	39.75	-4.2%	43.25	4.2%
MaxTnewCCWL [mths]	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.86	-0.1%	7.87	0.0%
MinTnewCCWL [mths]	1.49	-0.7%	1.52	1.3%	1.49	-0.7%	1.5	0.0%	1.45	-3.3%	1.54	2.7%
DETnewCCWL [mths]	49.88	-0.7%	50.38	0.3%	49.63	-1.2%	50.25	0.0%	48.75	-3.0%	50.5	0.5%
CumOP [pats]	18,783	0.0%	18,810	0.1%	18,765	-0.1%	18,822	0.2%	18,783	0.0%	18,784	0.0%
CumOPAC [pounds]	1,878,340	0.0%	1,881,004	0.1%	1,876,452	-0.1%	1,882,248	0.2%	1,878,262	0.0%	1,878,421	0.0%
CumCC [pats]	848	-0.1%	851	0.4%	845	-0.3%	849	0.1%	844	-0.5%	851	0.3%
CumCCAC [pounds]	528,776	-0.1%	531,103	0.4%	527,271	-0.4%	529,457	0.1%	526,388	-0.5%	530,895	0.3%
CumCCACATL [pounds]	515,842	-0.1%	518,015	0.4%	514,432	-0.3%	516,487	0.1%	513,594	-0.5%	517,826	0.3%
CumC [pounds]	2,439,066	0.0%	2,444,057	0.2%	2,435,673	-0.2%	2,443,655	0.2%	2,436,600	-0.1%	2,441,266	0.1%
CumOPWLAdds [pats]	19,936	0.0%	19,965	0.1%	19,915	-0.1%	19,981	0.2%	19,935	0.0%	19,937	0.0%
MaxRROP [pats/mth]	377.07	0.0%	377.07	0.0%	377.07	0.0%	386.26	2.4%	377.07	0.0%	377.07	0.0%
MinRROP [pats/mth]	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%
DStDemOP [mths]	9.63	0.0%	12.88	33.7%	9	-6.5%	9.63	0.0%	9.5	-1.3%	9.63	0.0%
CumCCWLAdds [pats]	946	0.0%	950	0.3%	944	-0.2%	948	0.1%	936	-1.1%	953	0.7%
Max RRCC [pats/mth]	22.31	0.0%	22.37	0.3%	21.97	-1.5%	22.52	0.9%	22.25	-0.3%	22.32	0.0%
MinRRCC [pats/mth]	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%
DStDemCC [mths]	12.25	4.3%	9.63	-18.0%	13.25	12.8%	11.75	0.0%	12	2.1%	11.75	0.0%

Performance Measure	**R18**		**R19**		**R21**		**R22**		**R23**		**R24**	
PrSIEOPWL [pressure]	159.15	2.8%	152.79	-1.3%	254.34	64.4%	110.27	-28.7%	23.62	-84.7%	13,847.55	8848.3%
MaxOPWL [pats]	442	0.0%	442	0.0%	442	0.0%	431	-2.4%	424	-4.0%	1017	130.0%
MinOPWL [pats]	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%
DEOPWL [mths]	21.13	1.2%	20.63	-1.2%	29.13	39.5%	25.88	23.9%	0	-100.0%	35.5	70.0%
PrSIECCWL [pressure]	1,059.46	19.0%	928.62	4.3%	1,353.32	52.0%	1,116.09	25.3%	971.95	9.1%	904.65	1.6%
MaxCCWL [pats]	115	0.9%	114	0.0%	114	0.0%	114	0.0%	114	0.0%	114	0.0%
MinCCWL [pats]	36	4.3%	32	-8.4%	50	42.9%	39	11.1%	29	-18.1%	58	66.1%
DECCWL [mths]	42.38	4.3%	42.75	5.2%	50.25	23.7%	46.25	13.8%	40.25	-0.9%	51.13	25.8%
PrSIETonOPWL [pressure]	0.15	0.0%	0.15	0.0%	0.24	60.0%	0.04	-73.3%	0	-100.0%	25.01	16573.3%
MaxTonOPWL [mths]	1.18	0.0%	1.18	0.0%	1.18	0.0%	1.16	-1.7%	1.15	-2.5%	2.37	100.8%
MinTonOPWL [mths]	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.12	-2.6%
DETonOPWL [mths]	13	2.9%	12.63	0.0%	20.75	64.3%	14.25	12.8%	0	-100.0%	30.63	142.5%
MaxTnewOPWL [mths]	1.17	0.0%	1.17	0.0%	1.17	0.0%	1.16	-0.9%	1.15	-1.7%	2.43	107.7%
MinTnewOPWL [mths]	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETnewOPWL [mths]	10.13	2.5%	9.75	-1.3%	19.38	96.2%	11.25	13.9%	0	-100.0%	35.25	256.8%
PrSIETonCCWL [pressure]	54.96	9.6%	52.47	4.7%	73.55	46.7%	62.56	24.8%	56.88	13.5%	41.04	-18.1%
MaxTonCCWL [mths]	5.08	-0.8%	5.18	1.2%	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.12	0.0%
MinTonCCWL [mths]	1.78	5.3%	1.7	0.6%	2.4	42.0%	1.99	17.8%	1.53	-9.5%	2.4	42.0%
DETonCCWL [mths]	45.5	9.6%	40.13	-3.3%	51.88	25.0%	46.38	11.8%	43.38	4.5%	52.63	26.8%
MaxTnewCCWL [mths]	7.93	0.8%	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%
MinTnewCCWL [mths]	1.58	5.3%	1.48	-1.3%	2.45	63.3%	1.94	29.3%	1.47	-2.0%	3.07	104.7%
DETnewCCWL [mths]	51	1.5%	48.63	-3.2%	54	7.5%	52.5	4.5%	48.63	-3.2%	54	7.5%
CumOP [pats]	18,785	0.0%	18,783	0.0%	18,834	0.3%	18,779	0.0%	18,719	-0.3%	19,436	3.5%
CumOPAC [pounds]	1,878,549	0.0%	1,878,273	0.0%	1,883,384	0.3%	1,877,949	0.0%	1,871,855	-0.3%	1,943,567	3.5%
CumCC [pats]	856	1.0%	847	-0.2%	868	2.3%	867	2.3%	861	1.5%	975	14.9%
CumCCAC [pounds]	534,410	1.0%	528,218	-0.2%	544,244	2.9%	544,114	2.8%	539,917	2.0%	618,360	16.9%
CumCCACATL [pounds]	521,110	1.0%	515,287	-0.2%	527,965	2.3%	527,834	2.3%	523,761	1.5%	593,102	14.9%
CumC [pounds]	2,444,910	0.2%	2,438,441	0.0%	2,460,079	0.8%	2,454,513	0.6%	2,444,222	0.2%	2,595,177	6.4%
CumOPWLAdds [pats]	19,939	0.0%	19,936	0.0%	19,992	0.3%	19,930	0.0%	19,865	-0.4%	21,866	9.7%
MaxRROP [pats/mth]	377.07	0.0%	377.07	0.0%	377.07	0.0%	372.65	-1.2%	367.87	-2.4%	441.44	17.1%
MinRROP [pats/mth]	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%
DStDemOP [mths]	9.75	1.2%	9.5	-1.3%	20.63	114.2%	20.25	110.3%	0	-100.0%	35.63	270.0%
CumCCWLAdds [pats]	969	2.3%	944	-0.3%	981	3.7%	965	1.9%	949	0.2%	1073	13.4%
Max RRCC [pats/mth]	22.78	2.1%	22.06	-1.1%	21.34	-4.3%	20.36	-8.7%	19.35	-13.3%	22.55	1.1%
MinRRCC [pats/mth]	9.6	0.0%	9.59	-0.1%	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%
DStDemCC [mths]	11.38	-3.1%	11.63	-1.0%	19.5	66.0%	19.5	66.0%	0	-100.0%	35.13	199.0%

Performance Measure	R25		R26		R27		R28		R29		R30	
PrSIEOPWL [pressure]	4,032.64	2505.9%	23.62	-84.7%	86.7	-44.0%	47.46	-69.3%	23.62	-84.7%	154.75	0.0%
MaxOPWL [pats]	569	28.7%	424	-4.0%	437	-1.2%	429	-2.9%	424	-4.0%	442	0.0%
MinOPWL [pats]	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%
DEOPWL [mths]	35.5	70.0%	0	-100.0%	17.13	-18.0%	13.63	-34.7%	0	-100.0%	20.88	0.0%
PrSIECCWL [pressure]	558.28	-37.3%	512.09	-42.5%	530.19	-40.5%	515.46	-42.1%	512.09	-42.5%	796.12	-10.6%
MaxCCWL [pats]	114	0.0%	114	0.0%	114	0.0%	114	0.0%	114	0.0%	114	0.0%
MinCCWL [pats]	56	61.2%	50	42.0%	53	52.1%	53	51.4%	53	51.1%	35	0.0%
DECCWL [mths]	38	-6.5%	19.38	-52.3%	26.75	-34.2%	23.13	-43.1%	19.38	-52.3%	35.75	-12.0%
PrSIETonOPWL [pressure]	6.78	4420.0%	0	-100.0%	0.06	-60.0%	0.01	-93.3%	0	-100.0%	0.15	0.0%
MaxTonOPWL [mths]	1.43	21.2%	1.15	-2.5%	1.17	-0.8%	1.16	-1.7%	1.15	-2.5%	1.18	0.0%
MinTonOPWL [mths]	1.14	-0.9%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETonOPWL [mths]	31	145.4%	0	-100.0%	8.25	-34.7%	4.88	-61.4%	0	-100.0%	12.63	0.0%
MaxTnewOPWL [mths]	1.43	22.2%	1.15	-1.7%	1.17	0.0%	1.16	-0.9%	1.15	-1.7%	1.17	0.0%
MinTnewOPWL [mths]	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETnewOPWL [mths]	35.25	256.8%	0	-100.0%	7.13	-27.8%	5	-49.4%	0	-100.0%	9.88	0.0%
PrSIETonCCWL [pressure]	32.91	-34.4%	32.27	-35.6%	33.97	-32.2%	33.63	-32.9%	33.47	-33.2%	49.22	-1.8%
MaxTonCCWL [mths]	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.12	0.0%
MinTonCCWL [mths]	2.4	42.0%	2.4	42.0%	2.4	42.0%	2.4	42.0%	2.4	42.0%	1.69	0.0%
DETonCCWL [mths]	40.5	-2.4%	36.5	-12.0%	46.38	11.8%	46.13	11.2%	45.25	9.0%	38.38	-7.5%
MaxTnewCCWL [mths]	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%
MinTnewCCWL [mths]	2.89	92.7%	2.76	84.0%	2.92	94.7%	2.91	94.0%	2.91	94.0%	1.5	0.0%
DETnewCCWL [mths]	46.38	-7.7%	38.38	-23.6%	48	-4.5%	47.75	-5.0%	47.75	-5.0%	48.5	-3.5%
CumOP [pats]	19,429	3.4%	18,719	-0.3%	18,755	-0.2%	18,737	-0.2%	18,719	-0.3%	18,784	0.0%
CumOPAC [pounds]	1,942,864	3.4%	1,871,855	-0.3%	1,875,515	-0.2%	1,873,738	-0.2%	1,871,855	-0.3%	1,878,361	0.0%
CumCC [pats]	956	12.7%	909	7.1%	928	9.4%	923	8.8%	918	8.2%	884	4.3%
CumCCAC [pounds]	605,976	14.5%	575,077	8.7%	573,375	8.4%	569,842	7.7%	566,804	7.1%	553,613	4.6%
CumCCACATL [pounds]	581,605	12.7%	552,922	7.1%	564,934	9.4%	561,443	8.8%	558,441	8.2%	538,213	4.3%
CumC [pounds]	2,582,089	5.8%	2,480,182	1.7%	2,480,734	1.7%	2,475,423	1.5%	2,470,503	1.3%	2,464,074	1.0%
CumOPWLAdds [pats]	20,911	4.9%	19,865	-0.4%	19,905	-0.2%	19,885	-0.3%	19,865	-0.4%	19,937	0.0%
MaxRROP [pats/mth]	404.66	7.3%	367.87	-2.4%	376.57	-0.1%	372.31	-1.3%	367.87	-2.4%	377.07	0.0%
MinRROP [pats/mth]	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%
DStDemOP [mths]	35.63	270.0%	0	-100.0%	7.63	-20.8%	7.38	-23.4%	0	-100.0%	9.63	0.0%
CumCCWLAdds [pats]	1025	8.3%	967	2.1%	991	4.7%	984	4.0%	979	3.4%	933	-1.4%
Max RRCC [pats/mth]	21.11	-5.4%	19.35	-13.3%	20.72	-7.1%	20.01	-10.3%	19.31	-13.4%	22.31	0.0%
MinRRCC [pats/mth]	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%
DStDemCC [mths]	34.75	195.7%	0	-100.0%	20.63	75.6%	17.63	50.0%	0	-100.0%	13.5	14.9%

Performance Measure	**R31**		**R32**		**R33**		**R34**		**R35a**	
PrSIEOPWL [pressure]	72.75	-53.0%	23.62	-84.7%	72.75	-53.0%	23.62	-84.7%	106.29	-31.3%
MaxOPWL [pats]	431	-2.4%	424	-4.0%	431	-2.4%	424	-4.0%	435	-1.6%
MinOPWL [pats]	424	0.0%	424	0.0%	424	0.0%	424	0.0%	424	0.0%
DEOPWL [mths]	17	-18.6%	0	-100.0%	17	-18.6%	0	-100.0%	18.75	-10.2%
PrSIECCWL [pressure]	759.86	-14.7%	736.06	-17.4%	846.36	-5.0%	818.09	-8.1%	889.62	-0.1%
MaxCCWL [pats]	114	0.0%	114	0.0%	114	0.0%	114	0.0%	114	0.0%
MinCCWL [pats]	33	-5.7%	31	-11.7%	33	-5.7%	31	-11.7%	35	0.0%
DECCWL [mths]	34.75	-14.5%	33.88	-16.6%	39.25	-3.4%	38.13	-6.2%	40.63	0.0%
PrSIETonOPWL [pressure]	0.03	-80.0%	0	-100.0%	0.03	-80.0%	0	-100.0%	0.03	-80.0%
MaxTonOPWL [mths]	1.16	-1.7%	1.15	-2.5%	1.16	-1.7%	1.15	-2.5%	1.16	-1.7%
MinTonOPWL [mths]	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.14	-0.9%
DETonOPWL [mths]	8.13	-35.6%	0	-100.0%	8.13	-35.6%	0	-100.0%	6.63	-47.5%
MaxTnewOPWL [mths]	1.16	-0.9%	1.15	-1.7%	1.16	-0.9%	1.15	-1.7%	1.16	-0.9%
MinTnewOPWL [mths]	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%	1.15	0.0%
DETnewOPWL [mths]	8.13	-17.7%	0	-100.0%	8.13	-17.7%	0	-100.0%	5	-49.4%
PrSIETonCCWL [pressure]	48.19	-3.9%	47.64	-5.0%	48.7	-2.9%	47.9	-4.4%	50.09	-0.1%
MaxTonCCWL [mths]	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.12	0.0%	5.12	0.0%
MinTonCCWL [mths]	1.71	1.2%	1.73	2.4%	1.71	1.2%	1.73	2.4%	1.69	0.0%
DETonCCWL [mths]	34.88	-16.0%	34	-18.1%	39.25	-5.4%	38.38	-7.5%	41.38	-0.3%
MaxTnewCCWL [mths]	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%	7.87	0.0%
MinTnewCCWL [mths]	1.43	-4.7%	1.39	-7.3%	1.43	-4.7%	1.39	-7.3%	1.5	0.0%
DETnewCCWL [mths]	46.63	-7.2%	45.5	-9.5%	48.63	-3.2%	47.75	-5.0%	50.13	-0.2%
CumOP [pats]	18,752	-0.2%	18,719	-0.3%	18,752	-0.2%	18,719	-0.3%	18,786	0.0%
CumOPAC [pounds]	1,875,212	-0.2%	1,871,855	-0.3%	1,875,212	-0.2%	1,871,855	-0.3%	1,878,607	0.0%
CumCC [pats]	876	3.3%	869	2.4%	841	-0.9%	834	-1.7%	848	0.0%
CumCCAC [pounds]	548,188	3.6%	543,543	2.7%	524,266	-0.9%	519,997	-1.7%	529,204	0.0%
CumCCACATL [pounds]	533,096	3.3%	528,701	2.4%	511,590	-0.9%	507,555	-1.7%	516,245	0.0%
CumC [pounds]	2,455,501	0.7%	2,447,498	0.3%	2,431,428	-0.3%	2,423,802	-0.6%	2,439,761	0.0%
CumOPWLAdds [pats]	19,901	-0.2%	19,865	-0.4%	19,901	-0.2%	19,865	-0.4%	19,937	0.0%
MaxRROP [pats/mth]	372.65	-1.2%	367.87	-2.4%	372.65	-1.2%	367.87	-2.4%	377.07	0.0%
MinRROP [pats/mth]	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%	367.87	0.0%
DStDemOP [mths]	9.25	-3.9%	0	-100.0%	9.25	-3.9%	0	-100.0%	9.63	0.0%
CumCCWLAdds [pats]	921	-2.7%	912	-3.7%	936	-1.2%	927	-2.1%	947	0.0%
Max RRCC [pats/mth]	20.77	-6.9%	19.35	-13.3%	20.77	-6.9%	19.35	-13.3%	22.38	0.3%
MinRRCC [pats/mth]	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%	9.6	0.0%
DStDemCC [mths]	12.63	7.5%	0	-100.0%	10.88	-7.4%	0	-100.0%	11.75	0.0%

Performance Measure	R0		R36	R37	R38		R39		R40	
PrSIEOPWL [pressure]	154.75	-29.9%	108.5	154.75	128.4	-17.0%	41.28	-73.3%	0	-100.0%
MaxOPWL [pats]	442	-0.5%	440	442	443	0.2%	431	-2.6%	424	-4.1%
MinOPWL [pats]	424	-0.6%	422	424	422	-0.5%	422	-0.5%	424	0.0%
DEOPWL [mths]	20.88	-47.9%	10.88	20.88	11.75	-43.7%	9.13	-56.3%	0	-100.0%
PrSIECCWL [pressure]	890.61	18.3%	1,053.78	1,030.75	1,173.01	13.8%	1,143.20	10.9%	1,126.14	9.3%
MaxCCWL [pats]	114	0.0%	114	114	114	0.0%	114	0.0%	114	0.0%
MinCCWL [pats]	35	8.7%	38	35	41	16.3%	39	11.3%	37	6.9%
DECCWL [mths]	40.63	12.6%	45.75	42.75	45.75	7.0%	45.38	6.2%	45.13	5.6%
PrSIETonOPWL [pressure]	0.15	-46.7%	0.08	0.15	0.14	-6.7%	0.01	-93.3%	0	-100.0%
MaxTonOPWL [mths]	1.18	-0.8%	1.17	1.18	1.18	0.0%	1.16	-1.7%	1.15	-2.5%
MinTonOPWL [mths]	1.15	-0.9%	1.14	1.15	1.14	-0.9%	1.15	0.0%	1.15	0.0%
DETonOPWL [mths]	12.63	-39.6%	7.63	12.63	9	-28.7%	3	-76.2%	0	-100.0%
MaxTnewOPWL [mths]	1.17	0.0%	1.17	1.17	1.18	0.9%	1.16	-0.9%	1.15	-1.7%
MinTnewOPWL [mths]	1.15	-0.9%	1.14	1.15	1.14	-0.9%	1.14	-0.9%	1.15	0.0%
DETnewOPWL [mths]	9.88	-12.7%	8.63	9.88	9.38	-5.1%	6.63	-32.9%	0	-100.0%
PrSIETonCCWL [pressure]	50.13	22.3%	61.33	50.13	59.43	18.6%	59.08	17.9%	59.01	17.7%
MaxTonCCWL [mths]	5.12	0.0%	5.12	5.12	5.12	0.0%	5.12	0.0%	5.12	0.0%
MinTonCCWL [mths]	1.69	11.2%	1.88	1.69	2.06	21.9%	2.13	26.0%	2.19	29.6%
DETonCCWL [mths]	41.5	13.6%	47.13	41.5	46.63	12.4%	46.63	12.4%	46.63	12.4%
MaxTnewCCWL [mths]	7.87	0.0%	7.87	7.87	7.87	0.0%	7.87	0.0%	7.87	0.0%
MinTnewCCWL [mths]	1.5	11.3%	1.67	1.5	1.79	19.3%	1.82	21.3%	1.83	22.0%
DETnewCCWL [mths]	50.25	5.0%	52.75	50.25	52.25	4.0%	52.13	3.7%	52.25	4.0%
CumOP [pats]	18,784	0.0%	18,785	18,784	18,782	0.0%	18,753	-0.2%	18,720	-0.3%
CumOPAC [pounds]	1,878,361	0.0%	1,878,541	1,878,361	1,878,176	0.0%	1,875,254	-0.2%	1,872,018	-0.3%
CumCC [pats]	848	-1.9%	832	848	835	-1.6%	826	-2.7%	819	-3.4%
CumCCAC [pounds]	529,150	-1.9%	518,934	529,150	520,347	-1.7%	514,501	-2.8%	510,316	-3.6%
CumCCACATL [pounds]	516,193	-1.9%	506,144	516,193	507,962	-1.6%	502,436	-2.7%	498,456	-3.4%
CumC [pounds]	2,439,461	-0.4%	2,429,425	2,439,461	2,430,473	-0.4%	2,421,705	-0.7%	2,414,284	-1.0%
CumOPWLAdds [pats]	19,937	0.0%	19,935	19,937	19,932	0.0%	19,898	-0.2%	19,865	-0.4%
MaxRROP [pats/mth]	377.07	0.0%	377.07	377.07	377.07	0.0%	372.65	-1.2%	367.87	-2.4%
MinRROP [pats/mth]	367.87	0.0%	367.87	367.87	367.87	0.0%	367.87	0.0%	367.87	0.0%
DStDemOP [mths]	9.63	0.0%	9.63	9.63	9.38	-2.6%	9	-6.5%	0	-100.0%
CumCCWLAdds [pats]	947	-0.3%	943	947	942	-0.5%	932	-1.6%	924	-2.3%
Max RRCC [pats/mth]	22.31	-0.1%	22.29	22.31	22.21	-0.4%	20.69	-7.3%	19.35	-13.3%
MinRRCC [pats/mth]	9.6	-0.1%	9.59	9.6	9.59	-0.1%	9.59	-0.1%	9.6	0.0%
DStDemCC [mths]	11.75	-13.8%	10.13	11.75	10.5	-10.6%	9.5	-19.1%	0	-100.0%

Performance Measure	R41		R42	R43		R44	R45		R46
PrSIEOPWL [pressure]	334.33	-56.9%	144.19	152.13	-15.6%	128.4	3,350.92	15.3%	3,861.95
MaxOPWL [pats]	442	0.2%	443	442	0.2%	443	456	1.2%	462
MinOPWL [pats]	424	-0.5%	422	422	-0.1%	422	424	-0.5%	422
DEOPWL [mths]	92.75	-75.7%	22.5	20.88	-43.7%	11.75	122.75	-7.4%	113.63
PrSIECCWL [pressure]	8,296.79	3.4%	8,580.80	8,114.62	3.5%	8,396.38	14,190.08	2.1%	14,488.72
MaxCCWL [pats]	208	0.5%	209	204	0.5%	205	242	0.2%	243
MinCCWL [pats]	35	16.3%	41	35	16.3%	41	35	16.3%	41
DECCWL [mths]	108.75	2.8%	111.75	108.75	2.8%	111.75	138.75	2.2%	141.75
PrSIETonOPWL [pressure]	0.15	-6.7%	0.14	0.16	156.3%	0.41	3.85	35.8%	5.23
MaxTonOPWL [mths]	1.18	0.0%	1.18	1.18	0.0%	1.18	1.19	1.7%	1.21
MinTonOPWL [mths]	1.15	-0.9%	1.14	1.15	-0.9%	1.14	1.14	0.0%	1.14
DETonOPWL [mths]	12.63	-28.7%	9	15.63	368.7%	73.25	111.75	-3.1%	108.25
MaxTnewOPWL [mths]	1.17	0.9%	1.18	1.17	0.9%	1.18	1.19	1.7%	1.21
MinTnewOPWL [mths]	1.15	-0.9%	1.14	1.15	-0.9%	1.14	1.15	-0.9%	1.14
DETnewOPWL [mths]	12.13	-22.7%	9.38	9.88	665.5%	75.63	111.75	-0.4%	111.25
PrSIETonCCWL [pressure]	415.47	4.3%	433.46	411.19	4.4%	429.11	708.34	2.7%	727.18
MaxTonCCWL [mths]	11.35	0.5%	11.41	11.22	0.5%	11.28	12.8	0.3%	12.84
MinTonCCWL [mths]	1.69	21.9%	2.06	1.69	21.9%	2.06	1.69	21.9%	2.06
DETonCCWL [mths]	107.5	4.8%	112.63	107.5	4.8%	112.63	137.5	3.7%	142.63
MaxTnewCCWL [mths]	12.31	0.3%	12.35	12.15	0.3%	12.19	13.63	0.1%	13.65
MinTnewCCWL [mths]	1.5	19.3%	1.79	1.5	19.3%	1.79	1.5	19.3%	1.79
DETnewCCWL [mths]	116.25	1.7%	118.25	116.25	1.7%	118.25	146.25	1.4%	148.25
CumOP [pats]	41,785	0.0%	41,794	41,540	0.0%	41,530	53,373	-0.1%	53,339
CumOPAC [pounds]	4,178,516	0.0%	4,179,355	4,153,954	0.0%	4,153,034	5,337,338	-0.1%	5,333,864
CumCC [pats]	1,624	-0.8%	1,610	1,624	-0.8%	1,610	1,976	-0.7%	1,963
CumCCAC [pounds]	1,001,119	-0.9%	992,316	1,001,119	-0.9%	992,316	1,215,651	-0.7%	1,206,848
CumCCACATL [pounds]	988,162	-0.8%	979,932	988,162	-0.8%	979,932	1,202,694	-0.7%	1,194,463
CumC [pounds]	5,211,585	-0.2%	5,203,621	5,187,023	-0.2%	5,177,300	6,584,939	-0.2%	6,572,662
CumOPWLAdds [pats]	44,348	0.0%	44,344	44,084	0.0%	44,079	56,753	0.0%	56,749
MaxRROP [pats/mth]	377.07	0.0%	377.07	377.07	0.0%	377.07	382.58	0.0%	382.58
MinRROP [pats/mth]	367.87	0.0%	367.87	366.03	0.0%	366.03	367.87	0.0%	367.87
DStDemOP [mths]	9.63	-2.6%	9.38	9.63	-2.6%	9.38	9.63	-2.6%	9.38
CumCCWLAdds [pats]	2,104	-0.2%	2,100	2,096	-0.2%	2,092	2683	-0.2%	2678
Max RRCC [pats/mth]	22.31	-0.4%	22.21	22.31	-0.4%	22.21	22.31	-0.4%	22.21
MinRRCC [pats/mth]	9.6	-0.1%	9.59	9.6	-0.1%	9.59	9.6	-0.1%	9.59
DStDemCC [mths]	11.75	-10.6%	10.5	11.75	-10.6%	10.5	11.75	-10.6%	10.5

Performance Measure	R47		R48	R49		R50	R51		R52
PrSIEOPWL [pressure]	7,579.42	2.0%	7,731.43	154.75	-17.0%	128.4	23.62	-100.0%	0
MaxOPWL [pats]	505	0.0%	506	442	0.2%	443	424	-0.1%	424
MinOPWL [pats]	424	-0.5%	422	424	-0.5%	422	424	0.0%	424
DEOPWL [mths]	122.75	-7.4%	113.63	20.88	-43.7%	11.75	0	*	0
PrSIECCWL [pressure]	15,104.87	2.0%	15,405.46	1,186.06	12.0%	1,327.85	539.38	-1.0%	533.88
MaxCCWL [pats]	256	0.2%	256	114	0.0%	114	133	-0.1%	133
MinCCWL [pats]	35	16.3%	41	35	16.3%	41	56	-0.2%	56
DECCWL [mths]	138.75	2.2%	141.75	46.13	7.8%	49.75	38	-4.6%	36.25
PrSIETonOPWL [pressure]	11.11	3.9%	11.54	0.15	-6.7%	0.14	0	*	0
MaxTonOPWL [mths]	1.28	0.0%	1.28	1.18	0.0%	1.18	1.15	0.0%	1.15
MinTonOPWL [mths]	1.13	0.0%	1.13	1.15	-0.9%	1.14	1.15	0.0%	1.15
DETonOPWL [mths]	112	-3.1%	108.5	12.63	-28.7%	9	0	*	0
MaxTnewOPWL [mths]	1.28	0.0%	1.28	1.17	0.9%	1.18	1.15	0.0%	1.15
MinTnewOPWL [mths]	1.15	-0.9%	1.14	1.15	-0.9%	1.14	1.15	0.0%	1.15
DETnewOPWL [mths]	111.75	-0.4%	111.25	9.88	-5.1%	9.38	0	*	0
PrSIETonCCWL [pressure]	730.68	2.6%	749.44	64.36	13.0%	72.74	21.91	-1.3%	21.63
MaxTonCCWL [mths]	13.21	0.2%	13.24	5.12	0.0%	5.12	4.84	-0.2%	4.83
MinTonCCWL [mths]	1.69	21.9%	2.06	1.69	21.9%	2.06	2.4	0.0%	2.4
DETonCCWL [mths]	137.5	3.7%	142.63	45.63	2.2%	46.63	52.25	-2.6%	50.88
MaxTnewCCWL [mths]	14.13	0.1%	14.15	15.97	2.8%	16.41	32.95	0.0%	32.94
MinTnewCCWL [mths]	1.5	19.3%	1.79	1.5	19.3%	1.79	2.76	0.0%	2.76
DETnewCCWL [mths]	146.25	1.4%	148.25	51.63	2.4%	52.88	6.88	0.0%	6.88
CumOP [pats]	54,238	0.0%	54,227	18,784	0.0%	18,782	18,719	0.0%	18,720
CumOPAC [pounds]	5,423,824	0.0%	5,422,689	1,878,361	0.0%	1,878,176	1,871,855	0.0%	1,872,018
CumCC [pats]	1,976	-0.7%	1,963	813	-1.3%	802	953	0.0%	953
CumCCAC [pounds]	1,215,651	-0.7%	1,206,848	506,789	-1.4%	499,741	579,875	0.0%	580,034
CumCCACATL [pounds]	1,202,694	-0.7%	1,194,463	494,523	-1.3%	487,952	579,875	0.0%	580,034
CumC [pounds]	6,671,425	-0.1%	6,661,487	2,417,049	-0.3%	2,409,817	2,451,730	0.0%	2,452,052
CumOPWLAdds [pats]	57,879	0.0%	57,874	19,937	0.0%	19,932	19,865	0.0%	19,865
MaxRROP [pats/mth]	393.62	0.0%	393.62	377.07	0.0%	377.07	367.87	0.0%	367.87
MinRROP [pats/mth]	367.87	0.0%	367.87	367.87	0.0%	367.87	367.87	0.0%	367.87
DStDemOP [mths]	9.63	-2.6%	9.38	9.63	-2.6%	9.38	0	*	0
CumCCWLAdds [pats]	2719	-0.2%	2715	925	-0.4%	921	1010	0.0%	1010
Max RRCC [pats/mth]	22.31	-0.4%	22.21	22.31	-0.4%	22.21	18.7	0.0%	18.7
MinRRCC [pats/mth]	9.6	-0.1%	9.59	8.79	0.0%	8.79	18.69	0.1%	18.7
DStDemCC [mths]	11.75	-10.6%	10.5	9.25	-5.4%	8.75	0	*	0

2. Results of Experiments for the Veinbridge General Case

Performance Measure	**V0**	**V1**		**V2**		**V3**		**V4**		**V5**	
PrSIEOPWL [pressure]	11,262.63	0.16	-100.0%	0.16	-100.0%	11,262.19	0.0%	0.16	-100.0%	201.58	-98.2%
MaxOPWL [pats]	650	338	-48.0%	338	-48.0%	650	0.0%	338	-48.0%	355	-45.4%
MinOPWL [pats]	338	338	0.0%	338	0.0%	338	0.0%	338	0.0%	338	0.0%
DEOPWL [mths]	54.88	0	-100.0%	0	-100.0%	54.88	0.0%	0	-100.0%	15.88	-71.1%
PrSIECCWL [pressure]	5,043.48	2,041.30	-59.5%	3,458.85	-31.4%	3,380.28	-33.0%	6,027.37	19.5%	1,347.84	-73.3%
MaxCCWL [pats]	235	171	-27.3%	200	-14.7%	200	-14.8%	356	51.5%	197	-16.2%
MinCCWL [pats]	128	128	0.0%	128	0.0%	128	0.0%	128	0.0%	128	0.0%
DECCWL [mths]	58.88	58.88	0.0%	58.88	0.0%	58.88	0.0%	58.88	0.0%	57.38	-2.5%
PrSIETonOPWL [pressure]	16.89	0	-100.0%	0	-100.0%	16.89	0.0%	0	-100.0%	0.04	-99.8%
MaxTonOPWL [mths]	1.47	0.92	-37.4%	0.92	-37.4%	1.47	0.0%	0.92	-37.4%	0.94	-36.1%
MinTonOPWL [mths]	0.88	0.92	4.5%	0.92	4.5%	0.88	0.0%	0.92	4.5%	0.91	3.4%
DETonOPWL [mths]	50.63	0	-100.0%	0	-100.0%	50.63	0.0%	0	-100.0%	5.75	-88.6%
MaxTnewOPWL [mths]	1.49	0.92	-38.3%	0.92	-38.3%	1.49	0.0%	0.92	-38.3%	0.94	-36.9%
MinTnewOPWL [mths]	0.92	0.92	0.0%	0.92	0.0%	0.92	0.0%	0.92	0.0%	0.91	-1.1%
DETnewOPWL [mths]	54.88	0	-100.0%	0	-100.0%	54.88	0.0%	0	-100.0%	5.25	-90.4%
PrSIETonCCWL [pressure]	0	0.97	*	0	*	0.02	*	166.58	*	18.99	*
MaxTonCCWL [mths]	3.5	3.59	2.6%	3.5	0.0%	3.52	0.6%	8.99	156.9%	4.74	35.4%
MinTonCCWL [mths]	3.23	3.39	5.0%	3.37	4.3%	3.36	4.0%	3.5	8.4%	3.4	5.3%
DETonCCWL [mths]	0.5	17.63	3426.0%	0.5	0.0%	2.25	350.0%	58.88	11676.0%	47	9300.0%
MaxTnewCCWL [mths]	4.3	4.3	0.0%	4.3	0.0%	4.3	0.0%	29.64	589.3%	4.78	11.2%
MinTnewCCWL [mths]	3.49	3.49	0.0%	3.49	0.0%	3.49	0.0%	3.5	0.3%	3.45	-1.1%
DETnewCCWL [mths]	46.13	34.88	-24.4%	42.25	-8.4%	46	-0.3%	63.5	37.7%	54.75	18.7%
CumOP [pats]	29,092	25,755	-11.5%	25,755	-11.5%	29,092	0.0%	25,755	-11.5%	25,968	-10.7%
CumOPAC [pounds]	2,909,213	2,575,511	-11.5%	2,575,511	-11.5%	2,909,208	0.0%	2,575,511	-11.5%	2,596,827	-10.7%
CumCC [pats]	3,922	3,089	-21.2%	3,482	-11.2%	3,460	-11.8%	2,427	-38.1%	2,723	-30.6%
CumCCAC [pounds]	2,882,470	2,254,412	-21.8%	2,550,975	-11.5%	2,534,520	-12.1%	1,618,850	-43.8%	1,849,855	-35.8%
CumCCACATL [pounds]	2,616,239	2,060,416	-21.2%	2,322,870	-11.2%	2,308,308	-11.8%	1,618,850	-38.1%	1,816,304	-30.6%
CumC [pounds]	6,801,121	5,839,361	-14.1%	6,135,924	-9.8%	6,453,166	-5.1%	4,194,362	-38.3%	4,453,820	-34.5%
CumOPWLAdds [pats]	30,295	26,364	-13.0%	26,364	-13.0%	30,295	0.0%	26,364	-13.0%	26,582	-12.3%
MaxRROP [pats/mth]	439.39	366.16	-16.7%	366.16	-16.7%	439.39	0.0%	366.16	-16.7%	384.47	-12.5%
MinRROP [pats/mth]	366.16	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16	0.0%
DStDemOP [mths]	55.25	0	-100.0%	0	-100.0%	55.25	0.0%	0	-100.0%	13.25	-76.0%
CumCCWLAdds [pats]	4,140	3,219	-22.2%	3,653	-11.8%	3,630	-12.3%	2,552	-38.4%	2,805	-32.2%
Max RRCC [pats/mth]	67.1	48.77	-27.3%	57.22	-14.7%	57.16	-14.8%	36.7	-45.3%	50.29	-25.1%
MinRRCC [pats/mth]	36.7	36.7	0.0%	36.7	0.0%	36.7	0.0%	14.06	-61.7%	36.7	0.0%
DStDemCC [mths]	58.88	58.88	0.0%	58.88	0.0%	58.88	0.0%	0	-100.0%	25	-57.5%

Performance Measure	V6		V7		V8		V9		V10		V11	
PrSIEOPWL [pressure]	201.58	-98.2%	201.58	-98.2%	11,262.63	0.0%	11,685.63	3.8%	12,004.38	6.6%	10,566.53	-6.2%
MaxOPWL [pats]	355	-45.4%	355	-45.4%	650	0.0%	654	0.5%	656	0.8%	645	-0.8%
MinOPWL [pats]	338	0.0%	338	0.0%	338	0.0%	338	0.0%	338	0.0%	338	0.0%
DEOPWL [mths]	15.88	-71.1%	15.88	-71.1%	54.88	0.0%	55.63	1.4%	56.5	3.0%	53.25	-3.0%
PrSIECCWL [pressure]	3,707.92	-26.5%	1,398.19	-72.3%	4,891.64	-3.0%	2,771.85	-45.0%	5,168.84	2.5%	4,925.58	-2.3%
MaxCCWL [pats]	222	-5.6%	197	-16.2%	235	0.0%	135	-42.3%	235	0.0%	235	0.0%
MinCCWL [pats]	128	0.0%	128	0.0%	128	0.0%	94	-26.7%	128	0.0%	128	0.0%
DECCWL [mths]	58.88	0.0%	58.88	0.0%	58.88	0.0%	58.88	0.0%	58.88	0.0%	58.88	0.0%
PrSIETonOPWL [pressure]	0.04	-99.8%	0.04	-99.8%	16.89	0.0%	17.64	4.4%	18.21	7.8%	15.65	-7.3%
MaxTonOPWL [mths]	0.94	-36.1%	0.94	-36.1%	1.47	0.0%	1.48	0.7%	1.49	1.4%	1.46	-0.7%
MinTonOPWL [mths]	0.91	3.4%	0.91	3.4%	0.88	0.0%	0.87	-1.1%	0.87	-1.1%	0.88	0.0%
DETonOPWL [mths]	5.75	-88.6%	5.75	-88.6%	50.63	0.0%	52	2.7%	53	4.7%	48.38	-4.4%
MaxTnewOPWL [mths]	0.94	-36.9%	0.94	-36.9%	1.49	0.0%	1.5	0.7%	1.5	0.7%	1.48	-0.7%
MinTnewOPWL [mths]	0.91	-1.1%	0.91	-1.1%	0.92	0.0%	0.92	0.0%	0.92	0.0%	0.92	0.0%
DETnewOPWL [mths]	5.25	-90.4%	5.25	-90.4%	54.88	0.0%	55.63	1.4%	56.63	3.2%	53.38	-2.7%
PrSIETonCCWL [pressure]	2.95	*	19.9	*	5.35	*	6.14	*	0	*	0.08	*
MaxTonCCWL [mths]	3.73	6.6%	4.74	35.4%	4.87	39.1%	3.5	0.0%	3.5	0.0%	3.54	1.1%
MinTonCCWL [mths]	3.16	-2.2%	3.4	5.3%	3.23	0.0%	1.69	-47.7%	3.2	-0.9%	3.23	0.0%
DETonCCWL [mths]	39.38	7776.0%	47	9300.0%	9	1700.0%	23.88	4676.0%	0.5	0.0%	3.5	600.0%
MaxTnewCCWL [mths]	4.3	0.0%	4.78	11.2%	6.76	57.2%	4.12	-4.2%	4.3	0.0%	4.3	0.0%
MinTnewCCWL [mths]	3.5	0.3%	3.45	-1.1%	3.5	0.3%	1.74	-50.1%	3.49	0.0%	3.5	0.3%
DETnewCCWL [mths]	42.13	-8.7%	61.63	33.6%	50.88	10.3%	34.38	-25.5%	45.63	-1.1%	46.75	1.3%
CumOP [pats]	25,968	-10.7%	25,968	-10.7%	29,092	0.0%	29,171	0.3%	29,234	0.5%	28,959	-0.5%
CumOPAC [pounds]	2,596,827	-10.7%	2,596,827	-10.7%	2,909,213	0.0%	2,917,112	0.3%	2,923,406	0.5%	2,895,900	-0.5%
CumCC [pats]	3,524	-10.1%	2,721	-30.6%	3,798	-3.2%	4,106	4.7%	3,957	0.9%	3,889	-0.8%
CumCCAC [pounds]	2,386,208	-17.2%	1,859,679	-35.5%	2,789,920	-3.2%	3,021,232	4.8%	2,908,733	0.9%	2,857,773	-0.9%
CumCCACATL [pounds]	2,351,207	-10.1%	1,815,319	-30.6%	2,533,436	-3.2%	2,739,041	4.7%	2,639,481	0.9%	2,594,382	-0.8%
CumC [pounds]	4,990,166	-26.6%	4,464,013	-34.4%	6,708,570	-1.4%	6,947,781	2.2%	6,841,576	0.6%	6,763,110	-0.6%
CumOPWLAdds [pats]	26,582	-12.3%	26,582	-12.3%	30,295	0.0%	30,387	0.3%	30,461	0.5%	30,139	-0.5%
MaxRROP [pats/mth]	384.47	-12.5%	384.47	-12.5%	439.39	0.0%	439.39	0.0%	439.39	0.0%	439.39	0.0%
MinRROP [pats/mth]	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16	0.0%
DStDemOP [mths]	13.25	-76.0%	13.25	-76.0%	55.25	0.0%	56	1.4%	56.88	3.0%	53.75	-2.7%
CumCCWLAdds [pats]	3,689	-10.9%	2,808	-32.2%	4,014	-3.0%	4,160	0.5%	4,176	0.9%	4,106	-0.8%
Max RRCC [pats/mth]	64.87	-3.3%	50.29	-25.1%	67.1	0.0%	67.11	0.0%	67.12	0.0%	67.09	0.0%
MinRRCC [pats/mth]	36.7	0.0%	36.7	0.0%	15.87	-56.8%	36.7	0.0%	36.7	0.0%	36.7	0.0%
DStDemCC [mths]	58.88	0.0%	33.5	-43.1%	55	-6.6%	58.88	0.0%	58.88	0.0%	58.88	0.0%

Performance Measure	V12		V13		V14		V15		V16		V17	
PrSIEOPWL [pressure]	79,633.84	607.1%	24,924.20	121.3%	1,784.22	-84.2%	0.16	-100.0%	3,562.03	-68.4%	11,481.19	1.9%
MaxOPWL [pats]	2,793	329.4%	900	38.4%	372	-42.8%	338	-48.0%	406	-37.6%	652	0.3%
MinOPWL [pats]	338	0.0%	468	38.5%	338	0.0%	338	0.0%	338	0.0%	338	0.0%
DEOPWL [mths]	54.88	0.0%	72	31.2%	54.75	-0.2%	0	-100.0%	54.88	0.0%	55	0.2%
PrSIECCWL [pressure]	5,694.71	12.9%	4,934.20	-2.2%	2,409.03	-52.2%	128.75	-97.4%	5,165.12	2.4%	276.35	-94.5%
MaxCCWL [pats]	256	9.3%	234	-0.3%	177	-24.7%	141	-40.1%	236	0.7%	148	-37.1%
MinCCWL [pats]	128	0.0%	118	-7.5%	128	0.0%	126	-1.2%	128	0.0%	128	0.0%
DECCWL [mths]	58.88	0.0%	58.88	0.0%	58.88	0.0%	21.13	-64.1%	58.88	0.0%	42.25	-28.2%
PrSIETonOPWL [pressure]	127.74	656.3%	16.85	-0.2%	0	-100.0%	0	-100.0%	0	-100.0%	17.32	2.5%
MaxTonOPWL [mths]	5.2	253.7%	1.47	0.0%	0.92	-37.4%	0.92	-37.4%	0.92	-37.4%	1.48	0.7%
MinTonOPWL [mths]	0.84	-4.5%	0.88	0.0%	0.9	2.3%	0.92	4.5%	0.88	0.0%	0.88	0.0%
DETonOPWL [mths]	51	0.7%	50.63	0.0%	0	-100.0%	0	-100.0%	0	-100.0%	51.25	1.2%
MaxTnewOPWL [mths]	5.7	282.6%	1.49	0.0%	0.95	-36.2%	0.92	-38.3%	0.98	-34.2%	1.49	0.0%
MinTnewOPWL [mths]	0.92	0.0%	0.92	0.0%	0.92	0.0%	0.92	0.0%	0.92	0.0%	0.92	0.0%
DETnewOPWL [mths]	54.88	0.0%	54.88	0.0%	6.5	-88.2%	0	-100.0%	7.25	-86.8%	55.13	0.5%
PrSIETonCCWL [pressure]	0	*	0.58	*	0.32	*	2.79	*	0	*	0.05	*
MaxTonCCWL [mths]	3.5	0.0%	3.74	6.9%	3.6	2.9%	3.74	6.9%	3.5	0.0%	3.51	0.3%
MinTonCCWL [mths]	3.22	-0.3%	3.23	0.0%	3.44	6.5%	3.46	7.1%	3.22	-0.3%	1.91	-40.9%
DETonCCWL [mths]	0.5	0.0%	7.75	1450.0%	8.25	1550.0%	23.75	4650.0%	0.5	0.0%	8.75	1650.0%
MaxTnewCCWL [mths]	4.3	0.0%	4.31	0.2%	4.25	-1.2%	4.21	-2.1%	4.3	0.0%	4.09	-4.9%
MinTnewCCWL [mths]	3.5	0.3%	3.33	-4.6%	3.49	0.0%	3.4	-2.6%	3.49	0.0%	1.91	-45.3%
DETnewCCWL [mths]	63.5	37.7%	59.38	28.7%	39.88	-13.5%	16.13	-65.0%	43	-6.8%	8.38	-81.8%
CumOP [pats]	29,111	0.1%	40,278	38.5%	27,646	-5.0%	25,755	-11.5%	29,530	1.5%	29,108	0.1%
CumOPAC [pounds]	2,911,117	0.1%	4,027,818	38.5%	2,764,573	-5.0%	2,575,511	-11.5%	2,952,973	1.5%	2,910,827	0.1%
CumCC [pats]	4,102	4.6%	3,884	-1.0%	3,191	-18.6%	2,569	-34.5%	3,955	0.9%	4,071	3.8%
CumCCAC [pounds]	3,018,599	4.7%	2,855,019	-1.0%	2,331,326	-19.1%	1,847,355	-35.9%	2,907,927	0.9%	2,994,675	3.9%
CumCCACATL [pounds]	2,736,711	4.6%	2,591,324	-1.0%	2,128,484	-18.6%	1,713,735	-34.5%	2,638,768	0.9%	2,715,561	3.8%
CumC [pounds]	6,939,154	2.0%	7,892,274	16.0%	6,105,337	-10.2%	5,432,304	-20.1%	6,870,337	1.0%	6,914,939	1.7%
CumOPWLAdds [pats]	34,168	12.8%	41,942	38.4%	28,333	-6.5%	26,364	-13.0%	30,295	0.0%	30,318	0.1%
MaxRROP [pats/mth]	512.62	16.7%	608.38	38.5%	402.78	-8.3%	366.16	-16.7%	439.39	0.0%	439.39	0.0%
MinRROP [pats/mth]	366.16	0.0%	506.98	38.5%	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16	0.0%
DStDemOP [mths]	55.25	0.0%	55.25	0.0%	55.25	0.0%	0	-100.0%	55.25	0.0%	55.38	0.2%
CumCCWLAdds [pats]	4,347	5.0%	4,101	-0.9%	3,330	-19.6%	2,642	-36.2%	4,176	0.9%	4,145	0.1%
Max RRCC [pats/mth]	73.53	9.6%	72.48	8.0%	50.44	-24.8%	36.7	-45.3%	67.56	0.7%	67.11	0.0%
MinRRCC [pats/mth]	36.7	0.0%	25	-31.9%	36.7	0.0%	36.7	0.0%	36.7	0.0%	36.7	0.0%
DStDemCC [mths]	58.88	0.0%	58.88	0.0%	58.88	0.0%	0	-100.0%	58.88	0.0%	58.88	0.0%

Performance Measure	**V18**		**V19**		**V20**		**V8**		**V21**
PrSIEOPWL [pressure]	439.39	-96.1%	219.7	-98.0%	0	-100.0%	11,262.63	1.9%	11,481.19
MaxOPWL [pats]	402	-38.2%	370	-43.1%	338	-48.0%	650	0.3%	652
MinOPWL [pats]	338	0.0%	338	0.0%	338	0.0%	338	0.0%	338
DEOPWL [mths]	22	-59.9%	19.5	-64.5%	0	-100.0%	54.88	0.2%	55.00
PrSIECCWL [pressure]	279.7	-94.5%	171.77	-96.6%	67.86	-98.7%	4,891.64	-92.0%	391.34
MaxCCWL [pats]	149	-36.6%	140	-40.4%	137	-41.6%	235	-34.3%	154
MinCCWL [pats]	128	-0.1%	128	-0.1%	126	-1.2%	128	-1.9%	126
DECCWL [mths]	39.75	-32.5%	36.88	-37.4%	19.75	-66.5%	58.88	-24.6%	44.38
PrSIETonOPWL [pressure]	0	-100.0%	0	-100.0%	0	-100.0%	16.89	2.5%	17.32
MaxTonOPWL [mths]	0.92	-37.4%	0.92	-37.4%	0.92	-37.4%	1.47	0.7%	1.48
MinTonOPWL [mths]	0.77	-12.5%	0.84	-4.5%	0.92	4.5%	0.88	0.0%	0.88
DETonOPWL [mths]	0	-100.0%	0	-100.0%	0	-100.0%	50.63	1.2%	51.25
MaxTnewOPWL [mths]	1	-32.9%	0.96	-35.6%	0.92	-38.3%	1.49	0.0%	1.49
MinTnewOPWL [mths]	0.77	-16.3%	0.84	-8.7%	0.92	0.0%	0.92	0.0%	0.92
DETnewOPWL [mths]	4.38	-92.0%	4.13	-92.5%	0	-100.0%	54.88	0.5%	55.13
PrSIETonCCWL [pressure]	0.05	*	0.05	*	1.44	*	5.35	-99.1%	0.05
MaxTonCCWL [mths]	3.51	0.3%	3.51	0.3%	3.65	4.3%	4.87	-27.9%	3.51
MinTonCCWL [mths]	1.89	-41.5%	2.54	-21.4%	3.46	7.1%	3.23	-40.9%	1.91
DETonCCWL [mths]	8.75	1650.0%	10.25	1950.0%	27.88	5476.0%	9	-2.8%	8.75
MaxTnewCCWL [mths]	4.09	-4.9%	4.08	-5.1%	4.08	-5.1%	6.76	-35.1%	4.39
MinTnewCCWL [mths]	1.89	-45.8%	2.54	-27.2%	3.41	-2.3%	3.5	-45.4%	1.91
DETnewCCWL [mths]	8.38	-81.8%	9.13	-80.2%	11.5	-75.1%	50.88	-76.2%	12.13
CumOP [pats]	29,699	2.1%	27,727	-4.7%	25,755	-11.5%	29,092	0.1%	29,108
CumOPAC [pounds]	2,969,878	2.1%	2,772,689	-4.7%	2,575,512	-11.5%	2,909,213	0.1%	2,910,827
CumCC [pats]	4,117	5.0%	3,261	-16.8%	2,570	-34.5%	3,798	3.9%	3,944
CumCCAC [pounds]	3,029,578	5.1%	2,384,560	-17.3%	1,848,017	-35.9%	2,789,920	4.0%	2,900,576
CumCCACATL [pounds]	2,746,450	5.0%	2,175,618	-16.8%	1,714,342	-34.5%	2,533,436	3.9%	2,631,387
CumC [pounds]	7,008,894	3.1%	6,166,686	-9.3%	5,432,966	-20.1%	6,708,570	1.7%	6,820,841
CumOPWLAdds [pats]	30,318	0.1%	28,341	-6.4%	26,364	-13.0%	30,295	0.1%	30,318
MaxRROP [pats/mth]	439.39	0.0%	402.78	-8.3%	366.16	-16.7%	439.39	0.0%	439.39
MinRROP [pats/mth]	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16	0.0%	366.16
DStDemOP [mths]	55.38	0.2%	55.25	0.0%	0	-100.0%	55.25	0.2%	55.38
CumCCWLAdds [pats]	4,191	1.2%	3,334	-19.5%	2,642	-36.2%	4,014	0.1%	4,019
Max RRCC [pats/mth]	67.65	0.8%	50.45	-24.8%	36.7	-45.3%	67.1	0.0%	67.11
MinRRCC [pats/mth]	36.7	0.0%	36.7	0.0%	36.7	0.0%	15.87	0.1%	15.89
DStDemCC [mths]	58.88	0.0%	58.88	0.0%	0	-100.0%	55	0.0%	55