ANNUAL SINKING FUND MODELLING FOR HOUSING ASSOCIATION MAJOR REPAIRS PROVISION
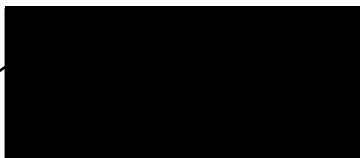
GRAEME BOWLES

A thesis submitted in partial fulfilment of the requirements of the
University of Abertay Dundee for the Degree of Doctor of Philosophy

November 1995

I certify that this thesis is the true and accurate version of the thesis approved by the
examiners.

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ABSTRACT

This study carries forward the investigation of sinking funds in housing asset management. Under the new financial framework, established as a result of the 1988 Housing Act, Housing Associations are required to create sinking funds to finance future Major Repairs on all new and rehabilitated stock. The assessed maximum annual sinking fund contribution adequate for this is expressed in directives issued by Scottish Homes and the Housing Corporation.

Mathematical programming models were developed, as an alternative to applying conventional financial calculations, to project sinking funds over a sixty year planning horizon for a number of new-build developments. Linear programming models were solved with both deterministic and stochastic maintenance data, in order to determine how robust a conventional deterministic life cycle costing model is for sinking fund projection. Maintenance programming is a dynamic problem and the timing of projected maintenance works will have to be reviewed periodically using information obtained from condition surveys. As a consequence the sinking fund strategy will have to be amended in the light of any new information. Using a dynamic model the extent to which these inevitable changes affect the original sinking fund strategy were investigated by simulating "actual" policy as it would evolve throughout the planning horizon.

A number of conclusions are drawn using the results from the various models. Firstly, current assumptions on what constitutes an adequate level of annual sinking fund are likely to be inadequate to fund the long term Major Repair needs of new stock. Secondly, it is apparent that many diverse sinking fund strategies can be modelled that will fund a series of major maintenance expenditure at optimal cost. Thirdly, mixed-integer linear programming shows that under certain circumstances a conventional sinking fund, which is always in credit, can be inefficient. For some profiles of expenditure it may be more efficient, in terms of overall cost, if it is permissible for the fund to be overdrawn. Finally, the dynamic sinking fund model shows that making significant amendments to maintenance projections is likely to have an adverse effect on a sinking fund policy to the extent that many funds will be seriously underresourced. Therefore more accurate long term forecasts will reduce the likelihood of substantial changes having to be made to the sinking fund strategy in the future, minimising its cost.

ACKNOWLEDGEMENTS

Contents

Chapter 3   Sinking Funds For Long Term Maintenance

Chapter 4   A Mathematical Programming Methodology For Sinking Fund Projection

Chapter 5 Data Needs For Sinking Fund Projection

Chapter 6 Results

Chapter 7   Simulating The Maintenance Data

Chapter 8   A Dynamic Sinking Fund Model

Chapter 9 Discussion

Tables

Figures

CHAPTER 1 INTRODUCTION

1.1 Preface

Awareness of the need to plan for the long term needs of buildings, their owners, and their users has been growing for some time, but the motivation for this study originates from changes made to housing legislation in 1989. Life Cycle Costing (LCC) and Sinking Funds (SF) are now implicit in the regulations (1, 2) governing the long term maintenance management of Housing Association (HA) stock. This report begins with a treatise on the SF requirement and questions the assumptions made by their funding bodies on adequate levels of Annual Sinking Fund (ASF) investment. Operational Research (OR) techniques for SF modelling are then introduced, and models are developed and the results compared with those from conventional methods of calculation. The research effort is justified on the grounds that, if we are to treat SFs as a serious function in asset management, more sophisticated alternatives to the relative inflexibility of mechanistic calculation merit investigation.

1.2 Scope of Study

The calculation of a SF is a simple matter, but with a number of variables to be accounted for, the problem is far from explicit, and to date there is not much evidence of any wide scale use in building asset management. Figure 1.1 shows the background of existing knowledge which was studied to converge on the research area detailed in this report.
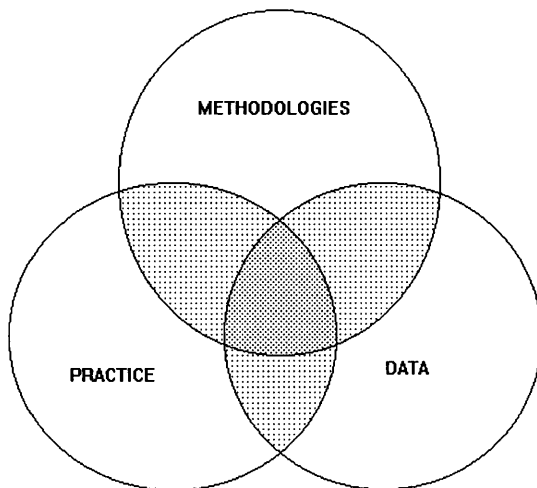
Figure 1.1 Converging on the Research Area

- Methodologies

  The literature in this category is concerned with models for maintenance prediction and methodology for the calculation of SFs. Key predictive housing maintenance models referred to are those developed at the Dutch research agency Bouwcentrum (3) (later adapted and used in a UK study by NBA Construction Consultants (4) and the Australian agency, CSIRO (5). SF calculation methodology using conventional financial calculations are explained, and then Mathematical Programming (MP) methodologies, for which there is no precedent in SF projection are developed. The Linear Programmes (LPs) and Mixed-Integer Linear Programmes (MILPs) in Chapter 4 are used for SF projection for the case study data described in Chapter 5, and comparisons are made with calculated strategies. From the models' results a number of conclusions are drawn and discussed, providing a basis for much of the original contribution element of the report.

- Data

  For SF projection the timing and cost of Major Repairs (MR) that are likely to occur in the planning horizon have to be assessed. The credibility of LCC depends very much on being able to make realistic projections and there has been considerable research activity in the past directed to refining maintenance predictions, A review of the literature that will allow such projections to be made in housing LCC is carried out.

- Practice

  An investigation of published experience of SFs in asset management is made, to determine weaknesses in the literature, and identify areas where the research effort should be concentrated. Most of the literature deals with SFs in an exploratory way, detailing how they could be used and outlining their advantages. It was concluded after the literature survey that their was a very low user base and there is a dearth of material in this area.

Separate bodies exist to both fund and represent associations in Scotland, England and Wales, and this study is concerned in particular with the Scottish position, making reference to key regulatory notes and responses of Scottish Homes (SH) and the Scottish Federation of Housing Associations (SFHA). However, the problem is not relevant to Scotland only since the position is substantially the same throughout the UK.

1.3 Format of Thesis

The format of the thesis is summarised as follows:

Chapter 2 is essentially background material, describing the context of the research and recent key events that have brought SFs to prominence in the HA movement. Developments in defining construction maintenance are briefly alluded to and compared with the requirements now being placed on Scottish HAs in respect of the long term upkeep of the their housing stock. Finally, parallels are drawn between housing maintenance finance in the UK and comparable housing bodies elsewhere in Europe, using a study conducted by the NFHA (6)

Chapter 3 continues the treatise in greater detail, reporting on published experience of SFs in building asset management, and draws on the various responses to the legislation that ushered the system in, and subsequent regulatory guidance notes on SFs. The mathematics of SF calculation are considered and two alternative means of using conventional financial calculations are developed.

In Chapter 4 the use of OR techniques is introduced with a review of their applicability to construction management. OR has what may be categorised as "hard" and "soft" elements. "Hard" deals with the analytical aspects of specific solution techniques and "soft" deals with practical issues of bringing OR to bear on some part of an organisation. Both of these themes are developed. Two main types of LP model, continuous and mixed-integer, used in SF projection are examined and the process of introducing modelling for the practical study is described and its success evaluated.

Since projections of MRs are required for upwards of 60 years, it is clear that LCC underpins any SF projection. Chapter 5 identifies the factors that lead to the need for maintenance, and considers the literature on the various types of data (historical cost, technological) and their appropriateness for long term maintenance projections in housing. Finally, the data used in the case studies is considered.

In Chapter 6 the results of SF analyses using the LP models and conventional valuation mathematics are presented and compared. Comparison is also made with SH current and proposed yardsticks of what constitutes a maximum ASF adequate for the long term SF needs of developments.

In Chapter 7 selected models are again solved, but using stochastic data instead of the deterministic data used in Chapter 6. The parameters of the stochastic data are approximate to those laid down by Damen and Botman (3) in their research into predictive maintenance

modelling. By comparing results based on stochastic and deterministic data it is possible to determine how robust the more conventional deterministic data is.

The maintenance, and therefore SF, problem is not a static one. The projected timing of the need for element and component replacement is likely to change over the building life cycle, only becoming apparent as the effect of degradation agents take their toll. It is clear then that the SF strategy must be dynamic, evolving as information from periodic condition surveys is gathered. Chapter 8 investigates how the SF strategy, planned at the outset, compares with "actual" experience by simulating the information as it evolves throughout the planning horizon. The results show the value of having accurate data, from the outset of a buildings life, when the overall cost of the SF strategy is considered.

CHAPTER 2   BACKGROUND

2.1 Introduction

In this chapter the rise of the HA movement and its role in Government housing policy over the last ten years is briefly described.

2.2 Nature of the Housing Association Movement

The role Housing Associations (HA) play in social housing policy is unclear in the perception of the general public, even though they are firmly established and form the largest group in the voluntary housing sector (7). This is hardly surprising since they are not precisely defined bodies, either in composition or by statute. Indeed there is no statutory requirement to provide them at all. They are entirely voluntary organisations, registered with charitable status and exist to provide decent quality, affordable housing for rental to people unable to pay market rents, those with special needs such as the disabled and the elderly. In financial terms HAs may be thought of as quasi-commercial organisations in that they are expected to yield revenues in trading, though not for the purposes of profit. In addition to being sensitive to the social and political influences that characterise national housing policy they are expected to operate subject to the same commercial considerations as any other business.

Within this broadly defined framework the characteristics of individual HAs vary enormously, not least in size. Out of the 2600 HAs and Housing Co-operatives registered in 1990 in Great Britain 75% of the total stock was owned and managed by 5% of HAs each managing in excess of 1000 housing units (8). The smallest HAs are run by volunteers in their spare time, usually resident tenants who have set up a HA to manage their own accommodation. The largest are run by salaried professionals who carry out the policies of an elected committee of management. As well as managing several estates they may also provide agency services to smaller associations with advice on feasibility of new schemes, financing and development advice and architectural services. The factor common to all associations, though, is the voluntary nature of the housing they provide. The initiative to provide it originates from individuals in the community.

2.2 The Growth of Housing Associations

The importance of the HA movement in Britain can be charted by its rapid growth. Between 1974 and 1987 it more than doubled in size (9), and has emerged as a politically favoured alternative to Local Authorities (LAs) as a provider of social housing. Before the Conservative Government took office in 1979 LAs were overwhelmingly viewed as the most important source of rented housing and at their high point in the 1970s nearly 32% of all dwellings in Great Britain were rented from LAs. In Scotland, with a strong tradition of LA housing tenure, this figure was over 50%. Since that period the growth of the social housing sector has been volatile, though this must be viewed against the macroeconomics background (10). In the early eighties the government gave precedence to maintaining stringent deflationary monetary and fiscal policies by implementing a series of cutbacks to public expenditure. These policies resulted in slow growth and rising unemployment. Inevitably the construction industry suffered and public house building fell. In 1980 public housing output fell by 17%. Tender approvals were 52% below the previous year's level, translating into an all time low of new starts in the HA and LA sectors in 1981, as shown in Figures 2.1 and 2.2, and continued to recede in 1983 and 1984. Although both the HA movement (through cuts in HCorp funding) and LAs suffered throughout the recession HAs fared consistently better. After 1985 there was a pronounced boom in the national housing market (11) that slumped in 1988. Inflation had remained low until this time but rose to almost 10% in 1989 as the economy overheated. Significantly, new HA developments overtook those of LAs for the first time in 1989 and have been increasing year on year since then. The decade of Government economic and housing policies brought about a distinctive change in the Scottish housing system. There has been a modest real increase in public investment in housing contrasting with the reduction throughout Britain as a whole.
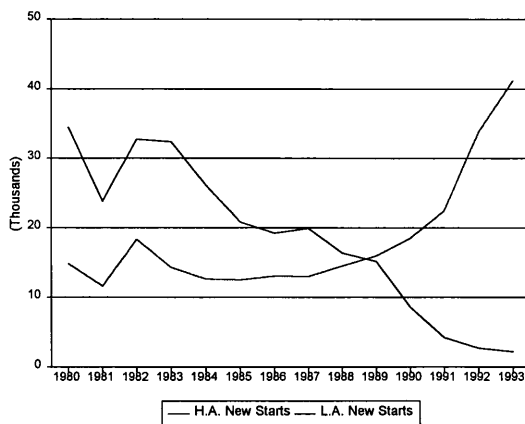
Figure 2.1 Permanent Dwellings Started: UK
Source (12)
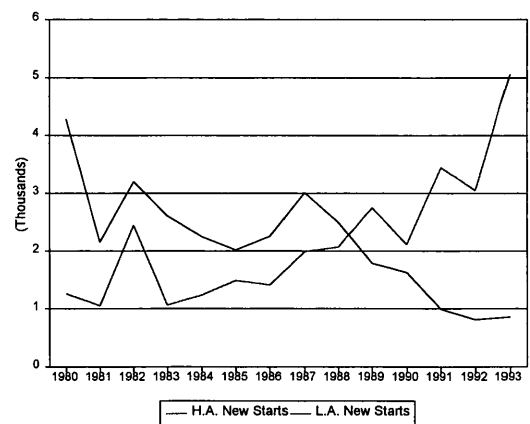
Figure 2.2 Permanent Dwellings Started: Scotland

A clearer appreciation of the rise in the expansion of HAs, against the proportionate decline in the importance of LA housing, is gained when the tenure patterns are viewed. Throughout the eighties there was a steady decline in the number of dwellings rented from the public sector, as

shown in Figures 2.3 and 2.4. This trend will continue as the programme of large scale housing stock transfers from LAs to HAs gains momentum.
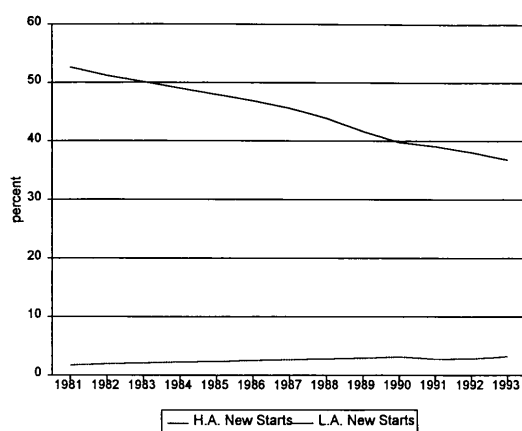
Figure 2.3 Stock of Dwellings by Tenure: UK
Source **(12)**
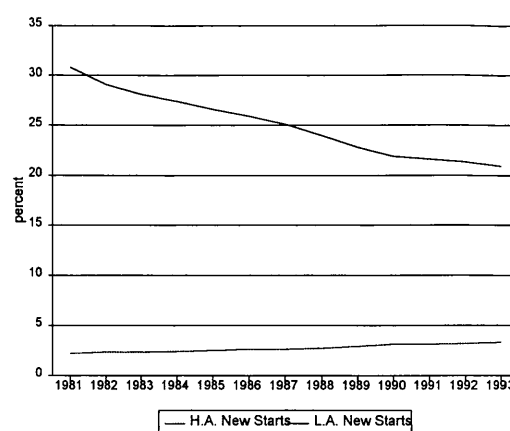
Figure 2.4 Stock of Dwellings by Tenure: Scotland

2.3 The New Financial Regime for Housing Associations

Current Government policy is to significantly increase the private rented housing market. At the forefront of this policy is a greatly expanded role for the HA movement. The Housing Act 1988 and Housing (Scotland) Act 1988 introduced a whole new climate for associations with completely revised funding arrangements. The objectives of these were to

- Gear public money to private funds so as to increase total investment in rented housing,

- Fix rents at levels that are affordable by those housed at present,

- Confer further independence and wider powers on HAs,

- Establish a wider enabling role for the Housing Corporation (HCorp) and SH.
Source **(13)**

The Government's objective of increased dependence on private finance is apparently being met with grant levels being reduced by 10% to an average 75% of project costs **(14)**. This poses difficulties for HAs who must now acquire new financial management skills to compete for and attract funds on the required scale. It was reported **(15)** that on the whole the movement has been unable to attract funds from sources such as pension funds. At present associations are obtaining finance from the clearing banks and building societies but the HCorp's chief executive cautioned that they cannot blindly assume they will continue to be funded by them regardless. The

7

reluctance to lend outwith these traditional sources appears to stem from a lack of understanding of HA culture and their absence of satisfactory creditworthiness indicators. As the continued expansion of the HA sector will depend on a reliable source of private finance, current arrangements are insufficient to stimulate growth in the rented housing market

Traditionally loans were made by LAs, and later by the HCorp to HAs on a fixed interest basis. This enabled associations to generate surpluses on schemes after a few years when rental increases overtook loan repayments. The surpluses would then be used to build up the associations reserves to strengthen its financial position. The reduced capital grant levels under the new financial climate means that associations will have to attract and subsequently service larger loans on their new developments. The most likely financial option is for associations to take on low-start mortgages for which repayments are geared toward income for the loan period. It is very unlikely that associations will be-able to create surpluses under these circumstances as the increasing stream of rental income is matched by increasing loan charges. The ramifications of this for SF policy is discussed in Chapter 3. Without reserves associations will be financially undermined with no collateral for future development and a reduction of options for financing a MR SF.

- Capital Funding of Schemes Before the Housing Act 1988

Up until the new financial regime Housing Association Grants (HAG) provided by the Government via SH and the HCorp were open ended subsidies, paid on completion of projects once all the final costs were known. The difference between the grant and total project costs was made up by a loan from the Local Authority (LA), calculated as the amount that could be serviced by the total rental income, net of management and maintenance allowances, from the completed project. Total rental income was determined, not by the HA developing the scheme, but by an independent Rent Officer who decided upon the 'fair rent' which would be payable. The traditional residual HAG system was generally regarded as being generous (7) averaging over 85% of the scheme costs and the Government began to view it as an over-generous and inefficient use of public resources. The National Federation of Housing Associations (NFHA) countered this view with research that suggested it was only the high levels of grant that allowed rents to be maintained at a level affordable by HA tenants. The question of affordability is still a crucial and controversial topic of debate between the H.Corp, SH and the various representative housing bodies (principally the NFHA and SFHA).

An inherent drawback of the old system was that the final amount of the grant being decided after construction placed minimal emphasis on cost control. A certain degree of cost over-runs were tolerated by the system which served to largely cushion associations from risk. It would be difficult to envisage such an approach ever operating in the commercial sector with the client unaware of the extent of financial commitment until a project is completed.

- Capital funding of Schemes : Post Housing Act 1988

The major difference for the development of new schemes is that the old system of a residual grant has given way to pre-determined levels of HAG based on SH matrix of Total Cost Indicators. These set cost limits for new schemes and include site acquisition, works costs, fees and VAT. Any cost over-runs must be paid for from reserves or the less desirable option of increasing rental levels for the scheme, allowed for under the deregulation of rents which freed associations from independently assessed rent control. In the view of the NFHA's chief policy officer **(16)** the most difficult part of rent setting may be assessing long term future maintenance needs as there is little collective experience of doing this in the movement. Yet significant errors in these predictions could have serious financial consequences. The new fixed grant rates are also lower than those which applied under the previous system making a rise in rental levels inevitable, over and above increases caused by the withdrawal of MR HAG.

2.4 A Review of Maintenance Management in Construction

Most HA staff involved in maintenance believe it has unwarranted low status compared with new housing development. The Chief Policy Officer for the NFHA believes **(16)** this cannot continue in the post-1988 Housing Act world. The standard - and possibly even the survival - of individual associations will depend on "the maintenance service provided to tenants and the accuracy of the financial predictions of future maintenance needs." The NFHA established a Maintenance Sub-Committee to look at the problems associations face in their efforts to keep homes in good repair. The removal of MR HAG and switch to SFs made them aware that they were entering an "area in which experience, expertise and research are woefully lacking." **(17)**

Guidance on the nature and practice of construction maintenance management is provided by the British Standards Institute in a series of documents. These have provided a framework of common definitions and model procedures to guide the development of various aspects of maintenance; policy, planning, execution and feedback.

Maintenance is defined in BS3811 in 1964 as

"work undertaken in order to keep or restore every facility, i.e. every part of a site, building and contents, to an acceptable standard."

The standard was prepared by the Committee on Terotechnology which sought to improve maintenance practice in industry. Terotechnology is defined as a holistic approach of management, financial, engineering and other practices applied to physical assets in pursuit of economic life cycles. The increasingly sophisticated attitude to maintenance is demonstrated by the growing number of terms used in its practice. The second edition (1974) and the 3rd edition (1984) defined 47 and 173 terms respectively. The latest edition (18), published in 1993, revised some of these terms to comply with internationally agreed standards. Terotechnology is not a discipline specific to building maintenance management and as such is neither exhaustive nor entirely applicable in this context. The Committee on Building Maintenance in their 1972 report preferred to define an acceptable standard as one which sustains utility and value of the facility. Over the lifetime of a building accepted standards of amenity and performance will rise substantially, so no definition of maintenance can therefore exclude a reasonable element of improvement. McDermott reported (19) that changing standards over time are a factor affecting the life of a building but no specific indicator has been devised that can take account of changes in standards. In its conclusions the committee recommended that the definition of building maintenance would be better described as "work undertaken in order to keep, restore every part of a building, its services and surrounds to a currently accepted standard and to sustain the utility and value of the facility." The main distinction between the BS and the Committee's rewording is the adoption of "currently" accepted standard to suggest it is a timeous concept.

SH state (1, 2) that the SF should provide "like-for-like" replacement of components in HA housing. This could be interpreted as ruling out improvements to properties but it is assumed the accepted standard prevailing at time of replacement, which are likely to be an improvement on the original, is considered "like-for-like". Improving standards are likely to be in the form of improved construction methods, greater plant efficiency and better thermal performance (improved 'U' values) of components, reflected in the higher standards of subsequent building legislation. There is nothing to suggest, however, that such improvements in specification will result in a longer lifespan for future building parts as the main materials of construction are not likely to change. It is not, of course, only technical factors that exert an influence on standards. Overall standards are most frequently determined by considerations other than purely of a statutory or technical need and the BMI report cited (20) tenant satisfaction as possibly being the dominant influence in housing decisions. This view is shared by Gow and Purdie (21) who regard LCC as having an inherent defect in housing in that it only values components and not their effect on the well being of occupants. The various influences on housing maintenance demand and expenditure are considered in Chapter 5.

The development of British Standards reflecting the importance placed on building maintenance continued with BS8210:1986 (22) with guidance on a systematic approach to the management of building maintenance, stressing the relevance of such a guide to all types of building from domestic premises to hospitals or large commercial organisations. Among its recommendations it advocated regular and planned maintenance, and highlighted the importance of up-to-date building fabric and services records. Significantly, the issue of maintenance finance was addressed with the recognition that financial considerations start with the development of maintenance programmes and preparation of budget proposals. Indeed, it is stated that decisions may be taken on repair and replacement of building parts and the optimisation of programmed planned maintenance. It is important that budget proposals are presented to management in a way that will identify the cost benefits of funds obtained, through explicit and rigorous justification of the need for funds. Then contends (23) such an approach is needed if budgets are to be prepared on a more detailed basis that "last years spending plus inflation." It would appear that this remains a dominant approach. The Property Occupancy Cost Analysis data collated by Building Maintenance Information (BMI) Ltd. contains information on the budget procedures of contributing organisations, including NHS and University estates with significant maintenance budgets. Frequently recurring procedures are schedules of work based on last years maintenance costs and maintenance estimates considered and compared with the previous years expenditure. There are no housing bodies subscribing to this scheme.

In a special report the BMI (24) reviewed the state of maintenance in the United Kingdom construction industry in 1988, using the 1972 Report of the Committee on Building Maintenance - the last fundamental review of the industry - as its basis. The conference examined development of procedures and practices and their relationship to previously set priorities. In their conclusions they postulated that, whilst building maintenance is less of a "Cinderella" profession, it is still to an extent a distress purchase. The BMI concluded the review with a belief that maintenance management should move from reactive to planned maintenance as a matter of policy.

A strong vindication of the merits of a planned maintenance culture within housing was provided by the Audit Commission (AC) (25). The largely uncoordinated maintenance effort prompted the AC to undertake a study of how maintenance should be carried out. Their research was based on data collected from many English and Welsh housing authorities and consulted the SSHA, PSA and Centre for Housing Research as well as large HAs. The AC put a figure on the repairs backlog of being in excess of £10 billion, reporting that the greatest backlog of repairs was in non-traditionally constructed housing with a higher incidence in the London Area. The AC believed that too much work had been done on a jobbing basis, costing approximately 50% more than the same work carried out as part of a maintenance programme. This faith in the cost benefits of planned maintenance is not universally held, however, and other views are discussed in succeeding chapters.

2.5 European Experience of Housing Maintenance Funding

As a result of the lack of experience in British HAs facing new maintenance planning and funding responsibilities, the NFHA undertook a study (6) of how maintenance is costed and funded by housing bodies elsewhere in Europe. Detailed reports were carried out on housing authorities in Holland and Denmark where social housing is provided by organisations constitutionally similar to UK housing associations and with more experience in financing repairs out of cost rents. The Dutch and Danish systems are briefly reviewed and comparisons drawn with the UK position.

- The Dutch System

Average associations in Holland have about 2000 homes. The smallest has about 60 homes and the largest over 40000 reflecting the variability in size characteristic of British associations. Compared to the UK, Dutch HAs play a more significant role in national housing provision, owning around 35% of all housing stock (1985 figures). This far exceeds LA stock which comprises only 7% and is second only to owner occupied housing which makes up 44% of stock. The rest is owned by private sector landlords. The NFHA reported that HA stock was generally in better than average condition and a superficial comparison with the AC report on conditions (carried out around the same time as a Dutch survey) would seem to confirm this position. In Holland the national stock condition survey found that about £1500 was needed to be spent per dwelling to bring the association stock up to standard. The AC estimated backlog for council housing in England and Wales at between £1400 and £4500 per dwelling, with the worst incidence of dilapidation occurring for non-traditionally constructed housing in the London area. The overall age profiles of the stock in both countries contributes significantly to the disparity in backlog estimates. About 70% of the social rented stock in Holland was constructed after 1964 compared to only 35% in England and Wales where much of the house building activity was concentrated in the post war period of 1945 to 1964.

For the funding of new schemes the Dutch Government provides loan guarantees and loans at market rates of interest. There is no capital grant comparable to HAG available for financing new schemes, instead the emphasis of Government help is shifted to revenue subsidy. The only capital grant which exists at the construction stage is where there may be exceptional, but acceptable, conditions increasing scheme costs such as site problems or land acquisition costs. The annual "object" subsidy funds the difference between the "dynamic" cost rent necessary to sustain a market loan and the legal rent that can be charged to tenants as decided by Parliament and the Rent Commission.

Dutch System of Maintenance Funding.

Three types of Maintenance are distinguished by Dutch Associations

1] Normal - This is equivalent to a combination of day-to-day and cyclical maintenance in British associations and includes response repairs, external painting and planned maintenance with less than an 8 year cycle.

2] Large - This is equivalent to MRs in Britain and includes refurbishment/replacement of components and repairs arising out of defects.

3] Renovation - This is for modernisation of properties and occurs about 25 years after construction.

Dutch HAs must invest an amount determined by the Government into a maintenance fund each year, primarily for funding Normal maintenance with any surpluses being transferred to the Large Maintenance Fund. Each year associations must also put 8% of rental income into a General Provision Fund to finance Large Maintenance. The fund also provides security against any deficits which may arise on new developments or in the general management of properties.

Renovations, occurring at about 25-30 year cycles are financed partly through the general provision and partly through government subsidies in the form of renovation grants. Part of the cost must be borne by tenants through higher rents where improvements are included such as double glazing and improved insulation. Such projects can be vetoed by tenants who must approve any improvements leading to rent increases.

The renovation cycle is a distinctive feature of the Dutch system of HA maintenance which bears some advantages by simplifying the management of property. Periodic renovation reduces the emphasis on strategic planned maintenance programmes, thus less skill is required in the maintenance management effort, since much of the work can be "rolled up" into large projects at renovation time with relatively simple management of repairs during the intervening years. The downside is that standards of housing can vary considerably across the stock depending on its age in relation to the renovation cycle. Unessential repairs arising near the end of the cycle will most usually be postponed until the renovation work is carried out.

There are incentives, however, to maintain the property according to a planned maintenance programme since associations pay a large part of renovation costs from their own funds. It is therefore in their best interests to avoid additional costs arising from a failure to keep the property in good condition. Associations are encouraged by the municipality to produce assessments of maintenance demand 15 to 20 years into the future- considerably shorter than the sixty year

planning horizon now being required of UK associations, but sufficient in the context of the Dutch system with its 25 year renovation cycle. These are then used by the Government in assessing future levels of requirement for renovation grants.

- The Danish System

Danish HAs owning 17% of national housing stock make up a less significant proportion of the national stock than Holland. Their associations tend to be larger and around 40% of associations have more than 500 dwellings.

In Denmark the capital financing of developments is also geared toward heavy dependence on loans with a mechanism for subsidising repayments to ensure the mortgage can be sustained. Loans are index linked and provided by a mortgage association. Typically they make up around 85% of capital costs on new schemes. Subsidy is provided in 3 ways by the Government. It pays all the interest on the loan, 10% of the repayments for the principal and provides a guarantee for 65% of the loan. In addition the association does not have to make regular repayments on its share of the loan on a given estate if the financial position of that estate does not enable it to do so. However it must repay the loan within 50 years.

Associations are required to draw up a 10 year rolling maintenance and repair programme which must be agreed by a board of elected tenant representatives. Up until 1986 the Government laid down standard levels of annual provision for planned maintenance divided into separate accounts for the various building elements. This is the easiest way to calculate a SF by conventional means whereby the total ASF contribution is arrived at by aggregating the individually calculated annuities (see Chapter 3.8.1). The levels were expressed as a percentage of the replacement costs of the components. There was no pooling of costs between estates and no transfer of funds between provisions in each account for the elements. New regulations introduced in 1986 allow considerably more flexibility in that provisions for all parts of the buildings on each estate are pooled, though there is still no pooling of repairs costs between estates. Associations are also free now to adjust the level of maintenance provision for each estate. In practice, though, few associations go through an explicit process in which they first establish the level of maintenance demand and then evaluate necessary provisions as part of a process of determining a repair programme. The NFHA found little evidence of LCC or condition monitoring systems for determining maintenance demand. The most common practice was to examine historical records of maintenance provision which had evolved over a number of years under the old regime. There are a number of reasons why the veracity of historical records may be questionable, making them inappropriate for future maintenance prediction. These reasons are explored in Chapter 5.7.

A distinguishing feature of the Dutch and Danish system is the absence of substantial capital allowances for new schemes. Instead subsidies are directed to the revenue accounts of

associations. This contrasts with UK funding where grants currently make up the majority of development costs, but there are no revenue subsidies (except in extreme cases.) UK associations are exposed to a greater degree of risk in ensuring that schemes will be economically viable throughout their life. This was one of the governments objectives under the new financial regime to ensure that their management is commercially oriented to extract the maximum possible from public money. UK associations must also attract development funding on the open market whereas Dutch and Danish associations receive funds from the government or through mortgage associations. This approach has been criticised for it raises fears that only the larger, financially stronger associations will be in a position to raise the necessary finance. It has been argued **(15)** that the creation of a capitalised intermediary would be able to attract funds by aggregating loans for individual associations into large marketable funds. This could meet apprehensions about creditworthiness through an insurance scheme or providing capital which can absorb the risk.

Perhaps the most important feature is that rental levels are protected for social housing tenants in Holland and Denmark, with government mechanisms operating where rental income cannot meet liabilities. In the UK it is feared by the SFHA and NFHA that the absence of any such protection in this country will lead to development drift in the future, or force HAs to increase rents beyond what is considered "affordable."

2.6 Choosing an Appropriate Discount Rate

In the absence of an easy method of establishing the discount rate by empirical means, one must be chosen which best suits the circumstances of the user, motives for carrying out the discounting exercise, and attitudes to risk. Taking these into account the most appropriate rate is a matter of informed judgement and will vary quite widely according to circumstance. In building economics the discount rate has rarely been considered in the context of SF projections, it is more usually used in investment appraisal exercises and for comparative analysis between competing schemes and designs in LCC exercises. These are briefly considered in the following sections to help illustrate the rationale behind discount rate selection.

2.6.1 Life Cycle Costing and the Discount Rate

Selecting an appropriate discount rate for discounted cash flow analysis remains somewhat problematical (112), and has been widely considered in the LCC literature. It is one of a number of difficulties associated with LCC, described in Chapter 5, that has constrained its use in practice. It is clear that there is no single "correct" discount rate, or range of rates for application in any of the types of DCF analysis commonly carried out. This is primarily due to the uncertainty inherent in economic forecasting. The problem is not confined to forecasting activity in the construction industry. The complexity of the macroeconomy is such that forecasting inflation and interest rates with any of the econometric models used by economists is fraught with difficulty. Many external factors such as Government intervention, wars, oil prices and technological advancement mean forecasting is very difficult. If it were not so then the Government would have greater success in stabilising the economy and severe bouts of recession and inflation would not occur. Even in short term projections it is difficult to make realistic discount rate assessments in unpredictable and dynamic market conditions. It is not surprising, therefore, that it is all but impossible to make meaningful longer term projections for the time frame associated with the life of a building. Holmes and Marshall (113) recognise this in making future housing maintenance cost decisions which do not attempt to account for inflation, a determinant of the discount rate, since these "tend to be meaningless." Green goes as far as to say that all discounted cashflow models are based on subjective beliefs about future outcomes (114)

Ashworth and Au-Yeung (115) suggest that LCC represents only a snapshot in time and solutions to such exercises will become quickly outdated. This gives the SF problem with its sixty year planning horizon some perspective, especially considering that the first MR activity is unlikely to occur even within a 10 year horizon. It would appear that these forecasting difficulties have intensified in recent years. The selection of a real discount rate was said to be fairly straightforward throughout the 1950s and 60s given the relative stability of both nominal interest rates and inflation rates (112) Since then, though, nominal interest rates have been highly sensitive to international financial crises and are as much educated guesswork as anything else because of the instability of world financial systems. Ashworth and Au-Yeung (115) liken the problem of LCC as akin to those involved in long range weather forecasting. Despite having huge databases, years of experience and developed skills they are unable to forecast accurately even a few days in advance.

2.6.2 The Discount Rate and Investment Appraisal

One of the main uses of DCF is for investment appraisal, which is carried out by government bodies and private investors when assessing the viability of proposed schemes. For a private investor the discount rate is chosen to reflect the company's cost of capital, set at a level which gives shareholders a rate of return at least equal to what they could obtain elsewhere i.e. it is the opportunity cost of tying up cash in a building project. The discount rate should reflect the rate of return available on the next best investment opportunity (116), whether this is the market rate of interest or it may be another investment opportunity.

Investment appraisal can be carried out using the NPV of a scheme, the technique used in calculating the objective function of models described in Chapter 4. Another common discounting method is the Internal Rate of Return (IRR). This is the discount rate which, when used to discount cash flows for a proposed investment, reduces the NPV to zero. The appeal of the IRR method is that it does not require the explicit choosing of a discount rate for its computation. Instead it is found by trial and error, with the most attractive of schemes being compared having the highest discount rate. The use of spreadsheet or calculator means the laborious arithmetic of trial and error is no serious impediment to its use.

2.6.3 The Discount Rate and the Sinking Fund Problem

The problem of discount rate choice in the sinking fund problem can be thought of as being more 'real' inasmuch as we are determining sums of money to be set aside each year of a scheme's useful life to provide for future Major Repairs. It is not simply part of a decision making tool applied during the design process. That is not to say that the discount rate is not important in comparative analysis since the ranking of alternatives, and viability of some schemes will be affected by it (117). The higher the discount rate employed the greater the weighting given to earlier cash flows, therefore projects involving expenditure at an earlier date but which produce savings in the future appear unfavourable at higher rates. From an economic standpoint, the amount to be set aside into a SF needs to consider the projected rates of interest and inflation to arrive at an appropriate discount rate. Specifically these are the return achievable on the invested SF, and the inflating costs of MRs. With regards to interest rates, the difficulties of making market predictions are compounded with the knowledge that there is no experience or data on the performance of Housing Association SFs. In addition their finances are volatile under the new regime. HAs are being forced to become ever more innovative in their financial management

which can only increase risk and uncertainty. The performance of SFs will be a matter for the capabilities and competence of individual associations.

2.6.4 Determinants of the Discount Rate

- Interest rates

    Interest rates have always been used to achieve some measure of control over the economy. Traditionally deflationary action is taken when the economy becomes overheated by increasing interest rates. Similarly, interest rates have been lowered when deemed advisable to stimulate business activity **(118)**.

- Inflation rate

    Inflation can be identified in 2 forms. General inflation and specific inflation. The former refers to increases in price of a whole range of goods and services i.e. the retail price index. Specific inflation relates to increases in price of particular goods. The cost of construction and cost of maintenance do not inflate at the same rate as their cost structure differs. New construction works tend to have a larger element of materials cost whilst maintenance tends to have a larger element of labour costs, as a proportion of the total costs of the works **(119)**. The BMI only make detailed forecasts for the coming year or so, based on returns from health service, local authorities and private contractors. Labour costs have a greater effect on maintenance costs than they do on new-build work, and forecasts are significantly affected by wage settlements with various trade representatives. The substantial impact of the effects that inflation can have in the construction industry is evidenced by the existence of contracts making provision for fluctuations in labour, material and plant prices over time **(120)**. Such contracts, designed to reimburse contractors for unforeseen escalation in costs during the project life cycle, are usually used for large and complex jobs. However, full fluctuations provisions are applied in contracts with duration's of as little as a year. The necessity for such provisions only serve to highlight the difficulty of making accurate forecasts.

2.6.5 The Real Rate of Interest as Discount Rate

Chapter 5 describes the approach taken to the choice of discount rate. In short, estimates of MR costs are based on prevailing price levels, and no attempt is made to explicitly account for escalating costs. To compensate, the inflation free 'real' discount rate is used. The rationale for this has been alluded to above. Namely, the difficulties in long term interest and inflation rate prediction mean that effort in explicit calculation of each is misplaced and only serve to give an illusion of accuracy which is not warranted. Although interest and inflation rates can be quite volatile and unpredictable over time, the Fisher Hypothesis states that the real interest rate does not change much (118). Higher or lower inflation will be offset largely by equivalently higher or lower nominal interest rates to maintain the equilibrium real interest rate. Although not exactly correct, the hypothesis is not a bad approximation. The real discount rate is roughly the difference between the nominal interest rate and the rate of inflation, and is calculated as.

(2.1)
$$d = \frac{(1+i)}{(1+r)} - 1$$

where

d = real discount rate

i = nominal interest rate

r = general inflation rate

2.6.6 Interpriting Results based on Forecasts

It is dangerous to present results of any LCC exercise without conducting sensitivity analysis for a range of feasible discount rates. The advantage of SA is that it shows how significant a single input variable is in determining the results of exercises. A disadvantage is that it gives no explicit probabilistic measurement of risk. Results of the SF calculation exercises in Chapter 6 are presented for discount rates of between two and four percent. Based on the literature 3% is used as the most likely real rate of return and is presented as a "risk neutral" input. Notwithstanding the difficulties in discount rate selection that have been highlighted in this section, it is contended that the trend in the results is strong enough to support the proposition that current assessments of an adequate annuity will not in fact be enough to sustain a long term programme of MRs.

2.7 Risk Analysis using Lifespan Distributions

Risk Analysis (RA) is developing as a means of helping decision makers assess their exposure and attitudes to risk so they can choose the best course of action open to them. Decision Analysis, Simulation and increasingly Expert Systems are becoming more familiar as means of carrying out RA in construction management. These techniques have their basis in OR and are academically robust. The present controversy lies not with their academic rigour, but with the availability of meaningful data critical to making them attractive to practitioners. Two sets of RA data from the literature have been described in Chapter 7. These two sets of data, both used for housing maintenance expenditure prediction, are apparently very different. This section suggests reasons as to why this may be so. It is contended that, at the present time, risk parameters have more to do with intuition than with any numerical justification. As such they are highly subjective and must be used with caution. Beta distributions which more closely match the Dutch parameters were used in the study on the basis that these were originally intended for a purely needs based attitude, free of organisational policy considerations, and are thus more objective, This is developed in the following sections

2.7.1 Risk Identification

The subjective nature of RA, in particular the element and component lifespan distributions used in the study, are best illustrated with reference to risk in investment appraisal. Risk identification is a necessary pre-requisite of carrying out RA, yet has received the least attention in the literature on risk (121). Risk identification requires the examination of two components, termed risk exposure and risk attitude (122). Risk exposure is the probability of a project having an economic outcome less favourable than that economically acceptable, and risk attitude is the willingness of a decision maker to take chances. The implication of different risk attitudes is that a given investment of known risk might be economically acceptable to an investor who is a risk taker, but unacceptable to another who is risk averse. In maintenance prediction risk exposure has a measure of objectivity inasmuch as it can be influenced by the quality of elements and components used in the housing, and the quality of workmanship in their installation. Environmental conditions affecting their performance in use are also largely predictable and are to an extent objective. Risk attitude on the other hand cannot be modelled as it relies on the intuition of the decision maker. In the practice of maintenance expenditure prediction, it is the emphasis on the latter that means an understanding of the reasoning behind shape characteristics in risk analysis exercises requires more than an examination of a housing organisation's stock of buildings and surrounding

environment. The attitudes to risk of those making future maintenance predictions and the culture and policies of the organisations are at least as important.

Construction risk management literature is biased toward theory, i.e. the methodologies and techniques of calculating risk. Little effort is actually expended in calculating and evaluating risks i.e. the development of data, even though there is a high level of awareness of its presence. Rather, activity appears to be directed to ways of responding to risks. A survey of Swedish Facilities Managers (123) showed that technical risks i.e. those associated with building and component performance over time, are generally accepted. It may be that more value would be gained from how to deal with risk when it arises rather than how to measure it. This would suggest that a lower priority, and value, is placed on refining lifespan distributions, which quantify probability of failure, and a higher priority is to deal with financial risks. It is certainly true that HAs are being forced to develop greater financial acumen and show innovation in manipulating incoming grants and private finance, to the extent that there are fears smaller, locally based HAs will be squeezed in favour of a 'super league' of organisations existing in the future. Whilst larger organisations may prove more efficient on paper there is a danger of what Cope terms 'development drift' (7), whereby local needs are not being met.

2.7.2 The Risk Parameters: Lifespan Distributions

In Chapter 7 expenditure profiles are simulated by sampling distributions representing the probable replacement intervals of elements and components that make up the MR regime for the planning horizon. The distributions are based on the Damen and Botman model of probabilistic expenditure on housing maintenance, reflecting a purely needs driven view of maintenance applied at national level. This is what the SFHA advises its members to base SF policy on. However the literature shows that, at the level of individual organisations, projections are more likely to based on a multitude of factors, and a distribution based solely on probable lifespan is unlikely to reflect their own attitudes to risk.

These factors are simplified and presented under 3 categories
- Buildings (technical)
- Organisation (policy)
- legislation (change of building standards/government)

It is only technical factors that are considered in the Damen and Botman model i.e. the likely lifespan of housing elements and components. The life of an incandescent light bulb is given as an

example of a component that has a variable lifespan. However, this tends to oversimplify the problem. The performance of an electric light bulb is easy to determine by objective means, it either illuminates or it doesn't. Such assessment of performance is much more subjective for most housing elements and components. Although there is substantial knowledge on the behaviour of materials, there is hardly any information on the behaviour of materials applied in specific conditions within buildings (124). The deterioration rate of components is influenced by the interaction of constituent materials and with surrounding components, by their method of connection, and with the characteristics of the surrounding environment. Chapter 5 develops this theme in greater detail. Concentrating on the technical aspect only is appropriate for the application of profiling expenditure need at the national level since it is not an exercise carried out for any particular organisation, but serves to estimate the order of magnitude of year by year expenditure required to maintain the habitability of the stock.

2.7.3 Current Attitudes to Risk Analysis in Maintenance Management Practice

The culture and policy of the organisation may actually have a greater influence on risk identification than any technical consideration. A survey (123) showed that performance characteristics of the buildings, their elements and components actually have a relatively little influence on maintenance expenditure profiles. Furthermore risk analysis and evaluation is seldom quantitatively performed, although sensitivity analysis is performed widely in practice. Simulation exercises of the type advocated by Flanagan and Norman (87) were not used by any respondents. Their common perception was that analytical tools have no real use since the chance of establishing objective probabilities, the risk exposure aspect described, is limited.

The idea that technological need is not the overriding factor at organisational level is reinforced by Holmes and Marshall (113). At its simplest level, prioritisation of expenditure is based on condition. The worse the property is the more likely it is to be refurbished. However, for effective decision making, a number of non-technological factors must be accounted for, including the condition of adjacent property, changing property demand, and area improvements. These are the type of factors that cannot be explicitly modelled for long term projections. "Building condition is only one of a number of factors which should influence decision making"

2.7.4 The Relationship of Planned to Reactive Maintenance and its Effect on Lifespan

Another important factor in maintenance projections is the relationship between planned maintenance expenditure, essentially renewal in the case of the SF, and day-to-day maintenance expenditure, funded from the notional management and maintenance allowance. The British Standard *Guide to Maintenance Management* (22) states that some expenditure is assumed to be reasonable throughout the service life of components for day to day repairs As there is no definitive categorisation, the relationship will be a matter of individual policy. Clearly, all major elements and components that are replaced out of the SF will be subject to some maintenance throughout their life, and this will have a direct influence on their replacement interval.

2.7.5 Simplified Approaches to Risk Analysis in Maintenance Prediction

Holmes and Marshall (113) list a number of factors shaping the long term housing maintenance planning, the majority of them non-technical in nature. The authors' have concluded, from research and consultancy work, that desktop studies are often as accurate as condition surveys in predicting long term repairs. This is interesting considering that much other studies cite the lack of data as a prime downfall of LCC techniques. Their forecasting model uses optimistic and pessimistic expenditure projections for element and component replacement at fixed intervals, and is therefore a deterministic model. This has the benefit of simplicity compared with probability distributions, and goes against the trend of stochastic forecasting means.

On the theme of simplification an alternative means of incorporating risk into long term maintenance projections is developed by (113). Optimistic and pessimistic assumptions (i.e. low and high) about expenditure are made at discrete points in time over the future. This avoids quantifying risk associated with timing of activities in the future, in favour of how much needs to be spent irrespective of how it is incurred.

Garnett and Holmes (125) have also identified the need to integrate relevant technical and non-technical issues in housing maintenance. The problem is how to identify and value the relevant technical and non-technical aspects in housing renewal decision making.

2.7.6 Data for Risk Analysis in Maintenance Prediction

There is very little evidence of a formal and structured process for managing risks. Strategy for doing so appears to be dependant on the organisations concept and history, as well as on the decision makers background and competence. No explicit routine for analysing and evaluating risks was found. The perception of risk was generally made intuitively upon subjective probabilities. This is an important point with regards to the characteristics of the two sets of distributions used by Australian and Dutch housing bodies that are described in this study. There can be little scientific rationale ascribed to the parameters chosen for each. It would be unwise therefore to lift risk parameters from one organisations predictive maintenance model for use in another. It is a highly subjective process and the less emphasis is placed on durability the more subjective it will be.

Shape parameters, to be of practical use, will have to reflect the decision-makers attitudes to risk. This will make them peculiar to individual organisations, and will not allow a universal database to be constructed. Tucker and Rahilly state that in their model "the default parameters [of the beta distribution] were chosen to allow replacement times to be no less than 90% and no more than 190% of the nominal times which are assumed to be most likely". A key word in the above sentence is allow, which suggests that risk attitude is more dominant than technical constraints. In a comparison of the limiting values (minimum and maximum replacement times as a proportion of average component life) of the two models, the risk parameters appear to vary greatly. However the beta distribution shape used by Tucker and Rahilly is such that the probability of exceeding 1.5 times, the upper limit assumption used in the Damen and Botman model, is less than 1%. Therefore, the risk parameters used in the models are not as varied as is immediately apparent.

2.8 Housing Associations and Sinking Funds: The Current State of Play

The current position as reported by Scottish Homes is that HAs have not developed the necessary SF calculation mechanisms, but were turning their attention to them. As recently as 1995, a Scottish Homes report (126) stated that "too many organisations are not making provision for future major repairs and the planned replacement of expensive components." Even where life cycle costing exercises were found to be being undertaken, organisations were criticised for not dealing adequately with their findings. It may be inferred from this that the necessary provision is not currently being made to provide for future major expenditure needs. Scottish Homes warned

that when properties are newly built or improved it is easy to forget that the main challenge is to prevent them from deteriorating over time.

Another source of pressure on HAs to produce accurate maintenance projections is from private lenders. As increasing proportions of HA development costs are coming from private financiers they expose themselves to greater degrees of risk. Assurances are being sought on financial probity with proper allowances being made for short, medium and long term maintenance needs (127). The pressure is mounting as SH attempts to reduce the HAG by reducing the Void allowance from 4% to 3.5%, and the Management and Maintenance allowances from their current levels. This will create more pressure for a fuller allocation of projected needs and an adequate provision for replacement. Private finance lenders wish HAs to evaluate real needs compared to current vague projections. The major advantage of the research is in the potential for treasury management, although the work on early spreadsheet projections using deterministic models is relevant to the same HAs who lack experienced staff to produce such documentation in the short and medium term.

CHAPTER 3   SINKING FUNDS FOR LONG TERM MAINTENANCE

3.1 Introduction

The withdrawal of Major Repair HAG under the new financial regime will have a significant impact on the finances of HAs and ultimately upon their tenants. Kearns believes (26) that an ASF contribution of 1% of reconstruction costs could easily necessitate a 25% increase in rents. Maintaining the "affordability" of rents is a key area of negotiation between the Scottish and National Federations of Housing Associations and their respective funding bodies, SH and the HCorp. In addition to a rent financed MRP there are many other aspects of the new financial regime that will put pressure on rents. The nature of ongoing negotiations and the extent to which tenants will be affected are outwith the scope of the project, work is directed to analysing the costs of Major Maintenance to the association. How association's cope with this burden will vary from case to case and may not be apparent for some time.

In the first part of this Chapter the old financial regime is compared to the new financial regime with respect to the funding of MR. The definition of MR is compared with the various construction maintenance definitions that the BSI has published. In the second part of the Chapter the mathematics of SF calculation are described and two approaches to calculating an ASF for a series of MR expenditures are outlined.

3.2 The Funding of Major Repairs

Under the old financial regime MR to the housing stock were financed by HCorp grants, made available to HAs who could demonstrate their need for the funds as required throughout its life. The H.Corp provided a loan to finance the work and, on completion, the association received sufficient HAG to enable it to pay off all qualifying costs, often the entirety of the loan (7). The H.Corp argued that the arrangement provided little incentive to contain costs, or to avoid the need for the repair work in the first place through careful maintenance management.

The new financial regime removed this system of grants. All associations are now required to generate the necessary finance for all non-reactive maintenance out of the revenue (i.e. rental income), a move which transfers development and management risks entirely to associations. The system was introduced in Scotland (27) with a directive published in January 1989, to take effect from September of that year. It concentrated on the governments objectives of improving cost control and value for money from the public sector, but no details were given as to how HAs might achieve this. For existing schemes an element of the HAG system will remain operable

under transitional arrangements put in place to allow HAs to build up SF reserves but it is intended to "get associations working as quickly as possible under the new procedures."

Under the new capital funding arrangements the use of low-start mortgage financing will increasingly be used to close the gap between scheme costs and reduced capital grants. In addition there is the burden of a MRP to be sustained. HAG rates for developments are based on the assumption that all private funding will involve deferred interest (low start) finance. Indeed it is unlikely that many developments will be feasible without deferring interest payments until surpluses can be built up. The rationale (7) behind the use of low start finance is that, although over the life of the loan the cost will be the same if not more than that of a conventional loan, initial rents can be lower as initial repayments are less. As rents increase it is argued that they will meet increasing repayments. However, low start finance does not find favour amongst HAs for several reasons. Social Housing outlined (28) a number of these, the most important being the unnecessary commitment of significant amounts of future rental revenues to pay interest on accumulated ("rolled-up") interest. In Scotland several HA committees considered that borrowing on a deferred interest basis constituted an unacceptable risk to their finances. SH acknowledged these fears by issuing a circular (29) on the matter. They accepted that HAs may still choose to use conventional loans, but warned that they would still be expected to provide the same number of houses at the same levels of return as would be the case using low-start finance. Future surpluses accruing, after the SF was provided for, could also be directed back to the Exchequer. Aversion to low-start finance is not only confined to Scotland. English HAs have also taken steps to avoid using it for development in favour of conventional finance. Chapter 3.6 describes one such approach.

An updated directive (1) dealing specifically with the treatment of maintenance and MR projects was issued by SH in October, 1990. The circular described the various classifications of maintenance with examples of the activities that would have to be funded from a SF. Although there is no definitive list of MRs, they are defined in (1) as the "replacement of, or repairs to, features of properties which have come to the end of their economic life" to ensure the continued habitability of properties. The level of SF contributions should be based on an associations assessment of the future stream of costs.

3.3 A Definition of Major Repairs

It is important to be clear what actually constitutes MR maintenance in defining the SF provision. HAs need to clarify which maintenance works it intends to finance directly from the management and maintenance allowance and which from the SF provision. The HAs own maintenance policy will therefore influence what constitutes an adequate SF as there is no definitive element list. The

elements included in the SF case studies in the following chapters are the authors own interpretations of a reasonable planned maintenance schedule.

BS8210 (22) provides a definition of terms used in maintenance management. Replacement is not included as a term on its own, but is classed "repair". Repair is described as restoration of an item to an acceptable condition by the renewal, replacement or mending of worn, damaged or decayed parts. It is assumed that replacement occurs at the end of the service life of components. The service life is the actual period of time during which no excessive expenditure is required on the operation, maintenance or repair of a component i.e. some expenditure can be assumed to be reasonable for day to day maintenance, and would be sourced from the management and maintenance allowance for the property. SH uses the term economic life to define the period before MR are essential for the dwelling's continued habitability. Thus, service life and economic life can be regarded as synonymous terms.

In the HA funding regime there are two sources of funding for maintenance.

- REVENUE FUNDING is raised from rental income and the expenditure falls under the classification of management and maintenance allowances.

- CAPITAL FUNDING is for MR to properties. Under the new financial regime this is also funded from rental income, via the SF, for all new developments.

The Management and maintenance allowance is a notional sum of money which it is assumed a HA will spend on managing and maintaining properties on a daily basis. This provides for day-to-day and emergency repairs, works to properties for re-let, inspections, pre-painting repairs and painterwork and also for the cost of administration and supervision of these activities. All other maintenance work is funded from a SF, and by implication is planned in nature. SH describes this category of work as cyclical maintenance which deals with the gradual deterioration of building components and finishes and is essentially preventative in nature. The AC (25) recommends at least 70% of repairs and maintenance expenditure should be incorporated in a planned programme.

In creating a SF associations are "expected to form their own judgement on what provisions it should make for future repairs, taking account of materials used in the construction, their expected life cycles and other factors such as usage by the tenant group, site exposure etc." The planning horizon was not to be restricted to the mortgage life of property but for a recommended "minimum building life term of 60 years." The burdens on associations were stipulated without any guidance as to how they may be achieved in practice. As a guideline SH stated that they

would not normally expect an ASF provision to exceed 0.7% of the works costs for both new build and rehabilitation schemes. The position for English and Welsh HAs is slightly different. The HCorp distinguishes between new-build and rehabilitated properties in their assessments of an expected level of provision. For new-build properties the figure is 0.8% and for rehabilitated properties it is 1% of reconstruction costs.

3.4 An Adequate ASF Provision

The latest SH Guidance Note on Maintenance and Major Repairs (2) was published in January 1992. This note was very similar to the previously issued guidance with the inclusion of a few new definitions and clarification's on previous points that had arisen from discussion between SH and the SFHA. With regard to the ASF guideline a minor, but significant, addition to the redrafted note stated that "An association may seek to persuade the District Office (of SH) that, on the basis of their life cycle costings, a different figure is more appropriate to their circumstances." This amendment would seem to suggest that the previous guideline of 0.7% may not always be adequate and a "different figure" will in fact mean a higher figure.

3.5 Sinking Funds in Practice

SFs are not a new mechanism and all students of estate management will be aware of their advantages for the replacement of fixed assets. However, they are not greatly used due to the burden they create on net incomes (30). This position is not confined to the UK. In a review (31) of the management of Australian University built assets, Bromilow and Pawsey found it to be "questionable" whether commercial organisations or public sector departments, let alone the educational institutions with which they were concerned, were using any of the discounting techniques in management of assets. Traditionally, SF's were intended as a means of compensating for the loss of value in a leasehold interest (32). Such an investment is a wasting asset and can be compensated by investing part of the rent each year in a SF, guaranteeing the replacement of an investor's capital when the leasehold interest expires. The traditional mediums for investing the fund are insurance companies. These institutions offer returns based on long term rates of interest which ignore abnormal movements in interest rates and give investors a reasonable guarantee that they can meet their obligations. Consequently the returns offered are low and an average real return of around 2.5% is cited as being a realistic yield. The actual yield will vary from HA to HA depending on how successful they are in investing their SF (26). Gaskell-Taylor states (4) that real interest rates will vary with the degree of risk. The real return today on a "no-risk" investment such as long term Treasury Bonds is about 3%. However over the past 40 years building society investments have shown only about a 1% real rate of return.

3.6 Interpretation of a SF

There is more than one interpretation of SFs in asset management. One definition is the lump sum that must be provided at the outset to provide the necessary finance for all future maintenance. Bromilow and Pawsey estimated (30) the sums that would have to be made available for Australian University buildings as equivalent to 8.1% of original cost provision (The NPV of future expenditure). Although the likelihood of such a facility being made available is not explored the authors' believed there was considerable merit in estimating the value of a fund that would, with interest accruing, service all recurrent expenditure over the life of the building. Similarly, Gaskell-Taylor gives credence to such a definition by calculating the lump sums that would service LA housing in England and Wales. It is hard to see, however, such a maintenance provision ever being made available either in the public or private sector. There is so much pressure from clients to reduce initial costs that LCC often plays little part in the decision making process. The sums of money involved would be vast and, in the social housing sector anyway, be politically unacceptable.

The more conventional definition is the diverting of a proportion of income each year into a fund to ensure future maintenance commitments are met. Gaskell-Taylor provides examples (4) based on equal annual contributions for a "smoothed" profile of expenditure. The spending assumptions were based on the Bouwcentrum maintenance model which assumes lifespans of components in a group of dwellings will conform to a normal distribution. This and other maintenance forecasting models are considered in Chapter 5. The profile is extrapolated for English and Welsh LA housing stock using estimated maintenance expenditure for a reference dwelling taken as being typical of the national stock. Although the calculated contributions are based on constant annuities, Gaskell-Taylor believes it is likely payments would be varied over time, to make a better long term match with need. It is stated that this would "merely require more sophisticated modelling," though the paper does not develop the theme.

A cruder method of determining SF's has been described (33) in which all projected expenditure for a 30 year period is aggregated and a constant annual sum is fixed which will fund these repairs. The annuity is arrived at by "trial and error" with the aim being that at the end of the 30 year period under consideration the total forecast cost of repairs will equal the total accumulated provision. This financial provision is made only for a 29 year period, before the property reaches the end of its financial life in year 30, at which point another loan will be taken out to fund improvements and repairs. With this system all MR are to be funded concurrently i.e. components which are replaced more than once in the projected life have all their renewal costs provided for in the ASF from the outset of a scheme. This would appear unfair to current tenants who are, in effect, financing all future maintenance work in addition to what they currently enjoy from the quality of the maintenance service afforded by the SF

provision. It also relies on projections being made further into the future than is required by a single elemental replacement strategy.

Early evidence that a constant SF annuity may not be appropriate, given the revenue stream from a development, is provided by an English HA. The SF strategy adopted by Circle 33 seeks to create a better match of SF investments with finances (34). Rather than follow the HCorp's provisioning policy of a constant annual 0.8% of replacement costs, they have embarked on a sliding scale provision of an annuity that increases over time. The reason behind this was to avoid the need to use low-start finance for new developments in favour of conventional finance, on the grounds that the long term implication of its use on the finances of the association are not fully known. With development HAG based on conventional finance the burden of servicing the full 0.8% annually required of the MRP after management, maintenance and cyclical repairs are accounted for would be unsustainable. Thus, a sliding scale provision is used whereby SF payments are reduced in the early years, with five-yearly increments (in real terms) to ensure the necessary finance has been generated in the longer term. Figure 3.1 shows the sliding scale provision. This method seeks to use the eventual surpluses that accrue with the ever-inflating income from rents. It has to be said that this approach is very much the exception. Initially Circle 33 had to prepare accounts based on the stipulated fixed provision to satisfy the HCorp that SF requirements were being fulfilled. The HCorp eventually relented, allowing new HAG submissions to be made based on a sliding scale provision for MR. The reasons for allowing the deviation from standard formula were not divulged.

YEAR	CONTRIBUTION
1	-
2-5	0.1%
6-10	1.0%
11-15	1.3%
16-20	1.6%
21-25	1.8%
26-30	2.1%

Figure 3.1 Circle 33 ASF Sliding Scale Provision: Percentage of Original Works Costs

It is noted that projections are only made for a 30 year period, with the aim that full reconstruction costs are covered in year 30 from the MRP. This is comparable with the Dutch system, outlined in Chapter 2, which favours a 25-30 year refurbishment cycle. The danger of this system, highlighted in Chapter 2, is that a backlog of maintenance may be allowed to build up, in the knowledge that it will be dealt with at the refurbishment. An acknowledgement of the risk undertaken with the sliding provision is made by Circle 33's financial director who makes the

point that if expenditure cannot be met at year 15, it is fatal for the build-up of provision in the subsequent 15 years. If this situation arose at year 15 it would be likely the maintenance programme would be cut in order that the build up of funds would not be jeopardised, the consequence being a poorer quality of accommodation experienced by the tenant. Alternatively a substantial increase in rental levels would have to be made if standards were to be maintained.

3.7 Are Sinking Funds the Way Forward?

The low-risk but low rate of return of traditional SFs are seen as inefficient as a means of investment in a Touche Ross report (34) on HA Treasury Management. This recommends that cash should be invested in interest-bearing sterling instruments such as money market deposits, certificates of deposits, corporate bonds or gilt edged securities. There are some well founded objections to this recommendation on the basis that they do not provide the long term protection against inflation needed by HAs to ensure adequate funds are available for future MR. The experience of investors in Lloyds, BCCI and Barings Bank illustrate the drawbacks of high risk investments only too well. Social Housing drew attention to the fact that Touche Ross did not address the management of inflation risks to ensure future availability of funds. The very concept of SFs are questioned in the same report on the basis that it can be inefficient to hold significant cash balances in SFs at a time when a HA is also carrying debt on mortgage repayments.

With regard to the considerable assets of Australian Universities, Bromilow and Pawsey believe (31) that only by the use of a SF or similar formula funding device will the Universities be sure that funds for the purpose of maintenance be available in the future when needed. It is also acknowledged that funds need to be actively managed on a long term basis- not only to ensure the fund is maintained at its programmed level in real terms from year to year - but also to preserve them for their intended functions. This would hint at guarding cash reserves from use by novel financial instruments or other administrators.

Leaving aside the argument as to whether SFs are an efficient financial instrument or not, they surely provide an important function. That is to put maintenance, and in particular long term planned maintenance higher up the management agenda than was ever the case. Dragging the profession out of its Cinderella status has been a goal of all involved in maintenance for many years. Much of the literature on maintenance management practice in recent years has emphasised the benefits of a planned and preventative approach to component replacement on the grounds that cost savings will be evident in the long term. The scale of cost savings was placed at between 30% and 50% by the AC for LA housing in England and Wales. Although the virtue of a greater degree of planning for maintenance is clear, the economic benefits of preventative maintenance are not universally believed. Henderson challenges (35) the AC's belief that a high degree of total maintenance work should be undertaken on a planned and preventative basis on

the basis that significant cost savings can be made. A fundamental difference, though, between HA and LA maintenance management is the HA need for a formula funding mechanism, sustained through rents, to be in place from the outset. Assessing an adequate SF therefore requires that maintenance be planned; if not for its administration then at least for its funding. Henderson highlights the inflexibility of planned maintenance programmes if slavishly followed, but does not acknowledge the dynamic nature of maintenance planning which admits the possibility of refining maintenance projections over time. Chapter 8 considers the effect ongoing condition monitoring has on maintenance projections and the SF burden.

3.8 Mathematics of SF calculation

The SF calculation is derived from the theory of compound interest. There are several calculations used by valuation surveyors derived from this theory, based on the premise that expenditure occurring at different points of time cannot be directly compared. This is commonly referred to as the "time value of money" and is well covered in the literature. The actual mathematical content is quite limited and the calculation of an ASF is straightforward. However, in the same way that valuing property has been described as partly an art and partly a mathematical process (36), so the determination of an adequate MRP using SF theory is more than the mechanistic application of the calculations. There are many decisions to be made and judgement to be exercised in projecting a SF in the asset management of housing stock. Chapter 5 deals with the important issues that must be addressed in long term maintenance forecasting.

Traditionally tables of constants, such as those found in Parrys (37), were used in the calculation of valuation problems without the need to use the equations. Today, these tables have largely been superseded by calculator and latterly the spreadsheet. This tool lends itself to the repetitive arithmetical manipulation involved in such calculations.

3.8.1 Method 1: Conventional SF Calculation

A SF is nothing more than a savings fund into which a series of equal annual payments are made to ensure a specific sum of money is saved by a specific point in the future

Let £x = Annual payment credited to the SF. Under an interest rate of 100i% pa the accumulated value at the end of N years is S_N

$$S_N = x + x(1+i) + x(1+i)^2 + \ldots + x(1+i)^{N-1}$$

Summing the standard geometric series gives

$$S_N = \frac{x((1+i)^N - 1)}{i}$$

(3.1)

$$\Rightarrow \text{£}x = S_N \frac{i}{(1+i)^N - 1}$$

Since the profile of MR needed to maintain a dwelling over the long term will come from a stream of intermittent expenditures several SF calculations are needed - one for each year an outlay is forecast. The required ASF for a single scheme will therefore be the aggregate of individually calculated SF annuities for the various replaceable components (38). A MRP made in this way is not new. Under the old Danish system (6) of maintenance provisioning (pre 1986), HAs were required to show individual SF accounts for each element. No transfer of funds between them was permitted. The new system relaxed this rule allowing maintenance provisions for the various parts of buildings on each estate to be pooled.

A characteristic of a SF plan based on the above calculation is that the required total annual deposits reduce towards the end of the planning period at intervals when work is carried out which is not repeated i.e. no more provision need be made for it. Since the SF is based on expenditure occurring within a fixed planning horizon, the value of the fund will be wiped out at the end of the period. This is appropriate if the planning horizon is as long as the minimum expected life of the building itself. Thereafter it will gradually deteriorate with only ad-hoc repairs carried out to ensure its habitability until demolition time. Alternatively, the profile of SF payments is kept constant over time by not reducing the amount of deposits after final replacement of components. The consequence of this is that there will be a significant surplus in the fund at the end of the projection. Although this could be used for future repairs it must be asked at what point in the life of the building is it uneconomical to spend large systems of money

34

on MR? Also, by accruing a surplus it can be argued that earlier generations of tenants are paying more than they need to into the fund.

3.8.2 Method 2: Alternative Approach

Under certain conditions it is possible to derive an annual SF payment that will fund a planned maintenance programme using a single calculation. This avoids treating the MRP as a number of discrete parts as Method 1 does, and fixes a constant annuity for the entire projection.

The compounded value of all expenditure during N years is

$$\sum_{n=1}^{N} C_n (1+i)^{N-n}$$

(3.2)

where

C_n = Expenditure in year n (n=1,..,N)

S_n in (3.1) is replaced by (3.2) to give

$$\pounds x = \frac{i \sum_{n=1}^{N} C_n (1+i)^{N-n}}{(1+i)^N - 1}$$

(3.3)

The limitation of this method is that it ensures only that the payments made in the SF are sufficient to meet the sum of compounded expenditure (at the end of the horizon). There is no guarantee that it will raise the balance in the SF account to a level which will meet the expenditure in each and every year. Such problems will occur if there are disproportionately high expenditure towards the beginning of the horizon. The plan is feasible if the values at the end of each year are non-negative, that is

$$f_n = f_{n-1}(1+i) + x_n - C_n$$

(3.4)

If $f_n \geq 0$ for $n = 2,...,N$ then the SF strategy is feasible.

where

f = Value of the fund at the end of year n (n=1,...,N)

CHAPTER 4   A MATHEMATICAL PROGRAMMING METHODOLOGY FOR SINKING FUND PROJECTION.

4.1 Introduction

The emergence of construction management as a research discipline has provided a focus for the advancement of new and better planning techniques using quantitative models. Many of the recent models use OR techniques more commonly associated with planning in engineering and financial services industries. Two factors have encouraged the development of cost modelling. Firstly the limitations of traditional cost models, such as the Bill of Quantities (BQ), are becoming increasingly apparent, and secondly the means of solving new models are continually improving as Personal Computer (PC) technology advances.

The first part of this chapter considers the need for new cost models in construction with a review of relevant literature, and identifies areas where progress has been made. The principles of model building are then discussed in the context of SF modelling. Reference is made to what may be termed the "soft" aspects of OR, concerning the practical issues involved in bringing techniques to bear on some part of an organisation. There are particular difficulties where such approaches are advocated in untried areas. From the experience gained the potential for further development in the field is considered. The second part of the chapter deals with the "hard" aspects of the OR research work, presenting and describing various models for making SF projections as an alternative to the financial calculations of valuation mathematics described in Chapter 3. Linear Programming (LP) is used to optimise series' of SF contributions for various strategies. The data used in these models and an analysis of the results are described in succeeding Chapters.

4.2 Cost Modelling

A variety of names exist for the body of techniques that bring quantitative analysis to managerial decision making. The terms Operations Research, Operational Research and Management Science (MS) are synonymous and used interchangeably. The body of relevant literature tends to fall into two fairly crude categories. On the one hand there is material dealing with the mathematical and algorithmic side to problem solving i.e. numerical solution procedures employed in quantitative analysis. On the other hand, and more readily appreciated by the non-mathematician, is the literature describing the relevance and application of techniques in a practical environment to aid decision making in real life problems. Up until the last ten years or so, most of the literature dealt with the refining of algorithms and solution techniques used for problem solving. This treated OR more as a mathematical rather than management subject, discouraging non-mathematical developments appearing as OR. Attitudes, at least in the UK, are

changing though as powerful computer hardware and sophisticated software becomes more widely available. Mathematical sophistication is no longer considered a prerequisite for research in OR. The changing fashion in its presentation is mirrored by the shift in focus of textual material. Earlier books are full of mathematical techniques which contrast with the more discursive style of later ones (39). The latest texts by notable authors, such as Williams (40), Rivett (41) and Mitchell (42) have shifted their attention to the more practical aspects of model building and their uses in an organisation, stressing that OR can be both practical and mathematical. This is of great importance if the resistance inherent in the construction profession (including maintenance management) to novel approaches is to be overcome, so encouraging quantitative modelling techniques to find widespread application in practice.

4.3 Traditional Cost Models in Construction

In pre-contract cost planning the various processes that culminate in the BQ are the traditional construction cost models used (43). The BQ remains possibly the most important cost model and serves several functions for all parties to the construction contract, both in pre-contract cost planning and post contract cost control. It was used as the main source of data, both directly and indirectly, for making long term MR expenditure forecasts for the case study developments in Chapter 5. Direct analysis was undertaken from the BQs supplied by collaborating HAs, and indirect analysis through Detailed Cost Analysis supplied by the Building Cost Information Service (BCIS). However, the pricing of the BQ normally bears little resemblance to how costs are actually incurred on site. Furthermore the way in which it is priced by the estimator is likely to be based on a different model than the earlier stages of the cost plan. Modelling how costs are actually incurred on site is not usually undertaken until the post contract stage. Brandon argues (43) that the BQ has reached the highest degree of improvement that can be expected. As a black box model it does not attempt to represent the way in which costs actually arise and thus, limited meaningful information can be derived from it since many of the assumptions upon which data is based are missing.

4.4 Development of Alternative Cost Models

It has been the growing dissatisfaction with the deficiencies of traditional methods, together with the greater opportunities available for alternatives, that have provided the incentive to consider other means. Simulation models, based on the actual site activities having a cost consequence, were seen by Brandon (44) as the best means of cost planning. An increasing use of simulation models was forecast and this has been borne out by a recent review of construction cost models (45). The perceived advantages of simulation are that there is no changing model structure as information is refined and, with regard to pre-contract cost planning, communication is enhanced

from sketch design through to construction. The computer is seen as the main pressure for change but for the foreseeable future difficulties will remain, not in hardware and software development, but with the collection and collation of data to feed new models. The availability of quality data is a universal research problem, but it is probably the most important and widely discussed issue in LCC. The extent of this problem is explored in Chapter 5.

The advances in modelling that have taken place, though, have been relatively unco-ordinated. There has been no real focus in the academic community and no common "language" **(44)** that puts modelling in a construction management context. Instead research work is bound by individual techniques and terminology. This inevitably leads to a perceived heavily mathematical slant in modelling papers that seems remote from the problem in practice, confirming the view that OR is regarded as a mathematical subject. Newton believes this has a "stultifying" effect on research, confirming Brandon's view **(44)** that much work is destined to be isolated. He attempted to address the need for a common framework, to provide future research direction, by devising a reference system for construction cost models. By analysing over 50 models developed since 1960 a series of "descriptive primitives" were laid down that could be used to classify models. Whilst such a classification system may not have the intended unifying effect on research (there appears to have been little in the way of response to the call for a standardised format) it was useful for identifying trends in research direction. Using his system of descriptors Newton identified the pattern of cost modelling and highlighted where the emphasis has lain in some 30 years of research. The most likely cost model is one which applies to a standard proposal , using abstract units of measurement to price a project at macro level, and is most likely applied early on in the design process. Assumptions are likely to be implicit and have a deterministic outcome. On current trends the most likely model of the future will use as-built units of measurements i.e. they will be intended for use by project managers to plan and programme operations on-site. Considerably more use will be made of stochastic techniques, as in simulation. This is not surprising due to the uncertainty inherent in construction and the need to take formal account of it. It is interesting to note that all the simulation models reviewed had been published in the last decade, reflecting the fact that the technique is only really practicable with the recent widespread availability of powerful computing facilities. Newton contends that as the cost problem is better understood there will be a drift toward optimisation models. This seems logical since simulation is regarded as a "last resort" technique **(46)** suitable for use in situations where there are many unknowns. However this shift toward optimisation is not likely to occur for many years. Advances in simulation, to the point of practical application may itself take decades.

39

4.5 Optimisation Models

Those models that appear to have had the least success in making the transition from academia to industry are MP models. In the 1950s project planning methods such as CPM and PERT were developed (47) to model the time parameter of projects, and these techniques are widely used today in project management. In the 1960s attempts were made develop them using MP algorithms to optimise the time and cost parameters of construction activities. The limited technology that was available stifled their development as they were dependant on mainframe computers to run, making them very impractical. Throughout the 1960s and 1970s the development of mathematical models continued but still they remained impractical and unworkable. The prevailing problem was their complexity which commanded a great deal of expensive computer time. More recently a proliferation of models have appeared in the construction management press, however the resistance engendered in the industry to over-sophisticated mathematical models remains as the barrier to practical implementation of the numerous techniques advocated. As a result models become ever more sophisticated, but lack the data needed to make them widely usable.

4.5.1 Mathematical Programming Models

In recent years the emphasis in MP models has been to attempt to optimise the time and cost parameters as described above by co-ordinating construction activities on site. Cusack (46) stresses the importance of taking care in selecting only the most important variables with the greatest cost significance. This is, of course, applicable to any type of modelling. Data must be used carefully and the effect it has on the accuracy of the model considered. For example, labour is a major resource but actual output can vary considerably in different situations and from individual to individual. This contrasts with plant levels of production whose output is relatively consistent and easier to assess. In summary Cusack outlined the steps needed to model the resource scheduling problem on site.

- Determine variable factors in order to control and predict them. Identify those having a significant effect on time and cost parameters.
- Explore relationships between time and cost parameters.
- Formulate the model, then test it.

These steps are not unique to resource scheduling problems in construction. They are typical of the process for the development of any quantitative model, and are variously described in most OR texts, such is their fundamental importance. Chapter 4.5.4 analyses each of these stages with regard to the SF research.

4.6 Towards a Sinking Fund Model

It is only in the last few years that SFs have attracted widespread interest as a means of long term financial planning for maintenance. In British HAs the motivation has been wholly due to the new funding regime. In a wider context, though, there is a growing awareness that the long term management of built assets must be improved to preserve the value and utility of buildings. From the reported experiences described in chapter 2, SFs have been derived in two ways using financial calculations. The first is to determine a single capital sum to be invested at the outset; the second is to calculate a constant sum to be invested annually. The literature deals with the issue of SFs in an exploratory way. Beyond the straightforward calculation of SF's there appears to be little investigation into other methods of maintenance provisioning, or feedback from any system in operation. It is contended that this is because there has been little demand for refining the means of planning.

Modelling, rather than merely calculating SFs, offers a flexible planning tool for maintenance management, allowing managerial as well as purely technological considerations to be formally accounted for. Chapter 3.6 described how one HA had sought to manage its SF strategy to reconcile with repayment of loan charges. In a maintenance organisation this will involve the body that plans and administers maintenance, and the body that sanctions the funds. The traditional problem faced by maintenance departments is that annual budgets are dictated more by prevailing financial pressures on the organisation rather than actual need of the stock. This has been identified as a problem (48, 49), with the proposed solution being to prepare a well argued case, using sophisticated projections of need before approaching management.

4.6.1 Mathematical Programming Model of Sinking Funds

The necessity for creating SFs for all HA stock under the new financial regime justifies a more sophisticated investigation into the problem. It was decided on this basis to apply Mathematical Programming (MP) to the problem to build models of SFs. MP must not be confused with computer programming. It is "programming" in the sense of planning, and as such it need have nothing to do with computing. Inevitably, though, MP becomes involved with computing since problems can only be reasonably solved by computer. There are several types of MP models, but the most widely used type is the LP and this is the type applied in the research. The software used in the project to solve the models is described in Chapter 4.8.

There are various types of models used for problem solving and the most suitable type will depend on the nature of the problem. Three broad categories of problems have been identified (49) that will influence the type of model applied. It may be that a model is used, (1) where the choices in decision making are overwhelming, (2) where the consequences of decision are

obscure, or (3) where there is a lack of knowledge about objectives. Although it is true to say that all three may be evident in any problem it is likely that one will predominate. The first category best describes the characteristic of the SF problem. In this area the consequences of diverting amounts of money are understood, but the arithmetical labour involved in determining the best strategy is not practical. Linear Programming models, where the processes can be represented by quite elementary algebra, are used to determine the best strategy for various criteria. There are of course many factors at play and it should be understood that the notion of a "best" strategy is a mathematical rather than real world idea. The value of quantitative models' are widely interpreted by individuals. At one extreme people deny they have any value at all for planning purposes, basing criticism on the impossibility of satisfactorily quantifying much of the required data - the "other" factors mentioned. At the other extreme people put too much faith in a model which is unwarranted and dangerous. It must be remembered that a model is a selective representation of reality and should only be used as one of a number of means for decision making.

There are a number of motives for building MP models of problems, two important ones are described by Williams (40). Firstly, the actual exercise of building it often reveals relationships in some system that were not apparent to people, and as a result a greater understanding is achieved. This can only really be true where the modelling exercise is carried out from within the organisation, with input from all affected personnel. Section 2 describes the practical process of introducing modelling to the collaborating associations. Secondly, having built a model it is possible to analyse it mathematically to help suggest courses which might not otherwise be apparent. This was the main motive for the modelling research. With analysis of the different means it was intended to compare approaches and determine under which circumstances MP models could be justified.

4.6.2 Structure of Linear Programming Model

Linear Programming is used to determine how to achieve an objective whilst satisfying all the basic requirements of a problem situation (51). LP typically deals with the problem of allocating limited resources in order to maximise profit or minimise cost. Two essential features of any LP model are:

- There is a single linear expression to be maximised or minimised.
- There are a series of constraints in the form of linear expressions which must not exceed, fall below, or must equal a specified value.

The SF models described have minimisation as their objective function. That is to say the objective is to fund the series of forecast expenditures in the MR maintenance programme for the

lowest possible cost in accordance with the funding strategy set out. Introducing the concept of a strategy is what separates mechanistic calculation from modelling. Different strategies are modelled by altering the objective functions and constraints. Depending on the policy objectives of the HA it may be desirable to minimise the total amount of contributions over the entire building life, or for a specified shorter planning period. As the results in Chapter 6 show different objectives may not necessarily be conflicting and there may be many alternative profiles that will satisfy the maintenance requirements at minimum overall cost. This property of LP is known as degeneracy and occurs where different solutions have the same overall cost. The series of constraints that are formulated in the LP provide the desired SF contribution strategy, reflecting the allowable changes in deposit from year to year. It may for example be decided that the deposits each year should fall within a certain range, or remain fixed for a set number of years before increasing, or increase by a constant amount each year. By modifying the constraint relating to the deposits in each year, many profiles are obtained, some of which will enable the maintenance demand to be met at minimum NPV. Clearly, when the constraints are made unduly restrictive, the NPV will increase. It is in this respect that the flexibility of LP is realised, allowing HAs to examine the impact of various funding strategies (52).

4.6.3 Components of a Model

A model can be described as an abstract representation of a real life system, or problem, being studied. The success of bringing OR techniques to bear on the decision making process depends very much on sound model building practice. There are general principles for building models to guide the developing process stage by stage which are instrumental in successful problem solving. The practice of these principles are considered in the context of the SF model in Part 2.

A simple conceptual representation of a quantitative model of any type is shown in Figure 4.1. To obtain a solution to the problem two types of input are needed - uncontrollable and controllable. Controllable inputs are determined by the decision maker and in an LP model are represented by the decision variables. These are the amounts deposited and the balance of the fund for each year of the plan. Uncontrollable inputs are, as the term suggests, factors affecting the solution that are not under the control of the decision maker. Timings and costs of the stream of major maintenance activities, and the rate of return achievable are uncontrollable inputs. The terms are not absolute, though. In the short term timing of maintenance is determined by management, but these decisions are taken in response to the condition of the stock, influenced by degradation factors outwith the control of management. Similarly, the balance of the fund - a controllable input - is controlled to the extent that management decides how much should be invested, but expenditure is influenced by maintenance need. In the construction of a model uncontrollable inputs can either be treated as if they are known with certainty, as in a deterministic model, or their uncertainty can be explicitly represented. Stochastic programming is

a technique that can be employed in the latter case where the data is supplied in the form of a probability distribution. Williams states **(40)** that it is fairly rare for sufficient information to be known to be able to specify a distribution. Although data in many models is uncertain, he argues that their representation by expected values is usually sufficient. In the SF studies all the values of the uncontrollable inputs in the LP models are deterministic. Account is taken of the uncertainty inherent in maintenance forecasting though, in the way the data used by the models are generated. Monte-Carlo (MC) simulation is applied in Chapter 7 to provide probabilistic projected replacement costs for the case studies. Results from using the more sophisticated data are then compared with results from pure deterministic models.

Popular, off the shelf software has emerged in the last 10 years and permeated all levels of management, giving power to "generalist" users to build and use their own models. This has been a source of concern amongst some OR practitioners, who see poor model building skills in an increasing number of personnel in key positions who are using models in quantitative decision making. This concern has appeared in a number of papers highlighting the apparent shortfall in skills. Powell contends **(53)** that because the capability of today's hardware and software does not necessitate a highly disciplined approach to modelling the result has been some "sloppy" modelling practices. The most common form of practical model building amongst both specialist OR practitioners and generalist users occurs with spreadsheets. A survey **(54)** of actual spreadsheet models in use, drawn from a varied range of organisations, revealed that a quarter were unsatisfactory in some way. Common errors were found in the assumptions made, the logical relationships between variables and a lack of proper problem definition or documentation. The overriding concern is that the decline of specialist modellers is resulting in an erosion of model building skills amongst the new breed of modeller **(55)**. The OR lobby appears concerned that their traditional roles and client base are diminishing with the DIY approach of many managers, but argue that they could contribute skills to the model formulation process. A structured approach to formulation is a process widely recognised to be almost as valuable as the model output itself since a clear problem definition reveals much about the system being modelled.
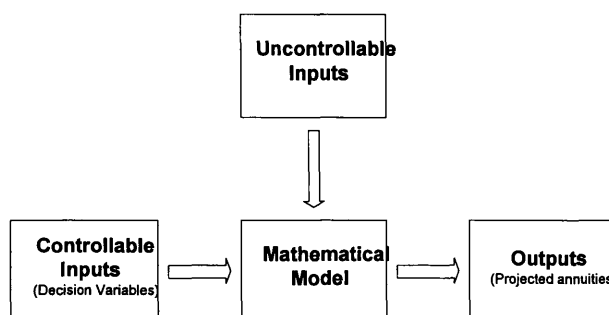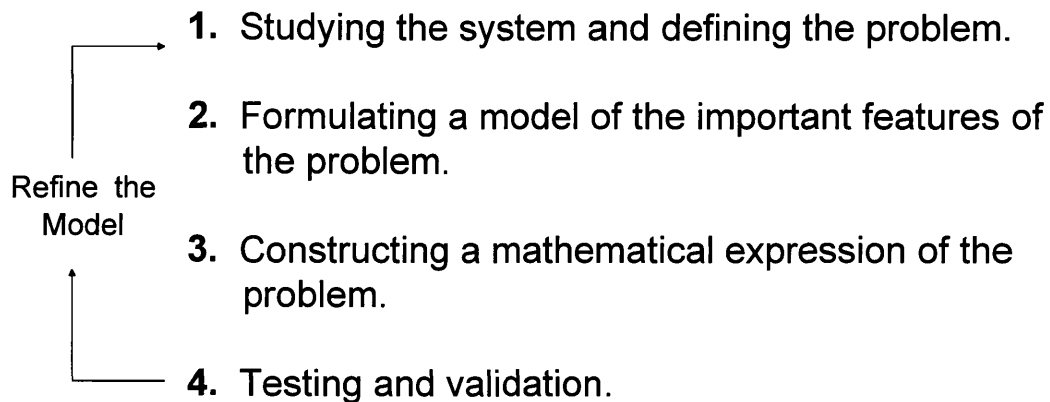

Figure 4.1 Classic representation of a model. Source **56**

4.6.4 Building a Model of the Problem

Traditionally OR texts have described the work involved in constructing any quantitative model by a number of steps to be followed. The following are typical of the many variations which exist on the theory of good model building practice.

1. Studying the system and defining the problem.

2. Formulating a model of the important features of the problem.

Refine the Model

3. Constructing a mathematical expression of the problem.

4. Testing and validation.

These stages, whilst providing convenient categories with which to analyse the modelling research, imply a rigid structure which is rarely present in practical situations, particularly in new areas. This was experienced in the development of SF modelling, mainly because the initiative for the project was taken by the author and not the organisations' under study. The traditional stages describing model building appear to indicate a largely reactive role for the researcher/analyst, but a proactive approach had to be adopted to advance the development of the modelling. Some strong parallels existed between the experience of dealing with HAs and the relationships between analysts and organisations in the field of Community OR. This was an initiative (57) launched by the OR society in an attempt to diversify the practice of operations research by introducing voluntary organisations to methods and techniques of potential benefit to them. The "interventionist" approach necessary in such cases (as opposed to the traditional client-led approach) provides many obstacles to successfully realising the potential of applications in novel fields. Reference is made to these relevant factors throughout the following description of the stages undertaken.

4.6.5 Problem Definition

Studying the system and defining the problem is widely regarded as being one of the most important stages in OR, setting out the basis upon which the whole exercise is conducted. The term "problem definition" is widely used for this stage of the process, but this is slightly misleading as it suggests a precise and unambiguous specification can be drawn up at the outset. There is usually no absolute definition applicable to the problem because everyone in an

organisation involved in the modelling will have their own views as to what the objectives are. Some objective parameters are evident in the problem description, provided for by the regulatory guidance note (2). Thus, it is external factors which provide a structure to the problem, rather than from parameters set within the organisation. This at least provides a starting point with which to build models and introduce the concept to associations. At this stage there are no further manifest constraints because no SF system has been operating in the HAs. Progressing from this point, the description of the problem and the objectives become subjective since any further constraints are imposed from within. Ultimately the models will be a compromise of the views of anyone with an input to the formulation since different parts of an organisation are given different criteria of performance and objectives which may be conflicting (41). Ideally, in the development of a problem description everyone affected by the system would contribute.

In a HA the amount of money invested into a SF will have consequences for various functions of the association, most tangibly on the maintenance policy and service offered. The amount of free financial reserves will also be affected, with implications for the associations financial strength and ability to attract private finance. Perhaps most importantly is the effect the SF policy will have on rental levels. In can be seen then, that a comprehensive model could conceivably involve maintenance staff, development staff, accounting staff and housing officers if a group were set up to study the problem. From the organisational structure of a typical medium sized association (Figure 4.2) it can be seen that nearly all branches would be affected. However, practical considerations must intrude to allow development of the model. There is a need to simplify the problem in order to make progress.
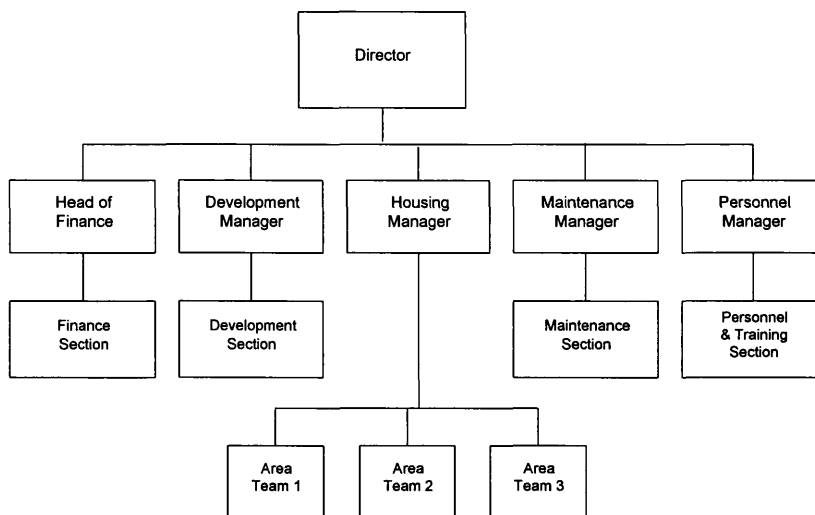

Figure 4.2 The Organisational Structure of a HA. Source (7)

4.7 Attempts to Develop SF Modelling : The "Soft" Dimension

In moving from the calculations of valuation mathematics to a MP approach it was originally intended to involve the HAs who supplied data in the actual modelling process. By doing so, the resulting models would be more realistic and of practical benefit to the associations. However, the nature of the relationship was one of the author developing a range of optimum SF models without input from HA staff, and periodically reporting back on the results. In practice successful OR depends very much on organisational involvement. The emphasis of much of the recent literature reflects this and argues how it could be developed. Several reasons are presented for the lack of a more interactive client\modeller approach and the effect this has on the development of the modelling. Some of these reasons are acknowledged in the OR literature and applicable to many types of organisations, and some are unique to the research.

Once a relationship had been established with the two participating HAs, the first stage was to analyse the SF need for various live schemes. The analysis was based on using the newly issued SFHA model procedures (2), based on financial calculations. At the time of reporting back on the results of the study, the potential for modelling SF payments as an alternative to mechanistic calculation was raised. The approach in the case of both HAs was different. At Association A, the research being carried out was described in specific OR terms, and how the techniques could be directed to the issue of informing SF policy. Explicit reference was made to optimisation models and linear programming. With hindsight it is felt that communicating in terms of these techniques merely distracted from the core issues and was not helpful to the process. It was possible that this may have created a perception the study would not be relevant to the organisation. The original intention was to elicit some criteria through interview with key personnel to provide a specification for model formulation. Instead, it was agreed the way forward would be to present sample SF strategies on the data provided that would demonstrate the benefits of LP. With Association B it was decided, in the light of experience, not to mention the mechanics of the proposed methods before embarking on the modelling. The research was simply described as an investigation into managing the SF as an alternative to simple calculation. In the subsequent reports to both associations no mention was made of any of the techniques employed, only the results and perceived benefits were concentrated upon.

It became apparent that producing various LP models from the data provided would have little chance of being used as a basis for forming SF policy. The embryonic nature of SF systems in use suggests that, for the time being, there is a considerable gulf between the LP research and its application. In a general sense successful application is more probable in cases where the initiative is client-led, for then the organisation has a vested interest in using the results of a study.

In the research project it was simply not possible to proceed in such a way since the work was not accorded the status by the HAs necessary for such an approach. Common to the Community OR

studies described, the paucity of time managers have available to discuss SF modelling is an inhibiting factor in advancing practically based models. As involvement with each HA was limited to infrequent meetings with senior managers the emphasis of the modelling work was on the "hard" dimension i.e. quantitative analysis on the data provided using the LP models. Various models of SF policy for the case study data were produced and solved, enabling the results to be compared with those derived from conventional valuation calculations. In the evolvement of community OR it was originally believed that using quantitative analysis techniques such as LP in organisations unfamiliar with them, would be too rigid and insensitive for their requirements. However, from experience reported (57) in recent survey results, it was concluded this was not the case. "Harder" OR methods were used across the range of case studies. Rivett (41) has observed that, in the absence of evolving problem formulation there comes a point where the modeller must state his own definition of the problem, objectives, constraints and assumptions. With the research "unsolicited," and being in an area unused to OR, this proactive approach had to be adopted in SF modelling. Thus, the "real world" situation is modelled from the perspective of the author.

4.7.1 Validation

The process of model building is only a part of the function of OR. Once a model of the system being studied has been constructed it must be tested and validated before it is accepted and used to influence real decision making. For an organisation to adapt part of its decision making operations is the clearest vindication of the usefulness of a model. However, it is also true to say that successfully introducing it into an aspect of an organisations activities presents one of the most difficult tasks for the OR practitioner in any field. Gaining acceptance of a model is made possible through its validation and testing of the results, but it is notable that many models stumble fatally at this stage (40). The task is easier where a model is built to represent some existing system operating within the organisation. In these cases the results that are produced can then be compared with historical data and the performance of the model appraised by anyone connected with the system. Such a clear route to validation was not open in the case of the SF LP models produced. The HAs from which data was sought had not yet created any system of SF management as part of their maintenance management practice. Although the regulations have been in place since 1988, the absence of a system operating in two progressive HAs demonstrated how limited experience was in Scotland. The fact that the nature of planning is so long term and that the consequences of inaction will not manifest themselves for such a long time appear to be responsible for "putting off" the issue. The need for associations to adopt a methodology for calculating maintenance provisions was impressed on delegates at the SFHA conference on Property Management (58). The set of model procedures (59) based on valuation mathematics were commended to delegates as a starting point. It was reported that some HAs had taken steps to building up SF provisions by applying the SH yardstick, whereby a fixed

percentage of original construction costs are committed to a SF each year. The research carried out, however, indicates that the provision accruing from such an approach will not be enough to sustain the major maintenance demand that new developments will give rise to.

The development and validation of models are not discrete processes whereby validation begins only once the models are developed, though it does often seem this way from the theory presented in many MS texts. The steps involved are more accurately described as iterative rather than sequential (60). Building and validation of a model is a two way process which should gradually converge on a more and more accurate representation of the situation being modelled (40).

For a SF model to be used by an association to influence policy the motivation for building it would almost certainly have to come from within, with the involvement of a number of key members of staff. The activities of each HA are unique and it is not possible to "deliver" a model at some point in time and expect it to be relevant to the changing needs of an association. The problem is a dynamic one and the type of OR work envisaged would be more characteristic of on-going consultancy or in-house work to develop a bespoke system. Providing occasional reports of modelling can only act as an incentive for adopting some form of modelling (not necessarily LP.) As it is it would appear that, for HAs, the issue of SFs for long term MR does not yet demand such detailed study. This should not perhaps be surprising as maintenance is still largely balance sheet oriented - budget driven rather than needs driven as the SFHA describes it. HAs are still in receipt of substantial sums of public money and, for as long as this is the case, many of the organisational decisions made, including those on maintenance, will be politically motivated.

4.8 The SF Models

The formulations presented in this section represent two general model structures. These are combined with the sets of data from chapter 5, providing many model instances to be solved and analysed. The data provides the models' with the forecast maintenance demand for each housing development and criteria for SF payment strategy. Appendices 1 and 2 contain listings of the text files of XPRESS-MP code generated from the models.

There are some basic assumptions present in the SF calculations that are also implicit in the model. All adjustments to the fund are made at the end of each year in the following order. Interest is credited to the fund (or debited from the fund at a higher rate if overdrawn) the annuity is deposited, and expenditure (if any) is deducted from the balance.

4.8.1 Model Type 1

This shares the characteristics of conventional SFs described in the literature and examined in Chapter 3. The solution provides a profile of deposits that ensures there are always sufficient funds to meet the projected maintenance requirements for the planning horizon. Unlike conventional calculation the profile of deposits can be manipulated to reflect the desired strategy by specifying upper and lower bounds on changes in the value of SF payments. They may be set to rise by a specified amount or change within a predetermined range from year to year. By modifying the constraints relating to deposits in each year many profiles are obtained. Some of the profiles enable the maintenance demand to be met at minimum total NPV of SF payments - the stated objective function. Clearly when the constraints are made unduly restrictive the NPV will increase. It is in this respect that the flexibility of LP allows the impact of various funding strategies to be examined. A variation of the model is provided by substituting the objective function to minimise the initial contribution instead of minimising the total NPV. This is an important value since it is in the early years of a scheme's life that the burden of SF payments are greatest on a HAs finances. The model is a continuous LP. All of the variables can take on the value of any real number i.e. fractional values are acceptable.

Model 1 Formulation

Variables

L_j = Lower bound value of current SF payment as a proportion of previous years payment
    (i.e Amount below which SF payment cannot fall)

U_j = Upper bound value of current SF payment as a proportion of previous years payment
    (i.e. Amount above which SF payment cannot rise)

N = Length of planning horizon(years)

x_j = SF deposit at the end of year j

    j = Year of projection $(j = 1, ..., N)$

$\Delta_A = (1 + i_A)$, where $100 i_A \%$ is the interest earned on the SF provision.

C_j = Cost of Major Repairs, assumed to occur at the end of year j

f_j = Fund value at end of year j

Limits between which subsequent SF contributions must fall.

$$L_{j+1} \leq \frac{x_{j+1}}{x_j} \leq U_{j+1} \quad \text{for } j = 1, ..., N-1 \qquad (4.1)$$

The value of the SF at the end of each year. Interest is credited to the fund at the end of each year, immediately before the current SF contribution is deposited and MR expenditure (if any) is deducted.

$$f_{j+1} = f_j \Delta_A + x_{j+1} - C_{j+1} \qquad \text{for } j = 1, ..., N\text{-}1 \qquad (4.2)$$

The value of the fund at the end of the first year is equal to the first SF contribution.

$$x_1 - f_1 = 0 \qquad (4.3)$$

The objective function is to minimise the total value of SF contributions over the planning horizon, as measured by their Net Present Value (NPV). A feature of this model is a considerable amount of degeneracy in the solutions.

$$\text{minimise} \quad \sum_{j=1}^{N} \Delta_A^{-j} x_j \qquad (4.4)$$

4.8.2 Model Type 2

Some profiles of maintenance requirement are more efficiently funded if the fund is allowed to go into deficit. This model exploits this by not restricting the "fund" to remain in credit for the entire period of the projection. It is permissible for the fund to go into deficit up to some maximum level, expressed as a series of constraints, one for each year, in the model. It is natural to suppose that the interest rate charged on funds in deficit will exceed interest earned on funds in credit. This imposes a penalty for being overdrawn reflecting the cost (actual or imposed) of obtaining finance from sources other than the MRP. To model the state of being in credit or debit in the formulation requires some of the variables to assume integer values of either 0 or 1. These 0-1 variables represent "yes" or "no" decisions to determine which rate of interest to apply. The principles behind the use of 0-1 variables to impose the logical conditioning are discussed by Williams (39). As there are both conventional continuous variables and integer variables present the model is classified as a Mixed Integer LP (MILP). It is computationally much more difficult to solve than continuous LP models with the consequence that considerable computing time is needed to produce results.

Model 2 Formulation

Variables

  m = lower bound value of interest earning SF

  μ = lower bound value of overdrawn SF

  ε = Value below which interest charges apply to SF

M_j = Upper bound value of SF

  δ_j = Status of SF (credit / debit) in year j

Limits between which subsequent SF contributions must fall.

$$L_j \leq \frac{x_{j+1}}{x_j} \leq U_j \qquad \text{for } j = 1, \dots, N-1 \tag{4.5}$$

Set the 0-1 variable, δ, to indicate whether the fund is in credit or overdrawn,

$m \leq f_{j-1} \leq M \rightarrow \delta = 1$, fund is in credit

$u \leq f_{j-1} < m \rightarrow \delta = 0$, fund is overdrawn

$$f_{j-1} + \mu\delta_j \geq \mu \qquad \text{for } j = 2, \dots, N \tag{4.6}$$
$$f_{j-1} \leq M\delta_j - \varepsilon \qquad \text{for } j = 2, \dots, N \tag{4.7}$$

The fund can only be in one state (credit/debit) each year.

where

λ_j = Status of SF (credit / debit) in year j

$$f_{j-1} \geq \mu\lambda_j \tag{4.8}$$
$$f_{j-1} + M\lambda_j \leq M - \varepsilon$$

If the fund is in credit, indicator variables δ' and δ'' will both equal unity, forcing constraints (4.10) and (4.11) to apply.

$$\delta_j^{'} + \delta_j^{''} = \delta_j + 1 \qquad \text{for } j = 1, \dots, N \tag{4.9}$$

These constraints apply the rate of interest earned on the fund if it is in surplus, determined by constraints (4.6) and (4.7). The equality constraint is implied by ensuring $\leq$ and $\geq$ cases hold simultaneously. If $\delta=0$ either the $\leq$ or $\geq$ constraint is forced to be broken.

$$\Delta_A f_{j-1} + x_j - C_j + M\delta_j^{'} \leq f_j + M \quad \text{for } j = 2,...,N \qquad (4.10)$$

$$\Delta_A f_{j-1} + x_j - C_j + m\delta_j^{''} \geq f_j + m \quad \text{for } j = 2,...,N \qquad (4.11)$$

If the fund is overdrawn , indicator variables λ' and λ'' will be set to unity, forcing constraints (4.13) and (4.14) to apply.

$$\lambda_j^{'} + \lambda_j^{''} = \lambda_j + 1 \quad \text{for } j = 1,...,N \qquad (4.12)$$

Similar to constraints (4.10) and (4.11). If the fund is overdrawn both constraints will hold implying equality. Interest charges are levied at the higher rate,
where
$\Delta_B = (1 + i_B)$, where $100 i_B \%$ is the interest charged on overdrawn SF, $\Delta_B > \Delta_A$

$$\Delta_B f_{j-1} + x_j - C_j + M\lambda_j^{'} \leq f_j + M \quad \text{for } j = 2,...,N \qquad (4.13)$$

$$\Delta_B f_{j-1} + x_j - C_j + \mu\lambda_j^{''} \geq f_j + \mu \quad \text{for } j = 2,...,N \qquad (4.14)$$

The value of the fund at the end of the first year is equal to the first SF contribution.

$$x_1 - f_1 = 0 \qquad (4.15)$$

The objective function is to minimise the total value of SF contributions over the planning horizon, as measured by their Net Present Value (NPV).

$$\text{minimise} \quad \sum_{j=1}^{N} \Delta_A^{-j} x_j \qquad (4.16)$$

4.9 Solving the LP models: The XPRESS-MP Software

Linear Programming need have nothing to do with computer programming, but in practice a computer is all but essential. The computer software used in the project serves two functions.

(1) To build the model into a solvable form that is acceptable to the optimiser.

(2) carry out the arithmetic of the solution algorithm (the optimising function).

The XPRESS-MP package **(61)** is both a mathematical modelling and optimisation package. Its modelling module (MP-MODEL) provides the language for describing the problem. The optimisation module (MP-OPT) provides the solution algorithm that reads in and solves the problem description produced by the modeller. The software can use a variety of front-ends to suit the user, and for the project the QPRO V.4 **(62)** spreadsheet was used. This provided a convenient means for both inputting data to the models and analysing the subsequent solutions. Spreadsheets also have their own Macro programming language and use was made of this in the development of the simulation and dynamic forecast models (see Chapters 7 and 8). Figure 4.3 shows the steps typically involved in creating and solving an LP using the XPRESS modules.
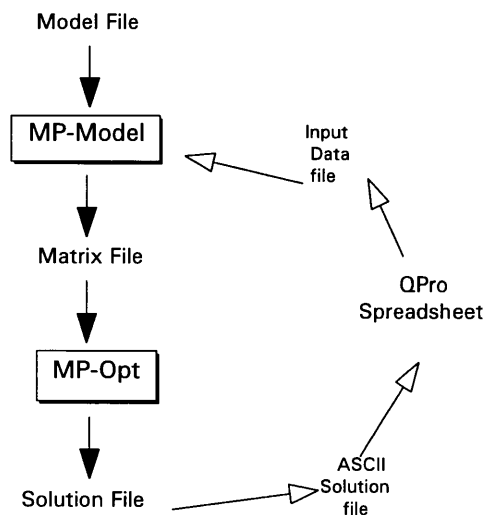
Figure 4.3 Interface between spreadsheet and XPRESS

MP-MODEL - is a matrix generator language which structures and outputs the problem to the solution module in the form of a model. Matrix generators can be thought of as high level programming languages in their own right **(40)**. They convert the form in which the model is conceived by the human modeller, using natural algebraic formulation, into the form of model

solved by the optimiser **(63)**. Using XPRESS the formulations were provided to MP-MODEL using standard ASCII text files, written with the text editor supplied in MS-DOS V.5.

MP-OPT - the optimiser uses a standard numerical solution technique, known as the revised simplex algorithm, to solve the LP matrices generated by MP-MODEL. For mixed integer programming the optimiser uses the branch and bound technique.

CHAPTER 5   DATA NEEDS FOR SINKING FUND PROJECTION

5.1 Introduction

In the UK interest in predicting the long term maintenance costs of buildings originates in the 1950s, when the discipline of LCC emerged (64). The life cycle cost is the total cost of owning and managing a building, and includes initial procurement, energy costs, cleaning costs, rates, maintenance and disposal/demolition costs at the end of its life. Under the new funding regime for HAs these costs (excluding procurement and disposal) are all borne by the tenant, some directly, but most through rent paid to the HA. Expenditure on MR will represent a major proportion of the total costs. Both practitioners and clients acknowledge the importance of LCC, and several models have been developed. However, there are a number of reasons which hold back its widespread use in practice - the main one being the difficulty of predicting future costs. There are many factors that influence the need for maintenance on buildings. Furthermore, actual expenditure on maintenance when carried out may not reflect the extent of the need. This combination of organisational and technological factors has frustrated attempts to collect data that could be used to drive models. This Chapter reviews the development of LCC techniques used for predicting future costs, and reflects on the efforts to collect meaningful data. To make SF projections sixty year forecasts of MR expenditure have to be made for each new scheme. In the research this data was derived from two types of source. The derivation of the data and its appropriateness is described.

5.2 Development of Life Cycle Costing

LCC's primary concern is to compare and rank, on a purely financial basis, alternative schemes at the design stage of the construction process. The concept is to compare the flow of monies associated with each scheme on an equal basis by taking into account their relative value over time. The importance of LCC is frequently underlined by the fact that initial capital costs account for less than half of the total costs incurred in owning and managing an asset. Although the SF problem is not concerned with comparative analysis, the data needs are common to both exercises i.e. the timing and extent of maintenance costs over the life of the building.

The concept of quantifying total costs (capital, maintenance and running costs) were originally used to consider alternative investment strategies for plant and machinery. Stone (64) transposed the principles from engineering to buildings. Since then a large amount of literature has been devoted to the subject and the basic theory is now well established (65, 66, 67). Most texts are aimed at practitioners and focus on the benefits offered by LCC, describing the techniques of discounting and applying the principles. It is only in recent years that attention has focused on the

availability of data that can actually be used for effective LCC to be practised. Although there is general acceptance that LCC leads to better decision making in many areas **(68, 69)**, academic activity has not been followed to any great extent by practical application and there remains a considerable gap between theory and practice.

5.3 Limitations of Life Cycle Costing

The main reason why LCC is not more widely used is because it deals with future events which are, by their nature, uncertain. The discount rate, lifespan and replacement costs of building parts are all variable and cannot be predicted with certainty. The appropriate discount rate will depend on the circumstances. In development economics a high discount rate is used, reflecting the high risk, speculative nature of property investments which favours lowest initial cost short term options. When appraising public sector construction projects government organisations are concerned with long term returns and apply lower test discount rates. As the implied real rate of interest is 4%-5%, Flanagan and Norman advocate **(68)** that, in the absence of better information, a discount rate of 4% be used. The actual discount rate appropriate for SF projections will depend on the return that can be achieved by the HA. Sensitivity Analysis (SA) is essential to show the effects changes in the rate have on SF projections. Dealing with uncertainty has led critics of LCC to dismiss the technique as irrelevant. Ferry & Brandon believe **(43)** that, in practice, LCC techniques can only work well in two key areas.

1. When dealing with short life and high cost components such as mechanical and electrical equipment.
2. Where a rolling maintenance programme for major installations can be planned.

The first is more relevant to industrial plant, but the second is required for effective estate management. Despite thirty or so years of LCC research in construction there is still no definitive guide to building and building component lifespans. Although the atmospheric agents that cause deterioration of building components are well understood **(19, 70)** the complex nature of their interaction makes it impossible to accurately assess the durability of individual components in use. The longer the planning horizon the less confident one can be about estimates of element lifespan and cost. It is not hard to see why SF's, with a planning horizon of 60 years, has been perceived as a problem which can be "put off" because of more pressing problems in the short term.

5.4 Sources of Data for Maintenance Forecasting

With the lack of a refined forecasting model empirical evidence is the only means of providing data for predicting the lifespan of building parts under varying conditions of use. However this information simply does not exist in any usable form, and where recorded data is available its use in maintenance forecasting has not been successful, as discussed in section 5.7. There is an "inadequate amount of data at present available to implement the method [LCC]" (71). The data in many of the sources are unscientific in nature, and its use for making predictions is often qualified. There is no definitive assessments for the case studies. McDermott (19) illustrated the substantial variation of assessed lifespans for similarly specified components in similar building types, based on a review of manufacturers information and research based literature. Dell'isola's data (71) is "subject to wide variations...and is based on part on opinions of those in the field." The Property Services Agency is a little more blunt, conceding that their cost-in-use data is "inevitably based largely on informed opinion rather than hard fact. In short, predicting durability is not an exact science and periods arrived at for predicted lives will sometimes be no more than an informed estimation (72). In researching housing lifespans (19) concluded that there was no evidence to substantiate or disprove the conventional assumptions made for housing lifespans. The traditional and widely accepted assumptions are notional and not based on any sound scientific basis. The "normal" life of new housing is categorised as having a minimum life of sixty years.

The NBA report (73) attempted to draw together published knowledge and opinion relating to life expectancies and maintenance cycles to distil the material into relevant summary form. The report was commissioned by the AC in advance of its study on improving council house maintenance to provide it with background information and for subsequent use by maintenance managers upon publication. More than 7000 titles on technical literature published between 1965 and 1985 were reviewed and it represents probably the most comprehensive collation of data and sources on planned maintenance. However, from the vast array of information gathered, sourced from government, professional and research organisations, the author is careful to point out that the estimates of lifespan and maintenance cycles reproduced are, at best, broad approximations.

5.5 Factors Influencing Maintenance Expenditure

The amount of money actually absorbed by housing stock for long term maintenance is not solely determined by the durability of the constituent components. It is influenced by a mixture of degradation factors, and factors which are relevant to the particular organisation. The former occurs when elements no longer fulfil their functional requirements and manifest themselves through defects and the normal deterioration mechanisms. The latter is a matter of the maintenance standards adopted and type and quality of service provided by the organisation that

makes up the overall maintenance policy. These relative factors have frustrated attempts to build up a useful historical cost database.

- Maintenance Policy and Standards
- Patterns of Usage
- Obsolescence

5.5.1 Maintenance Policy and Standards

Before a maintenance plan can be drawn up management must have a clearly defined maintenance policy, setting objectives for the standard of maintenance offered by the organisation and the type of service that will deliver it. The purpose of the policy is to provide a framework within which maintenance programmes are devised (4), and a means of measuring the performance of the programme. A pervasive problem in building maintenance has been the lack of a measurable set of performance standards (74). The lack of a clearly quantifiable need for, and measure of effectiveness of performance, has undoubtedly inhibited the development of maintenance management. The usefulness of objective performance standards in building maintenance for assessing and measuring the efficiency of the maintenance effort are recognised (74, 75). However advances in defining a set of meaningful standards, beyond the legally required minimum, have not been made to date. Minimum acceptable standards for building new houses and renovation works to existing houses are set out in the Building Standards regulations. These relate to the integrity of the dwelling with regard to the suitability of materials and construction methods. Statutory Tolerable Standards exist to ensure the continued habitability of housing throughout its life. These were introduced by the Housing Scotland Act in 1969 and relate to the condition and amenity of dwellings. There are nine criteria which housing must meet, set out in the Housing Scotland Act 1987. Local Authorities are responsible for applying the criteria to all housing in their district, irrespective of tenure, and for closing, demolishing or bringing up to standard those that don't within a reasonable period of time (76). SH lay down a very loose standard for associations to work within, directing them only to maintain the habitability of dwellings for upwards of 60 years (2) which is required by statute anyway, only the time scale guidance is significant. Associations decide themselves the level of maintenance effort required to achieve this, through their own maintenance policy.

Even legislative standards are not truly absolute. The Scottish Development Department guidance (77) on meeting statutory minimum tolerable standards relies on qualitative measures of criteria such as "satisfactory" and "sufficient" which are open to interpretation. Maintaining a building "as new," may seem easy to define as being characterised by an absence of disrepair/repairs backlog. However there is no overall agreement as to what this may be (78).

Without standards, all maintenance organisations are affected by discretion in terms of interpreting policy, which varies as it passes down through management (79).

House standards are not static over time. As society and technology advances and buildings increase in complexity, so peoples aspirations rise. The last 100 years or so has seen a consistent rise in floor area of housing and the introduction of the essential facilities of drainage, water and more recently electricity, gas and central heating. Although no specific indicator has been devised to take account of changes in standards estimates based on historical records show that floor area has been increasing on average by 0.4% per annum since 1840 (19). This increase in standards serves to blur the demarcation between what constitutes improvement and essential maintenance in housing (80). For example, the necessary replacement of an old heating system by its modern equivalent is likely to be accompanied by improvements in efficiency and capacity compared with the old. The distinction is important to HAs since MR HAG and SF provisions are only intended to cover replacement of worn out elements and components on a like for like basis (2), ostensibly ruling out improvement. The rationale is that improvements should be financed from rent increases.

5.5.2 Usage

Non-technological factors affecting public housing maintenance demand have been investigated by (77). In a study involving the housing records of several local authorities, the effect the social status of estates had on costs were analysed. It was found that, contrary to the hypothesis, the less desirable areas had the lowest maintenance costs. This may have been due partially to the different perceptions of a satisfactory service between tenant groups. If the perception was high, as was the case in the best estates, tenants may have been motivated to ask for more to be done. Conversely, estates lacking a high social status showed a backlog of maintenance and reduced standards. Thus, artificially low maintenance costs were recorded for these estates.

5.5.3 Obsolescence

Social obsolescence influences decisions on maintenance (43), with the result that work may be carried out prematurely because society demands it. This factor is outwith the scope of the research. A SF provision is intended to finance maintenance to ensure continued habitability, and is thus concerned with physical deterioration whilst obsolescence is concerned more with acceptability. It is recognised, however, that future replacements and renewals will incorporate some degree of improvement, if only because of the new techniques and improved standards brought about through the passage of time.

5.6 Maintenance Need versus Resources.

Traditionally the maintenance effort in all sectors of construction has been inadequate, being accorded a lowly status by management and consequently meagre budgetary resources. It is often viewed as a residual activity, the extent of which is governed by the funds available after expenditure in other areas has been satisfied. In this case a "top down" approach **(81)** to maintenance is adopted, where the available resources are divided between competing maintenance projects. Conversely a "bottom up" approach seeks to begin with actual needs, based on desired standards, to estimate the resources needed. The SFHA recommends that the SF projections should be based on the needs of the stock and not be influenced in any way by the projected reserves. With buildings, particularly housing, some disrepair will always be tolerated **(78)** and has been a feature regardless of its tenure, particularly owner occupied. Clearly, the stock of the HA movement will be no different as it ages. In reality the only way to avoid disrepair would be to adopt a fully comprehensive planned preventative maintenance approach, only attainable at extremely high cost to the detriment of affordable rental levels.

McDermott describes two extremes of long term maintenance strategy that can be implemented to resist the deterioration in housing stock. At one extreme, minimal maintenance can be carried out with major rehabilitation of the entire building at set intervals. This is the approach favoured by Dutch HAs, described in Chapter 2. At the other extreme is a strategy of regular stage by stage element and component replacement. This is the strategy that the SF mechanism provides for. McDermott found **(19)** little information on the long term effects of different strategies, though some research had shown that extending the painterwork cycle increased the cost of the work considerably. More recently Meikle and Connaughton analysed **(82)** the long term implications of conventional maintenance strategies on the stock of housing at national level. The authors' believe that present, and likely future, rates of new housing provision are insufficient to replace existing housing stock based on conventional notions of housing and component lifespan. If the current trend in replacing stock is maintained, it is believed housing will have to last anywhere between two hundred and fifty and one thousand years if it is meet the demands of the population. A new approach to housing maintenance is needed to address the problem of projected shortage in housing stock. Such an approach will consider-

1) How to maintain the existing stock of housing in habitable condition and at affordable cost.
2) How to design and deliver acceptable and maintainable new housing.

The authors' question if there is a need for housing design to recognise that new housing will have to last indefinitely. From a technological viewpoint this is simply not possible as all buildings have a finite lifespan, though properly maintained housing can last for well in excess of the notional 60 year life. The authors suggest other approaches that could alleviate the problem. One challenge may be to develop components that are cheap, easy to install and replace, and are

adaptable to a variety of housing types (system built). The real challenge, though, is a cultural one; to persuade owners that their ownership responsibilities involve replacement - either of the entire asset or of key components- rather than continual repair and maintenance. The challenge is not restricted to housing, but applies to the management of any built asset, where maintenance is still seen largely as a distress purchase. It is only by adopting a long-term needs oriented approach that the value of stock can be preserved in the way envisaged by Meikle and Connaughton. An attitude which accepts that periodic replacement of components is an inevitable and desirable part of any maintenance regime may drive what Holmes calls a "decision approach" to the lifespan of elements (83). Such a policy seeks to determine their life span in order that long term maintenance plans can be relied upon, addressing the criticism of LCC that future uncertainty undermines its usefulness. It is acknowledged, however, that this may not be the most cost effective approach. The wide variability of lifespan in use may mean elements being replaced earlier than necessary.

5.7 Predicting Future Maintenance Using Past Data

The many influences on the long term maintenance demand, and therefore expenditure required for the upkeep of stock, have been identified. The problem remains, however, that there is no means of quantitatively measuring their effect, and there would appear to be little prospect of a significant improvement in this position for the foreseeable future. Investigations have used empirical cost data to try to establish trends over time in an attempt to ascertain future maintenance expenditure. When LCC techniques were first introduced the search for data concentrated on historical data. The assumption was that past trends would be a realistic guide to future costs (84). On this basis considerable research effort was directed to collecting and collating historical information on maintenance and other running costs. The Building Research Establishment (BRE) analysed data from samples of buildings, including housing, and concluded that factors other than physical characteristics influenced maintenance costs. Bird concludes that the hypothesis that running costs may be predicted from historical costs are now discredited. This opinion is largely confirmed elsewhere in the literature. Ashworth and Au-Yeung believe (83) that the inappropriateness of historical data is due to the nature of its recording. Maintenance costs have not traditionally been recorded for the purpose of forecasting, but to satisfy accounting and book keeping requirements. More emphasis is placed on recording the magnitude of cost figures rather than the causes which give rise to them. Spedding offers (86) a similar view in that historical data merely informs on what has been spent but may tell little of the actual need at the time. Recorded figures may not reflect the necessary extent of repairs to a component, but instead represent how much was affordable at the time. The problem of maintenance being budget driven rather than needs driven has already been discussed in Chapter 3. Holmes and Droop analysed (79) a large amount of recorded data relating to LA schools and housing, and although average maintenance costs showed some consistency, the standard deviation fluctuated

considerably. It was clear from this that the contextual nature of the data, which was not recorded was an important factor. Without this, historic information can be misleading.

There are other problems of a more practical nature with using historical data. All data costs money to collect, classify, store, manipulate and retrieve **(86)**. The problem is more relevant to traditional means of manually recorded data than to modern data storage. The routine use of computers to store and perform analysis on maintenance data will largely solve the above problems. However it will take years to build up a worthwhile computerised database that will be of use in maintenance planning. Although computerised storage and manipulation of data is becoming cheaper, the cost of data capture i.e. collecting the type of information needed to improve maintenance projections will always be manpower intensive and therefore costly. Other reasons have been suggested **(85, 86)** as to why historical cost data cannot be considered reliable for making future projections. Technological developments and product improvements mean that non-identical replacements with components having different characteristics are likely. As these will have different performance characteristics in use like-for-like is not being compared and recorded data will serve to distort LCC predictions. Individual organisations also have their own data recording systems and this presents problems of comparability.

It can be concluded therefore that historical costs, taken alone, may be an unreliable guide to future costs **(84)**. Indeed Ashworth and Au-Yeung believe **(85)** that problems inherent in using recorded data discount its reliability to serve the purposes of future cost prediction. Unless the database provides explanatory information it is doubtful whether collecting quantities of detailed data is likely to be particularly useful **(86)**. A long term solution proposed by Ashworth and Au-Yeung **(85)** is to refine cost databases by providing contextual information which could be achieved if standard data recording formats were adopted. Spedding describes **(86)** a research project where a "reason code" was included in the recording of maintenance work to try and provide contextual data. The majority of orders were ascribed to "fair wear and tear."

5.8 Maintenance Forecasting Models: The Techniques of Life Cycle Costing

Conventional LCC exercises are based on deterministic component lifespans. This approach to decision making assumes that the future is known with certainty and predicts precisely when replacement occur. It takes no account of the considerable variability of lifespan. A prevailing criticism of LCC is the quality of decision making it can afford with the crude data that exists. The uncertainty inherent in LCC should not, however, act as a disincentive to employing the techniques. Over the past decade or so the trend has been to use Risk Analysis (RA) in managing the uncertainty. This development is not surprising since the construction industry is subject to more risk and uncertainty than perhaps any other industry **(65, 87)**. We are therefore in a

situation of moving from deterministic forecasts to stochastic forecasts that recognises the random element in component lifespans.

Research at the Bouwcentrum (3) introduced the concept of dynamic lifespan modelling for housing elements. In addition to the single variable of time in static models, a deterioration variable was introduced. The model was applied at the macro level to calculate the future maintenance need of Dutch Corporation housing stock. The lifespan variability of all the building parts making up a reference dwelling were modelled using a truncated normal distribution to represent their replacement need. The lifespan data was based on the arbitrary supposition that 99.7% (6 standard deviations) of all replacements would occur between 0.5 times and 1.5 times the average lifespans. It was concluded that the model gave reasonably accurate indication of the future need for maintenance, although the usefulness of the model is distorted where a backlog of repairs exist. Predictive maintenance techniques are only valid for existing stock if the backlog is first assessed and dealt with. For the AC study on council housing a version of the predictive model was applied to the stock in England and Wales (4). The aim was to set up a profile of the need for expenditure on programmed repairs well into the next century. Applied at a national level the model was, necessarily, fairly crude, using one reference dwelling to be representative of all the stock. In common with the Dutch model the forecast took no account of the current physical condition of the housing i.e. the extent of the backlog of work needing to be carried out to bring it up to standard. The order of magnitude of the backlog revealed by the AC would distort the estimates considerably.

The dynamic modelling of housing lifespans was refined by the CSIRO division of building research in Australia (5). The Government Employee Housing Authority (GEHA) which holds a substantial number of housing properties commissioned a housing asset management system to improve the effectiveness of its housing maintenance operations. The replacement interval was modelled with a beta distribution which can take on many shapes to reflect the decision makers judgement about the durability of the buildings. This advancement on the Dutch work allows optimistic and pessimistic assessments in addition to the neutral assessment reflected by the normal distribution. The beta distribution id considered further in Chapter 7.

Although these dynamic models are more representative than the deterministic one, it is important to note that their parameters are based on subjective assessments of risk. For the Dutch model the normal distribution was considered to provide a good fit with the failure of a sample of incandescent lamps offered as evidence. However lamps operate within relatively closely controlled environments unlike the elements and components being considered in the maintenance demand profile. The SF results presented in Chapters 6,7 and 8 are based on deterministic and stochastic maintenance forecasts, to consider the effect different sets of data have on the results.

5.9 The Case Studies - Sources of Data

The maintenance data for the SF models were based on sixty year deterministic forecasts of MRs need for nine new-build HA developments. For each scheme there are three types of data needed:

1. All elements and components requiring replacement in the planning horizon have to be identified.
2. The lifespan of each building part identified is ascertained.
3. The replacement cost of each building part is ascertained.

A needs oriented approach is adopted in that the maintenance regime is based on technological factors only i.e. replacement of each element/component occurs at the end of its assessed lifespan. For each Scheme the schedule of elements/components and their replacement intervals are listed in Appendix 3. The replacement intervals are derived mainly from the Housing Maintenance Kit (88) and NBA report (73), selected to suit the specification of each component as best as possible. It is assumed that expenditure occurs at the time of each replacement.

For Schemes 1 to 4 the long term maintenance needs were derived from full Bills of Quantities (BQs) for each development. Two recently completed projects were selected from each of the two collaborating HAs. The housing includes flatted developments, cottage units and houses with external works in some cases. All are of traditional construction and procurement and there were no extraordinary design features, site works or construction problems encountered in any of the schemes. The BQ was deemed the most appropriate source of data as it provides all the basic cost and specification on which to base all predicted maintenance activities and costs. Although maintenance forecasts are refined over time the BQ is the best source of information at the outset, which is when initial SF projections have to be made.

Each of the BQs were analysed and all work items associated with each identified maintenance activity were grouped together. Estimates of replacement cost had to be made for each of the activities. There are two ways to deal with future costs. The first is to build the assumed effects inflation will have into cost projections, and use the gross rate of interest earned on SF investments in the calculations. It is however very difficult, if not impossible, to make meaningful long term estimates of the general inflation rate, let alone inflation specific to maintenance work. The labour and material cost inputs can be expected to inflate at different rates. In the absence of meaningful long term estimates it is appropriate to discount inflation in calculations and use a real discount rate for assumed SF yields (65). This assumes inflation will apply equally to all future cash flows. Analysis indicates (65) that when inflation rates are reasonably low there is quite a stable relationship between inflation and bank base rates. Costs extracted directly from the BQ will not be representative of the equivalent work carried out as part of a maintenance programme. Work carried out as part of a refurbishment contract is very

different in nature to the equivalent original work carried out and allowances will have to be made for this. Some factors which must be allowed for in costing the maintenance programme are :

- Professional fees involved in maintenance work.
- Stripping out and disposing the original work being replaced must be allowed for.
- Work will always be less accessible than would be the case during initial construction
- Care must be taken not to damage existing surfaces. Surrounding work will be required to be made good.
- Use of plant may be restricted and work will be more labour intensive.

All the above factors serve to enhance the cost of refurbishment work against new-build work. There is no definite method of assessing, though, by how much the new-build values in the BQ should be inflated to reflect this. The actual degree of enhancement will depend on the circumstance. In a similar exercise Bromilow and Pawsey calculated (31) replacement costs by using a 10% loading on the initial construction costs. The only justification for this was that it would cover increases on "replacements on a completed building rather than placing ab-initio." The pricing of Preliminaries in the BQ will also have a bearing on the loading of initial construction costs. Where priced preliminaries are substantial, a proportion of the sum may be attributable to the individual work packages and allowances should reflect this. Where the Preliminaries value is relatively small it can be assumed that much of the overheads attributable to the individual work sections are included in the relevant rates. Only Scheme 1 had a substantial amount of separately priced Preliminaries, and an element of these were apportioned throughout the measured work items. Ultimately, though, there is no way of knowing exactly how the Preliminaries value should be apportioned throughout the BQ. It is priced as a lump sum with no explanation of how it is built up.

For Schemes 5 to 9 the data was sourced indirectly from BQs, using Detailed Cost Analysis from the BCIS. The Detailed Cost Analysis do not provide the same level of cost and specification information as their source BQ, but it is felt it does provide a reliable basis for illustrating these SF projections. The developments in the examples are sited throughout England as no analysis of Scottish stock is available. Some maintenance activities that are included in the BQ analysis have been left out of the BCIS analysis because of a lack of detail. Brickwork repointing is an example of work that should be planned for, though its omission will not significantly affect the calculated contribution because is likely to be a one-off activity in the long term. Door entry systems have a short life (assumed 15 years) compared to the general electrical installation, but in only one of the BCIS case studies has it been costed separately. It is assumed to be included in the value of the electrical installation in the other studies. The cost of the roof element (element 2C) is given as a lump sum, but for the purposes of the exercise the costs associated with the roof coverings (slates or tiles, underfelt, sarking etc.) should be separated from the cost of the roof structure. Only the coverings will require renewal. Half the total cost of the roof is assumed to

be attributable to its coverings. Similarly windows and external doors are treated as one element (element 2F) but are likely to need replacing at different intervals in the future. In each case study a quarter of the value is attributed to external doors. Some of the developments have minor building works (element 6D) such as binstores and electricity substation housing. These will need periodic maintenance but no allowance has been made in the SF calculations. The element values including the Preliminaries were used in the analyses.

5.9.1 Particular Project Details

The buildings are of traditional construction and procurement with full BQs providing the basis for tender.

Scheme 1

An 18 unit housing development comprising 8 one person, 2 four person, 4 three person and 4 /four person flats. Contract sum: £548700 (Jun. 1991)

Scheme 2

Four blocks of flats and cottages, varying from one to three storeys high. Contract sum: £1108438, including £15707 for demolition of existing structures. (Jun. 1991)

Scheme 3

Ten single storey amenity houses, of traditional construction, in three blocks. Timber fencing and gates. Contract sum: £324332 (Nov. 1989)

Scheme 4

Four 2 person, 2 apartment cottage units and eight 2 person, 2 apartment flatted units. These are constructed in two blocks, each containing 4 flats in two storey modules with two single storey cottage units attached. Contract sum: £348081 (Dec. 1989)

Scheme 5

Three blocks of traditionally constructed housing. Block 1 contains 4 bungalows and 16 two storey flats; blocks 2 and 3 each contain 4 two storey flats. All landscaping is hard. Contract sum: £784630 (Apr. 1988)

Scheme 6

A two storey block of 16 flats. All landscaping is hard. Contract sum: £359276 (Feb. 1991)

Scheme 7

Three pairs of semi-detached two storey, 4 person flats and a two storey block of six single person flats. Contract sum: £604732 (Feb. 1991)

Scheme 8

Twelve single person flats in a two storey block. Contract sum: £387304 (Jun. 1991)

Scheme 9

Eight dwellings comprising five 2 storey houses and three bungalows. The site is bordered by strained wire fences which will require maintenance but no allowance is made for these in the SF calculations. Contract sum: £306263 (Jan. 1991)

CHAPTER 6   RESULTS OF THE SINKING FUND ANALYSES

6.1 Introduction

This chapter presents the results of the whole-life SF analyses, based on data from the nine new-build projects described in Chapter 5. The financial calculations described in Chapter 3 and LP models developed in Chapter 4 are used to project the series of annual SF contributions, necessary to fund the forecast MR. For each case study, four types of analyses are carried out - two are based on equations (3.1) and (3.3), and two are modelled using Linear Programming.

Each SF policy is measured and compared in two ways. The first is the SF payment value for year 1, expressed as a percentage of the development's work costs. The initial calculated payment will apply for a number of years, depending on how the annuity is derived. Using Method 1, multiple SF calculations (see eq. (3.1)) the initial value is constant for several years before intermittently reducing until the end of the forecast. Using Method 2 (see eq. (3.3)) this initial value remains constant throughout the whole SF plan. For the SF strategies derived by LP, the values change earlier and more frequently throughout the projection. The second value used for comparison is the projected total cost of the SF policy i.e. the NPV of all SF payments forecast for the planning horizon. For the most efficient SF policy (in terms of overall cost) the NPV of all SF payments is equal to the NPV of the total maintenance expenditure, in cases where the fund remains in credit throughout the horizon. To achieve this the value of the fund must equal zero at the end of the defined planning period i.e. no projected surplus. In cases where it is permissible to go into deficit, the NPV of SF payments will always exceed the NPV of total MR expenditure as a result of interest charges incurred.

N.B.

Method 1:   **Multiple SF calculations   (equation 3.1)**

Method 2 :   **Constant annual equivalent   (equation 3.3)**

6.2 Calculating the Sinking Fund

The results tabulated in Tables 6.1a to 6.1i and 6.2 are the calculated Year 1 contributions. For each Scheme a number of scenarios are presented.

- Tables 6.1a to 6.1i are based on Method 1. Sensitivity analysis is carried out on the real interest rate and estimated replacement interval of the elements and components in the programme. The percentage adjustments are uniformly applied to all component lifespans for the replacement cycles relevant to each Scheme. These are reproduced in Appendix 3.

69

Although the replacement cycle of long life elements may exceed 60 years in the optimistic scenarios of the sensitivity analysis (and therefore be beyond the planning horizon), all calculated annuities account for at least one replacement of every element. There are two different shadings of cells in each Table. The darker cells indicate values of 0.7% or less, SH current assessment (2) of what constitutes a maximum ASF investment adequate to fund all future MR (described in Chapter 3.4). The lighter shaded cells indicate values of 0.8% or less - the new upper limit being proposed by SH as adequate (89).

• The results in Table 6.3 are based on Method 2, with standard replacement cycles and a real interest rate of 3%. For comparison the results from Method 1 based on the same assumptions are shown.

6.2.1 Method 1: Multiple SF calculations.

The SF calculation (eq. 3.1) is used to calculate a constant annuity for each projected maintenance activity identified in the sixty year programme. These are aggregated to give overall need for each Scheme. The intermittent reduction in total annuity, forecast in the latter half of the plan, results from the maturing of individual SF's. This occurs when there is MR expenditure projected for replacement of a particular component which is not expected to be repeated within the planning horizon. Using this method to build up the required need from the individual maintenance activities, provides an optimum strategy in terms of overall cost for any given profile of expenditure. At the end of the defined planning horizon the fund is wiped out. Thus, the NPV of all stream's of expenditure are equal to the NPV of all ASF contributions.

The figures given in the Tables are the calculated ASF amounts, derived from the multiple SF calculations of Method 1, expressed as a percentage of initial works costs. The figure in the double line bordered cell indicates a "neutral" risk assessment i.e. the result for the most likely discount rate and component lifespan. The figures are projected to remain constant for approximately thirty years before intermittently declining as described above.

Table 6.1a   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 1**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	1.36	1.28	1.21	1.14	1.09
3%	1.20	1.12	1.05	0.99	0.93
4%	1.05	0.98	0.91	0.86	0.80

70

Table 6.1b   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 2**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	1.32	1.23	1.15	1.08	1.02
3%	1.16	1.07	0.99	0.92	0.86
4%	1.01	0.93	0.86	0.79	0.73

Table 6.1c   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 3**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	1.00	0.93	0.87	0.82	0.77
3%	0.88	0.81	0.76	0.70	0.66
4%	0.77	0.71	0.65	0.60	0.56

Table 6.1d   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 4**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	0.93	0.88	0.83	0.78	0.72
3%	0.82	0.77	0.72	0.67	0.61
4%	0.72	0.68	0.63	0.58	0.53

Table 6.1e   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 5**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	1.43	1.34	1.25	1.17	1.10
3%	1.26	1.16	1.08	1.00	0.94
4%	1.10	1.01	0.93	0.86	0.79

Table 6.1f   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 6**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	0.90	0.84	0.78	0.73	0.69
3%	0.78	0.72	0.67	0.62	0.58
4%	0.68	0.62	0.57	0.53	0.49

Table 6.1g   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 7**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	1.23	1.15	1.08	1.01	0.95
3%	1.09	1.01	0.94	0.88	0.82
4%	0.97	0.89	0.82	0.76	0.70

Table 6.1h   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 8**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	1.12	1.05	0.98	0.92	0.86
3%	0.98	0.91	0.84	0.78	0.73
4%	0.86	0.79	0.72	0.67	0.62

Table 6.1i   Calculated ASF Expressed as a Percentage of Initial Works Costs: **SCHEME 9**

Real Int. Rate	Adjustment to Standard Lifespans				
	-10%	-5%	0	+5%	+10%
2%	1.05	0.98	0.92	0.86	0.81
3%	0.91	0.84	0.78	0.73	0.68
4%	0.79	0.73	0.67	0.61	0.57

In only 26 out of the 135 scenarios above is the ASF value less than or equal to the SH yardstick of 0.7%. For Schemes 1,2 and 5 there are no scenarios where the calculated ASF is less than or equal to 0.7%. Under the new yardstick of 0.8% a further 26 cases, making a total of 52, would fall under SH assessment of a maximum adequate ASF. This still represents less than half the number of the annuities calculated. In the majority of cases it is only under the optimistic scenarios of high rates of return and prolonged lifespans that the results fall within the limit being proposed.

Table 6.2 shows the mean and median values from the sensitivity analysis for each Scheme. The dark and light shading again represents values less than 0.7% and 0.8% respectively. For only 4 out of the 9 Schemes were the mean or median values less than 0.8%.

Table 6.2 Mean and Median ASF Values

SCHEME	MEAN	MEDIAN
1	1.06	1.05
2	1.07	1.00
3	0.76	0.76
4	0.73	0.72
5	1.10	1.10
6	0.68	0.68
7	0.95	0.95
8	0.86	0.86
9	0.80	0.79
AVERAGE	**0.89**	**0.86**

It is questionable whether the constant percentage yardstick is an appropriate benchmark for SF assessment given that contributions can vary from year to year. Using multiple SF calculations, as in the exercise above, this will only occur after a substantial length of time (approximately thirty years) after which they are projected to reduce. However, this is not the case for the mathematical models described in succeeding sections.

6.2.2 Method 2 : Annual Equivalent of Total Need

Table 6.3 shows results derived from calculating the annual equivalent of the whole projected maintenance need using eq (3.3). As the annual equivalent is constant the annuity value shown applies to every year of the projection. The results shown are for neutrally assessed risks i.e. no adjustment is made to lifespans and a real interest rate of 3% is assumed. A feasible annual equivalent cannot be fixed using this method for Schemes 3 and 5. The calculated annuity does not provide sufficient funds for forecast MR throughout the planning horizon. This is established with equation (3.4) which returns negative fund values in the final ten years of the projection. Thus, the calculated SF payment for these Schemes cannot be directly compared with that of the other methods of calculation. It was observed that negative fund values become smaller if the discount rate is increased, but only an unreasonably high discount rate used in the calculation gives a feasible annuity.

Table 6.3   Calculated ASF using Method 1 and 2.

SCHEME	Method 1: Multiple SF Calcs.	Method 2: Annual Equivalent
1	1.05	0.99
2	0.99	0.94
3	0.76	-
4	0.72	0.69
5	1.08	-
6	0.67	0.61
7	0.94	0.88
8	0.84	0.80
9	0.78	0.73

6.2.3 Calculated Approaches Compared

Table 6.3 shows the initial ASF derived from multiple-SF calculations (Method 1) is always greater than the initial ASF derived by annual equivalent of total need (Method 2). For a real interest rate of 3% the average discrepancy is 0.064%. Sensitivity analysis shows that the difference between the two increases as the assumed real interest rate decreases. In every case the projected fund value for year 60 is zero (as for Method 1), therefore a constant annuity, where feasible, is efficient in terms of overall cost. The profile of projected SF deposits and SF provision can be seen in the two graphs for each Scheme in Figures 6.1 to 6.9. For each Scheme the properties of the profiles are very similar. Applying eq.3.1 to the forecast expenditure of each MR activity provides a SF profile of intermittently declining annual contributions. The difference in projected annuity displayed by both methods are constant until year 35, at which point the annuities first reduce for the multiple SF calculations (Method 1). In each case this is due to the projected replacement of sanitaryware which has an assumed lifespan of 35 years. No further provision need be made for this work for the remainder of the planning horizon. The reduction at this point in time is greater for those Schemes having concrete tiled roofing. For five of the Schemes this first drop is significant enough to reduce the annuity to below that of the annual equivalent method. Thereafter another two drops in annuity occur in year's 40 and 50, with annuity in the final ten years of the projection approximately between a half and a third that of the initial ASF. The final reduction is the greatest because it is in year 50 that many replacement cycles coincide; such as space heating, power and lighting installations, and drainage. No subsequent replacement of these major works is envisaged in the remaining life of the dwelling. The profile of MRP generated by both methods of calculation is very similar, but with the multiple SF calculations of Method 1 the fund is in credit by a greater margin for most of the planning horizon. This can be seen in the graphs of Figures 6.1b to Figure 6.9b

6.3 Modelling the Sinking Fund

6.3.1 Applying Model Type 1: The Continuous LP

Using the Structure of Model Type 1 (Chapter 4.7.1), four models were built -Model's A, B, C & D- by varying the L_j and U_j values in eq (4.1) These are used to formulate a long term SF strategy by specifying the limits between which subsequent SF contributions must fall. In Model's A, B and C, the objective is to minimise the total NPV of SF contributions over the whole planning horizon. In Model D, the objective is to minimise the SF deposit in Year 1. Thirty six model instances were provided by solving each of the models with the nine sets of data (Schemes 1 to 9). The formulation for the four model structures in XPRESS-MP model code is reproduced in Appendix 1.

- Model A

For this strategy payments are restricted to remain constant for five-yearly periods, with a fixed increase occurring every fifth year. The resulting profile is stepped and constant over the entire planning horizon.

Objective function: minimise $\displaystyle\sum_{j=1}^{N}\Delta_A^{-j}x_j$

Payment Constraints: $Lj=1$, $Uj=1$ for $j=1,..,N-1$ and $j\neq5,10,15,20,25,30,35,40,$
                                                                        $45,50,55$

                        $Lj=1.03$, $Uj=1.03$ for $j=5,10,15,20,25,30,35,40,45,50,55,$

- Model B

The profile of payments in this strategy are linked to forecast expenditure on MR, inasmuch as an increase in SF deposits is only allowed in years following expenditure. The rationale for this is that the Schemes SF burden is related directly to the quality of the housing enjoyed by tenants. An increase in SF deposits, and presumably rents to sustain them, will be easier to justify if the reason for doing so is tangible. A fixed increase of 6% has been imposed in the payment constraints, but a more sophisticated strategy would result from relating the size of the increase to the magnitude of expenditure occurring.

Objective Function: minimise $\displaystyle\sum_{j=1}^{N}\Delta_A^{-j}x_j$

Payment Constraints: $Lj=1$, $Uj=1$ for all j such that $Cj=0$
                        $Lj=1.06$, $Uj=1.06$ for all j such that $Cj>0$

- Model C

In this strategy the deposits are constrained to rise by a constant proportion each year, throughout the planning horizon. The specified annual increment of 3% represents an increase over and above inflation since the real interest rate is used in discounting. The profile of SF deposits is uniformly steep, and shows the sharpest rise over time compared to the other three strategies. A consequence of this is that payments in the former years of the forecast are comparatively low, but overtake the other strategies between approximately a third and a half way through the planning horizon.

Objective function: minimise $\sum_{j=1}^{N} \Delta_A^{-j} x_j$

Payment Constraints: $L_j = 1.03$, $U_j = 1.03$ for $j = 1, .. N-1$

- Model D

This strategy differs from the previous three in two ways. Firstly, the SF payment constraints do not specify the value that subsequent deposits will take on in relation to the previous year's. Instead, a range is specified each year within which the payment value can fall. Secondly, the objective function is to minimise the initial SF payment only. The consequence of less tightly defined criteria on SF annuities is that the projected profile will not result in as predictable a pattern as the previous three strategies. There is also a greater variation in profile between different Schemes.

Objective Function: minimise x_1

Payment Constraints: $L_j = 1$, $U_j = 1.03$ for $j = 1, .. N-1$

6.4 Observations and Results (Model Type 1)

The projected SF payments and corresponding MRP for each Scheme under the different strategies are graphed in Figures 6.10 to 6.18. Table's 6.4 and 6.5 show the NPV's for the different strategies for each Scheme. The properties of these profiles and the results are discussed in the following section.

6.4.1 Model's A and B

For all Schemes the projected profiles for these two models are very similar. As MRs are forecast to occur mainly in five yearly cycles, so increases in Model A, the quinquennial review of deposits, will mainly occur at the same time as model B, the expenditure linked increase. For both strategies, the SF payments are similar throughout the sixty year period in the case of every scheme. A consistent pattern is that the annuities for Model B are initially lower than those Model A, before overtaking them approximately half way through the projection. This is because the increments are greater in the case of Model B.

76

6.4.2 Model's C and D

For every scheme these profiles are identical at least till around half way through the projection. In the case of Scheme's 3 and 5 they are identical until year 50. After these points the profiles diverge as Strategy D flattens out whilst Strategy C continues to rise at a constant rate because it has been constrained to do so in the model. Out of the four strategies this generates the greatest surplus at the end of the forecast for every scheme. Strategy C is also therefore the least efficient, with consistently the highest total NPV of deposits over the 60 year period. In the shorter term these strategies offer the advantage of a low level of annual payments. The initial ASF of Strategies C and D is less than half that of Strategies A and B. This measure is of some importance since it is in the early years that a SF is most burdensome on HA finances.

6.4.3 Tabulated Results

Table 6.4   Results from LP Model Type 1 and 2.

Objective: Minimise NPV of SF Payments				
SCHEME	NPV of Projected MR Expenditure	Model	Objective Function Value	
			Model Type 1	Model Type 2
1	150100	A	150099	-
		B	150099	-
		C	173830	158220
2	289520	A	289520	-
		B	289520	-
		C	328639	296714
3	62130	A	64712	62712
		B	65557	62966
		C	71040	65796
4	66530	A	66528	-
		B	66528	-
		C	77940	69182
5	216210	A	220230	216755
		B	222452	217227
		C	241825	227814
6	60920	A	61817	61030
		B	62440	61144
		C	70516	64727
7	147440	A	149357	147656
		B	150864	147913
		C	172603	158019
8	85360	A	85363	-
		B	85363	-
		C	99235	88789
9	61911	A	61911	-
		B	61911	-
		C	68035	63295

Column 4 of Table 6.4 shows the objective function values (Model Type 1) of Model's A, B and C for each Scheme. It is immediately apparent that several of the values are the same. In five out of nine Schemes (Schemes 1,2,4,8 and 9) the objective function values of Model's A and B are identical. In all of these cases there are several optimal solutions, all having the property that the

fund value at the end of the horizon (f_{60}) is zero, i.e. there are degenerate optimal solutions. For the remaining seventeen solutions the forecast profile of payments is not the most efficient compared with the calculated method of multiple SF equations. For Schemes 3,5,6 and 7 (highlighted) none of the modelled strategies provide as efficient a strategy as any of the calculated results. This reflects the cost of imposing certain constraints as to how contributions can vary over time.

Table 6.5 Results from Model D Strategy for Model Type 1 and 2.

Objective: Minimise Year 1 Contribution				
	Objective Function Value		Total NPV of SF Cost	
SCHEME	Model Type 1	Model Type 2	Model Type 1	Model Type 2
1	0.54%	0.50%	153670	158820
2	0.51%	0.46%	289520	296710
3	0.38%	0.35%	69300	65800
4	0.38%	0.34%	66530	69180
5	0.52%	0.50%	235450	227810
6	0.34%	0.31%	64500	64730
7	0.49%	0.45%	156320	158020
8	0.44%	0.39%	85360	88800
9	0.38%	0.36%	61910	63290

Column 2 of Table 6.5 shows the objective function value of Model D for each of the nine Schemes. In each case the year 1 annuity is approximately half of that calculated by the conventional means. However, the profiles shown in Figures 6.10 to 6.18 show they rise year on year for most of the duration of the forecast. For four of the Schemes (2,4,8 and 9) the objective of minimising both initial deposit and NPV of all deposits is achieved. In the remaining Schemes the total NPV of deposits is only slightly greater than in Model's A, B and C where minimising this value is the explicit objective.

6.5 Applying Model Type 2: The Mixed Integer Linear Programme

The solution to a number of the modelled strategies were restricted by the non-negativity constraint implicit in LP i.e. none of the decision variables in the model could take on negative values. It follows that the fund, in common with the conventional calculation of Method 1, is restricted to remaining in credit in each year of the planning horizon. The reasons why this may not be desirable have been discussed in an earlier chapter. At least one strategy for every Scheme was restricted by this constraint. For Models A, B and C a surplus of funds at the end of the projection indicated that these solutions could be improved. Figure's 6.10 to 6.18 and Table 6.4 show that 17 out of 27 of the solutions could be improved. For Model D, which has an objective of minimising the year 1 payment, a forecast surplus of funds is no indicator as to whether the solution could be improved. The only way to determine if they could is to solve Model D for all Schemes with a relaxed lower bound i.e. the non-negativity constraint is removed.

SFs calculated for two of the Schemes using conventional calculations of Method 2 (described in Chapter 3) did not produce results which could be compared with Method 1 results because some of the projected fund values were negative. In these cases the same interest rate was applied whether the fund value each year was positive or negative. Relaxing the lower bound of the continuous LP models of Type 1 would have the same effect. As it is natural to suppose a higher rate of interest should be applied to negative fund values, Model Type 2 (Chapter 4.7.2) was developed to detect each year if the fund is overdrawn, and apply a higher rate of interest to the overdrawn fund. A total of 26 mixed-integer models were solved (17 from Table 6.4 and 9 from Table 6.5) where improvements to the solution could be made. A very large negative lower bound was set for values of f which would not restrict the solution in any of the models. The interest rate applied to negative fund values was 15%, some 12% more than interest earned on investments which represents a considerable penalty for being overdrawn. The formulation for the four mixed-integer LP model structures in XPRESS-MP model code is reproduced in Appendix 2.

6.5.1 Results (Model Type 2)

Column 5 of Table 6.4 shows the solution of every model of Type 2 yielded better results than Type 1. The objective function ranged from 1% for Strategy C in Scheme 7 to 12% for Strategy C in Scheme 4. The average improvement in objective function was approximately 6%. The interest rate of 15% illustrates that, even when the cost of borrowing is high, the overall cost of SF policy is cheaper when an overdraft facility is available. The improvement varies in inverse proportion to the interest levied on overdrawn fund values. Increasing the interest charge would show the value at which it simply becomes uneconomical to be overdrawn at any time. Figure 6.19 to 6.27 show that deficits are projected at points in time when expenditure peaks are forecast.

The profile of payments for the expenditure linked strategy change with Model Type 2. In each case a smooth upward curve, identical to that of Model D, is evident. For the other strategies the profile of payments are the same, only their magnitude changes.

Column 3 of Table 6.5 shows that the solution for each scheme was only marginally improved with the mixed integer LP. This varied from 0.02% for Scheme 5 to 0.05% for scheme 8. However, for some Schemes the improvement is achieved at the detriment of overall cost, with minimal increases in total NPV.

6.6 Degeneracy in the Sinking Fund Models

Much of the literature that deals with the simplex algorithm for solving Linear Programming problems makes reference to the phenomena of degeneracy. The XPRESS software **(61)**, in common with virtually all commercially available LP packages, uses the revised simplex algorithm to solve problems. Degeneracy is a potential problem with the simplex method and can occur at some stage prior to reaching an optimal solution. However a problem only arises if the algorithm iterates among the same set of basic feasible solutions without ever increasing the value of the objective function. In such circumstances an endless sequence of iterations is gone through without ever finding an optimal solution. This is known as "cycling" and, although in theory would cause a breakdown of the algorithm, is unheard of in practical problems **(51)**. Techniques are documented in the algorithmic orientated LP literature for avoiding such problems should they occur. It has been said that nearly all LP problems arising from practical applications yield degenerate basic feasible (but non-optimal) solutions at some stage of the simplex method **(128)**. Typically, though, this is only a temporary "stalling" of the algorithm which ends with a breakthrough in the form of a non degenerate iteration, allowing it to continue iterating toward an optimal solution. As use was made of an existing software package to solve the Sinking Fund LPs, the study did not involve detailed consideration of the algorithmic aspects of LP. Therefore, the potential problem of degeneracy in the computation of solutions was not an issue. Degeneracy was however exhibited in the solutions of the LP models.

SF Model Type 1 exhibits a considerable amount of degeneracy in the solutions. In this context degeneracy describes the fact that the solutions to many of the model instances have the same objective function value- the optimal overall cost of SF strategy as measured by the NPV of contributions. A particular model instance is given to the model structure by reformulating and re-solving it with different constraints governing how the value of SF contributions change from year to year. This provides different profiles of ASF contributions to reflect a chosen strategy.

Four possible strategies are described in Section 6.3.1. It is stressed that there is no single combination of values for the decision variables that provides the most efficient SF strategy, in terms of minimising the overall cost of the SF policy.

Tables 6.4 and 6.5 show that degenerate optimal solutions were obtained for those Schemes having a projected MR profile which peaks in the final year of the planning horizon. It is likely that there will be many more strategies other than those formulated in Section 6.3.1 that will result in the same objective function values. In practical terms the evidence of degenerate optimal solutions would give the decision maker considerable flexibility in planning an efficient SF strategy, and is one of the greatest strengths of the LP modelling approach over mechanistic calculation of SF annuities.
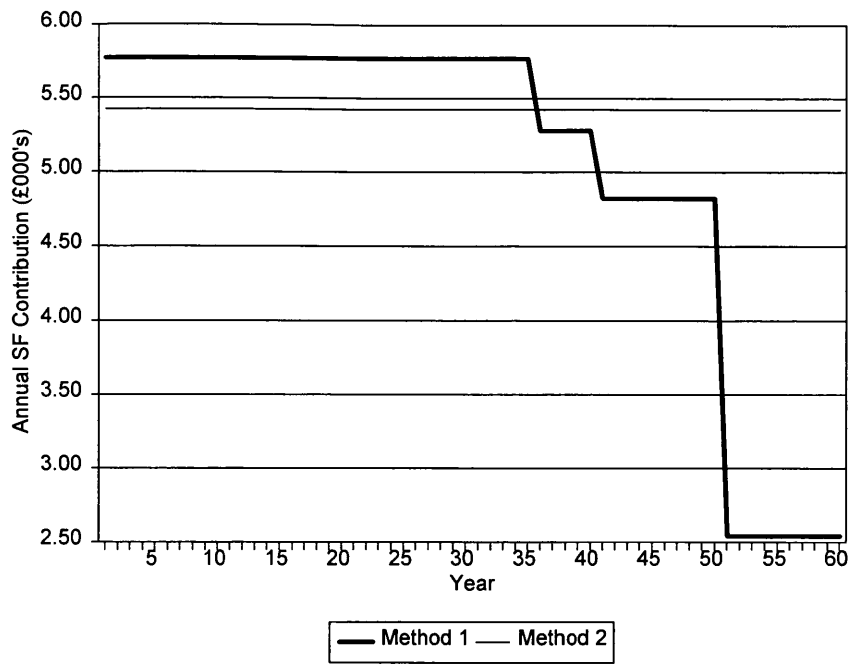
Figure 6.1a Alternative Methods of Calculating an ASF for SCHEME 1
Method 1: Multiple SF Calculations   Method 2: Annual Equivalent
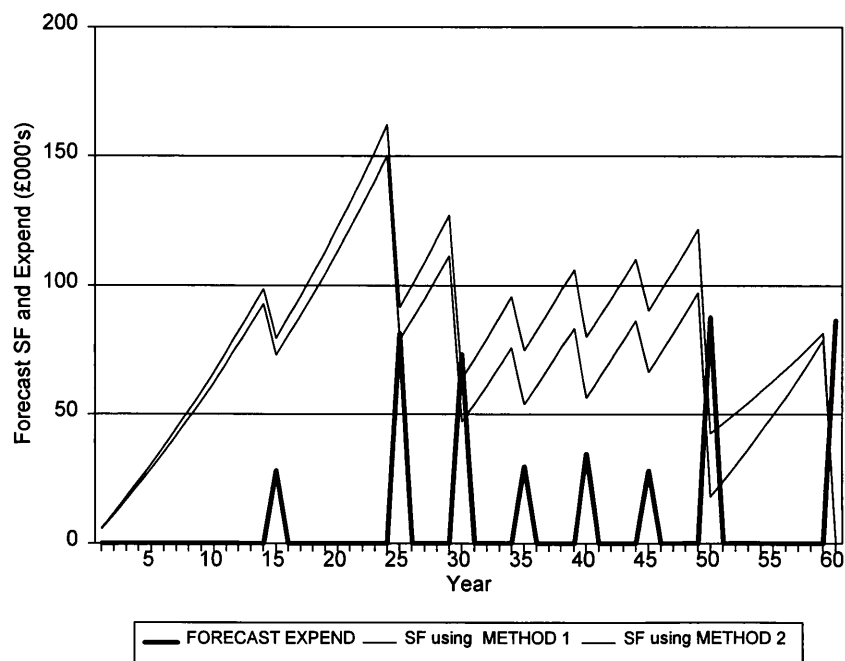
Figure 6.1b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 1
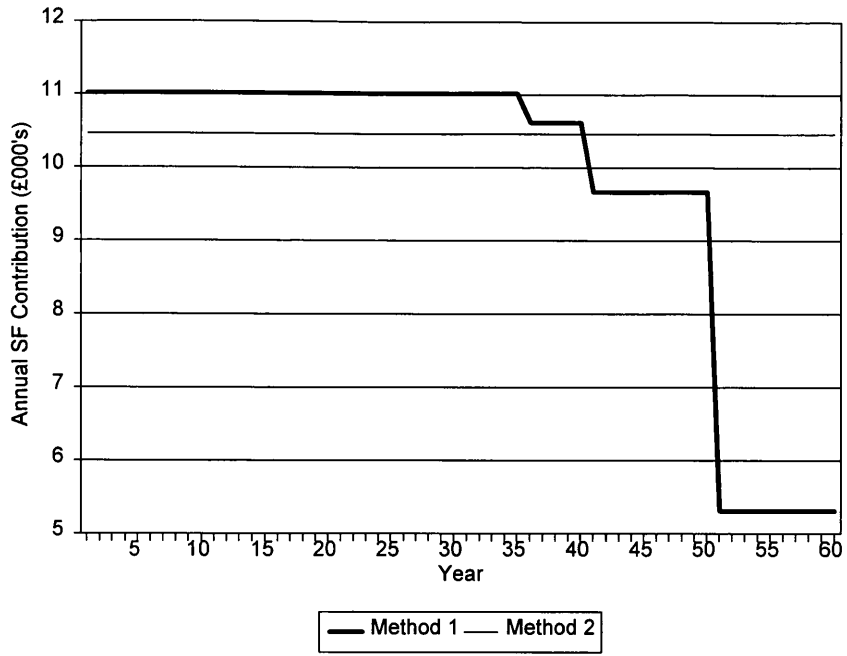
Figure 6.2a Alternative Methods of Calculating an ASF for SCHEME 2
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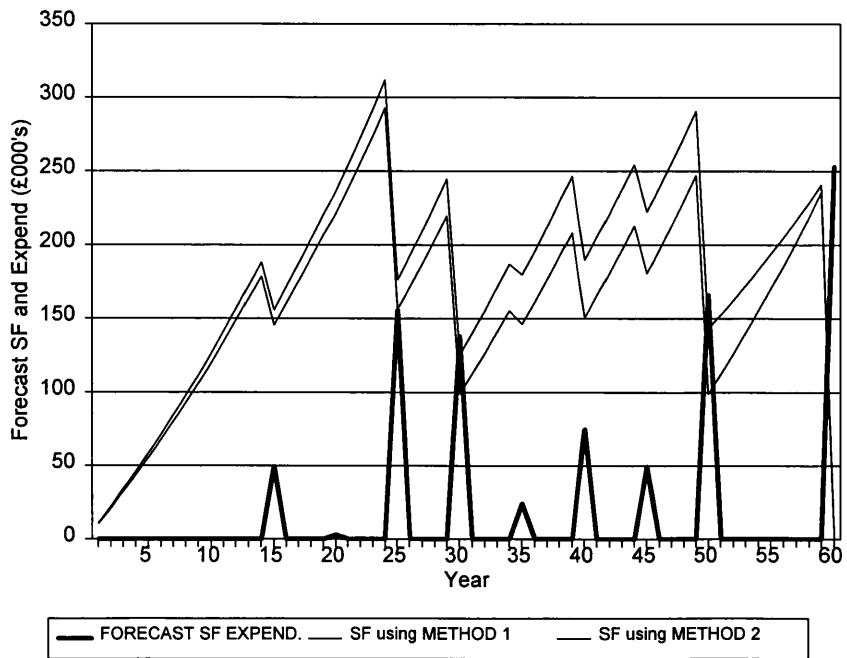
Figure 6.2b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 2
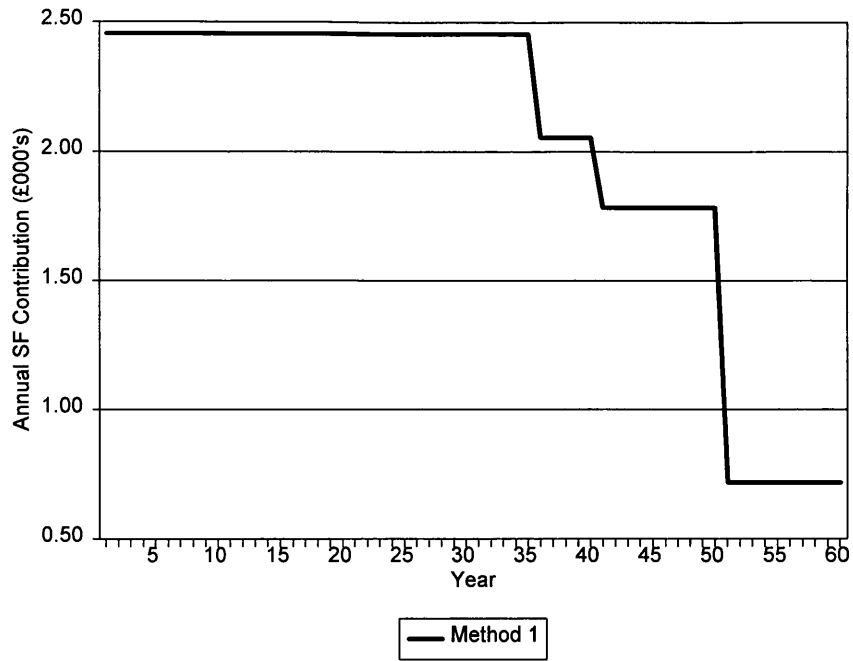
Figure 6.3a Alternative Methods of Calculating an ASF for SCHEME 3
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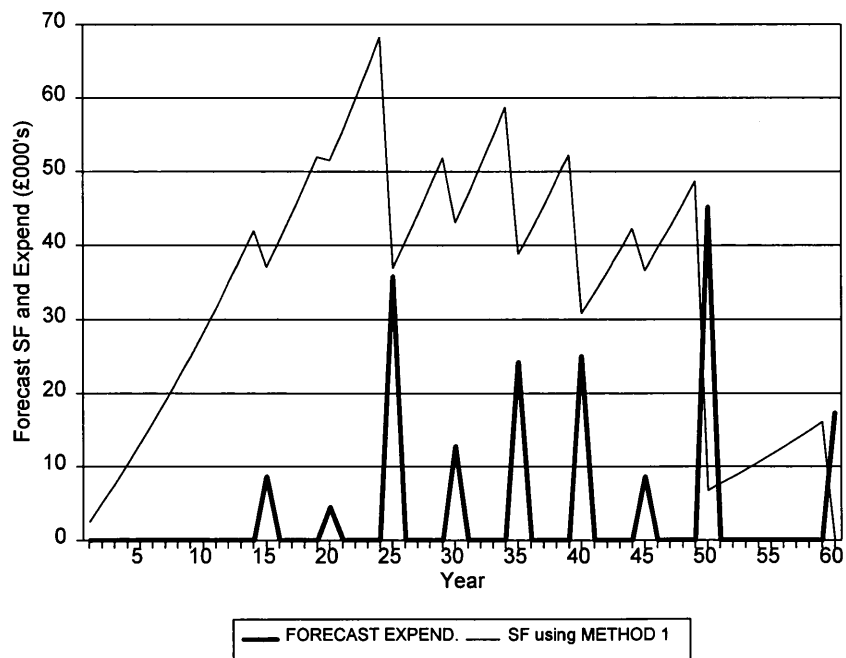
Figure 6.3b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 3
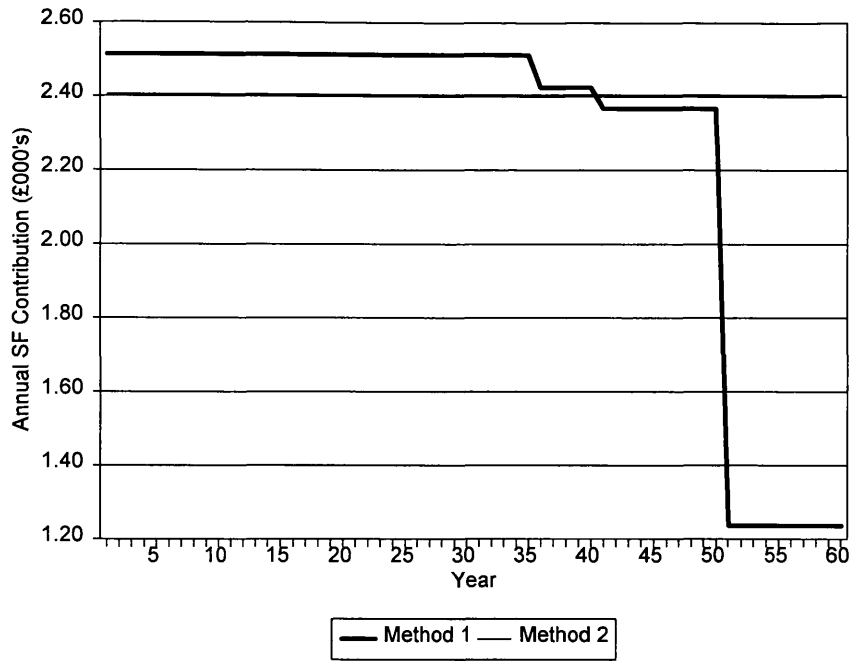
Figure 6.4a Alternative Methods of Calculating an ASF for SCHEME 4
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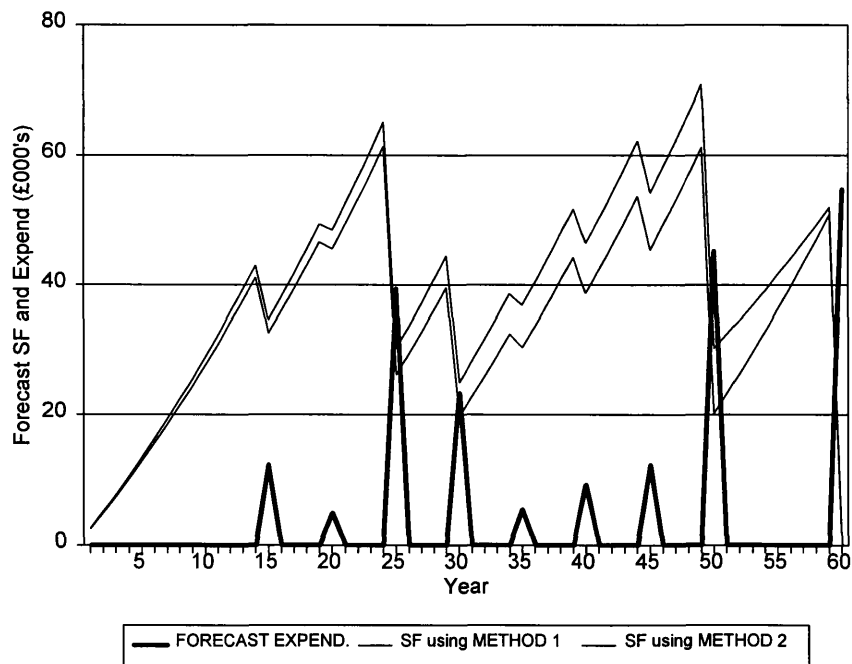
Figure 6.4b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 4
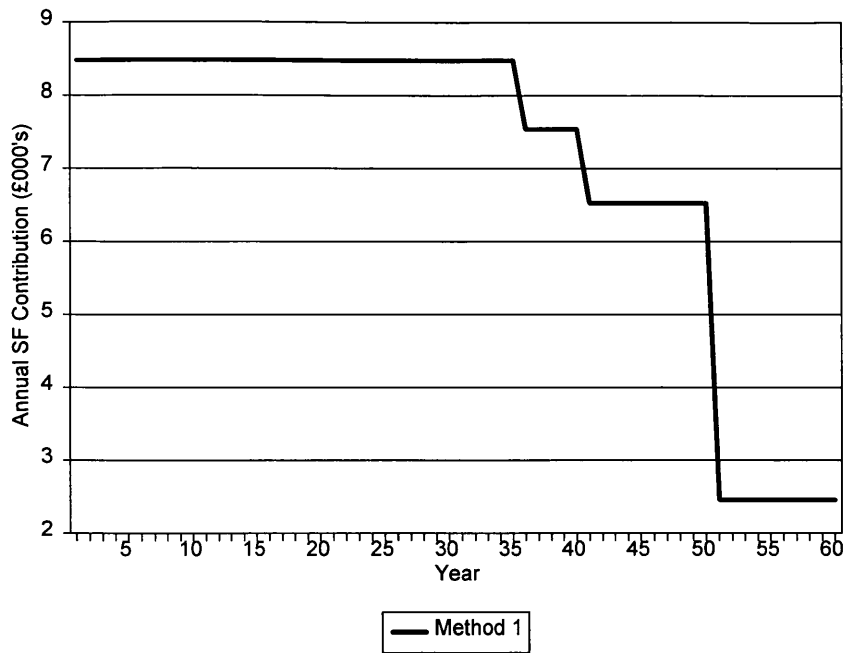
Figure 6.5a Alternative Methods of Calculating an ASF for SCHEME 5
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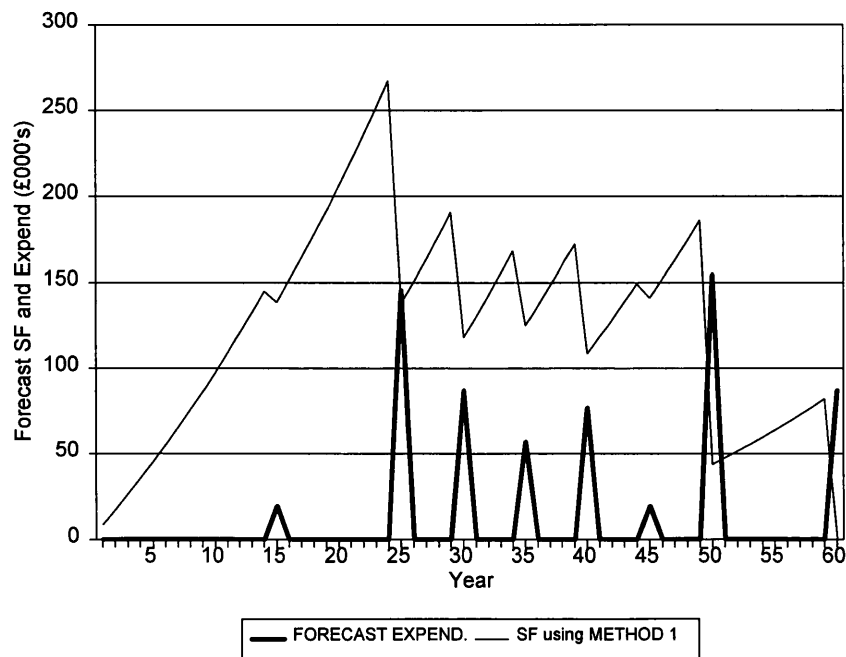
Figure 6.5b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 5
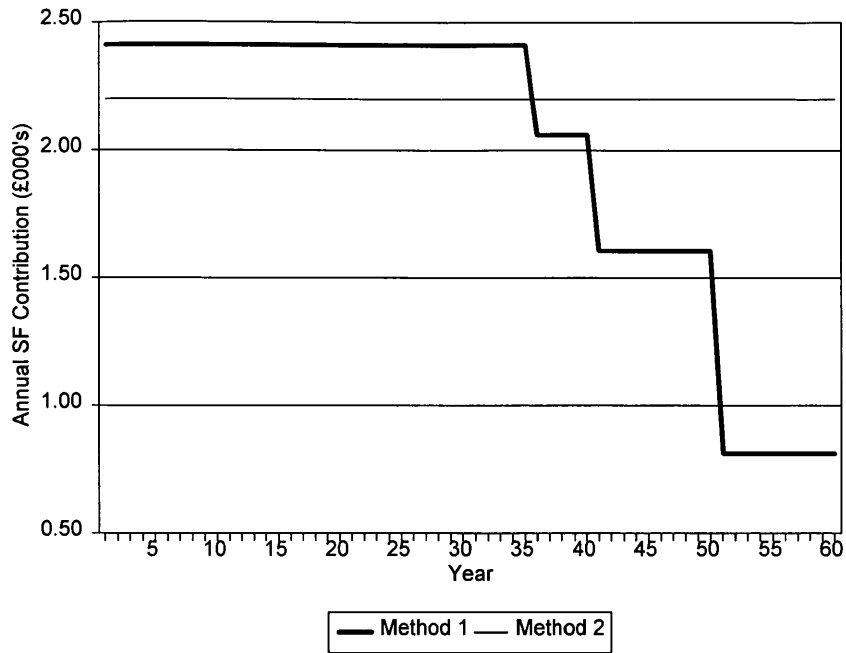
Figure 6.6a Alternative Methods of Calculating an ASF for SCHEME 6
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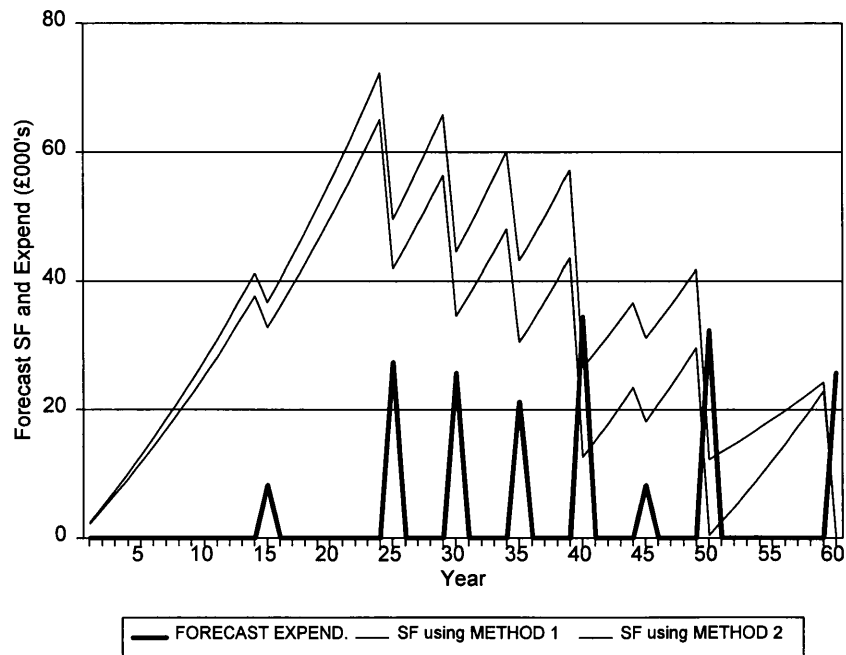
Figure 6.6b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 6
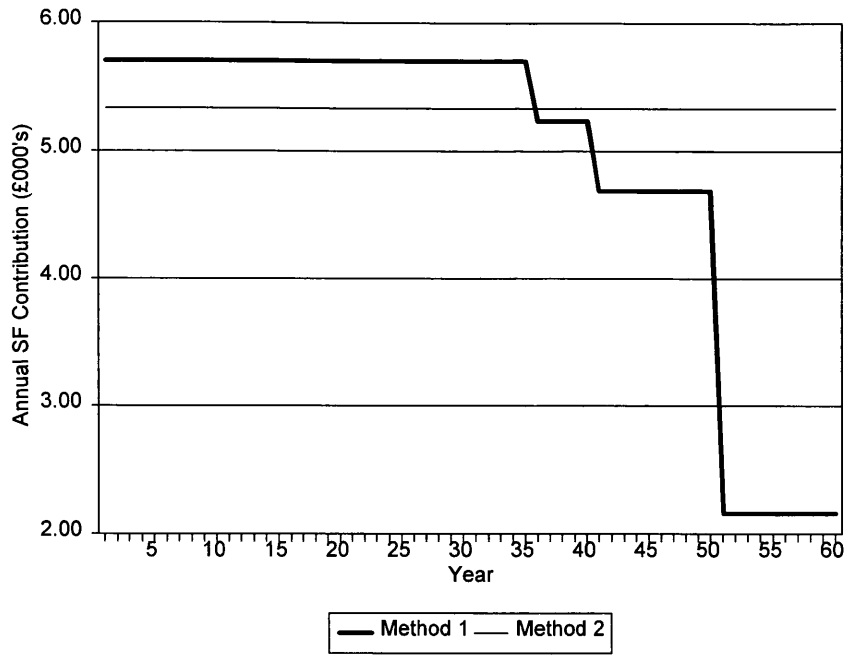
Figure 6.7a Alternative Methods of Calculating an ASF for SCHEME 7
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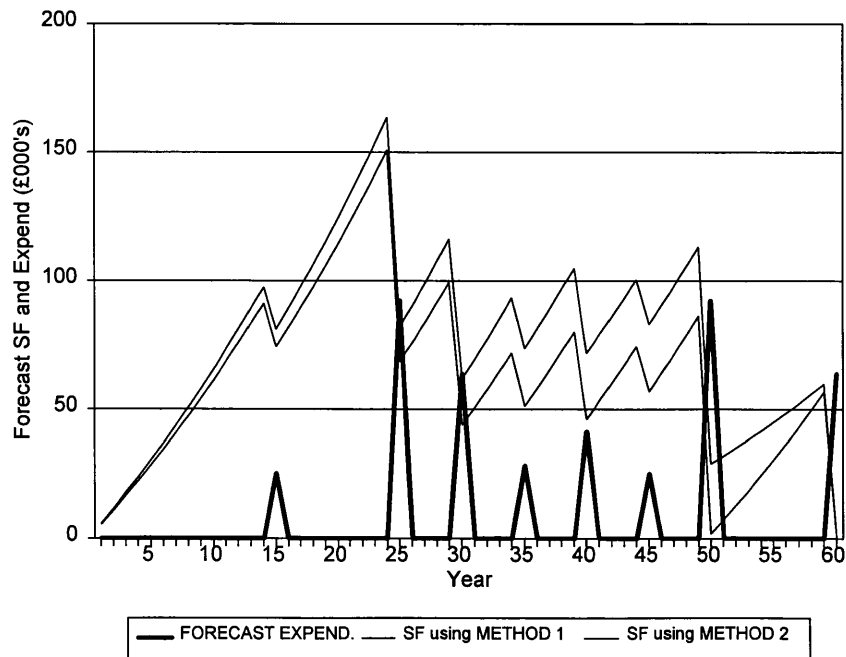
Figure 6.7b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 7
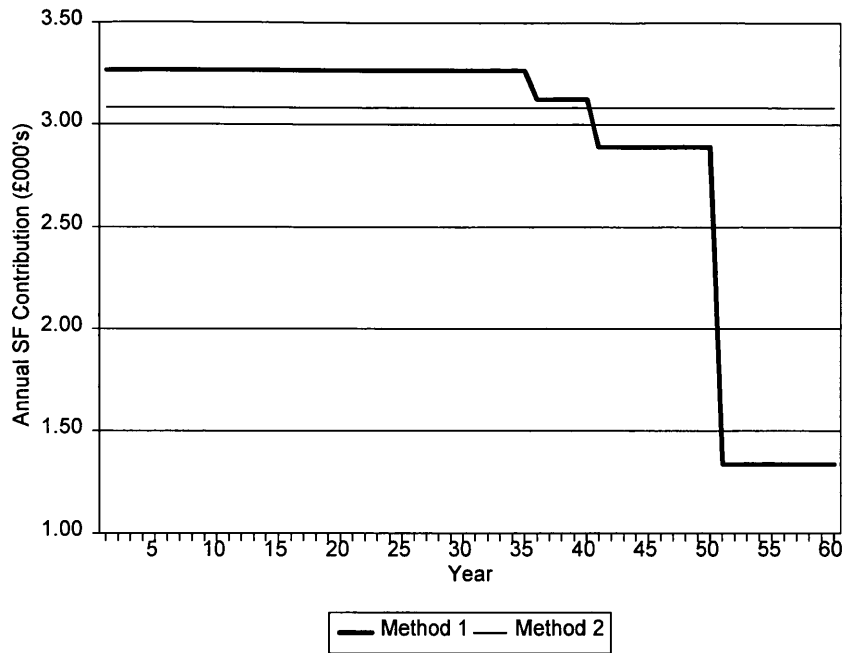
Figure 6.8a Alternative Methods of Calculating an ASF for SCHEME 8
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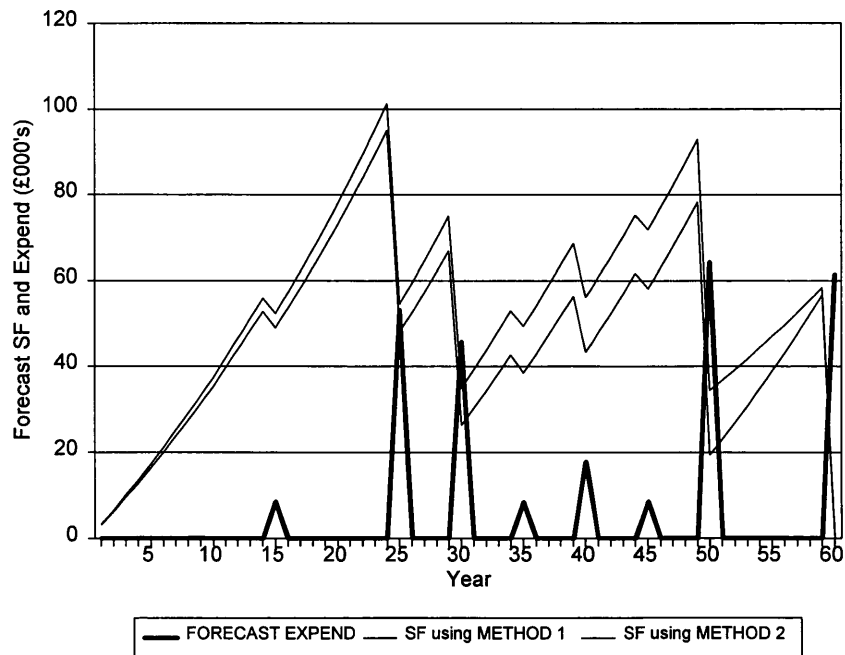
Figure 6.8b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 8

90
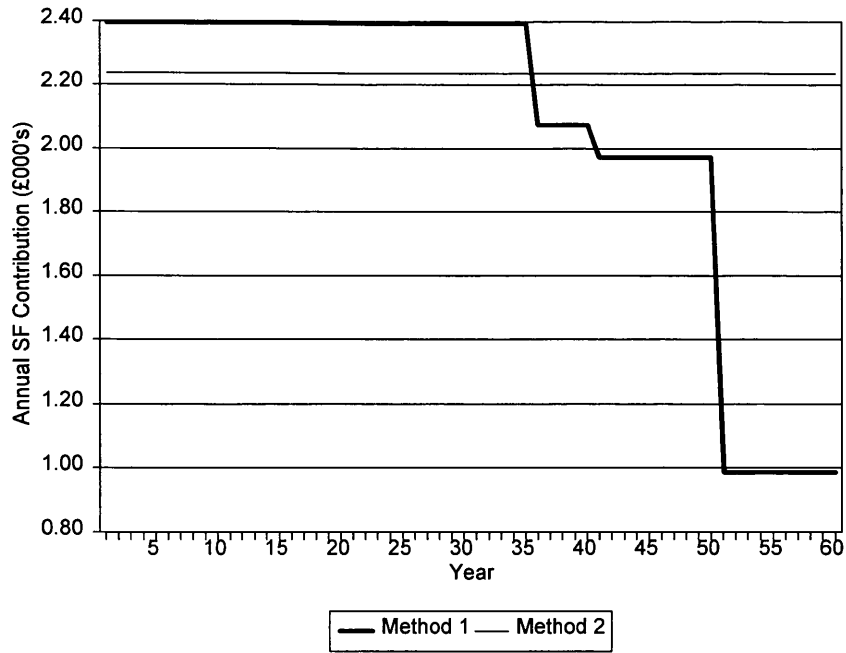
Figure 6.9a Alternative Methods of Calculating an ASF for SCHEME 9
Method 1: Multiple SF Calculations   Method 2: Annual Equivalent
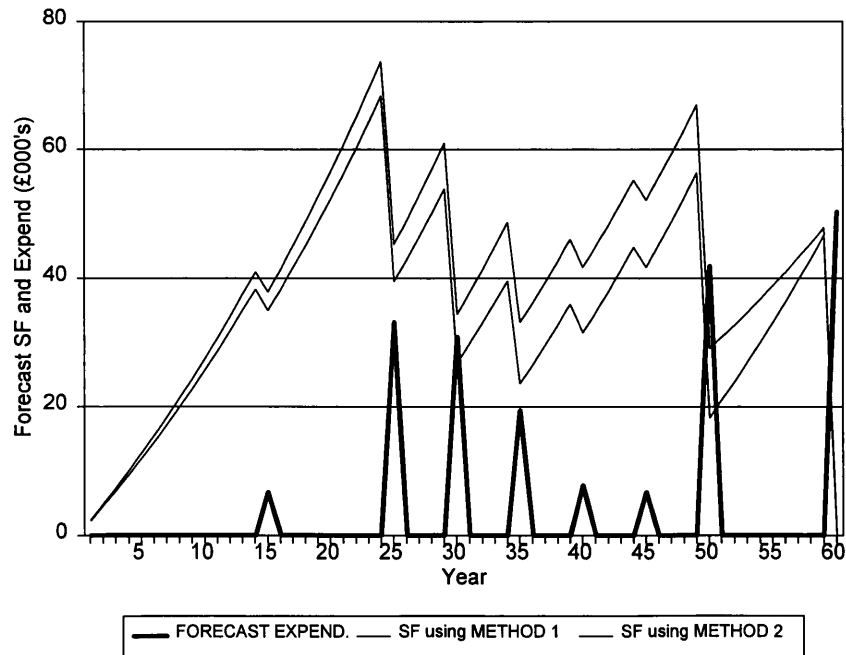
Figure 6.9b Projected Sinking Fund Provision and Major Repairs Expend. for SCHEME 9

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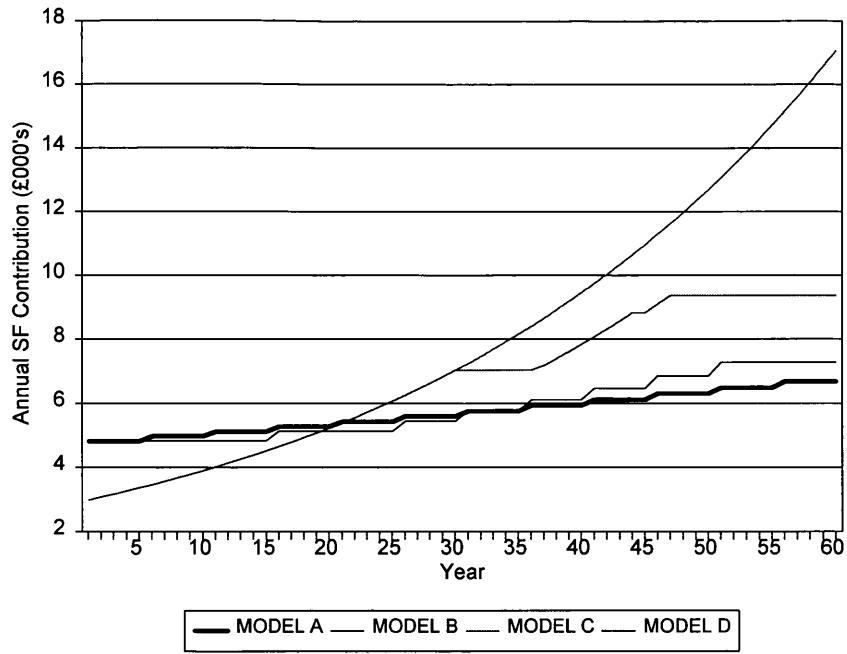
Figure 6.10a Alternative SF Strategies Using Linear Programming: SCHEME 1
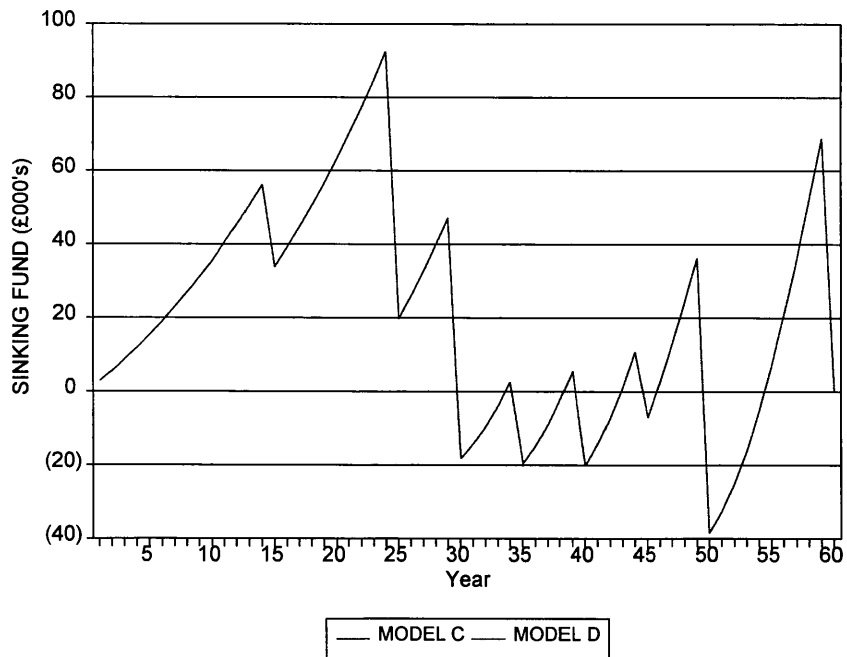A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit
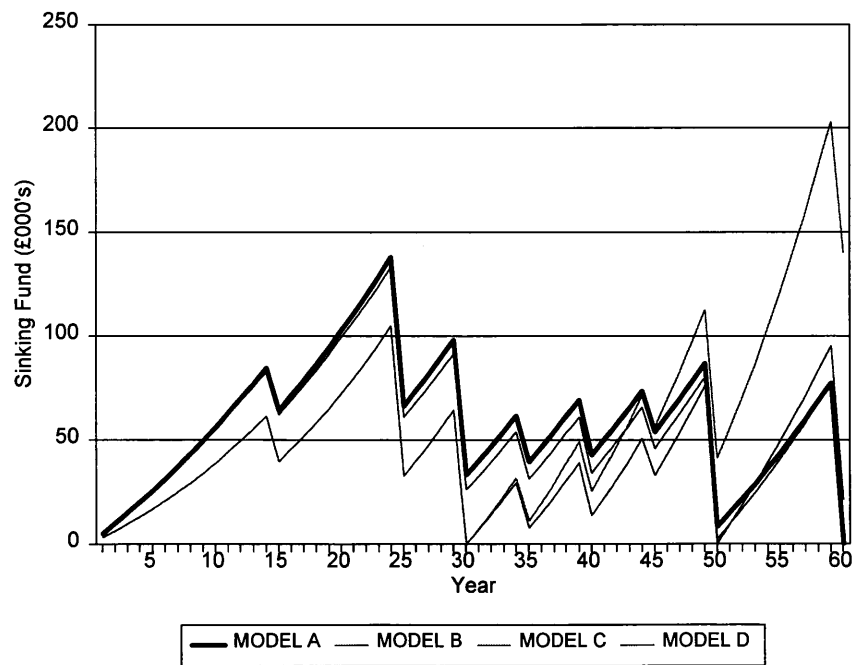
Figure 6.10b Projected Sinking Fund Provision for SCHEME 1
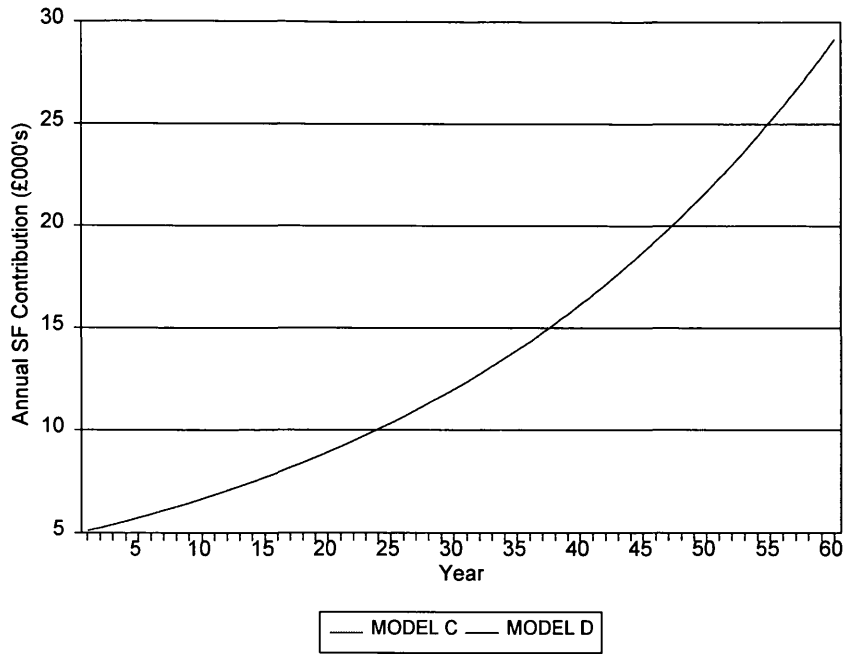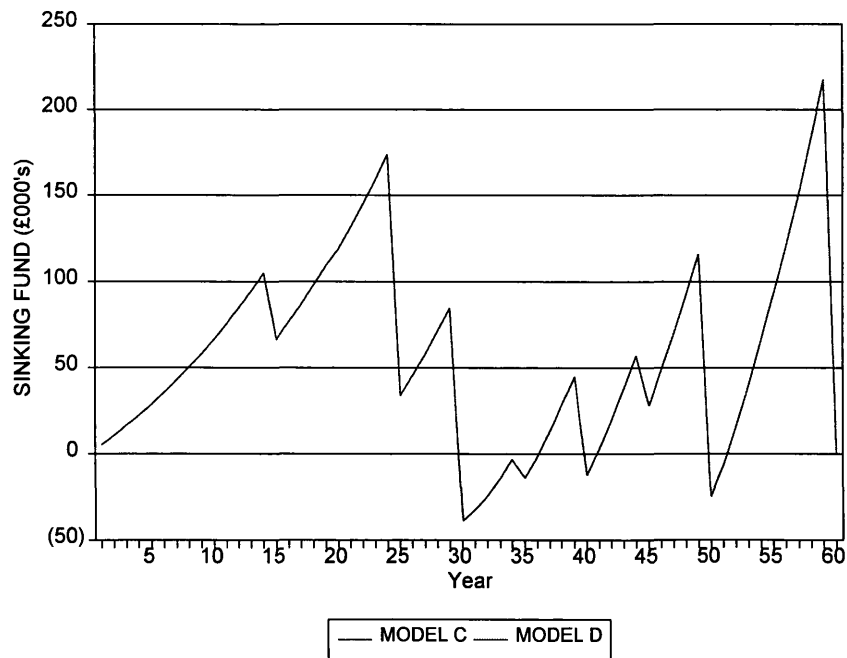
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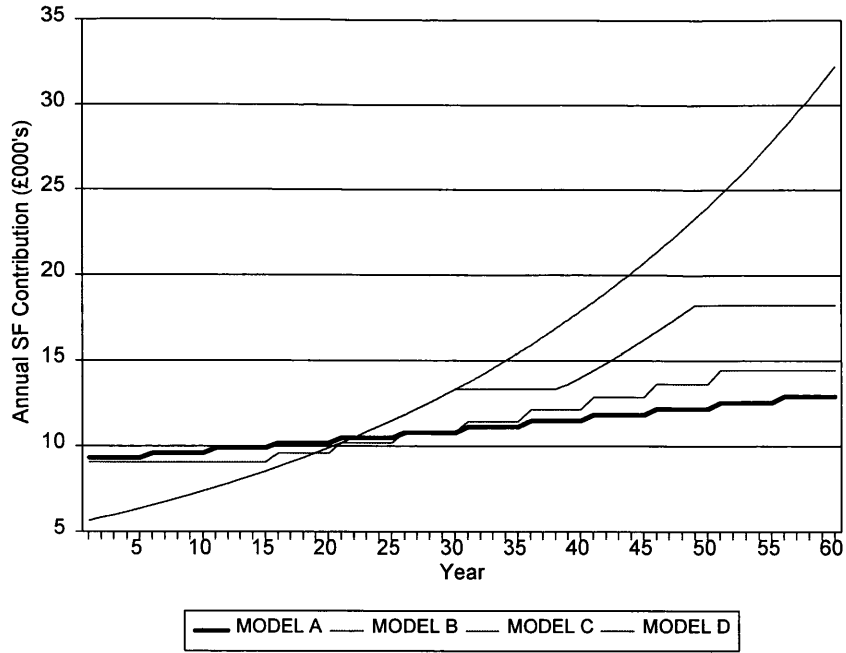
Figure 6.11a Alternative SF Strategies Using Linear Programming: SCHEME 1
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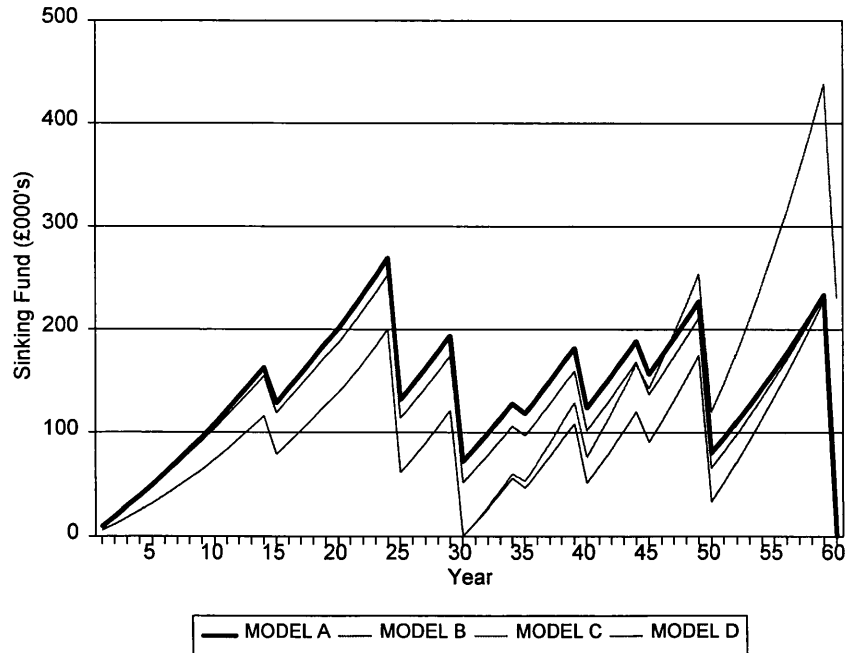
Figure 6.11b Projected Sinking Fund Provision for SCHEME 2
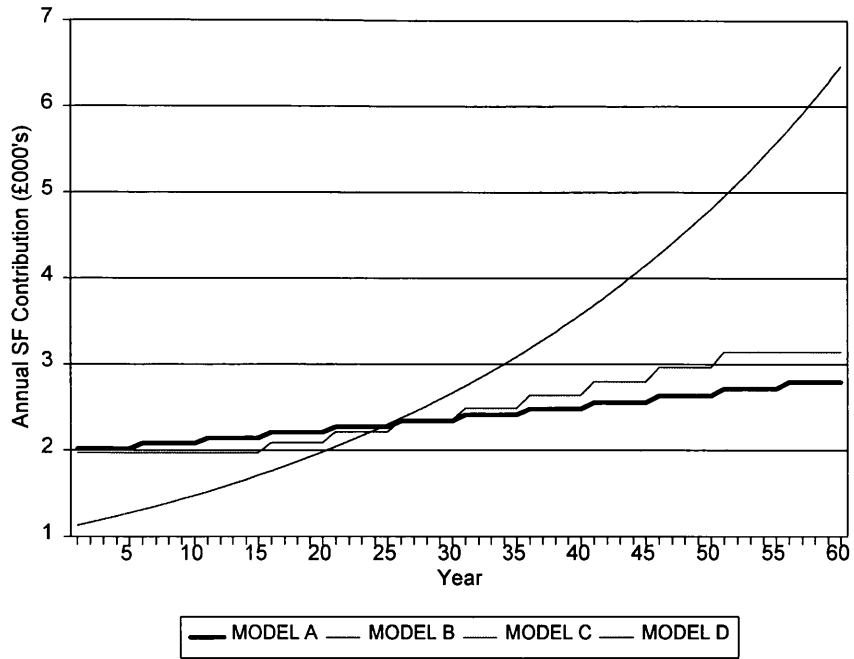
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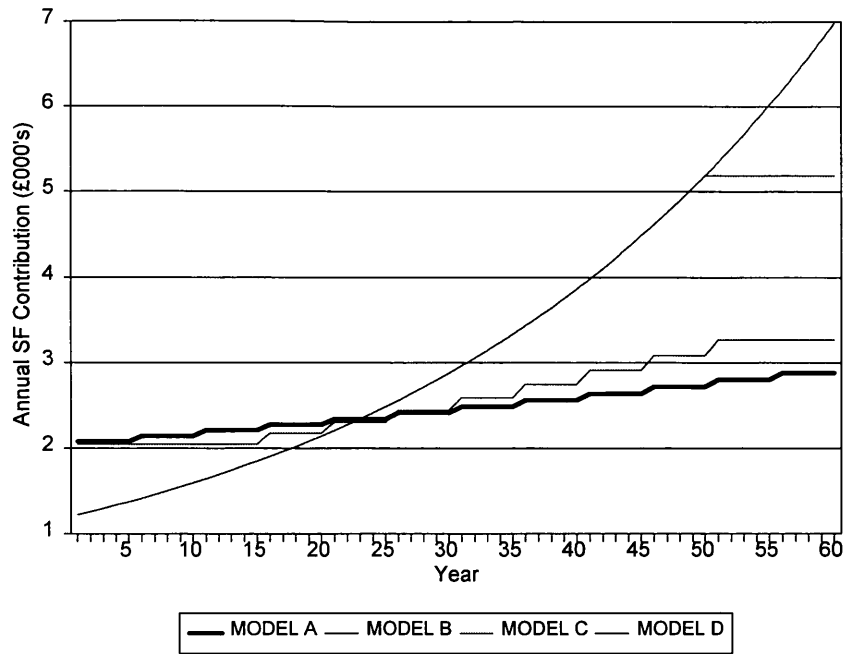
Figure 6.12a Alternative SF Strategies Using Linear Programming: SCHEME 1
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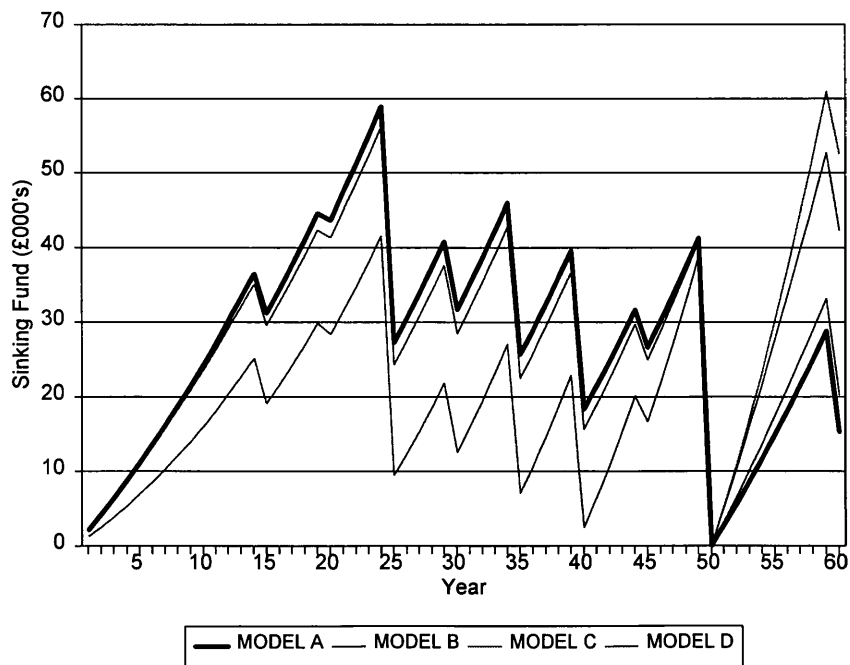
Figure 6.12b Projected Sinking Fund Provision for SCHEME 3

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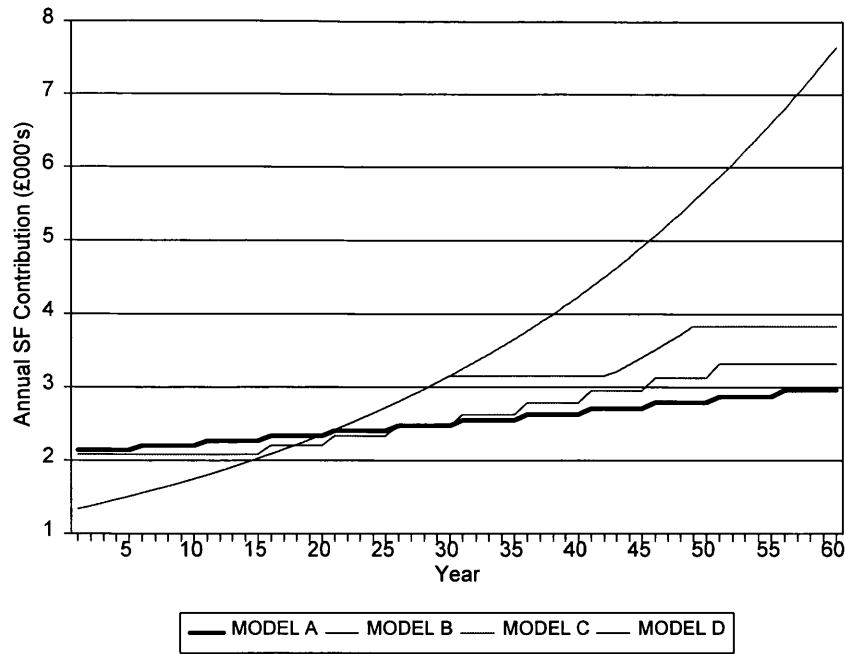
Figure 6.13a Alternative SF Strategies Using Linear Programming: SCHEME 1
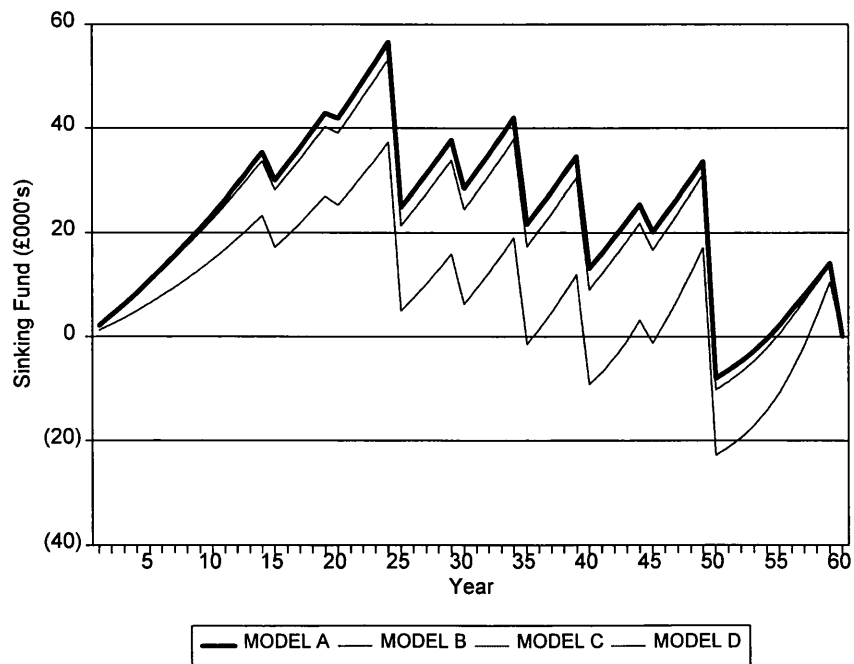A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit
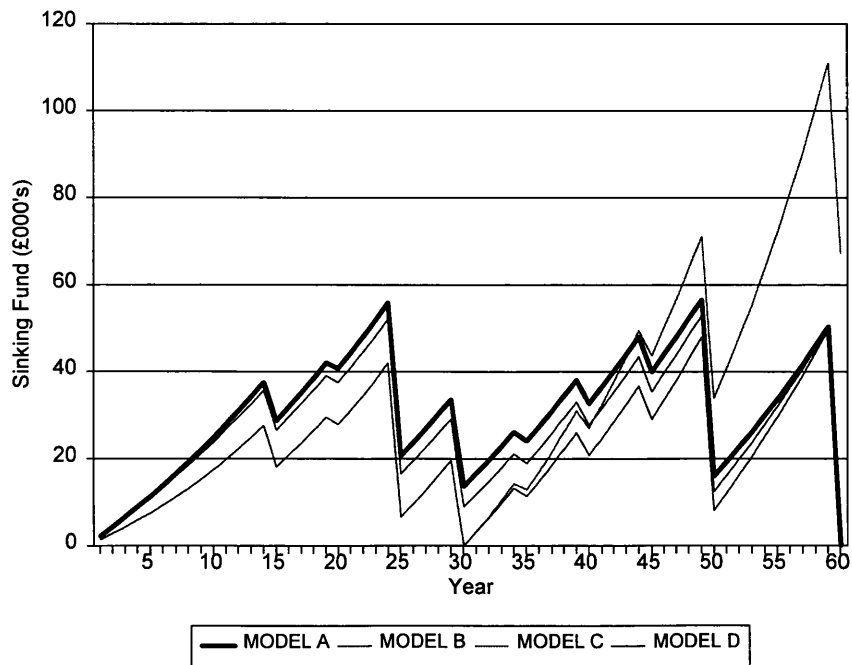
Figure 6.13b Projected Sinking Fund Provision for SCHEME 4

MODEL TYPE 1: Continuous Linear Programme
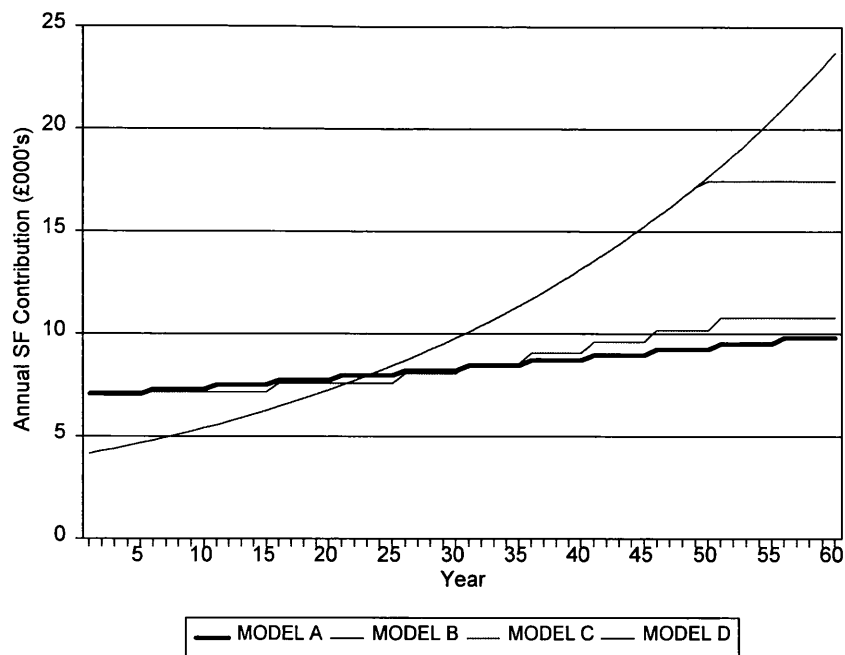
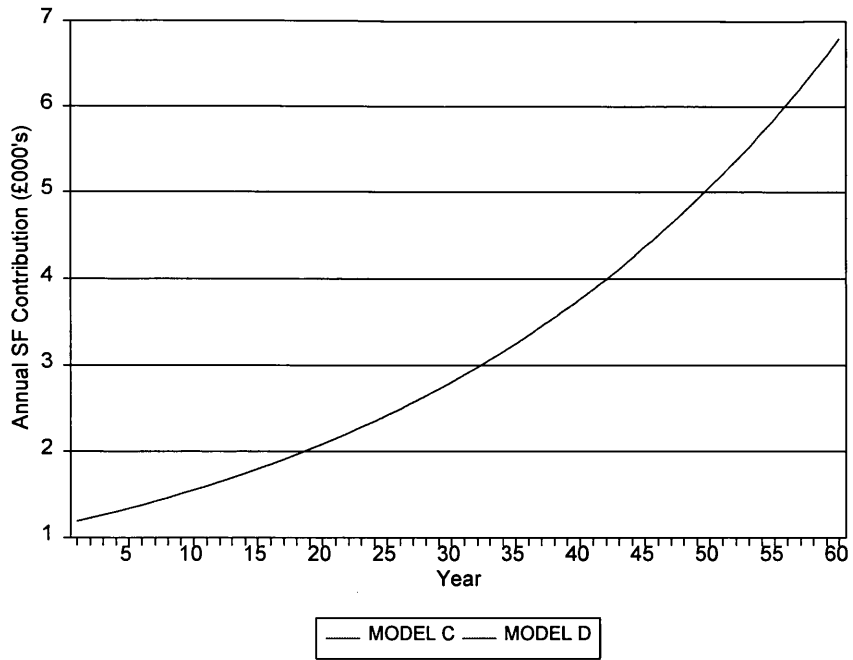
Figure 6.14a Alternative SF Strategies Using Linear Programming: SCHEME 1
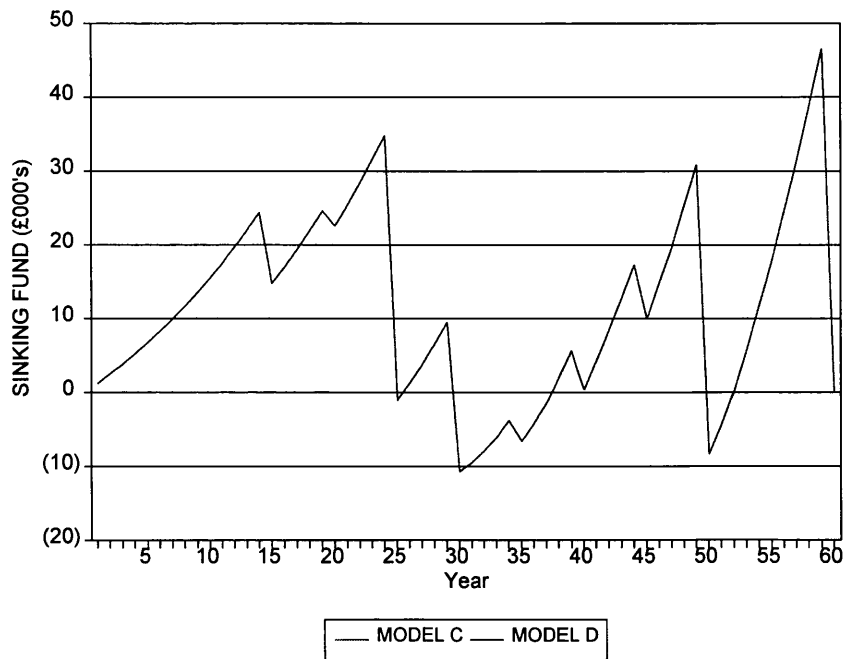A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit
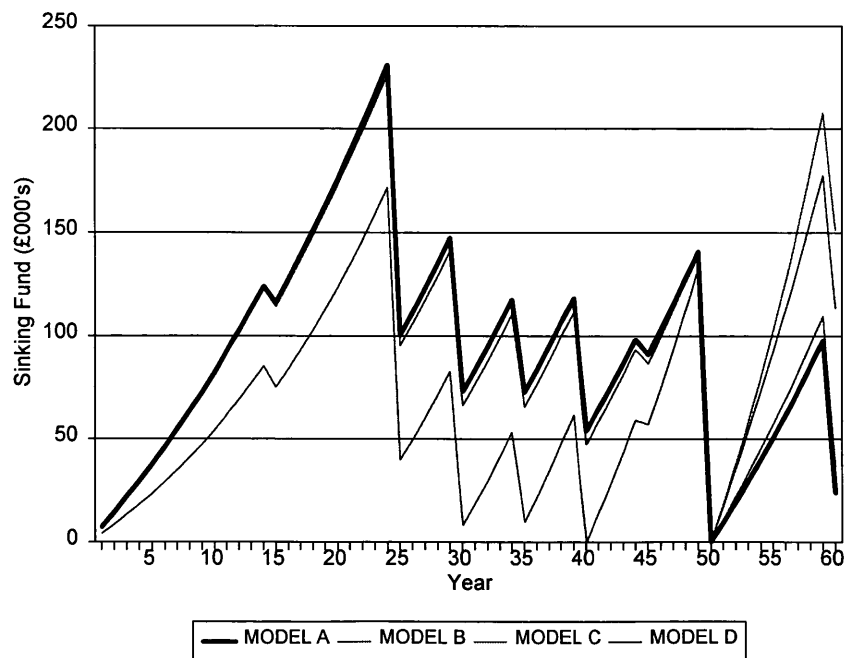
Figure 6.14b Projected Sinking Fund Provision for SCHEME 5

96

MODEL TYPE 1: Continuous Linear Programme
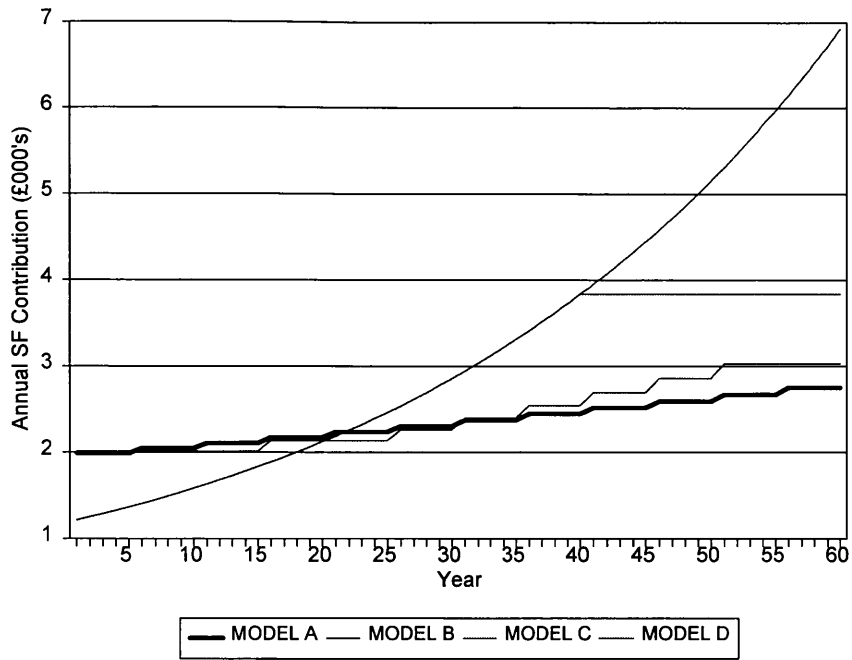
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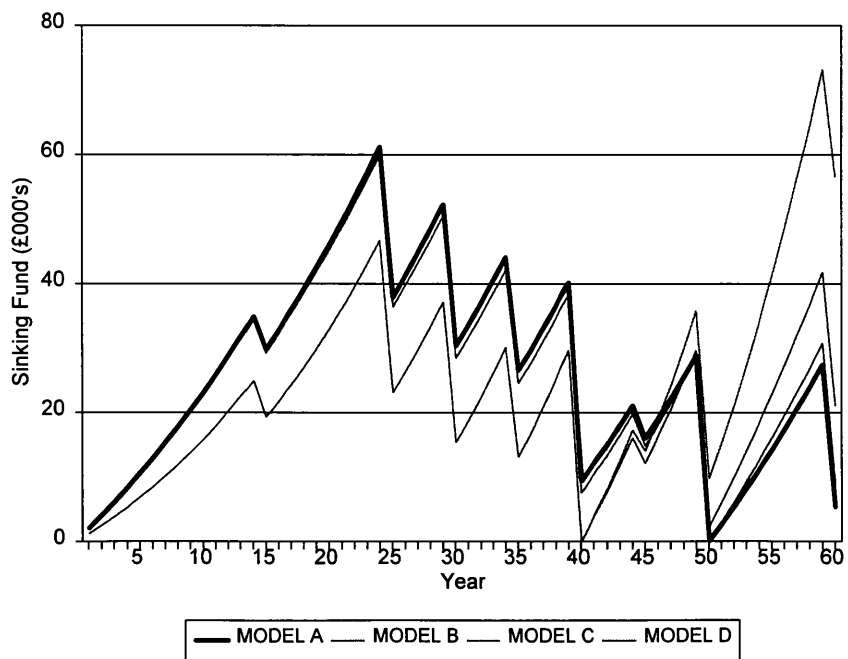
Figure 6.15b Projected Sinking Fund Provision for SCHEME 6

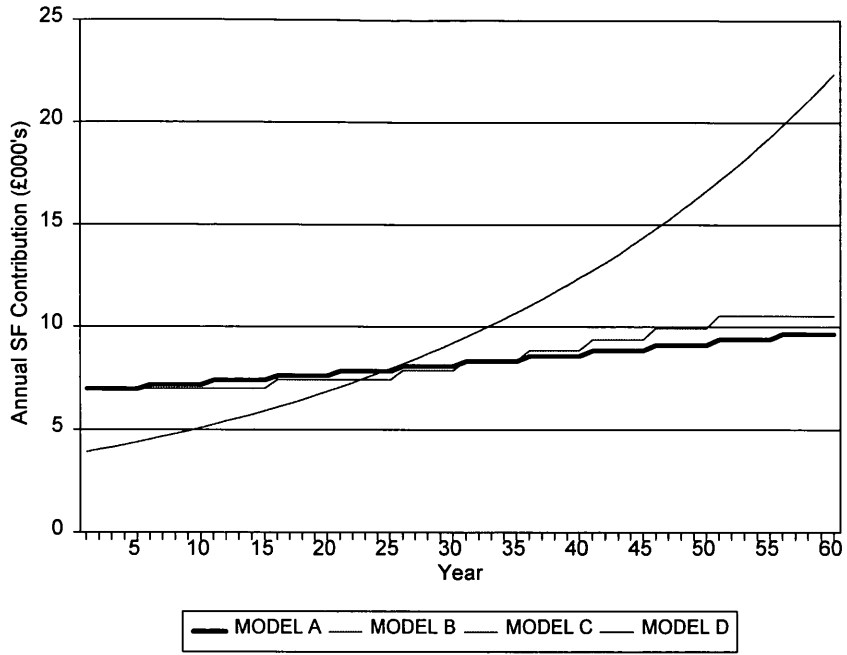**MODEL TYPE 1: Continuous Linear Programme**
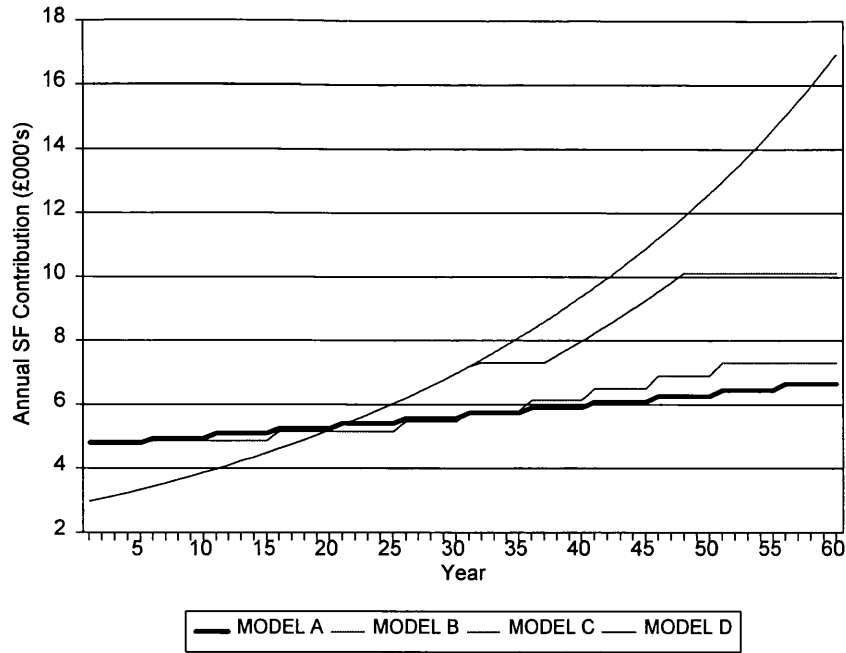
Figure 6.16a Alternative SF Strategies Using Linear Programming: SCHEME 1
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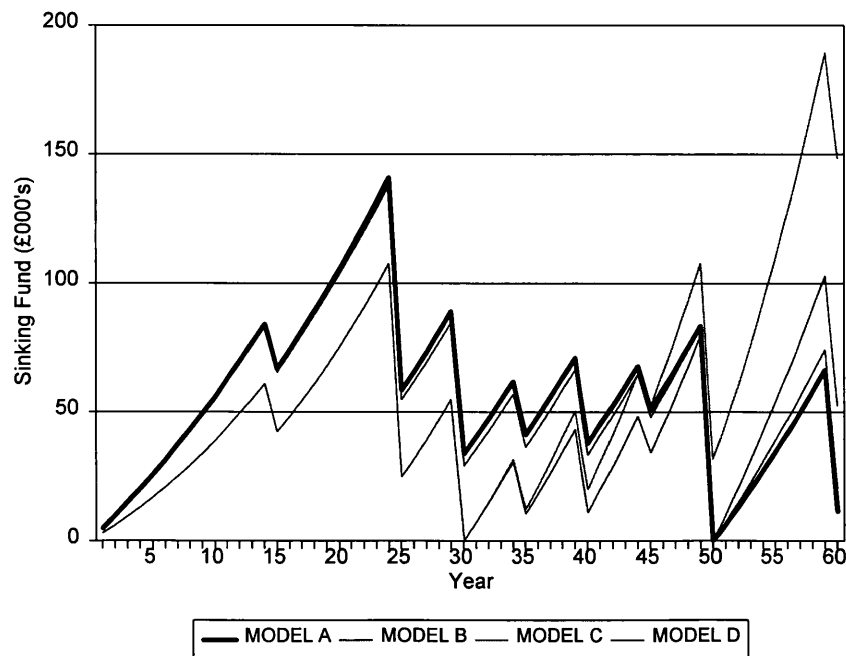
Figure 6.16b Projected Sinking Fund Provision for SCHEME 7

MODEL TYPE 1: Continuous Linear Programme
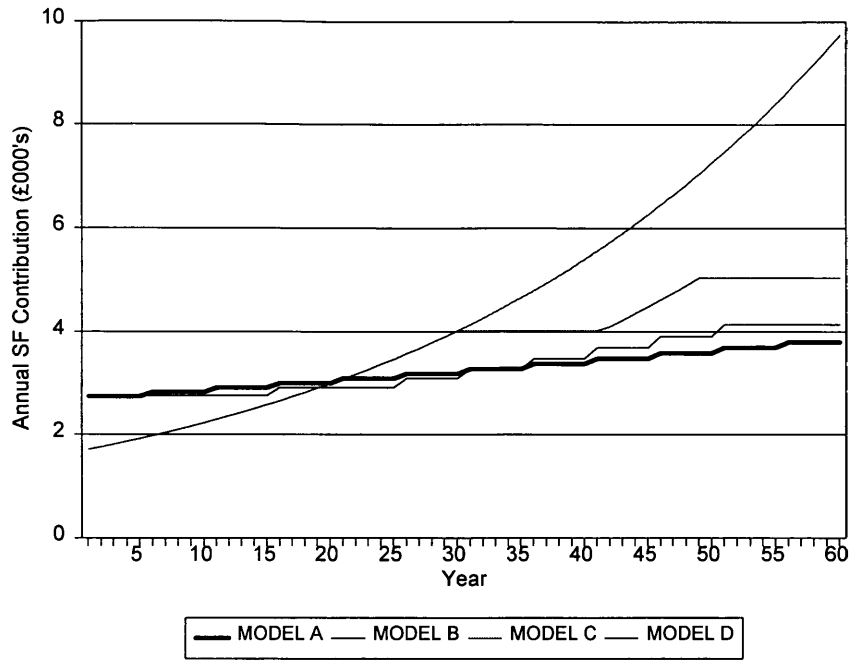
Figure 6.17a Alternative SF Strategies Using Linear Programming: SCHEME 1
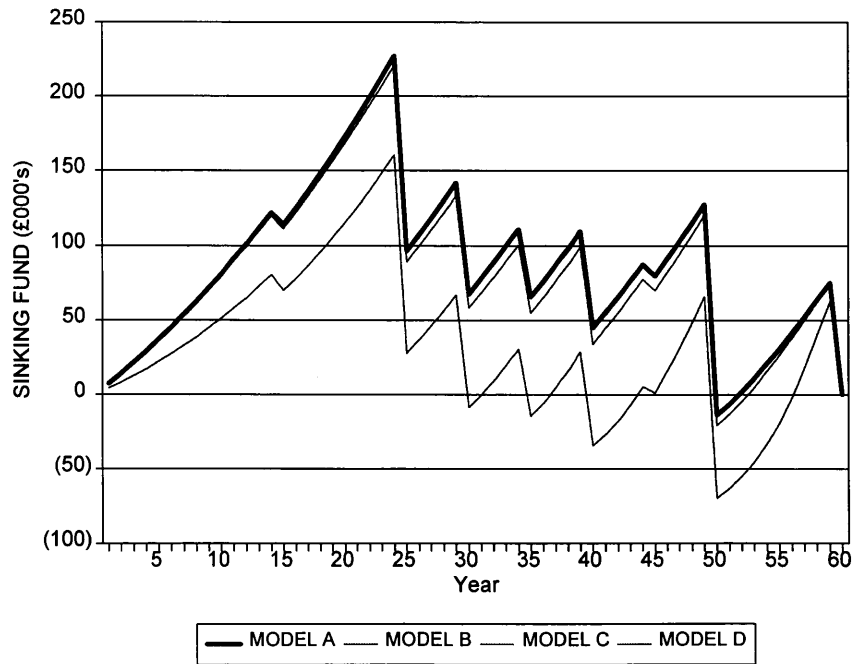A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit
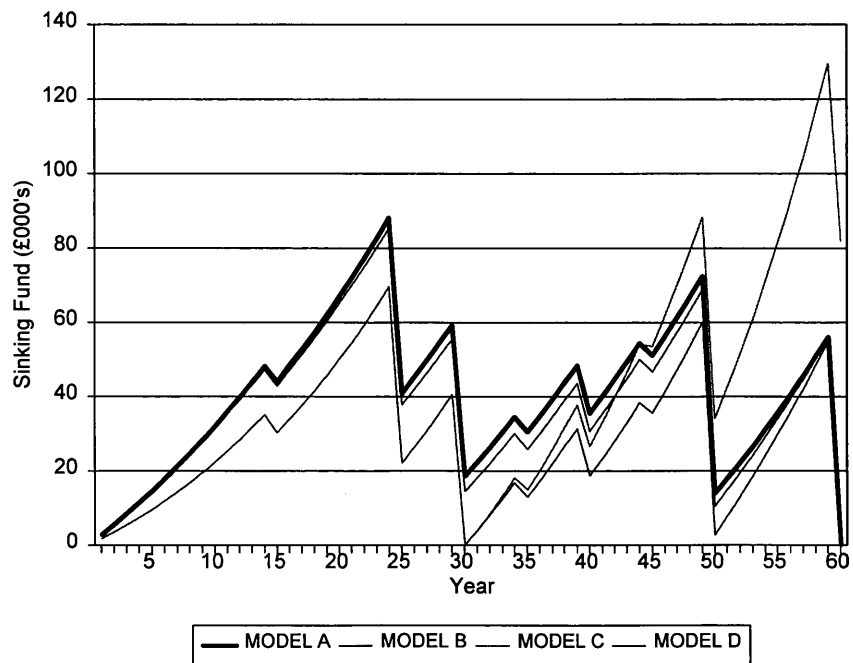
Figure 6.17b Projected Sinking Fund Provision for SCHEME 8
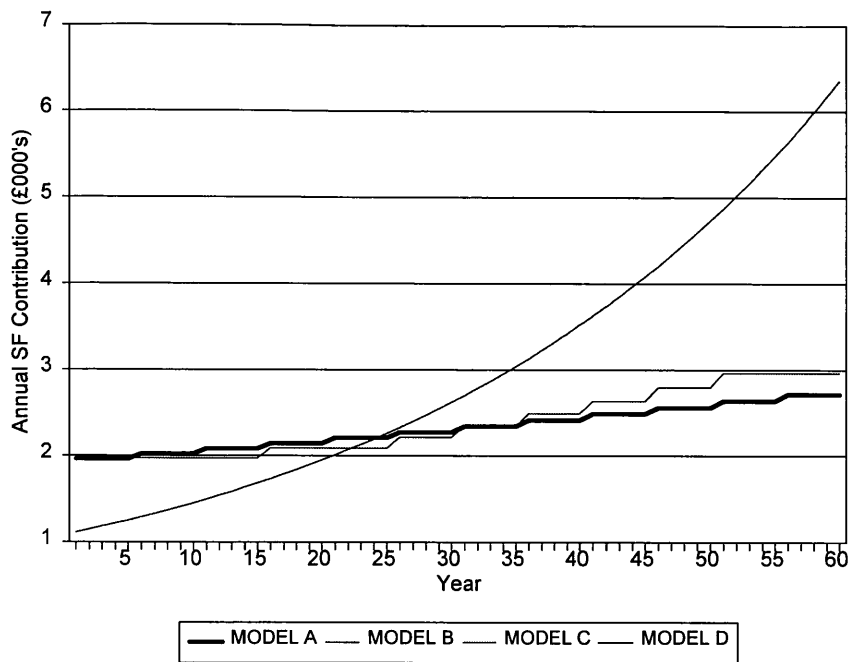
MODEL TYPE 1: Continuous Linear Programme
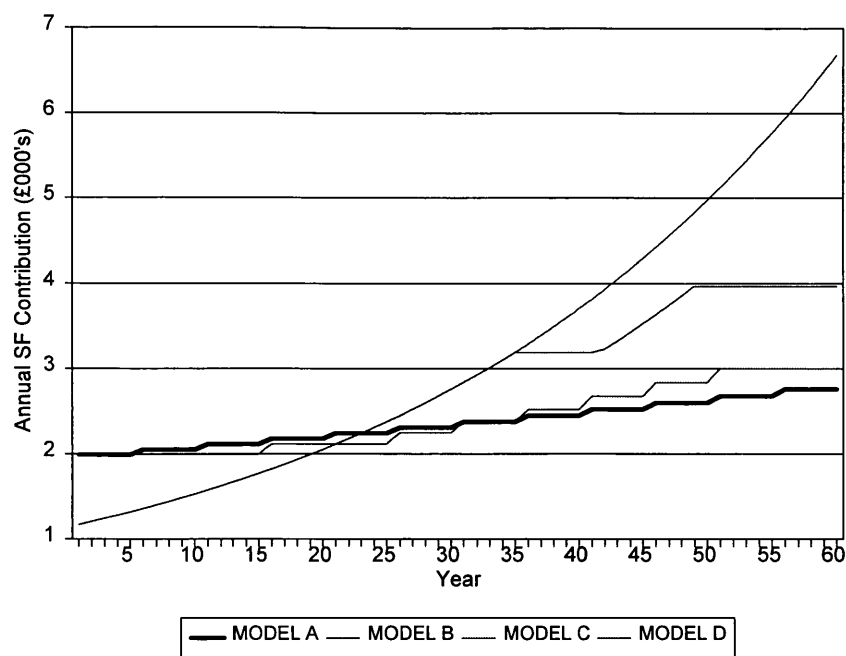
Figure 6.18a Alternative SF Strategies Using Linear Programming: SCHEME 1
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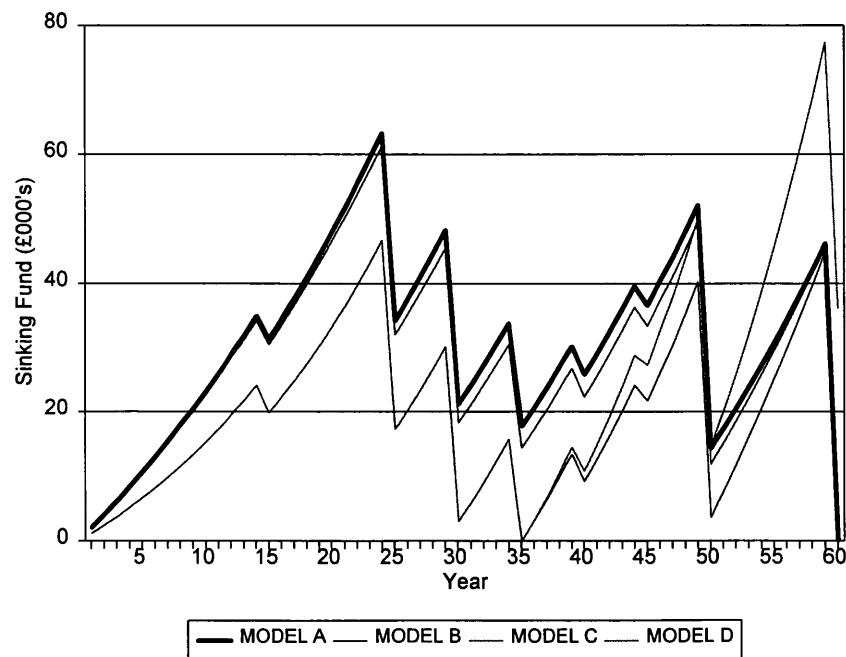
Figure 6.18b Projected Sinking Fund Provision for SCHEME 9

MODEL TYPE 2: Mixed-Integer Linear Programme
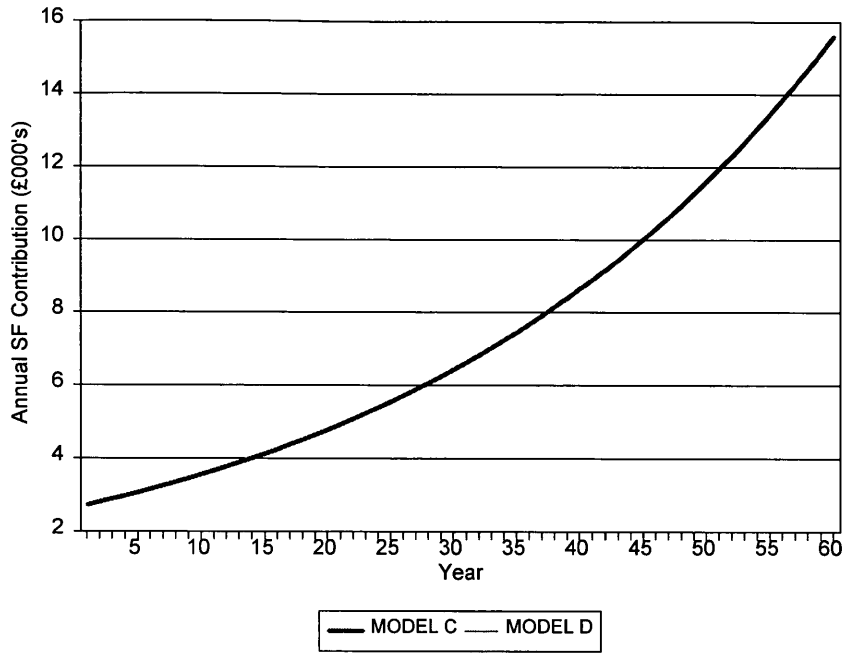
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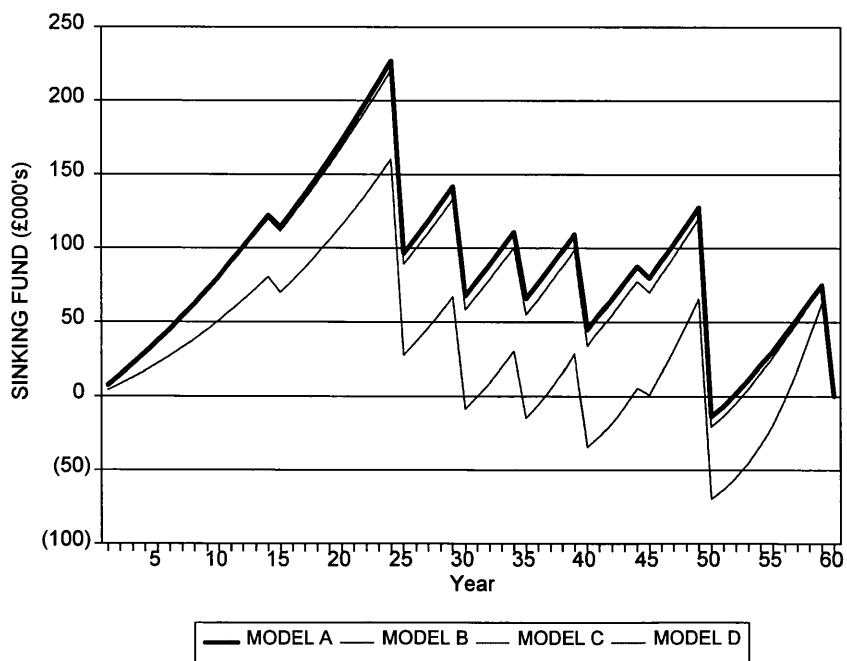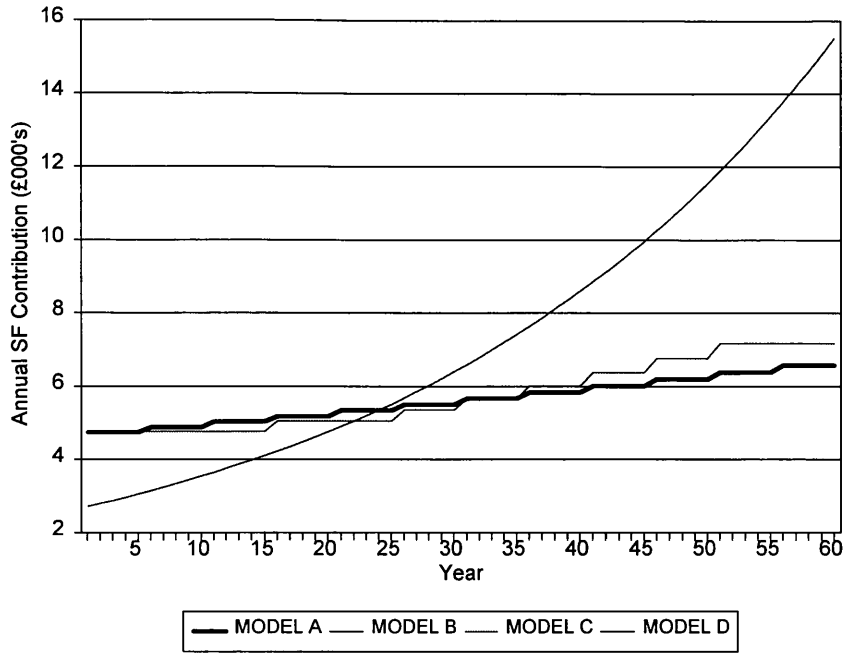A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit

Figure 6.19b Projected Sinking Fund Provision\Deficit for SCHEME 1

MODEL TYPE 2: Mixed-Integer Linear Programme

Figure 6.20a Alternative SF Strategies Using Linear Programming: SCHEME 1
C: Annual increase; D:Minimise initial deposit

Figure 6.20b Projected Sinking Fund Provision\Deficit for SCHEME 2

MODEL TYPE 2: Mixed-Integer Linear Programme

Figure 6.21a Alternative SF Strategies Using Linear Programming: SCHEME 1
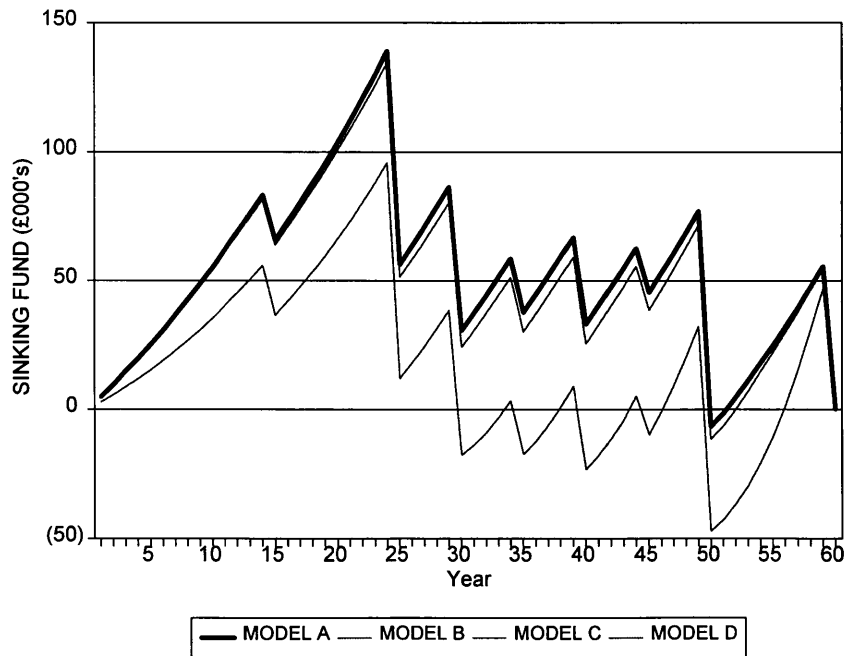A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit

Figure 6.21b Projected Sinking Fund Provision\Deficit for SCHEME 3

MODEL TYPE 2: Mixed-Integer Linear Programme

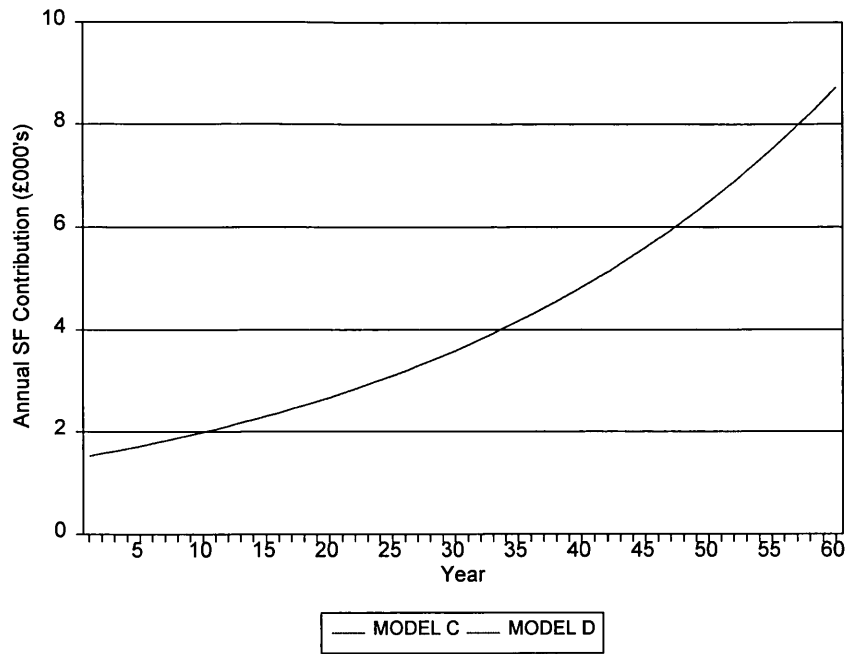Figure 6.22a Alternative SF Strategies Using Linear Programming: SCHEME 1
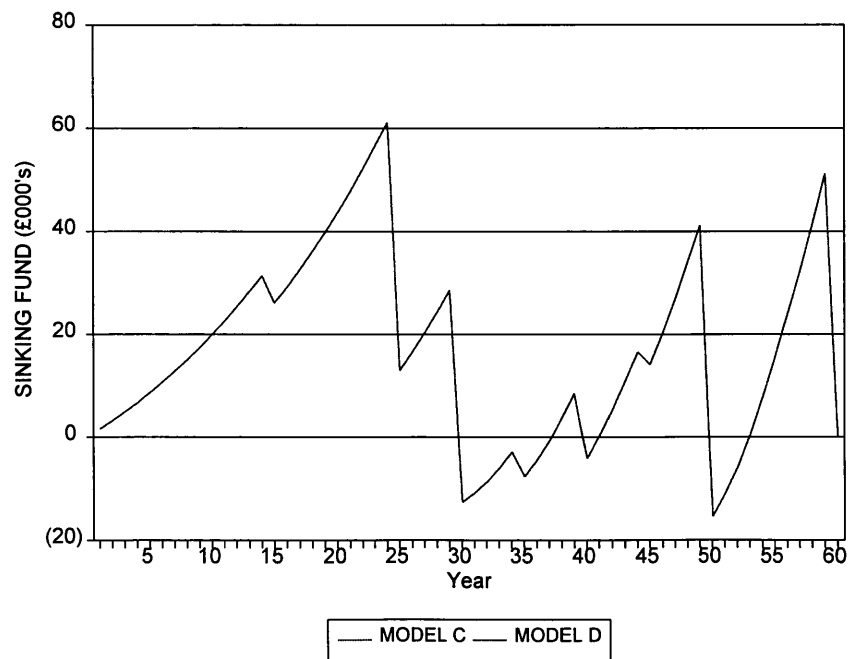C: Annual increase; D:Minimise initial deposit

Figure 6.22b Projected Sinking Fund Provision\Deficit for SCHEME 4

MODEL TYPE 2: Mixed-Integer Linear Programme

Figure 6.23a Alternative SF Strategies Using Linear Programming: SCHEME 1
A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit

Figure 6.23b Projected Sinking Fund Provision\Deficit for SCHEME 5

105

MODEL TYPE 2: Mixed-Integer Linear Programme

Figure 6.24a Alternative SF Strategies Using Linear Programming: SCHEME 1
A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit

Figure 6.24b Projected Sinking Fund Provision\Deficit for SCHEME 6

MODEL TYPE 2: Mixed-Integer Linear Programme

Figure 6.25a Alternative SF Strategies Using Linear Programming: SCHEME 1
A: Quinquennial increase; B: Expend. linked increase; C: Annual increase; D:Minimise initial deposit

Figure 6.25b Projected Sinking Fund Provision\Deficit for SCHEME 7

MODEL TYPE 2: Mixed-Integer Linear Programme

Figure 6.26a Alternative SF Strategies Using Linear Programming: SCHEME 1
C: Annual increase; D:Minimise initial deposit

Figure 6.26b Projected Sinking Fund Provision\Deficit for SCHEME 8

MODEL TYPE 2: Mixed-Integer Linear Programme
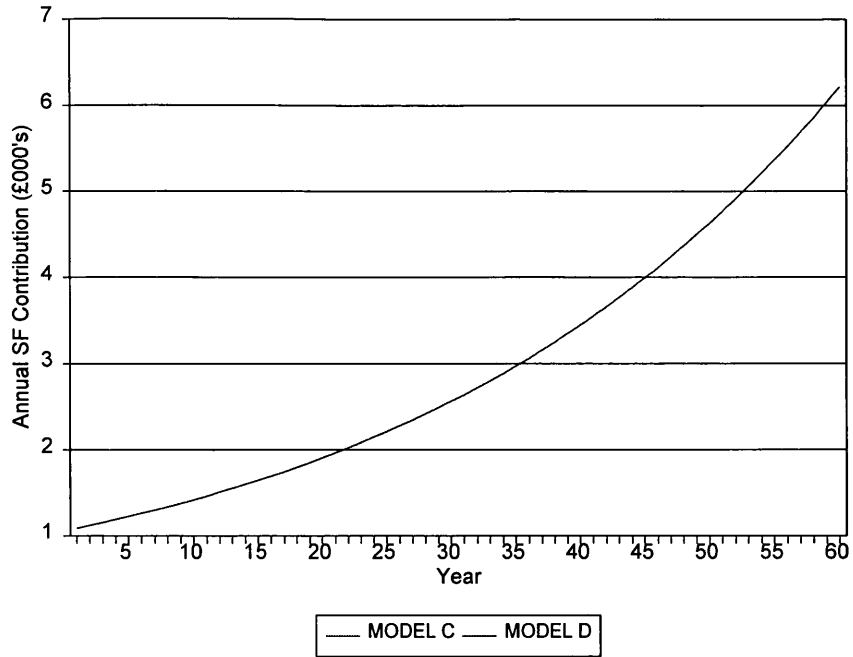
Figure 6.27a Alternative SF Strategies Using Linear Programming: SCHEME 1
C: Annual increase; D:Minimise initial deposit
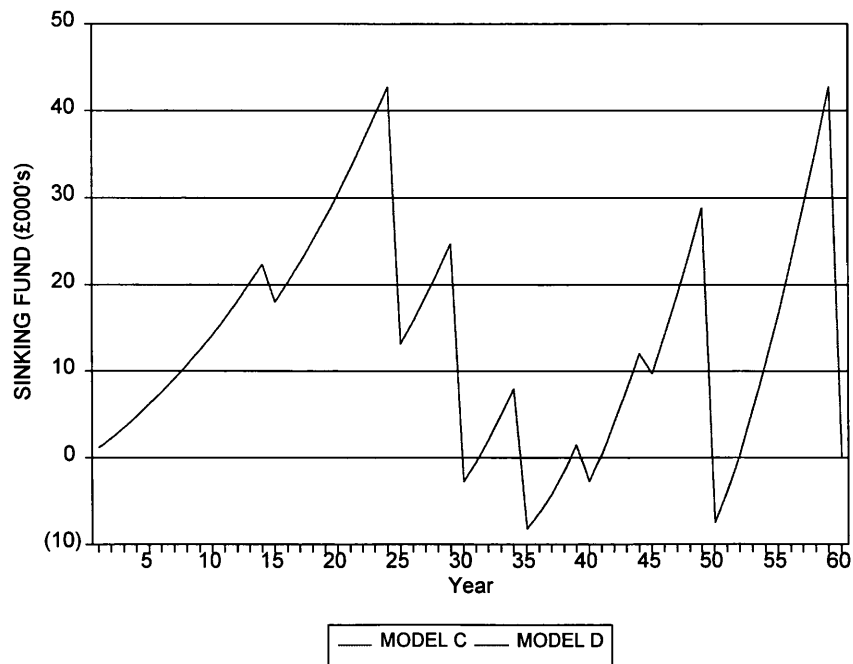
Figure 6.27b Projected Sinking Fund Provision\Deficit for SCHEME 9

109

CHAPTER 7   SIMULATING THE MAINTENANCE DATA

7.1 Introduction

The results in Chapter 6 are based on deterministic forecasts of the MR need for each scheme. The projections assumed that, for each Scheme, replacement of elements identified in the Schedules, as shown in Appendix 3, occurs in fixed cycles. The cycles are selected to represent the average lifespan of the element. It is clear from Chapter 5, however, that actual performance in use is very variable, and the "average" lifespan may not be representative in reality. Although this is widely recognised, traditional LCC treats the timing of future maintenance activity as a deterministic problem. An alternative approach which recognises the future is not certain is provided by simulation. This technique, increasingly popular in construction management (90), simulates "actual" behaviour by sampling events from probability distributions. Simulation is not without cost, however, in terms of time and effort to be invested in carrying out the exercise, and its ability to replicate "real life" depends very much on the quality of the data. In this chapter SF results based on fixed cycle assumptions are compared with those based on simulated (stochastic) data. The objective is to determine how robust the deterministic LCC model is. The MC method is used to simulate expenditure on MR over the development's lifespan by sampling when it occurs. Various data are required for a simulation model, and its availability is discussed with reference to recent applications of simulation in construction management. The methodology for carrying out the simulation exercise is described and both sets of results are compared and discussed.

7.2 Why Simulate?

Simulation is sometimes said (46, 91) to be a "last resort" technique, used in cases where there is no other analytical model available. This criteria is met in the various areas of construction management where it is now being applied. The traditional methods of forecasting and costing rely heavily upon intuition and "feel", but these are failing to serve the increasingly sophisticated construction industry effectively. The fundamental criticism is that, in an industry so prone to uncertainty, little rational account of risk is taken with the major variables in construction- those of time and cost. The risk associated with LCC is that the many factors which govern the lifespan of building parts, and therefore maintenance need, result in considerable variability of performance in use. Chapter 5 described how there is no satisfactory database of recorded data which can accurately inform on component lifespan under different conditions of use, geographical location etc. It could be argued that an opportunity to assemble such a source of data has been lost, considering the number of years the discipline of LCC has existed. Its emergence in the UK over thirty five years ago could have allowed co-ordinated observation of

building component performance by government research and other agencies. Thus the need for risk analysis, principally using the simulation technique, is becoming established as the best alternative in the absence of adequate data. It seems likely that the research and practice of risk analysis will continue to develop in this environment, encouraged by cheap and accessible PC technology.

7.3 Simulation Applications in Construction Management

Newton's review (90) of cost modelling activity in construction revealed how popular simulation is becoming as a construction management tool. This should not be surprising as it is best suited in applications which are complicated, variable and dynamic in nature (91), characteristics which are present in the procurement and cost in use of buildings. Ultimately the success of a simulation, in terms of how well it replicates the system, depends largely on the nature of the data. The most desirable type is derived empirically, by observation of some similar system to that being studied. The defects in recorded maintenance data, described in Chapter 5, means that historical records, where they exist, are of limited use for this purpose. Indeed, if comprehensive data of this type were available there would be little need for simulation, since we would have valid "real world" observations on which to base projections.

The most appropriate type of simulation model will depend on the type of data available and the difficulties involved in constructing a realistic representation. On the one hand, a black box model attempts to simulate a system without explicitly modelling the processes involved. Its value can only be assessed by comparing its predictive power with actual outcome. On the other hand, a white box model is transparent in that all the variables have to be identified, conveying a detailed understanding of the system. Examples of both types of simulation are most prevalent in construction cost estimating, where models can be classified as micro cost or macro cost. Traditionally a single-figure estimate is made for a project tender cost; a sum which itself is built up from single figure cost estimates of all the resources that make up the particular project. The shortcomings of this are apparent given the number of major high profile projects where actual cost has spectacularly exceeded the original estimate. Simulation in cost estimating can be categorised into micro price modelling and macro price modelling depending on the nature of the data.

7.3.1 Macro-cost models

Macro-cost models seek to estimate the total project cost without the need for analysing the particular construction activities giving rise to the costs. These models rely on the veracity of historical data, ideally from the estimator's direct experience of similar projects, or sources such as the BCIS Cost Analysis of comparable projects. The greater the number of sources the more representative a picture of likely cost will be gained, allowing systematic assessment and highlighting of the riskier aspects of a project at an early stage. The resulting total cost estimate is given as a probable cost range, built up from sampling the cost distributions of the building's constituent elements. The most risk prone aspects will be those elements showing a wide distribution of cost. An early example of macro-cost modelling was demonstrated by Mathur (92) who proposed that a format could be devised by adapting traditional cost planning practices, namely by extension of the BQ. It is suggested that a normal distribution be used for sampling for those elements where sufficient data is not available; a workable if rather crude assumption to make. Flanagan and Norman refines the approach (87) by considering the variety of distributions that can be used to represent variable aspects in construction. Particular attention is paid to the beta distribution, since this is regarded as being most suitable for several reasons. Firstly, the beta distribution is easily identifiable from a limited set of data (the minimum, maximum, mean values and variance from a data set.) Secondly, it has finite end points, and most importantly it can assume a rich variety of shapes.

7.3.2 Micro-Cost Models

In micro-cost modelling the components of the model represent all the resources - time, labour and material - that are to be input into a project. An example by Wilson (93) uses the MC method to simulate the cost of a single element in a project; a concrete floor slab. Data, collected by questionnaire sent to contractors estimator's, was used to build up triangular distributions of the probable cost range for each cost constituent. The triangular distribution may seems a crude assumption but the author defends it on the grounds that it would be unduly difficult to collect the data necessary for a more sophisticated - and realistic- distribution. This highlights the main problem associated with micro-cost modelling, the massive amount of data needed for a full understanding of the system. The time and difficulties in collecting necessary data may prohibit the approach. In Wilson's example a total of seventeen separate cost variables are identified in the floor slab, which constitutes only one of 32 possible elements in a building (94). The main advantage is that it is based on an objective measure of proposed design solutions, and thus necessitates a clear understanding of the construction process. On the other hand the macro price model is based on past projects and the data will be distorted by items such as profit, overheads and tactical marketing considerations that are peculiar to particular projects.

7.4 Practical Problems with Simulation

A common difficulty with simulation is that, no matter how sophisticated the models become, a paucity of satisfactory data will limit their practical use. Data may be prohibitively expensive to collect or may simply not be available. PERT and CPM, widely used in construction project planning, have been developed using simulation to account for uncertainty in the duration of construction operations. Karni's (95) stochastic project network uses samples from discrete probability states and not continuous distributions at the heart of other applications described. It is telling that Karni concentrates on the development of the model rather than the data needed to fill it, and uses a hypothetical (non-construction) project as an illustrative example. Attempts to incorporate the effects of variable site productivity and interference from external sources were undertaken by Bennet and Ormerod (96). Where possible, the risk element was addressed using historical data. In other cases a library of distributions, from which the user selected the most appropriate to model variability, were provided. Detailed data was easy to obtain from the meteorological office for the weather simulation module of their programme. In contrast attempts to quantify the variability of different site activities was plagued by a dearth of information, highlighting the extent of the problem in construction management. Data which were available was limited, and in the opinion of the author, of dubious accuracy. Baxendale models (97) project durations by recording the actual duration of certain major site tasks rather than trying to model the factors which influence them. Cost significant tasks which are repetitive in nature (such as pouring floor slabs in Wilsons example) make the best subjects for this type of modelling. Reliable data can only be obtained by direct observation, for example studying actual concreting observations to tabulate a frequency distribution. This type of simulation model is transparent, and assessable for white box validation. The components of the model represent known behaviour, and data can be collected from similar processes. This provides probability distributions with a good description of the range of possible values. The obvious drawbacks associated with this method are similar to those of Wilson's cost model, namely the great time and costs involved.

7.5 Simulation in Housing Asset Management

Many academics and practitioners have come to accept, over the last decade or so, that for LCC to remain a relevant and useful service a more sophisticated approach than that traditionally practised must be taken. To date, maintenance forecasting using fixed lifespans, from the many sources of life cycle data has predominated. This practice has the advantage of being readily understood and accessible, but it essentially ignores the considerable lifespan differences exhibited by building parts in use. The variability of component lifespans is reflected in the wide range of notional assessments that can be found in the various LCC publications, reviewed by McDermott 1985 (19). Risk analysis techniques are increasingly being used in response to the

113

uncertainty inherent in many areas of construction management. It is argued that these provide a sound scientific basis upon which more informed decision making can be made. A common method of risk analysis is carried out using the OR technique of MC simulation. This allows risks associated with forecasting to be identified and quantified, either objectively using observed historical data or intuitively, by bringing professional judgement to bear in the process or more commonly a mixture of both.

Simulation in housing asset management has been used in an attempt to more realistically assess when the need for maintenance will arise by modelling the deterioration of building elements. The probabilistic maintenance forecasting models described in Chapter 5 are all applied at macro level to forecast trends in expenditure. Damen and Botman's planning is undertaken at the level of all Dutch corporation dwelling's and Gaskell-Taylor builds a model of maintenance need for the entire stock of English and Welsh council housing. These applications were applied across stock numbering hundreds or thousands of units. The stock was of mixed age in each case and the effect was to "smooth" out the sharp peaks of a deterministic forecast , identifying trends in expenditure. Its use lies in strategic planning to forecasts the amount of resources needed in the future. Where the resources should be directed can, of course, only be ascertained at an operational level. This is matter of regular condition monitoring, to identify those building parts needing replaced and for assembly of contract documentation etc. The models use the projected maintenance need of a notional reference dwelling to represent that of the entire stock of housing. Gaskell-Taylor's model does not involve any sampling, instead the probabilistic expenditure profile is constructed by distributing replacement cost around the average lifespan for each element - not the probability of replacement. Gaskell-Taylor argues that the profile would represent expenditure on a large stock of housing if it were averaged. Both Damen and Botman, and Tucker and Rahilly's models sample the probability of replacement from distributions.

7.6 Simulation in the Sinking Fund Case Studies

The work in Chapter 6 is developed by applying SF modelling to simulated data from two of the nine Schemes considered previously. Comparison can then be made between the SF solutions based on stochastic data, and SF solution based on deterministic data. The motivation for the exercise is to provide quantitative evidence of how adequate deterministic forecasts are for making SF projections. It may well be adequate for strategic planning purposes to base SF policy on conventional "average life" assumptions for the planned replacement strategy.

The deterministic data from Scheme's 2 and 3 were selected for simulation. In terms of project size and specification these are two of the most diverse developments from the sample. The widely different profiles of projected MR need are observed in Figure 7.1. The most notable difference between the two profiles is where the peaks of expenditure occur. For Scheme 3 this is

in Year 50, and for Scheme 2 there is a considerable peak in expenditure in year 60. This is where many of the cycles coincide and renewal of the slate roofing, a substantial outlay, occurs.
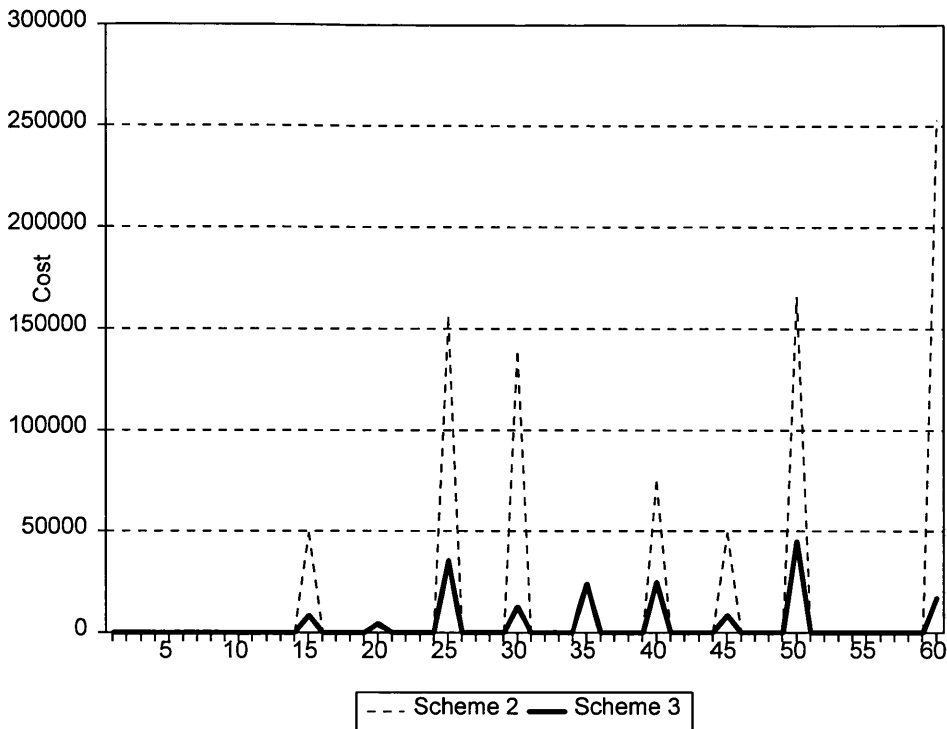

Figure 7.1 Projected MR Expenditure

7.6.1 The Model Parameters

Flanagan and Norman et al identified **(98)** three components in a risk management system; risk identification, risk analysis and risk response. In simulation, risk identification is carried out in the model by establishing the parameters that define the distributions to be sampled from. By using a distribution, rather than a single value, for each element's expected year of replacement, we have a probabilistic replacement model rather than a deterministic one. The replacement of each element will occur within a range of values covered by the distribution, the probability of particular values occurring being governed by the shape of the distribution. In this way assumptions are made about the likelihood of the replacement interval without knowing its precise value. The housing lifespan forecasting models, described in Chapter 5, use continuous probability distribution to represent replacement interval of the major building parts. Both Damen and Botman and Gaskell-Taylor's models' use a truncated normal distribution in the risk identification of element replacement interval. This bell shaped, symmetrical distribution is one of the most commonly encountered in simulation, and is completely characterised by two parameters: the mean and standard deviation. The minimum and maximum time to replacement were defined as 0.5 times and 1.5 times its mean (median and mode) respectively. The CSIRO model described uses a more sophisticated distribution-the beta distribution - to model maintenance demand. Although this requires more information to plot, it can assume a rich

variety of shapes which will reflect the decision makers attitude to risk. The minimum and maximum values were set as 0.9 times and 1.9 times the mean value, significantly different to that of the Dutch model.

As is the case with static lifespan data, no empirical underpinning is evident in the risk parameters for the models described. Ideally a distribution should be plotted from a collected data set, but such a database that would allow this does not exist. Instead, intuitive assessment must take the place of hard data in identifying the risks. This approach is taken in the simulation model described by Baxendale (97) for those random variables where data is sparse or non-existent. A library of distributions is stored within the software, allowing the decision maker to select whichever one reflects his attitude to risk.

The beta distribution is used in simulating expenditure profiles for the case study data. The advantage of this is that it has a finite range, allowing the rejection method of sampling to be used. Four values are needed to plot a beta distribution. Maximum and minimum values of the replacement interval define its end points, and its shape is fixed by two constants, alpha and beta. The parameters of each distribution have been chosen to closely resemble the Damen and Botman and Gaskell-Taylor models. For example, the probability distributions are shown, with both a truncated normal distribution and a beta distribution, for the replacement interval of kitchen fittings. The parameters used to plot Figure 7.2 are the mean lifespan of 15 years, and a standard deviation of five years, with the distribution truncated at a minimum and maximum of 10 and 20 years. For the beta distribution (Figure 7.3), the minimum and maximum values are required parameters, and the bell shape is fixed using alpha and beta constants of 3. The only element lifespans not sampled are those with a sixty year lifespan in the deterministic projections, this ensures that every maintenance activity is provided for at least once. Appendix 4 and 5 show the data and the risk parameters used in the simulation for the two Schemes.
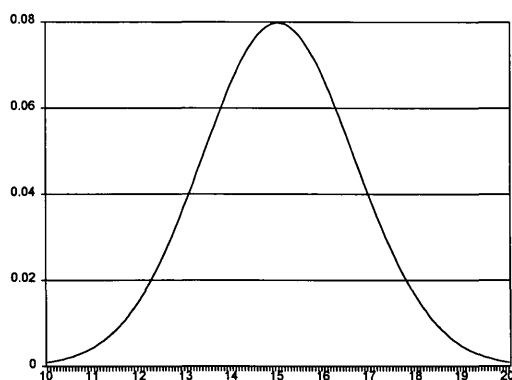
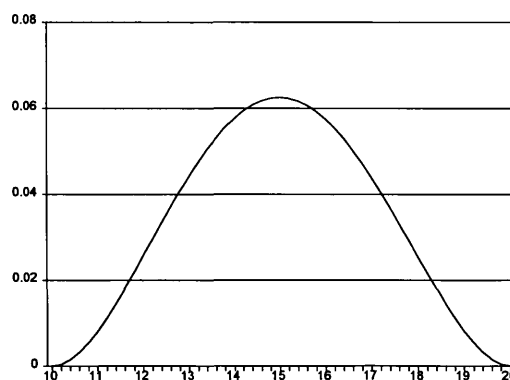Figure 7.2   Normal Distribution Curve

Figure 7.3   Beta Distribution Curve for
Alpha=3, Beta=3

116

7.6.2 Constructing the Simulation Model

A profile of simulated expenditure is derived by sampling the replacement cycle of all the components that comprise the deterministic programme. A complete realisation is a sixty year profile of projected annual expenditure. The greater the number of realisations carried out in a simulation exercise, the more representative the models will be. The number actually generated is necessarily a compromise between computing resources and accuracy. Two hundred and forty such realisations are generated for both case studies, each one representing a possible profile of MR expend. This provides a sufficiently representative spread of solutions for analysis. Any more would have been unworkable due to the limitations of the software on which it was implemented, and the computing time required for subsequent LP solutions and analyses.

Each profile of expenditure is then solved as an LP, using Models A and D, in the same manner as described in Chapter 6. This provides 240 optimum SF solutions, one for each realisation of the simulated data. Figure 7.4 shows the steps involved for one complete realisation.
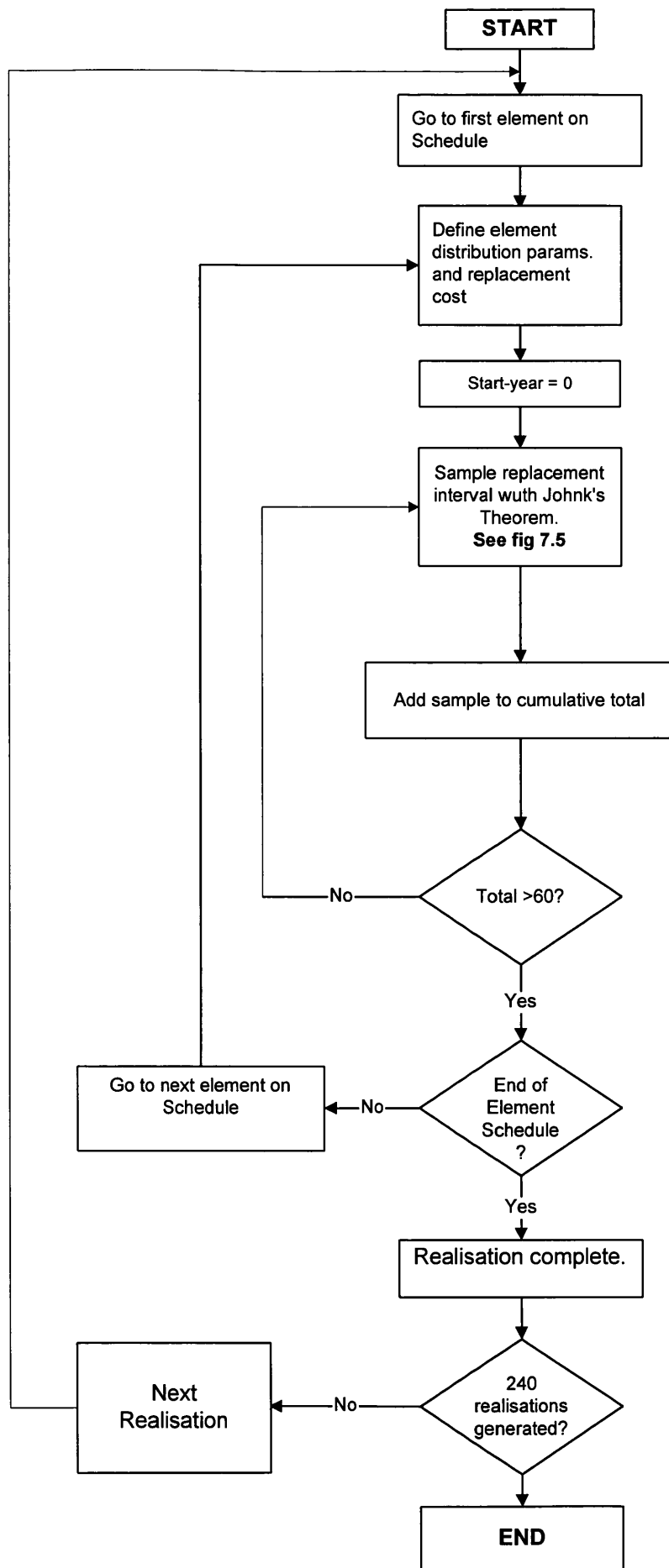
Figure 7.4   Simulation Process

7.6.3 The Sampling Process

For the sampling process a method of generating random numbers is needed. The Quattro Pro V4 spreadsheet was chosen as a platform for carrying out the simulation for a number of reasons. Firstly, familiarity with the software made it a natural choice. Secondly, the simulated data could easily be processed and analysed. Thirdly, the XPRESS-MP package used for SF modelling had the facility to import data directly from spreadsheet files. Thus, it was convenient to work with a data format that was common to the simulation model and the LP model. Spreadsheets are recognised as a convenient means of carrying out MC simulation. The most common approach is to use the concept of a graph of the cumulative distribution function for sampling, with probability (0 to 1) represented on the Y-axis and values to be sampled on the X-axis. Eppen and Gould (46) and Jackson (99) describe how to implement simulation in this way, using the VLOOKUP function common in popular spreadsheets to read off samples from a tabular representation of the graph. The disadvantage with this method is that what is being sampled is only an approximation to the distribution ,because the cumulative distribution function is being approximated by a series of straight lines. An exact and compact sampling process that does not rely on plotting distribution graphs is available using Jöhnk's rejection method (100). Conceptually, the method is equivalent to throwing darts at a dartboard and only counting those that strike certain values (91). Jöhnk's sampling method is easily implemented in the spreadsheet with a Macro used to control the whole simulation process. The flowchart represents the steps taken to implement the Jöhnk's rejection method. Each realisation of the replacement model comprises approximately 40 samples, the exact number depending upon how many sampled replacements for each building part occur within the planning horizon. Appendix 6 contains the spreadsheet Macro listing for the simulation.

7.6.4 The Rejection Method of Sampling

Jöhnks rejection method is used for the random sampling of element and component replacement intervals in the simulation of Major Repair expenditure profiles. Jöhnks is only one of a number of rejection techniques that can be used for sampling probability distributions. Sampling observations from a non-uniform distribution, such as the beta distribution described in Section 7.6.1, is known as random variate generation and is distinct from random number generation, which is simply observations sampled from a uniform distribution. The rejection method, however, makes use of random numbers generated by the spreadsheet to sample observations from the lifespan distributions. In fact the spreadsheet does not generate true random numbers, which are said to be a rather elusive concept (129), but the pseudorandom numbers it does generate have sufficient properties of random numbers for the purposes of the exercise.

A feature common to all rejection methods is that a trial value for a random variable is generated and subjected to a test involving one or more other random variables (130). The outcome of the test is that it may be accepted or rejected. Jöhnks requires the generation of one other random number as shown in the flowchart of Figure 7.5. If accepted we have our random sample of element lifespan, but if rejected the cycle of choosing and testing a trial value is repeated until an acceptance takes place. The process has been likened to throwing darts at a dartboard and only counting those that strike certain values (91). Continuing with this analogy, the generation of the first random number (the trial variate) is likened to the dart hitting the dartboard. However, we are only interested in the dart hitting certain areas of the dartboard, which represents the acceptance region of the beta distribution. If the trial value for the random variable is not rejected by the test, this is akin to our dart hitting the area of the dartboard of interest to us, and the trial value is accepted as the random variate.

A disadvantage of the rejection method is that it is not very efficient in generating random variates since many values could be rejected before acceptance takes place. However, this is becoming less of a problem as the capacity and processing speed of computers continues to improve. For the relatively small scale of the simulation carried out in the study the advantages of the Jöhnks rejection method far outweigh any perceived disadvantages it may have. The simulation of MR expenditure is under the control of the spreadsheet macro reproduced in Appendix 6.
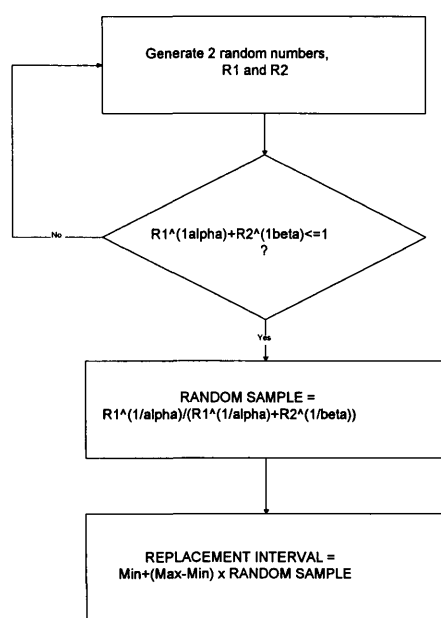
Figure 7.5 Jöhnks Rejection Method

7.6.5 Validation

One of the problems of simulating long term maintenance expenditure is the difficulty of validation. Testing how representative the risk parameters are in the simulation model is ideally done by comparing simulated results with "real world" observations. This is obviously not possible where an attempt is being made to simulate sixty years of MR expenditure by considering the random variable of lifespan. The model cannot therefore be shown to be valid in any absolute sense. There is no evidence that will confirm or refute the distribution parameters, based on supposition, of the models described. The limitation of the simulation model used is that only one random variable is considered. No attempt has been made to consider the interaction of maintenance work on a development, and the influence this will have on the programming and timing of work. Therefore the model is only valid where it is assumed each element is replaced at the end of its sampled lifespan.

7.6.6 Results

The simulated exercise provides three sets of results of interest :-

1. The spread of costs of the simulated MRP expenditure. Two hundred and forty realisations were carried out, each one providing a possible sixty year stochastic expenditure profile for the development. These are compared by calculating the total NPV of costs in each profile. A frequency histogram of the NPV's are constructed to show the distribution and most likely total cost of forecast expenditure.

2. The cost range of SF policies based on the simulated data. The SF models are solved using the expenditure data from each realisation, giving two hundred and forty projected SF strategies. The total cost of each solution is calculated, as in (1), and arranged into a frequency histogram.

3. The effect of implementing a SF policy based on conventional (deterministic) forecasting for a stochastic profile of expenditure. The objective is to determine how realistic, and thus how adequate, deterministic LCC forecasting is for a system exhibiting stochastic behaviour. The fund is projected with annual SF contributions based on a deterministic expenditure profile, but outgoings from the fund occur at the time of sampled element replacement. Consequently, either a surplus will accrue in the fund or it will be in deficit at some point. If the deterministic policy closely matches expenditure need for each profile then it can be supposed that it is adequate for planning purposes.

121
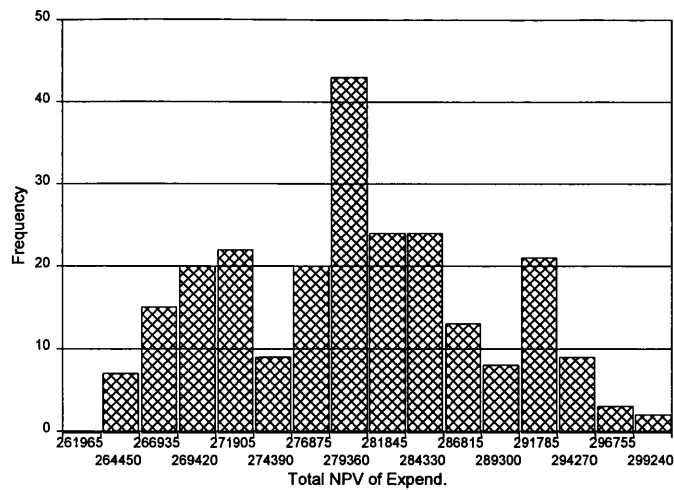
Simulated MRP Expenditure.

Figure 7.6   Simulated Total MR Expenditure Range for SCHEME 2

Figure 7.6 shows the spread of simulated total costs over the planning horizon. Costs range from 261965 to 299240 and the most frequently occurring cost range, by a significant margin, is 276875 to 279360. The total cost based on deterministic expenditure is 289519, some 3.6% to 4.6% greater than the most probable simulated range.
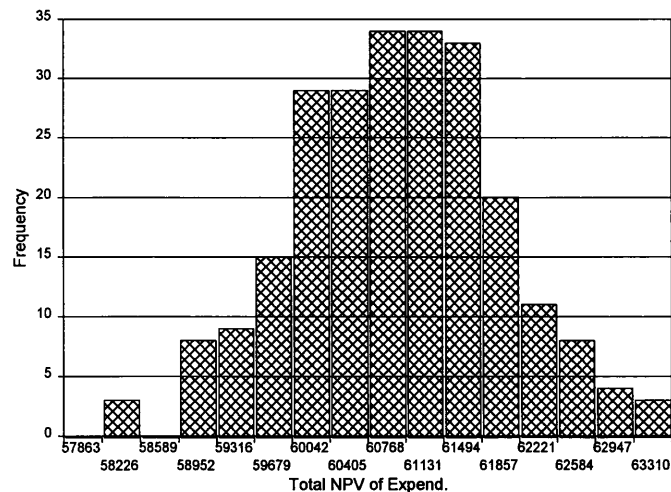

Figure 7.7   Simulated Total MR Expenditure Range for SCHEME 3

Figure 7.7 shows the most likely expenditure cost range is from 60405 to 61494, only 1%-2.8% less than the deterministic expenditure forecast of 62130. However the frequency of costs occurring in this interval is not much greater than in the two intervals below, and one above, giving a quite flat distribution.

Figures 7.8 and 7.9 show the total amount of SF contributions for each realisation of the SF models. These vary from 261965 to 299240 for both Model A and Model D.
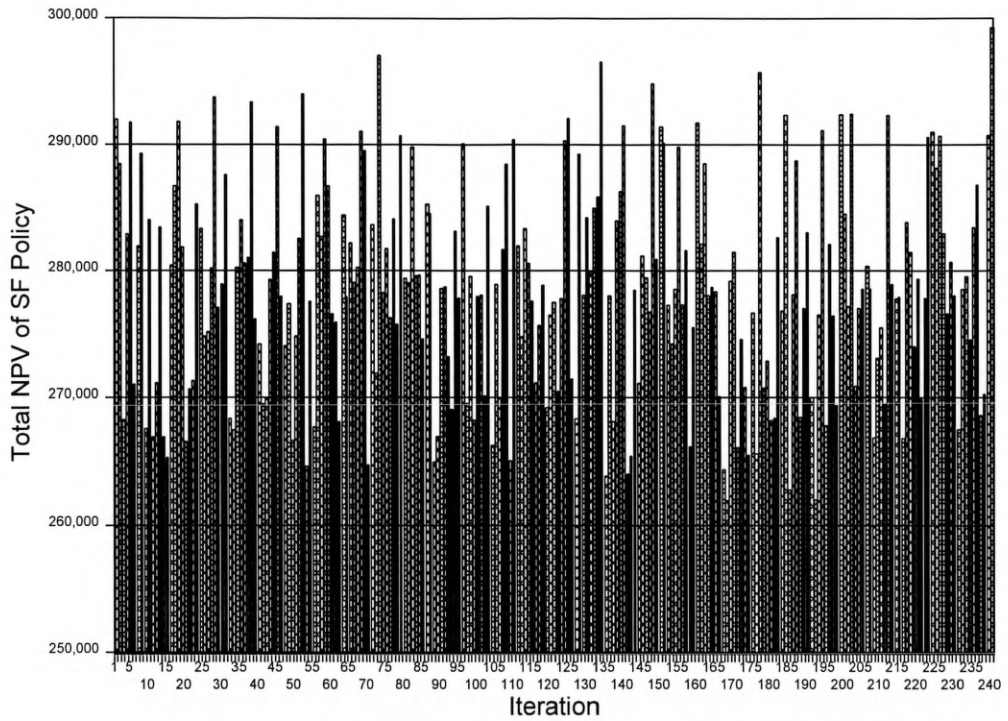
Figure 7.8   Projected Total Cost of SF Strategy for SCHEME 2 using Model A: 240 Iterations
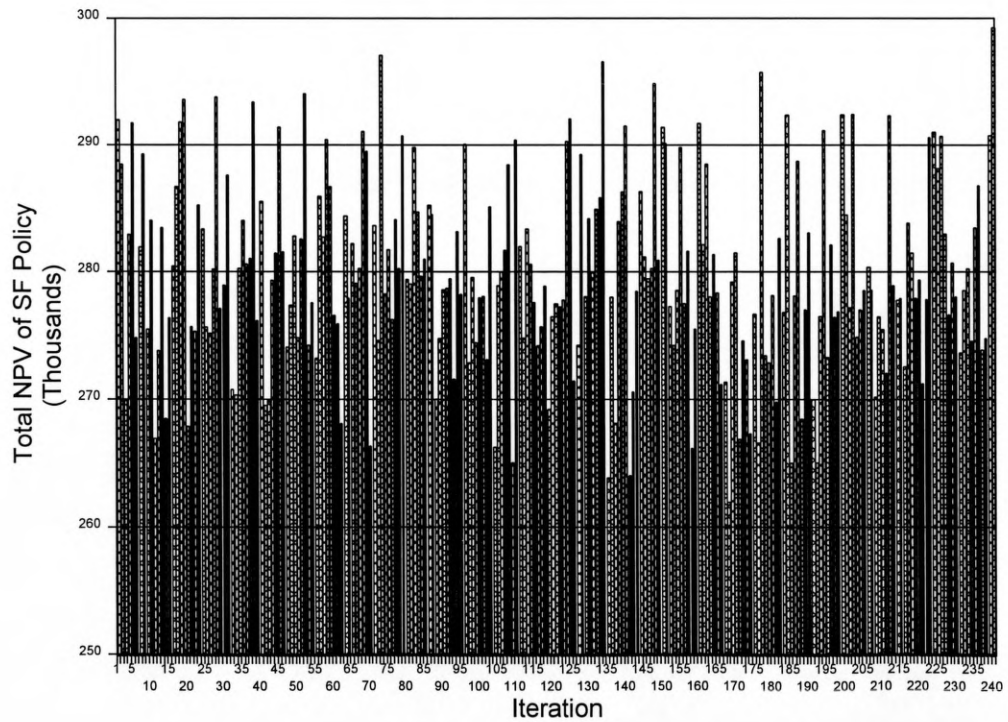
Figure 7.9 Projected Total Cost of SF Strategy for SCHEME 2 using Model D: 240 Iterations

Figures 7.10 and 7.11 show the total amount of SF contributions for each realisation of the SF models. These vary from 60495 to 65585 for Model A, and 61987 and 70157 for Model D.
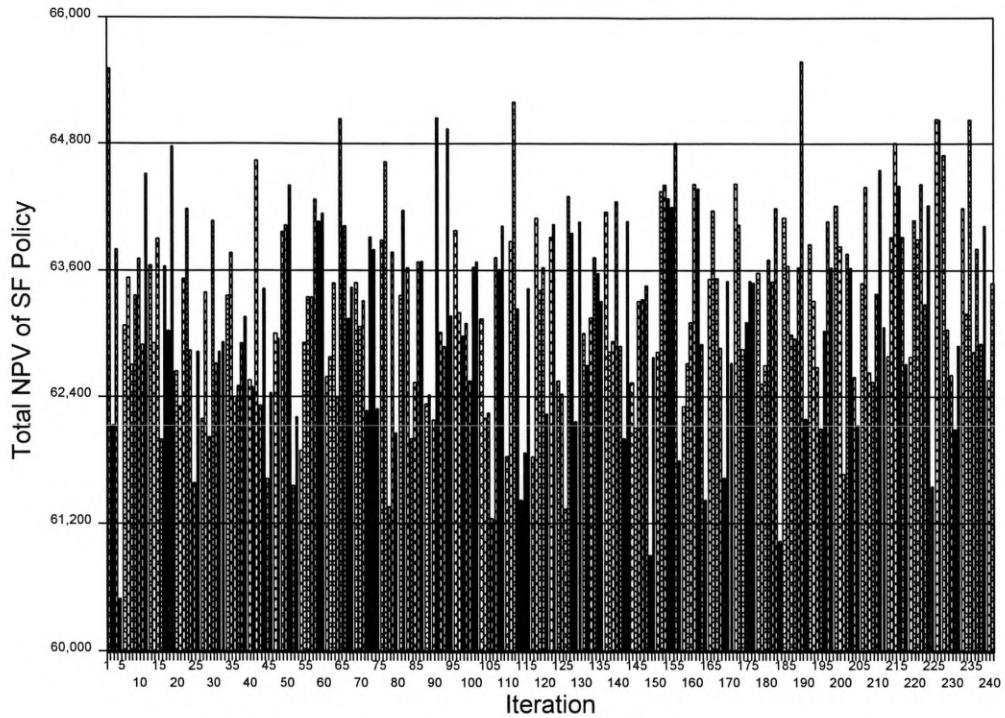
Figure 7.10 Projected Total Cost of SF Strategy for SCHEME 3 using Model A: 240 Iterations
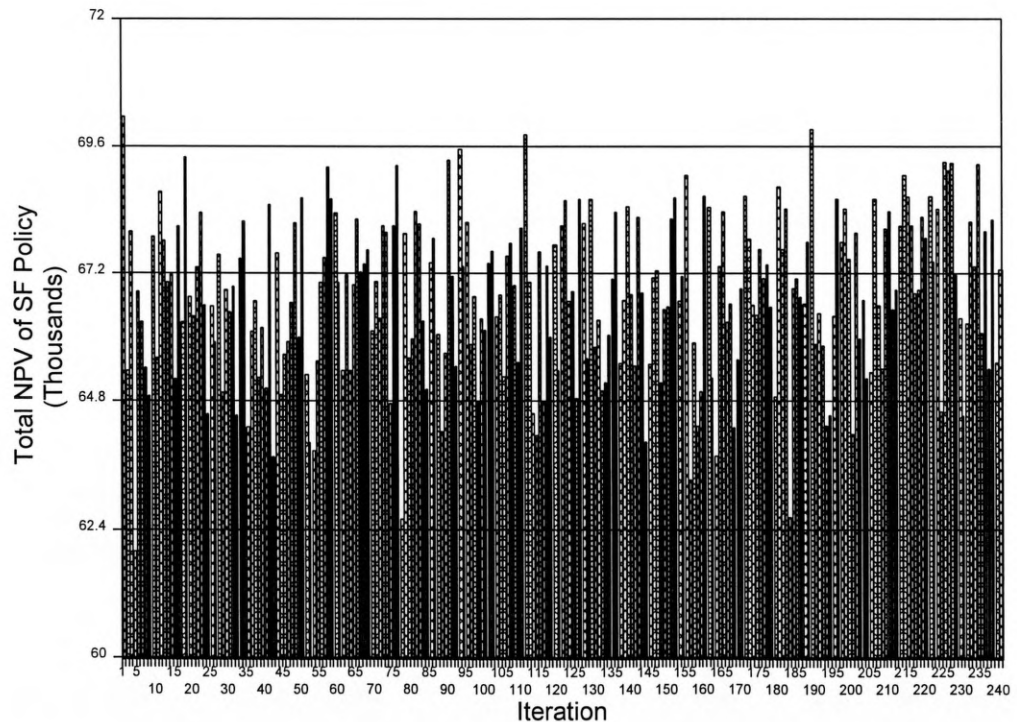
Figure 7.11 Projected Total Cost of SF Strategy for SCHEME 3 using Model D: 240 Iterations

Frequency Distribution for SF Policy Cost: Scheme 2
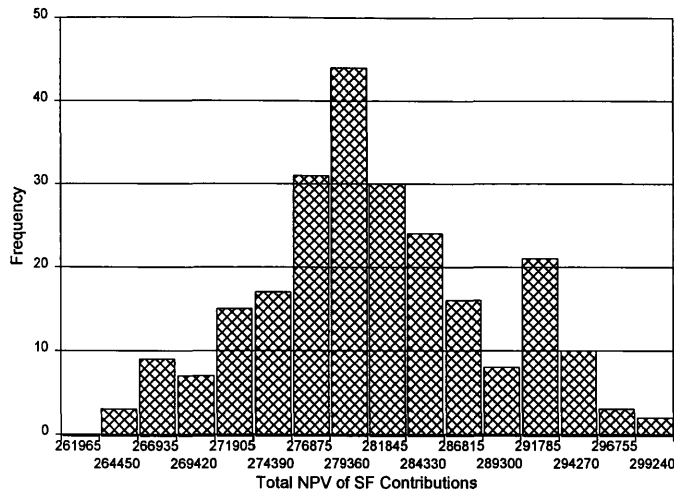
Figure 7.12 Spread of SF costs for SCHEME 2 using Model A

The distribution of total SF contributions in Figure 7.12 is very similar to that of the expenditure cost distribution. There is a slight skew to the right because the stepped SF strategy of Model A is not the most efficient, as the results from Chapter 6 show, and resulted in a surplus at the end of the projection. However this is not very significant as the most frequently occurring SF policy cost is in the same interval as the MRP expenditure range.
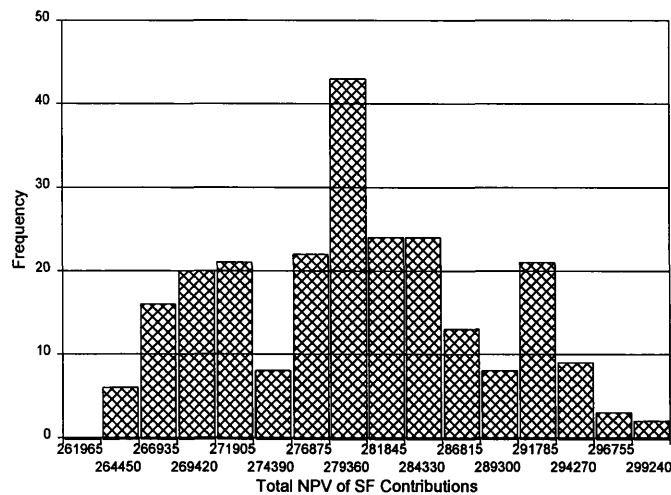
Figure 7.13 Spread of SF costs for SCHEME 2 using Model D

The frequency histogram (Figure 7.13) of the cost distribution for this strategy is almost identical to that of the MR expenditure distribution. This shows that this strategy is efficient, in terms of overall cost, for the vast majority of possible expenditure profiles.

Frequency Distribution for SF Policy Cost: Scheme 3
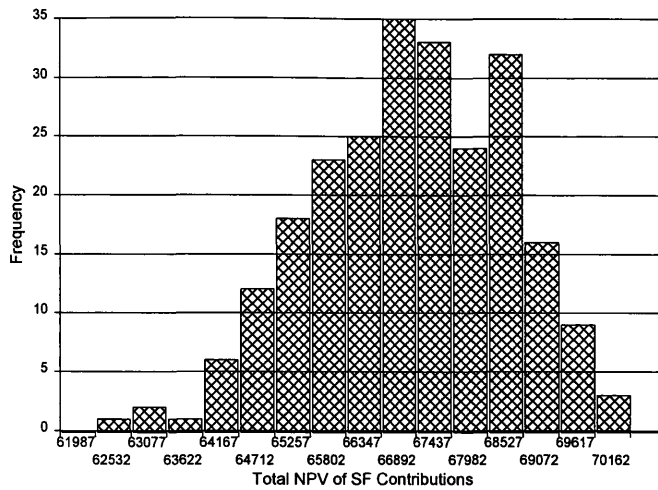
Figure 7.14   Spread of SF costs for SCHEME 3 using Model D

The distribution of costs is similar to that of the expenditure profile, with a slight skew to the right.   The skew is more pronounced than that for Scheme 2.   The most likely cost range is between 66347 and 66829.   The SF solution based on deterministic data is 69300, between 3.6% and 4.6% greater than the most likely solution based on stochastic data.
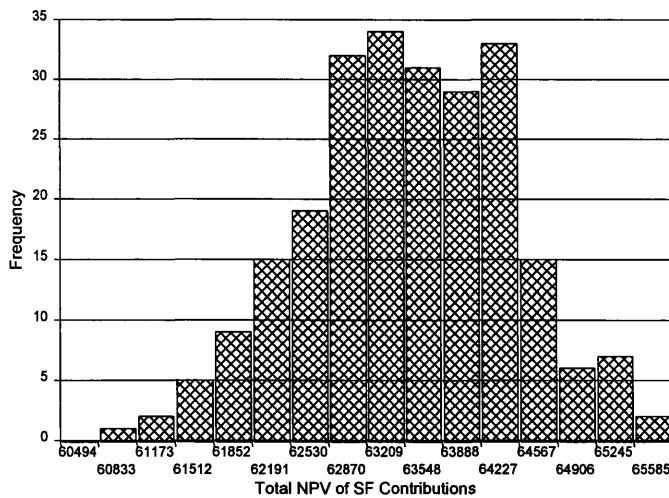

Figure 7.15   Spread of SF costs for SCHEME 3 using Model A

The distribution of costs for this strategy is also skewed slightly to the right.   It is fairly flat with no single interval clearly the most probable.   The most probable range, across five intervals, is 62870 to 64567, slightly below the deterministic solution of 64711.

7.6.7 Deterministic Model for Stochastic Replacement Programme

The purpose of using simulation was to forecast the most likely total amount of expenditure, and thereafter the most likely cost of SF policy. The Model A and Model D SF LP's were solved for each realisation of the stochastic expenditure data. Each realisation is still a deterministic forecast, projecting 60 years of expenditure by sampling element lifespans within this period The SF strategies are still based on the proposition that all MR expenditure is known at the outset. Therefore the observations made are only valid where we have perfect information, and there is an exact match of projected SF and actual need.

For the third type of analysis the SF policy is projected with annual contributions calculated for an expenditure programme based on fixed element replacement cycles, but with outgoings based on the stochastic expenditure profiles. This exercise will show how well long term deterministic SF projections approximate "actual" need. In each case either a surplus fund will be projected at the end of the planning horizon, or the SF contributions will be inadequate to fund the stochastic profile at some point in time. If many of the profiles show a significant surplus or deficit then it will be apparent that SF policy is sensitive to actual timing of maintenance activities.

Scheme 2

Table 7.1 shows the deterministic SF policy of both Models' A and D generates significant surpluses for many of the possible expenditure profiles. In each case 86% of the realisations resulted in a surplus, ranging from an insignificant £128 to £162338. The average surplus was 77956. At present day value, discounting these figures at 3% for 60 years, the maximum and average surplus is £27549 and £13229 respectively. The deterministic SF policy results in a deficit forecast at some point for comparatively few of the stochastic expenditure realisations (table 7.2). Both the Model A and Model D deterministic strategy led to a forecast deficit at the end of the planning horizon for 14% of the realisations. The amounts range from -1567 to -57268, with an average of -15656. The slower build up of funds that accrue from Model A strategy led to deficits occurring mid way through the planning horizon for 20% of the realisations. These range from -75 to -24909. This is due to the substantial expenditure occurring around year 30.

Scheme 3

All profiles result in a surplus at year 60, but this is also a feature of the deterministic model. For both strategies of Model A and Model D the average surplus for stochastic expenditure was slightly higher than the deterministic surplus. Very few of the profiles led to a deficit for either model. The SF for Model A only shows a deficit for 5% of the stochastic profiles, occurring between years 50 and 52. 4% of the profiles in Model D are in deficit by year 60. The amounts in each are comparatively trivial.

Table 7.1 Surpluses Accruing from Implementing Static Policy for Stochastic Expenditure Profile:

240 Realisations

PROJECTED SURPLUS								
	Scheme Value	SF Model	Realisations		Surplus Range			Deterministic Surplus
			Num	%	Min	Max	Avg	
SCHEME 2	1108438	A	206	86	128	162338	77956	0
		D	206	86	128	162338	77956	0
SCHEME 3	324332	A	240	100	8263	40345	23751	15209
		D	240	100	35296	67378	50792	42242

Table 7.2 Deficits Arising from Implementing Static Policy for Stochastic Expenditure Profile:

240 Realisations

PROJECTED DEFICIT								
	Scheme Value	SF Model	Projected Deficit (Year)	Realisations		Deficit Range		
				Num	%	Min	Max	Avg
SCHEME 2	1108438	A	60	34	14	-1567	-57268	-15656
		D	28-31	48	20	-75	-24909	-4888
			60	34	14	-1567	-57268	-15656
SCHEME 3	324332	A	50-52	12	5	-237	-3644	-1452
		D	60	10	4	-233	-5338	-1892

The surpluses and deficits arising from these projections are of similar magnitude for both Schemes (when compared as a proportion of their tender values). The differences that do occur are as a result of the different forecast maintenance expenditure profiles. In Scheme 3, where the peak in expenditure in the deterministic model is earlier than for Scheme 2, there is less chance of the fund running into deficit. Money is committed to the fund earlier to meet this expenditure peak and a comparatively larger cash reserve is built up. For the same reason there is also a greater chance of surpluses projected for Scheme 3 than Scheme 2. Although the amount of the surpluses may seem substantial, the total NPV of SF contributions that generate them do not greatly exceed the range of total SF contributions that provide the optimal strategies for the stochastic data. It is the effects of compounding interest that inflates them.

7.7 Conclusions

For both schemes implementing the static policy for stochastic profiles is much more likely to accrue a surplus of funds rather that result in a deficit. The reason for this is that, for the simulated data with the given risk parameters, the total NPV of the deterministic MR expenditure programme is more likely to be marginally greater than the total NPV of most of the stochastic expenditure profiles. This may be explained by having the same fixed planning horizon for the simulation model as for the deterministic one. The effect of this is that second or subsequent replacement of some elements, which occur at year 60 in the deterministic model, may not be provided for. This poses the question as to whether this fixed cut-off point is an appropriate way of approaching the SF. After all, provision is being made for replacement of major elements, such as roof coverings, at the end of the notional lifespan for the dwelling; 60 years after initial construction. The new covering may well have the potential to last a further 60 years. During this time financial provision will have to be made for replacement of the other elements, if the standard of utility is to be maintained. Inevitably, the dwelling will be demolished when it no longer fulfils its functional requirement, either because of social or technological obsolescence. It would obviously not be efficient to maintain the dwelling at the level set out, with provision being made for upwards of twenty elements and components, up until the point of demolition. A decision will have to be made on when the SF is scaled down. Clearly, though, a SF provision based on the sixty year MR programme implies a housing lifespan well in excess of sixty years. There is an argument that this is a necessity. Meikle and Connaughton believe **(82)** that new housing will have to last for many hundreds of years - well beyond the current notional life of housing - in order meet the population demand. Buildings are very durable, however, and if properly maintained will often last for centuries **(101)**.

As the overall cost of SF policies based on deterministic data is only marginally greater than the most likely actual cost of SF policy (from simulation) then deterministic LCC exercises are adequate for strategic planning. It can be said that a deterministic forecast provides a conservative basis for planning. The analysis carried out highlights that a review of the SF must be undertaken when it becomes apparent that assessment of remaining lifespan of elements differ from the original plan. The hypothesis only holds true considering a sixty year fixed horizon, and for the model parameters used in the simulation. Uniform risk parameters were applied to all the elements in the simulation, but undoubtedly housing elements have varying lifespan characteristics. It is contended that, if sophisticated planning using such techniques as simulation are to become more practicable, refined sets of data will have to be developed. The beta distribution provides the best means of maintenance modelling because of the many shapes it can assume. Rapidly improving technology will make the practice of simulation easier, but it will not be sufficient in itself to convince the industry of its worth.

CHAPTER 8   A Dynamic Sinking Fund Model

8.1 Introduction

The SF strategies modelled in the previous chapters are based on a single long term maintenance projection for each Scheme. This required a forecast of all MRs occurring in the sixty year period from the time of initial construction. The financial equations and LP's presented in Chapters' 3 and 4 respectively were used to determine a SF strategy based on this data. Whilst this long term plan is valid and necessary at the outset, it is true to say that maintenance projections will need to be reviewed over time, and the SF strategy will have to be amended accordingly. The objective of this Chapter is to investigate the extent to which these inevitable changes in maintenance projections affect the original SF strategy. It is intended to show how a planned SF policy compares with actual experience by simulating "actual" policy as it evolves throughout the planning horizon. A valid question is whether the presence of more accurate data, with attendant cost implications provides discernible benefits when formulating a policy of SF provision. This is addressed in two ways. Firstly, by measuring and comparing the total NPV of contributions for an "actual" SF strategy with those of a static model, where all future MR timings are known from the outset (i.e. no changes are made to original plan). Secondly, by observing how closely the 60 year profiles of contributions based on optimal and simulated profiles match.

8.2 The Model and Actual system

It is probably true to say that planned events in any complex system will never be replicated by the actual events; a good plan can only hope to model reality as closely as possible, given the simplifications that will necessarily be made. Similarly, given that building component lifespan is difficult to predict for the reasons explored in Chapter 5, the actual maintenance activities carried out over the life of a building will inevitably differ from the initial MR forecast. The SF models in previous Chapters have dealt with whole life projections having a sixty year horizon, and assume maintenance projections hold good throughout the plan. This is, of course, very unlikely and is one of the main reasons why LCC is so fraught with difficulty. In reality, maintenance projections must be refined over time as the building and its constituent elements deteriorate, and better information becomes available. This is achieved through a system of periodic condition monitoring.

For forecasting the long term maintenance need of housing two types of projection have been used, both of which have been dealt with in previous Chapters. The conventional, and most common, is the deterministic forecast which assigns fixed "average" life estimates to the various elements and components. The second type of forecasting is stochastic in nature and attempts to

address the problem of lifespan variability to allow more informed planning. Chapter 7 compared results from LP models using deterministic and stochastic data derived from the Schemes BQs. The analysis dealt with whole life assessments of MR need, typically carried out at the procurement stage of a building. This Chapter develops the study by considering the dynamic nature of maintenance management. A system of ongoing condition monitoring is necessary for effective asset management, meaning that stock condition information will evolve throughout the buildings life.

8.3 Stock Condition Monitoring

A maintenance plan is not a one-off operation devised at the outset to be adhered to rigidly throughout the planning horizon. Maintenance planning is a dynamic process which relies on feedback to regularly update it to remain relevant and effective. Condition surveys gauge effectiveness of maintenance programmes and guide future expenditure plans (76). The condition survey, collation and analysis of data are all components of a condition monitoring system. The diverse variability of lifespan exhibited by building parts, even in largely homogenous property groups, are what makes condition monitoring essential to assess remaining lives of buildings and components before replacement and repair is necessary. Although there is general agreement on the importance of surveys, standard definitions, procedures and reporting methods are not yet widespread in asset management. The health service has pioneered a range of surveys to provide a full appraisal of the requirements of hospitals. In addition to assessing the integrity of the fabric they assess suitability of use, thermal efficiency and safety. Much interest has been given over to the objectives of condition monitoring and condition survey methodology. This has arisen from the increasing awareness of the importance of building maintenance generally and also the emphasis on planned maintenance in housing which became very significant in the 1980's.

The objectives of condition monitoring will influence the nature and content of the data to be collected. It is therefore necessary to be clear on these objectives before effort is expended in collecting data. The purpose of assessing stock condition will include some or all of the following

- Assessing backlog.
- Preparing strategies.
- Establishing priorities.
- Preparing budgets.
- Upgrading property registers.   Source 102

Despite the importance of condition monitoring, efforts within the Scottish housing scene as a whole have traditionally been poor. Information is readily available on the numbers of properties in the various ownership sectors and statistics on construction activity but there is no readily

131

available source of information on the composition of housing by age and type, let alone condition (74). The Building Societies Association noted that comparatively little information is available on the condition of Scottish housing in their Housing in Britain publication. This contrasts with the position in England and Wales where National House Condition Surveys have been taking place since 1967 (1973 in the case of Wales and 1974 in Northern Ireland). Whilst there has been no co-ordinated national survey information on numbers, tenure, age and type of housing falling below tolerable standard, information was compiled from returns by Scottish Local Authorities on housing condition in 1990. However, it is significant that no consistent methodology was applied in the collection of data. This is the main reason why condition survey information, a potentially useful source of data, may be almost worthless for predicting future maintenance need. The various motives for collecting data and the lack of objective performance standards often render it inappropriate for use in LCC. The National Audit Office called the reliability of the figures into question as the majority of cases estimated provided by the LAs were not based on recent information and some were based on surveys up to 20 years old. The BRE examined the evidence available and concluded that only 16 out of 56 surveys carried out by LAs were consistent, reliable and objective.

Recognising the need for a systematic and comprehensive assessment of condition, the Scottish Development Department produced detailed guidance (77) for LAs on surveys. This updated the limited advice produced in 1977 taking account of the advances that had been made in sample survey techniques and provided a complete, ready made set of techniques.

8.3.1 Condition Monitoring Methodologies

In the past there has been a tendency for organisations to collect too much data from surveys which proves to be overcomplicated and unwieldy for operational use. In addition surveys are manpower intensive and costly to procure (103). As they only provide a snapshot of condition there is little to support extensive data collection when much of it will never be used. Single surveys have very little value after the first year of operation for detailed maintenance programmes (74). The prevailing attitude of what constitutes effective condition monitoring is to collect the minimum amount of data compatible with assessing the overall condition of the stock, striking a balance between quantity of data collected and cost effectiveness. This calls for sample surveys of the stock (74, 103) to assess its overall condition and determine how it is distributed geographically or between different population groups. In this way priorities can be identified. Surveys will be carried out regularly to update information on the condition of the stock. The data will:

- Account for annual deterioration
- Allow for acquisitions, disposals, alterations.
- Respond to changes in standards.

Typically a 10% sample is deemed satisfactory for obtaining a statistical picture of stock condition. Holmes advocates **(104)** a two stage approach to condition surveys. The first is to prioritise work in the manner described above, the second stage is to deal with those elements requiring attention in the first year of the programme. The latter stage requires a 100% survey of the elements identified so that sufficiently detailed contract documentation can be assembled. The most effective condition survey provides the simplest level of description commensurate with its objectives.

8.4 A Dynamic Sinking Fund Policy

The true cost of a SF policy to an organisation will be that actually incurred, and will only become apparent over time as it is implemented. In a real life system a projection is made at the outset based on the conventional means of average life assumptions for the elements and components. Over time these projections will change as new information is gathered through condition surveys and it becomes apparent when replacements will actually become necessary. Consequently the SF plan will be revised to take account of the new data. The hypothesis is that a SF strategy is sensitive to the updating of maintenance data over time. This is tested by deriving a dynamic SF model. The resulting SF plan is compared with one based on the same data, but solved by a single LP i.e. the replacement profile is known by the policy-maker from the outset.

8.4.1 Methodology

The dynamic SF model comprises twelve linked LP's solving the twelve sets of maintenance data prepared by spreadsheet macros. Each set of data represents the projections that would be made at five yearly intervals throughout the life-cycle. The structure of each LP is the same as for a sixty year static model of the types described in Chapter 6, but the planning horizon is successively reduced by 5 years from LP1 to LP12. For each LP the optimal SF strategy is projected until the end of the planning horizon, but only the first five annual contributions are actually committed to the SF, before the next review takes place. As the SF strategy must be maintained over the whole life cycle it is necessary to link the payment and fund constraints from year to year between the twelve LP's that make up the dynamic model, in the same way as the constraints within each model. Table 8.1 shows the variables of the dynamic model

The analysis assumes that the organisation will monitor the condition of its stock by carrying out surveys on elements every five years. An approach to maintenance management based on 5-yearly inspection of all building elements is described in the SLASH Maintenance Practice Manual **(105)** originally designed to improve the management of LA housing stock. If inspection is carried out on major components every five years then, by implication, it is not possible to accurately predict their remaining life greater than five years in advance. Therefore an average (deterministic) lifespan assumption is satisfactory for longer term forecasts.

Table 8.1   Variables in the Dynamic SF model.

―― DYNAMIC SF MODEL ――				
Linear Programme	Planning Horizon	Data	Decision Variables	SF Strategy Implemented
LP1 ↓	60 yrs	c1,...,c60	x1,...,x60 f1,...,f60	x1,...x5 f1,...f5
LP2 ↓	55 yrs	c6,...c60	x6,...,x60 f6,...,f60	x6,...x10 f6,...f10
LP3 ↓	50 yrs	c11,...,c60	x11,...,x60 f11,...,f60	x11,...x15 f11,...f60
LP4 ↓	45 yrs	c16,...,c60	x16,...,x60 f16,...,f60	x16,...x20 f16,...f20
LP5 ↓	40 yrs	c21,...,c60	x21,...,x60 f21,...,f60	x21,...x25 f21,...f25
LP6 ↓	35 yrs	c26,...,c60	x26,...,x60 f26,...,f60	x26,...x30 f26,...f30
LP7 ↓	30 yrs	c31,...,c60	x31,...,x60 f31,...,f60	x31,...x35 f31,...f35
LP8 ↓	25 yrs	c36,...,c60	x36,...,x60 f36,...,f60	x36,...x40 f36,...f40
LP9 ↓	20 yrs	c41,...,c60	x41,...,x60 f41,...,f60	x41,...x45 f41,...f45
LP10 ↓	15 yrs	c46,...,c60	x46,...,x60 f46,...,f60	x46,...x50 f46,...f50
LP11 ↓	10 yrs	c51,...,c60	x51,...,x60 f51,...,f60	x51,...x56 f51,...f56
LP12	5 yrs	c56,...,c60	x56,...,x60 f56,...,f60	x56,...x60 f56,...f60
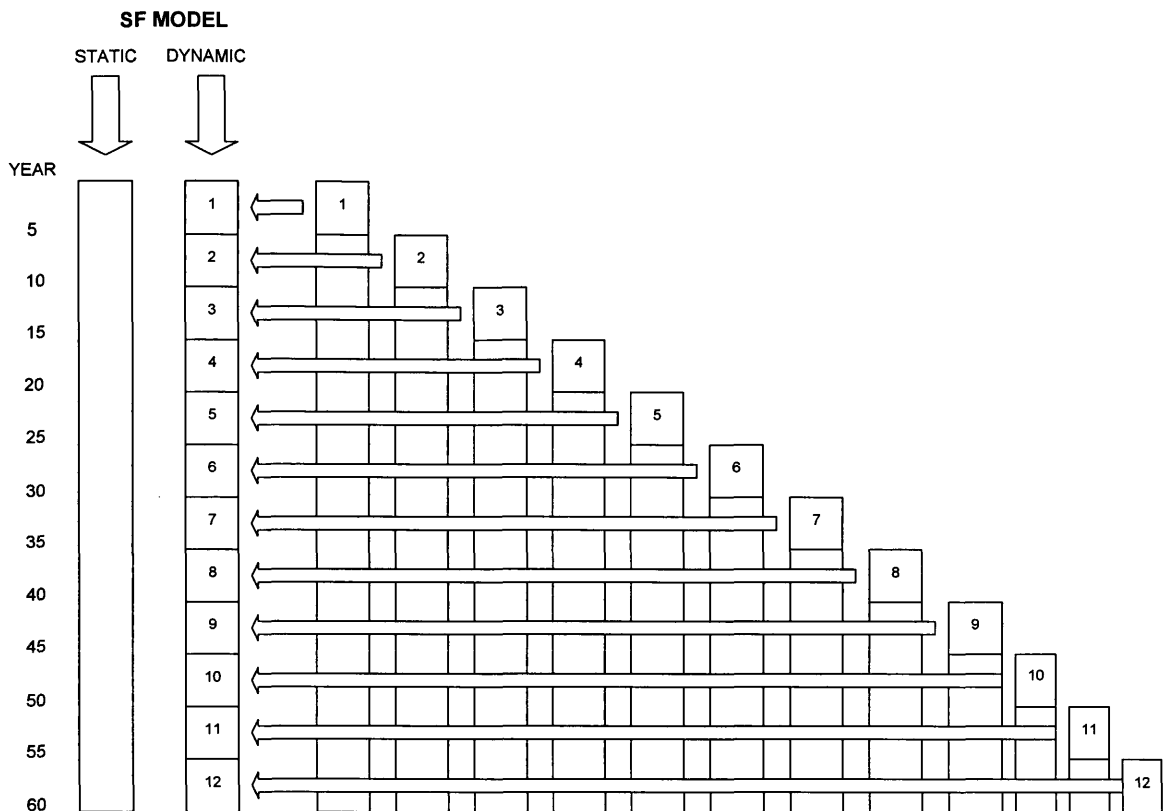
Figure 8.2 Dynamic SF Model

To produce the sixty year dynamic SF model twelve LPs are needed to solve the twelve maintenance datasets generated. Each solution provides annual deposits for the remainder of the planning horizon. Only the first five deposits calculated are actually implemented in the SF policy since it is reviewed every five years. Figure 8.2 represents how the dynamic model is constructed from twelve separate LP's.

Figure 8.3 summarises the steps involved in moving from the original deterministic data to the twelve sets of data needed for the twelve LP's in the dynamic model. From this simulated data the dynamic scheduling macro, reproduced in Appendix 7, prepares the twelve 'real-time' forecasts. These are then processed into twelve profiles of cost data in a form acceptable to the XPRESS modeller using the macro in Appendix 8. Each set of dynamic data is then solved using the Model A and Model D strategies to provide the dynamic SF profiles.

```
            STATIC DATA
                 |
                 v
        {simulation macro}
                 |
                 v
           MR Profile
                 |
                 v
      {Dynamic Schedules MACRO}
                 |
                 v
      {Dataset Processing MACRO}
                 |
        +--------+--------+
        |                 |
        v                 v
    Model A           Model D
        |                 |
        v                 v
    XPRESS            XPRESS
        |                 |
        v                 v
    Dynamic           Dynamic
    SF Profile        SF Profile
```
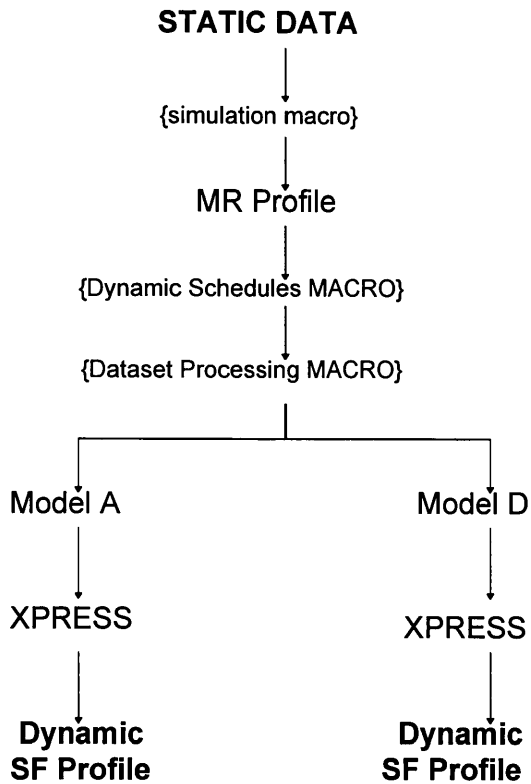
Figure 8.3   Preparing the Dynamic Model

8.4.2. The Cost Data

In the dynamic model we have to make several MR projections, based on the data that would be available at five-yearly intervals throughout the planning horizon. This means that next-due replacement dates for each element\component will be a mixture of forecasts, based on average life assumptions, and actual scheduled replacement, where the sampled replacement date is within five years from the projection. A series of forecasts of major maintenance need are made following each condition survey. Each one represents the best information that is available at the time it is carried out. As a quinquennial inspection policy is envisaged twelve such forecasts would be made in the sixty year planning horizon, carried out in year 5, 10, 15.. and so on with the final survey undertaken in year 55. The first forecast is made in year 0 i.e. at the outset of the project when a SF policy is initiated.

The replacement timings of all major components are sampled from the distributions. These sampled dates represent when the replacement and expenditure will actually occur. The timings are not predicted in the dynamic model until the survey review year which precedes the replacement - the time at which the actual year of replacement can be forecast and planned with any degree of confidence. In this way the SF policy is revised every five years in the light of fresh information. This requires the LP to be repeatedly solved with the new dataset and reduced planning horizon. As the planning horizon for the development is fixed at 60 years from initial construction, the range of major repair forecasts will reduce through time, successively reducing

by 5 years at each review. Thus the first projection (at year 0 and based entirely on deterministic assumptions) is of sixty years, and the final projection (at year 55) is of five years.

Table 8.2 below shows that actual scheduling of MR activity only has a five year horizon, beyond this it is only forecast and may change at a later review. For example, the first projected replacement is for kitchen units, forecast to occur 15 years after initial construction. The actual year of replacement will not be scheduled, however, until the 2nd or 3rd review of the SF (at year 10 or 15) depending upon its condition at these times.

Table 8.2   Forecast and Scheduled Major Repair Activity

Review Year	Forecast MR Activity (Range in Years)	Scheduled MR Activity (Range in Years)
0	15- 60	-
5	15 - 60	-
10	16 - 60	11 - 15
15	21 - 60	16 - 20
20	26 - 60	20 - 25
25	31 - 60	26 - 30
30	36 - 60	31 - 35
35	41 - 60	36 - 40
40	46 - 60	41 - 45
45	51 - 60	46 - 50
50	56 - 60	51 - 55
55	-	56 - 60

8.4.3 The Scheme Data

Scheme 2 and Scheme 3, for which maintenance profiles were simulated in Chapter 7, were used to derive a dynamic model. These two schemes are different in both scale and projected major maintenance characteristics. Appendix 3 shows the MR schedule, and the estimated replacement cost and average lifespan for each. Replacement of the 24 items on each schedule are forecast to occur at intervals of the average lifespan until the SF review preceding the sampled "actual" lifespan.

8.4.4 Dynamic SF Strategy

Various SF strategies were set out in Chapter 6 and formulated as LP's in Models A, B, C and D. Twenty five dynamic models are solved for both Schemes based on two of these strategies, A and D.

- Model A

For this strategy payments are restricted to remain constant for five-yearly periods. In the static model the increase was specified every fifth year to give an even stepped profile over the entire planning horizon. For the dynamic model this constraint has to be relaxed or the same profile is produced for every dynamic profile, since the changes in deposit are specified from year to year.

Objective function: minimise $\sum_{j=1}^{N} \Delta_A^{-j} x_j$

Payment   Lj=1, Uj=1   j≠5,10,15,20,25,30,35,40,
Constraints: 45,50,55

               Lj=1, Uj=1.03   for j=5,10,15,20,25,30,35,40,45,50,55

- Model D

The objective function is to minimise the initial SF payment. A range is specified each year within which the SF payment value can change. The consequence of less tightly defined criteria on SF annuities is that the projected profile will not exhibit the same uniform pattern as the other strategies

Objective Function: minimise x1

Payment Constraints: Lj=1, Uj=1.03   for j=1,..N-1

138

8.4.5 Note on Comparing the Dynamic Model With Static Model

For a representative comparison of the dynamic and static models the exercise described must be carried out for many realisations of simulated data. This will allow trends in the results to be detected. As a general rule the more realisations carried out in a simulation the more representative of the actual system the results from the model will be. The quantity will always be a compromise between accuracy and practical considerations in the exercise, such as time and computing power constraints. For this exercise there is a substantial amount of calculation and analysis required to derive the two profiles of SF contributions (dynamic and static) for each realisation. Four simulations are carried out by using two of the SF strategies, Model A and Model D, for each of the two Schemes. In each simulation there are twenty five realisations. This provided enough results for meaningful observations from which conclusions could be derived. These are described in Section 8.6

8.4.6 Infeasibility in Dynamic Models

In the case of both Scheme's 2 and 3, it was observed that, on attempting to solve the dynamic models, a number of LP's in each were infeasible. This was the case for all 25 simulated maintenance profiles. The infeasibility was caused by the upper bound constraint on increases in SF payments. The upper bound, which does not cause infeasibility in the sixty year static model, proves too restrictive for some of the LP's with reviewed maintenance projections in some of the realisations. For those LP's which were infeasible in each dynamic model, the upper bound on the initial SF payment was relaxed, and the model resolved to produce a feasible solution. Figures 8.4 and 8.5 show that several LP's in many of the dynamic models had to be amended. In many cases the first review of maintenance projections distorted the original strategy.

SCHEME 2

SCHEME 3

Figure 8.4 Infeasible LP's in Model A Dynamic Models

SCHEME 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
LP1																									
LP2																									
LP3	■	■	■			■						■	■		■	■		■	■						
LP4							■																■		
LP5		■	■	■		■			■	■		■	■	■	■	■	■	■	■		■	■	■		■
LP6	■	■	■	■		■			■	■	■	■	■			■	■	■	■	■	■		■		■
LP7							■							■	■						■	■			
LP8							■																		
LP9							■																		
LP10																								■	
LP11																									
LP12																									■

SCHEME 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
LP1																									
LP2																									
LP3	■		■	■	■			■	■			■		■	■	■		■		■		■	■	■	
LP4			■	■		■	■		■	■		■							■					■	
LP5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
LP6			■	■	■	■	■	■	■	■			■		■					■	■		■	■	
LP7								■	■		■	■		■		■				■			■	■	■
LP8		■			■				■		■			■	■	■	■								
LP9						■																■			
LP10						■	■	■						■		■									■
LP11																									
LP12																									

Figure 8.5 Infeasible LP's in Model D Dynamic Models

8.5 Results

The results from both models for the two sets of data are shown in the following four sets of graphs in Figures 8.1 to 8.100. Each set has the profiles of SF deposits for the 25 realisations. Those showing similar characteristics are grouped together. Two profiles are shown on each graph. The dynamic profile, i.e. SF strategy reviewed every five years and the static profile i.e. no changes are made to original plan.

8.5.1 The Dynamic SF Profiles

- Model A

Using the static model, the SF payment profile increased by a constant amount every five years throughout the projection, giving equal step heights in a staircase profile. With the dynamic model, however, the desired profile has been distorted in many cases because of the need to break the upper bound in the original model to accommodate changing projections. From an inspection of the graphs it can be said that for only nine in Scheme 2 (Figures 8.6 to 8.15) and 5 realisations in Scheme 3 (Figures 8.31 to 8.35), out of 25 in each case, does the actual profile closely resemble the original plan. In each of these cases the value of SF payment using the dynamic model is greater than that from the static model for most or all of the projection. For the remaining realisations the dynamic profiles can be roughly fall into one of three characteristic patterns.

For 6 realisations in Scheme 2 (Figures 8.15 to 8.20) and 4 realisations in Scheme 3 (Figures 8.36-8.39) the dynamic model payments exhibit a similar profile to the static model payments in the early years, before flattening around midway through projection with no further increases required for the remainder of the projection. As a consequence the static profile payments overtake the dynamic payments in the latter half of the projection.

For 5 realisations in Scheme 2 (Figures 8.21 to 8.25) there is a closely matching profile in the early years, again with dynamic payments greater than static. A sharp increase in payments occurs and is followed by an erratic profile of periodic smaller increases.

For 4 realisations in Scheme 2, (Figures 8.26 to 8.29) the profile is similar to above, but dynamic payments in the early years are markedly greater than static SF payments. Following the sharp increase the profile is flat for the remainder of the projection in most cases, or there is one or two smaller increases needed. SF payments in the dynamic model are consistently greater than SF payments in the static model.

For 14 realisations in Scheme 3 the profiles are similar until between years 25-40 (Figures 8.40 to 8.53). Thereafter the profiles diverge with a large increase in dynamic payments, followed by one or two smaller increases. The dynamic profile of payments is consistently more than the static.

- Model D

Using the static model for each of the realisations in Scheme 2, the SF payment profile is characterised by year on year increases for most of the projection, with level payments for a duration of between five and twenty years starting around mid-way through the projections. In some cases the profile remains flat for the rest of the planning period. For Scheme 3 the profile of payments for each realisation show consistent increases year on year for almost the entire projection, levelling off in the final five to ten years. From an inspection of the graphs it can be said that there is a close match between original plan and dynamic strategy in twelve out of twenty five realisations in Scheme 2 (Figures 8.56 to 8.67), but only five of the realisations in Scheme 3 (Figures 8.8` to 8.85).

For 12 realisations in Scheme 2 (Figures 8.68 to 8.79), and 9 realisations in Scheme 3 (Figures 8.86 to 8.94) using the dynamic model there is a close match until approximately half way through the projection, before the profiles diverge with sharp increases in the SF payments over two or three years. Thereafter the profile remains flat for the remainder of the period, being overtaken by the static profile payments toward the end of the projection.

For 5 realisations in Scheme 3 (Figures 8.95 to 8.99) the profiles are very similar until year 40-50, before flattening for the remainder of the projection and being overtaken by the static SF payments.

For 5 realisations in Scheme 3 (8.100 to 8.104) the profiles are similar in the early years, then there are erratic increases for the greatest part of the projection. A large increase occurs around year 40, thereafter the profile flattens for the remainder of the projection. The SF payments in the dynamic profile are consistently greater than the SF payments in the static profile.

Table 8.3   Comparison of total NPV of SF deposits - Dynamic and Static Models

	SCHEME 2				SCHEME 3			
	Model A		Model D		Model A		Model D	
Real.	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static
1	289845	280638	286276	295170	72364	63358	72912	67925
2	292017	279030	432977	289960	67422	63354	69775	67094
3	284426	272774	336291	280519	66153	62275	65559	67805
4	310256	265224	328964	279320	63307	63636	71667	67350
5	330083	281216	299725	289491	65690	64318	78381	67169
6	322409	289960	288224	272633	69134	62383	71387	68272
7	295694	279320	281995	281390	68158	62561	77036	62849
8	296551	289491	278676	277292	67422	62392	67611	67076
9	287086	281390	272528	276440	76291	63184	72755	66588
10	293551	293591	286276	282356	67800	63498	78381	64256
11	296174	265145	290804	283280	64802	64433	67708	69179
12	293485	289028	293797	289028	67844	63749	72939	67801
13	294747	295170	289845	280636	66435	63024	72527	66108
14	282776	268931	333164	266659	74360	60875	68931	68879
15	290804	283280	431955	268500	66765	63529	70820	67691
16	283177	277292	291533	292636	67263	63209	69290	67246
17	299950	280519	284171	284906	63750	63296	72069	66561
18	275752	266203	293551	293591	63220	64926	68821	66520
19	324167	266726	288322	279030	67227	62772	97785	66957
20	291618	292636	286642	272774	65512	63457	69709	65199
21	294371	265413	332891	268258	66444	63752	65493	67132
22	302813	263877	328503	265744	69667	64088	69784	68807
23	274261	274229	264262	274229	75250	60466	70344	67659
24	291988	282356	428688	266730	68601	63372	70336	66691
25	287728	284906	465630	281216	62974	64197	70964	65078
AVG.	295429	278733	319828	279672	67754	63204	72119	66956

The frequency histograms in Figures 8.106 to 8.109 show graphically how the total NPV of SF contributions from dynamic models compare with those from static models. For each Scheme and strategy the results from the dynamic model show a wider distribution of costs than the static model. The likelihood that the cost of a static policy will be less than a dynamic policy can be seen in the concentration of static model results at the lower end of the range in each case.

8.6 Conclusions

From the comparison of dynamic and static SF models, it can be concluded that making significant amendments to maintenance projections is likely to have an adverse effect on the overall cost of a SF policy. In an overwhelming majority of cases, 91% from Table 8.2, the NPV of SF payments in the dynamic model exceeds those of the static model i.e. imperfections in forecasts result in higher costs. Since plans are being changed quinquennially, in the light of changing information, it can be said that, in retrospect, the policy implemented over the previous five years was not optimal. In a few of the cases there is an extreme difference, caused by

substantially changed data early on in the projection. More accurate long term forecasts will reduce the likelihood of substantial changes having to be made to maintenance projections in the future. Therefore, there are financial benefits, based on the above measure, from carrying out a thorough LCC exercise at the procurement stage. However, the lack of available maintenance data remains a real impediment to practising such an exercise.

Comparison of Dynamic and Static ASF Profiles
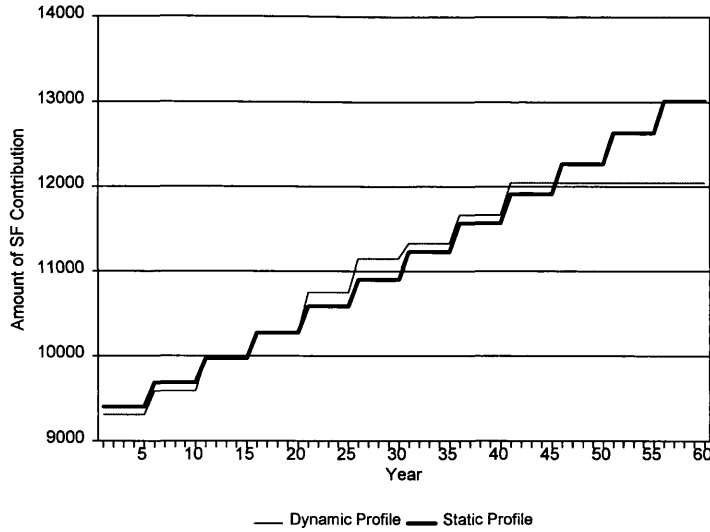
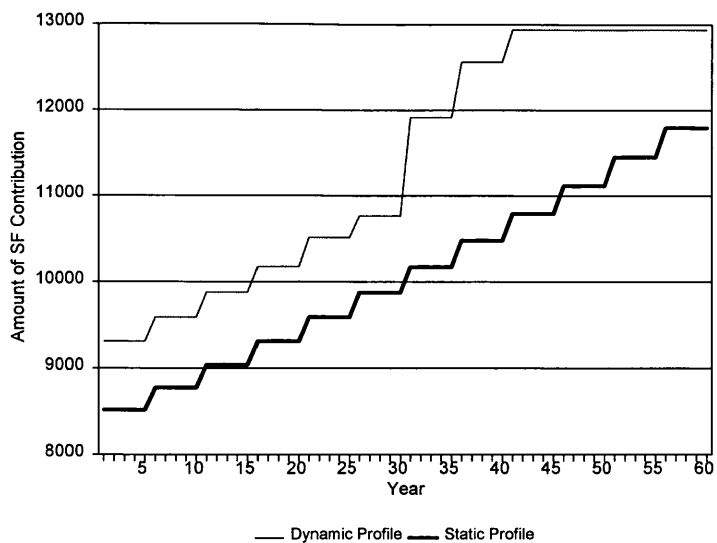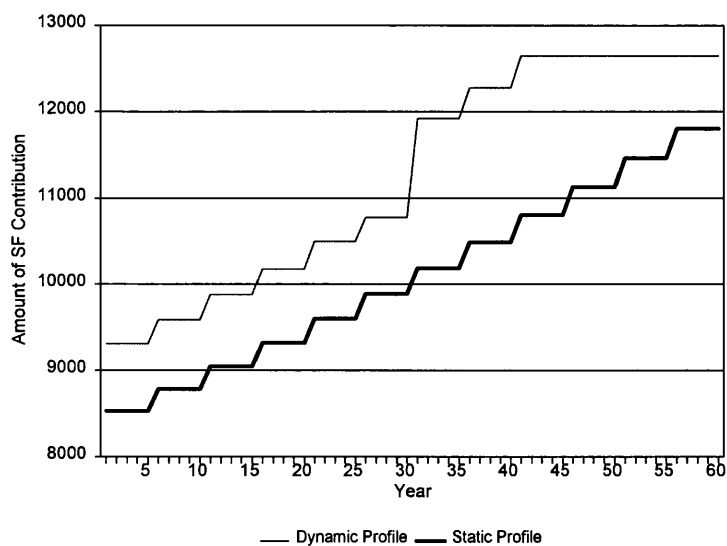Figure 8.6 Realisation 1: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
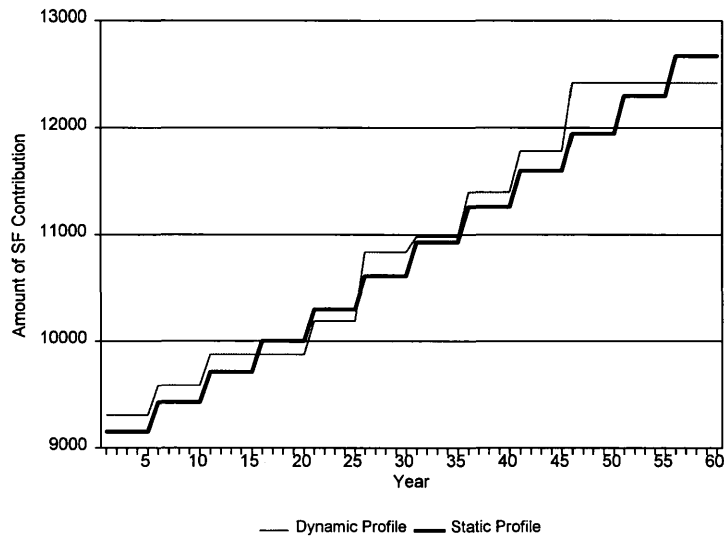
Figure 8.7 Realisation 2: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
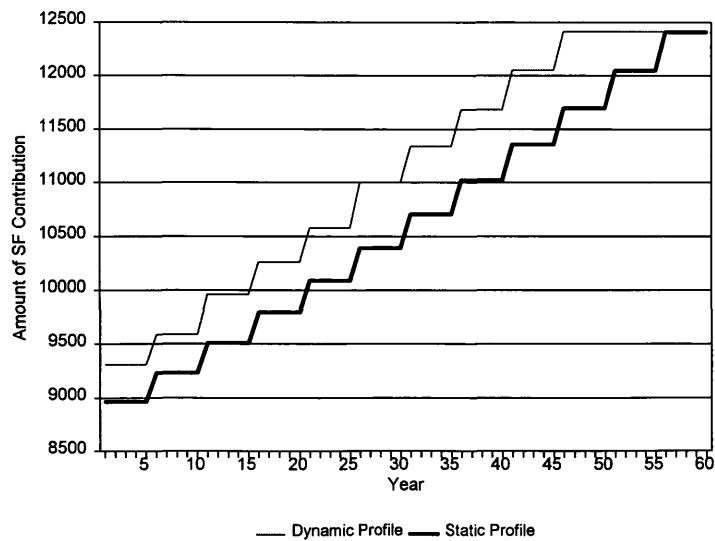
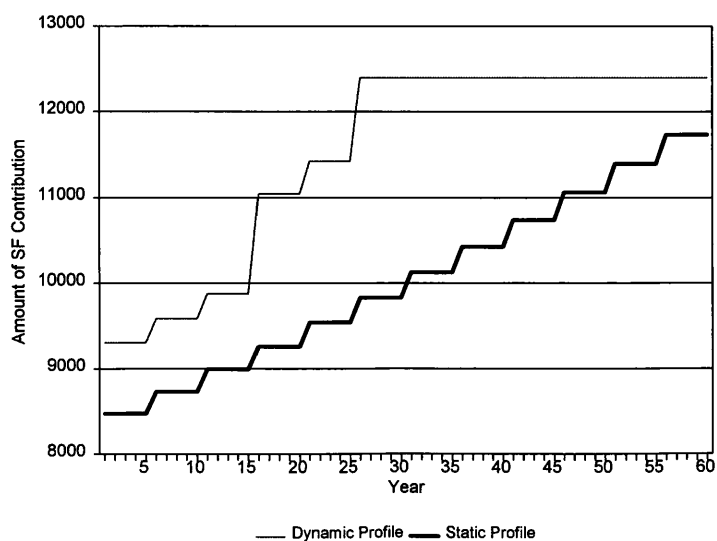Figure 8.8 Realisation 3: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

Comparison of Dynamic and Static ASF Profiles
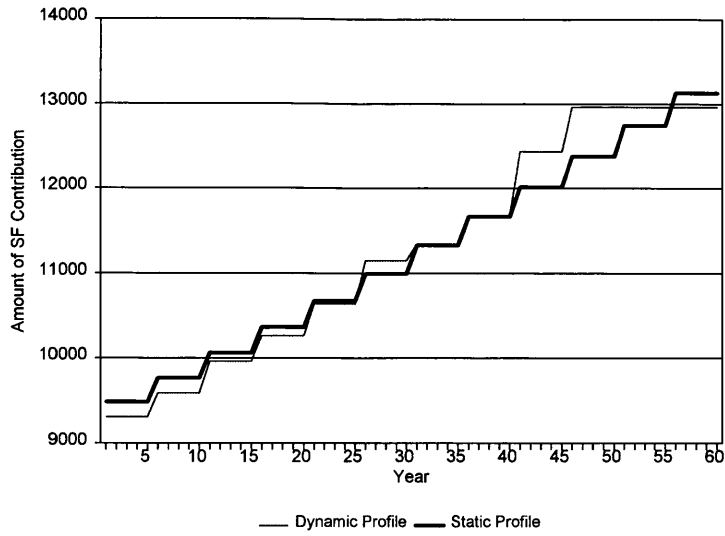
Figure 8.9 Realisation 4: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
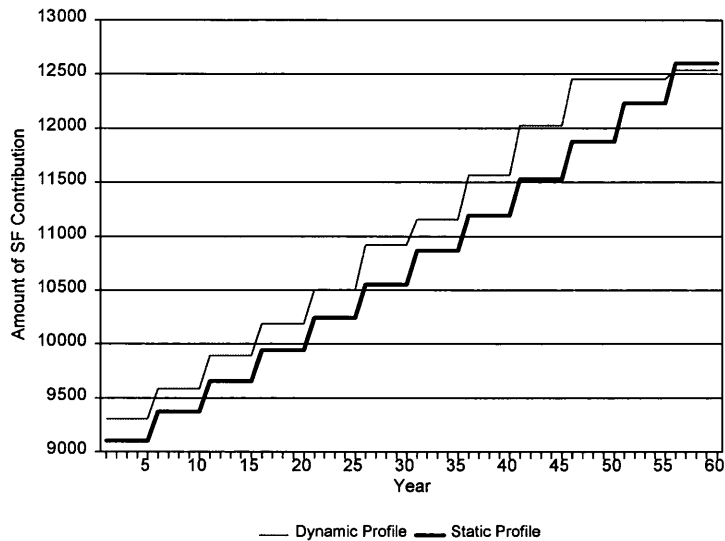
Figure 8.10 Realisation 5: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
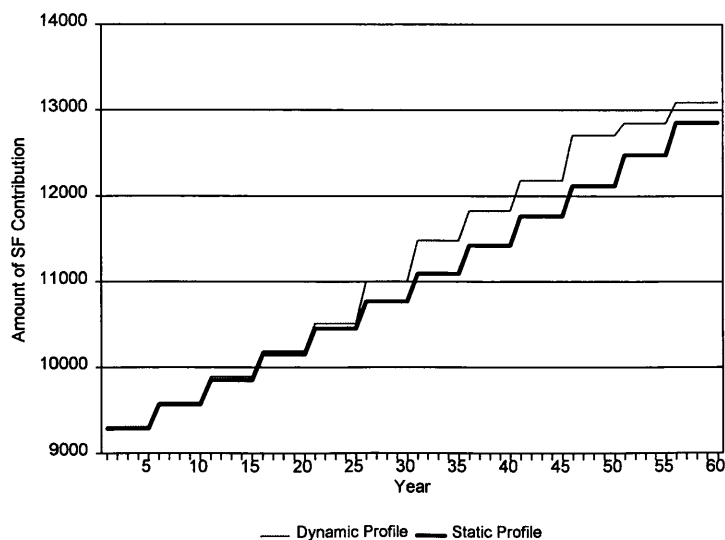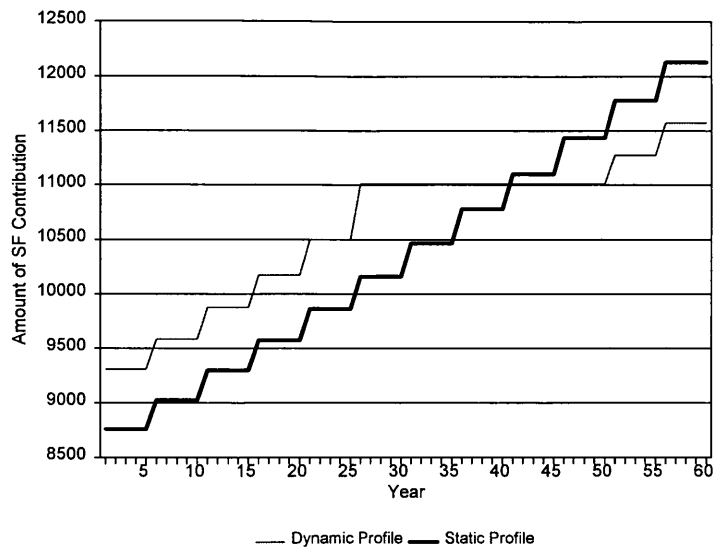

Figure 8.11 Realisation 6: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

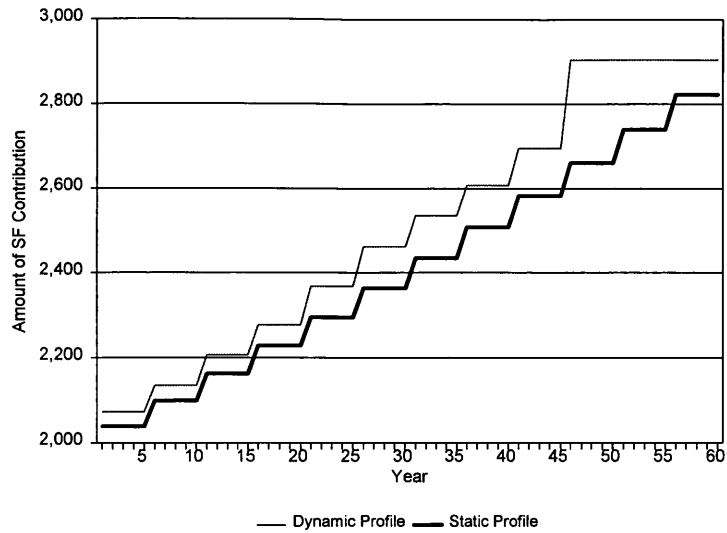## Comparison of Dynamic and Static ASF Profiles
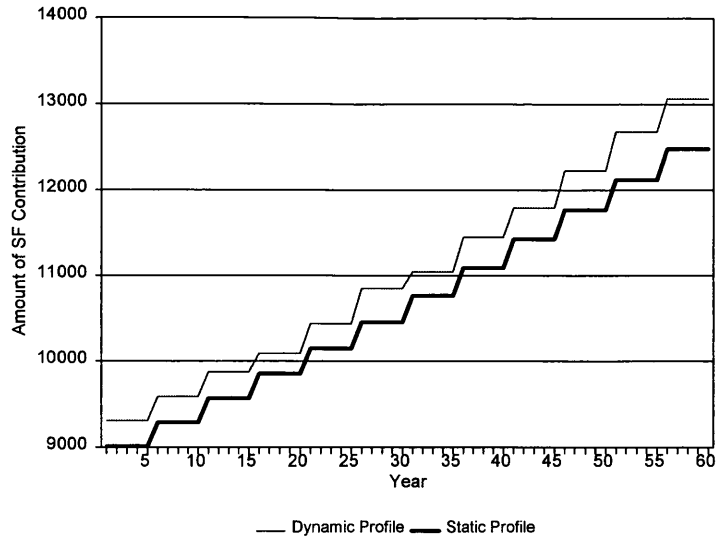
Figure 8.12 Realisation 7: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
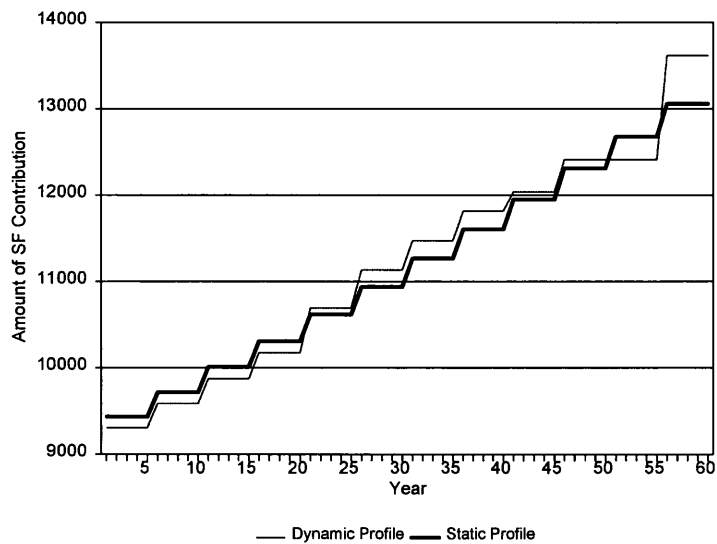
Figure 8.13 Realisation 8: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
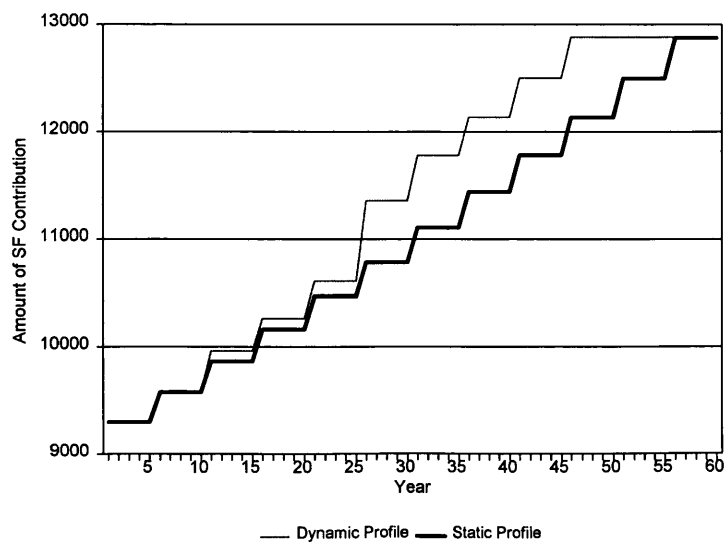
Figure 8.14 Realisation 9: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

148

Comparison of Dynamic and Static ASF Profiles
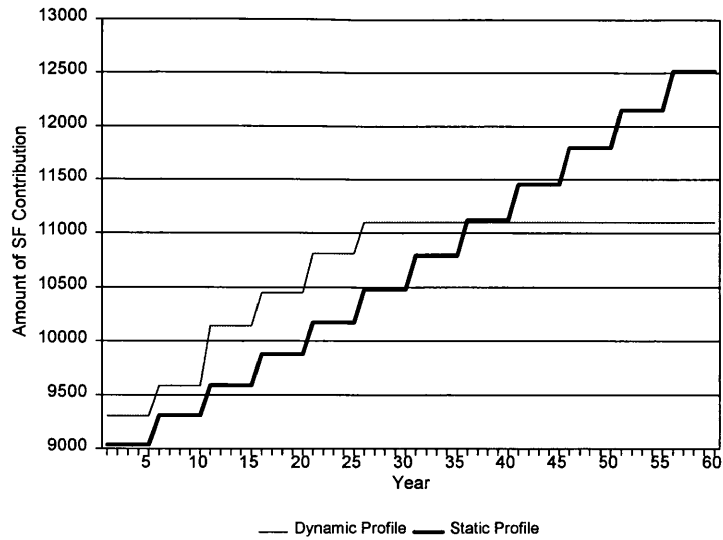
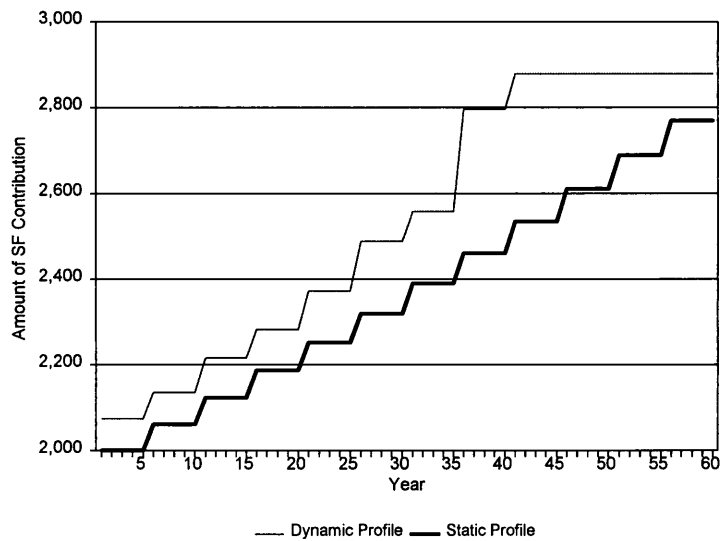Figure 8.15 Realisation 10:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
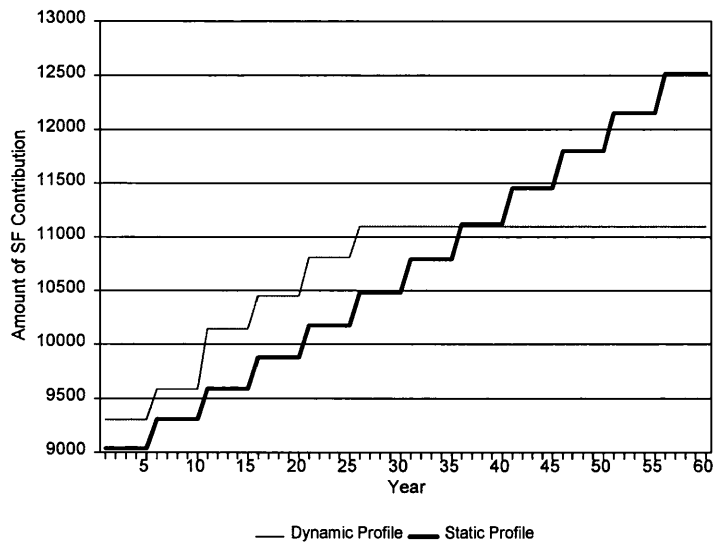
Figure 8.16 Realisation 11:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
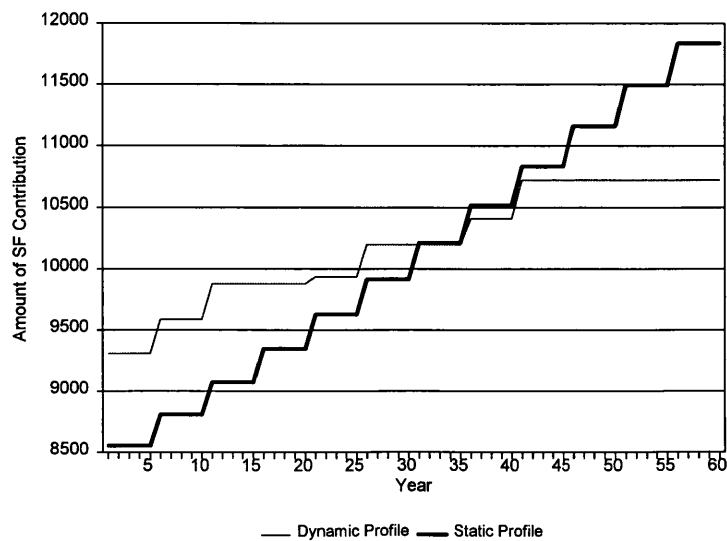
Figure 8.17 Realisation 12:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
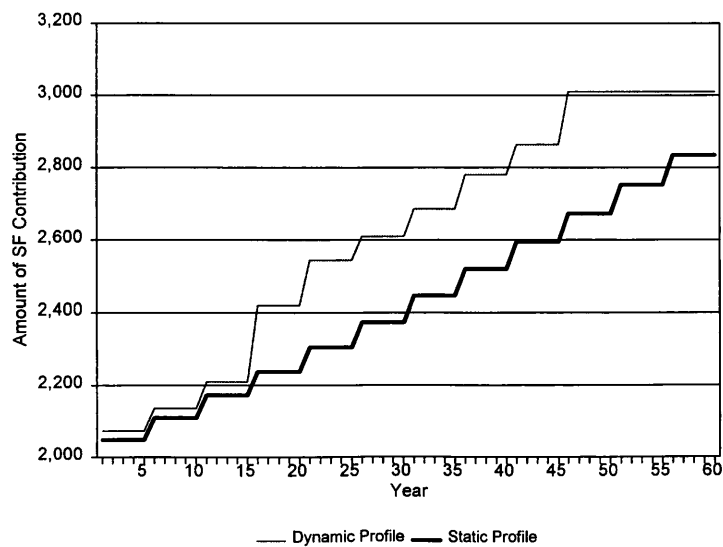
Comparison of Dynamic and Static ASF Profiles
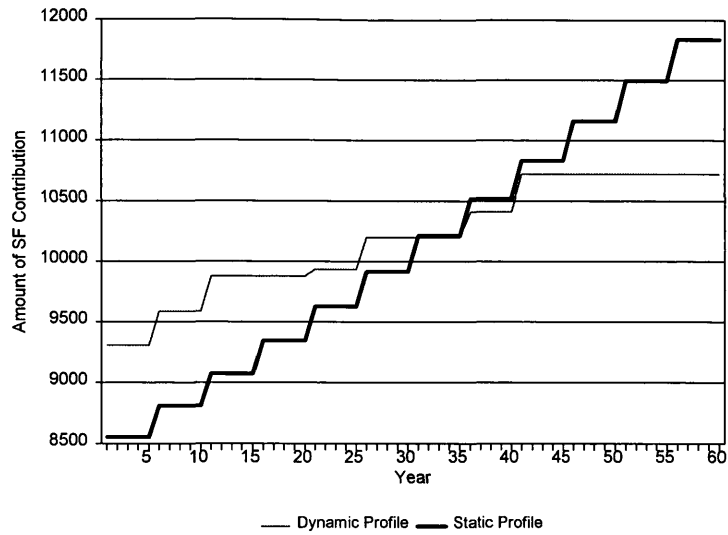
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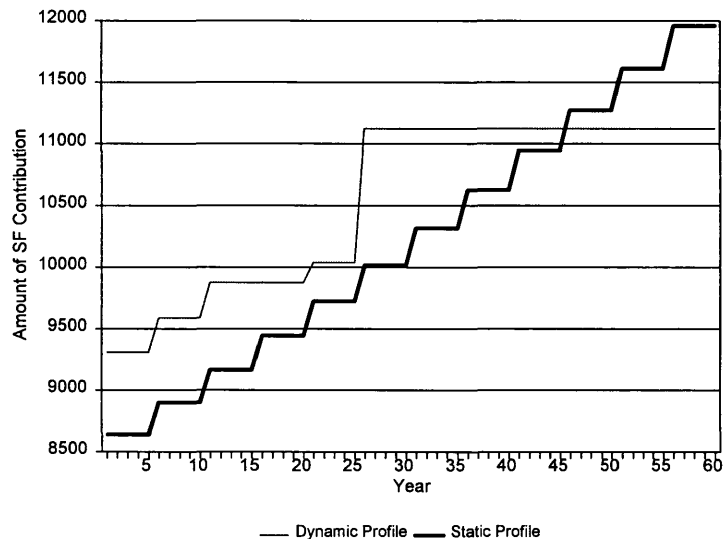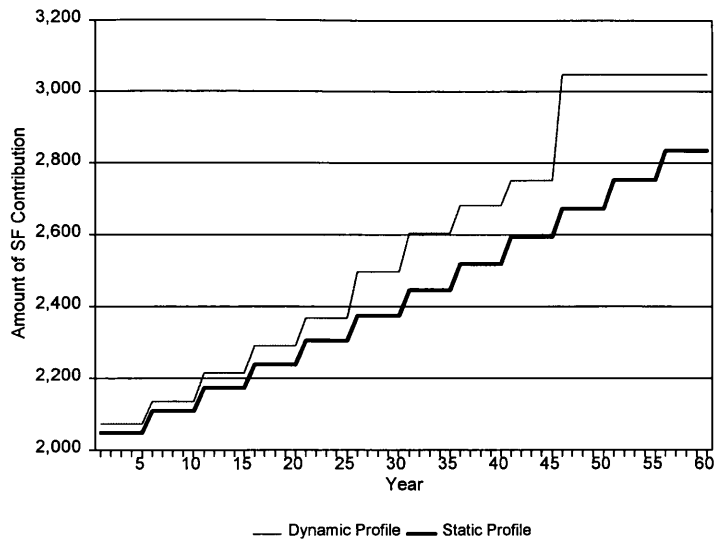

Figure 8.19 Realisation 14:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
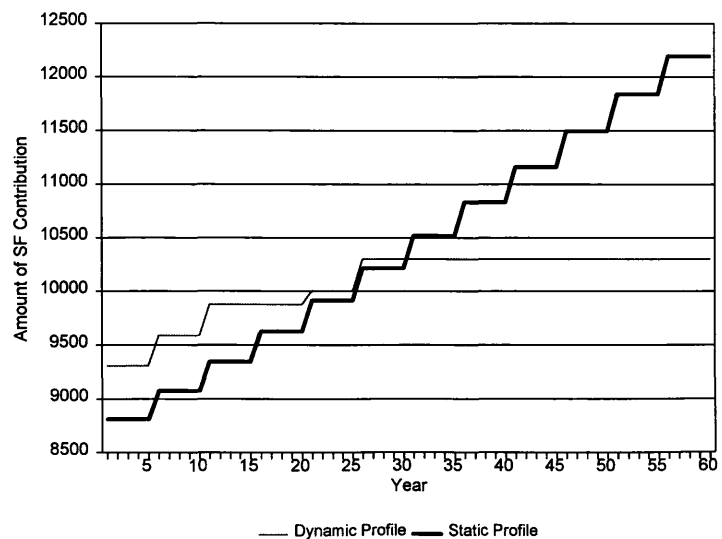
Figure 8.20 Realisation 15 Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

Comparison of Dynamic and Static ASF Profiles
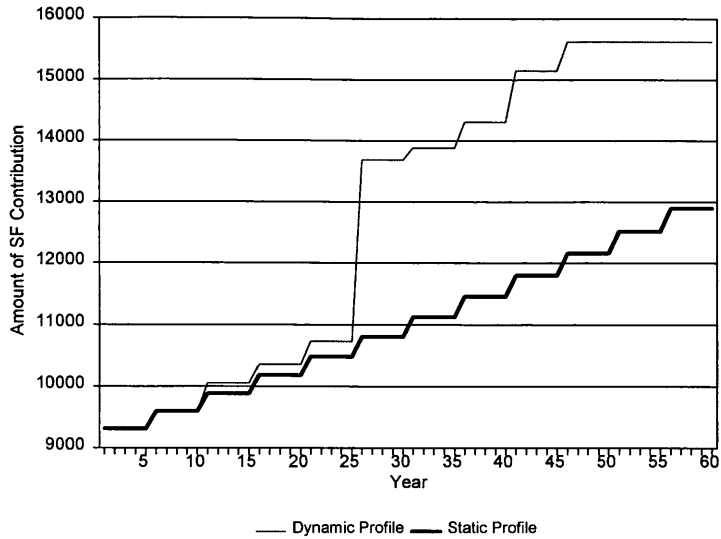
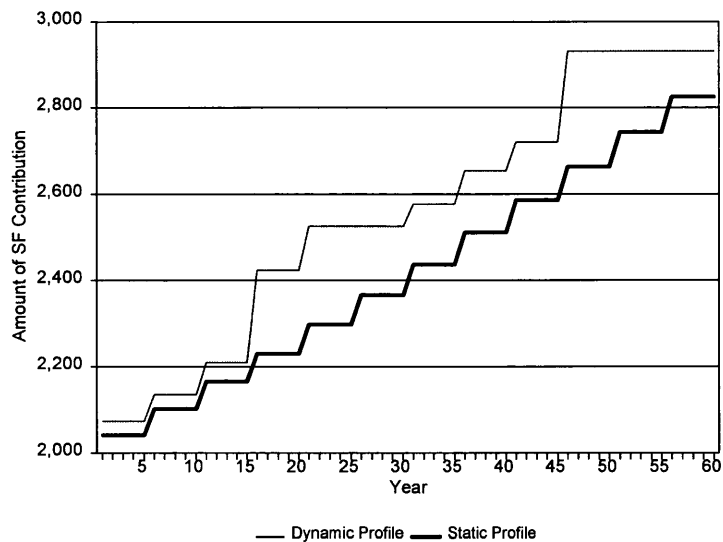Figure 8.21 Realisation 16:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
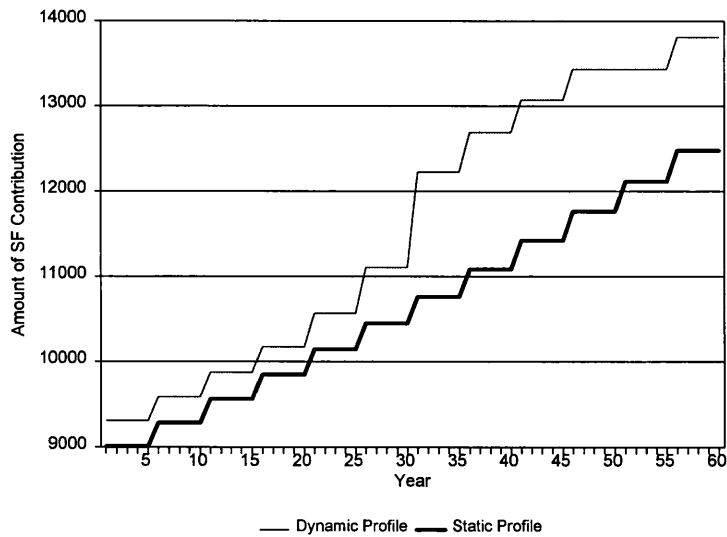
Figure 8.22 Realisation 17:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
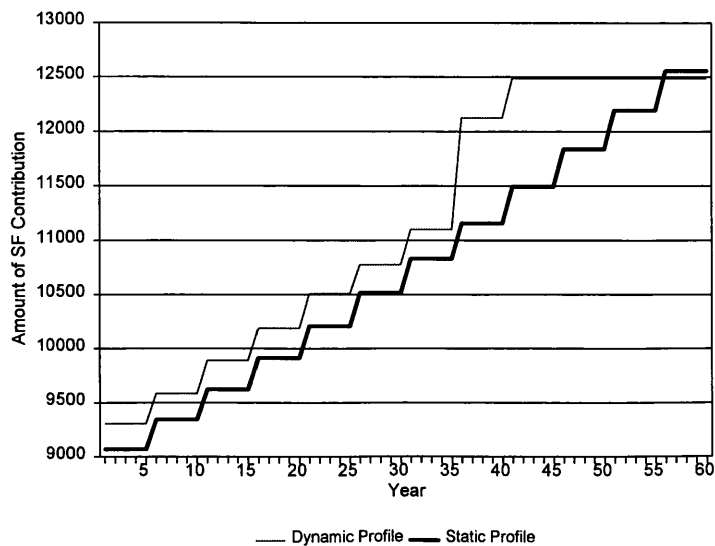
Figure 8.23 Realisation 18:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

Comparison of Dynamic and Static ASF Profiles
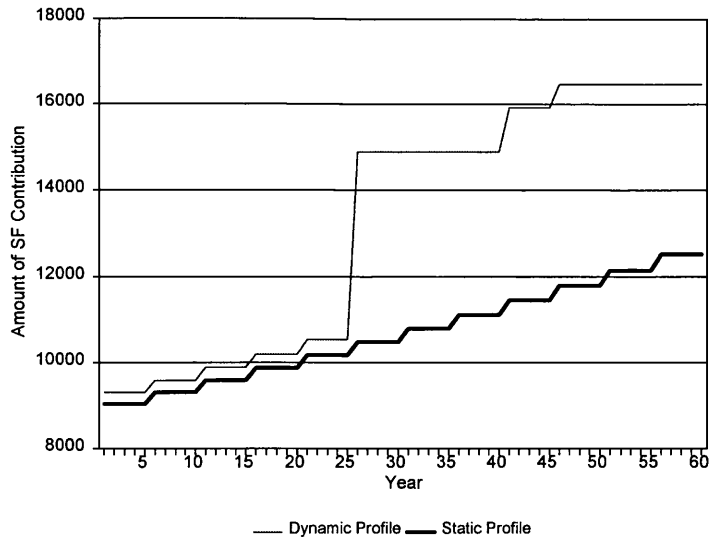
Figure 8.24 Realisation 19:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
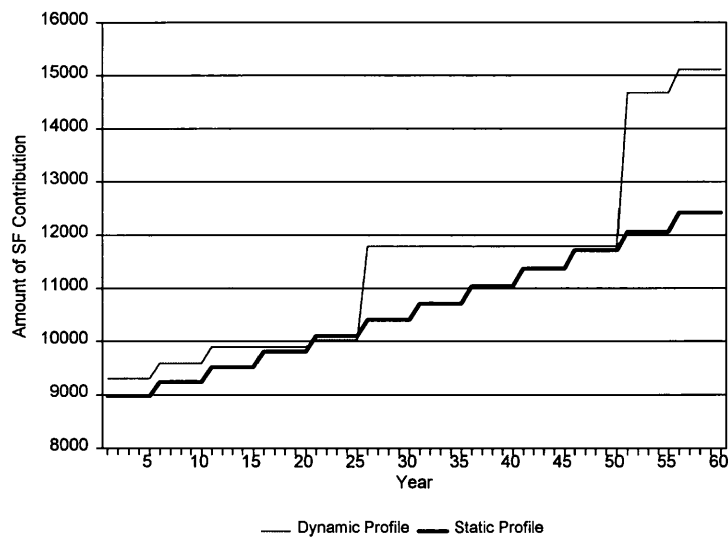
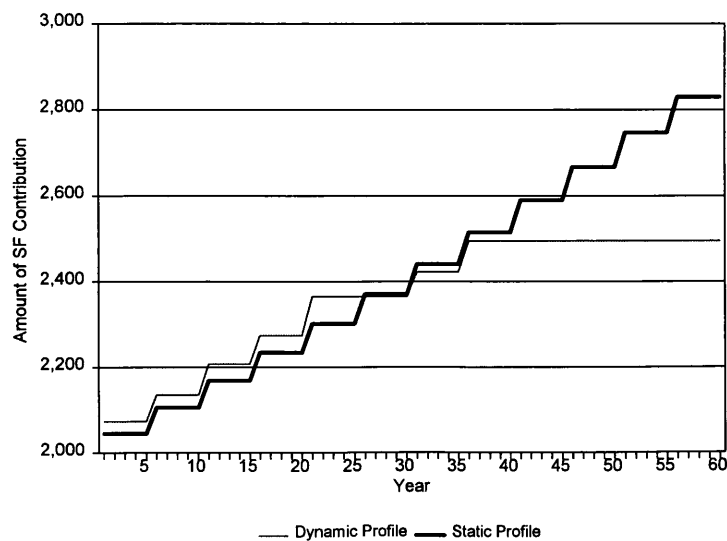Figure 8.25 Realisation 20:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2
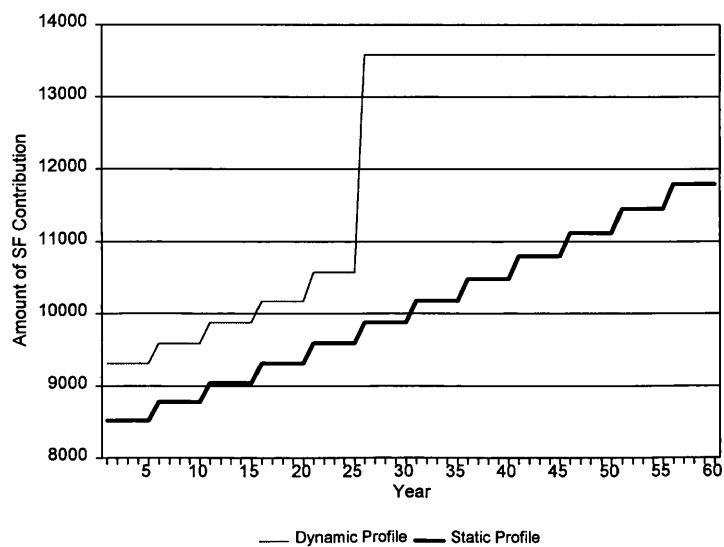
Figure 8.26 Realisation 21:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

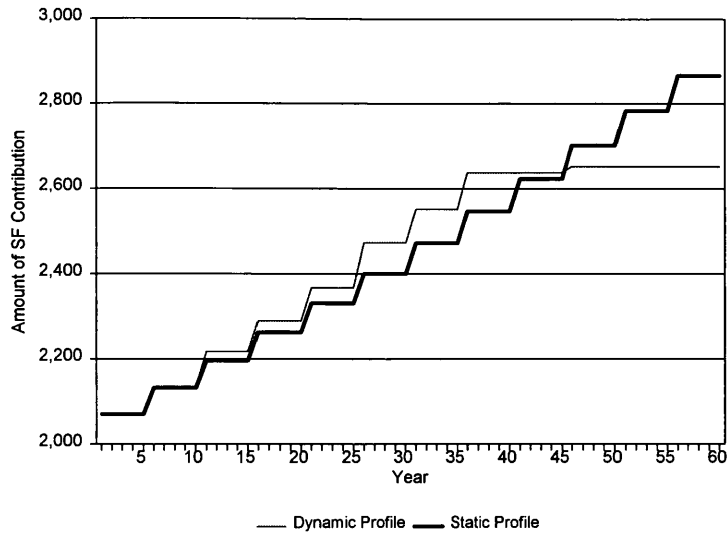# Comparison of Dynamic and Static ASF Profiles

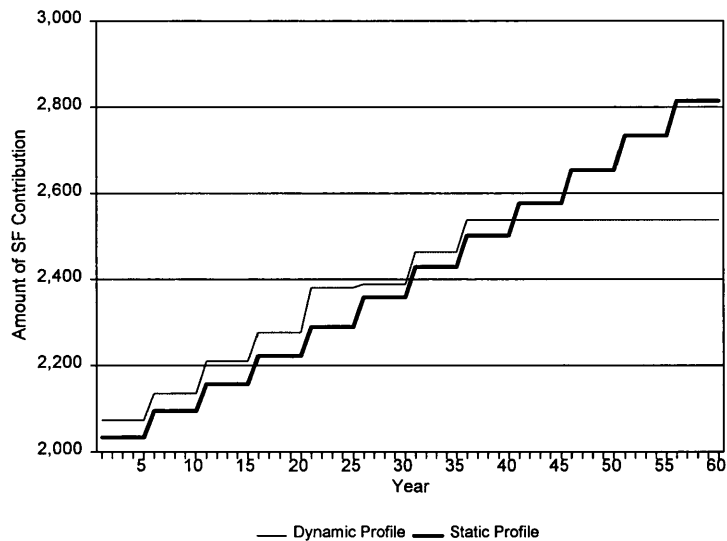Figure 8.27 Realisation 22:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

Figure 8.28 Realisation 23:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

Figure 8.29 Realisation 24:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

Comparison of Dynamic and Static ASF Profiles

Figure 8.30 Realisation 25:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 2

Comparison of Dynamic and Static ASF Profiles

Figure 8.31 Realisation 1: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.32 Realisation 2: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3
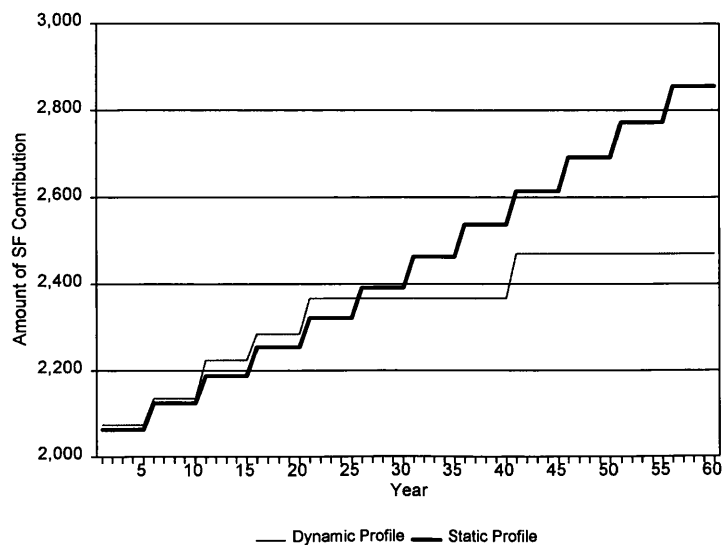

Figure 8.33 Realisation 3: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

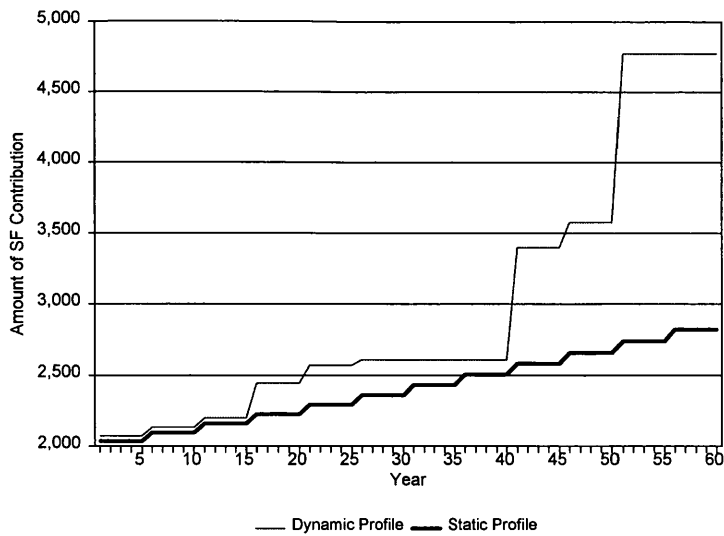## Comparison of Dynamic and Static ASF Profiles

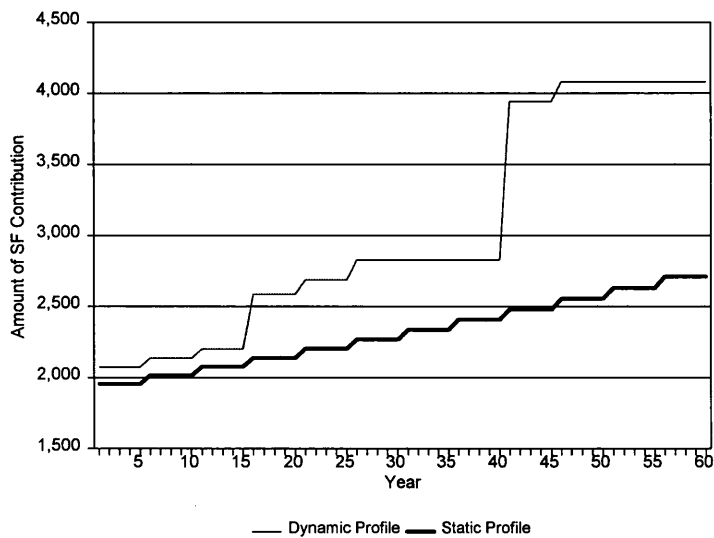Figure 8.34 Realisation 4: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.35 Realisation 5:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.36 Realisation 6: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

156

Comparison of Dynamic and Static ASF Profiles

Figure 8.37 Realisation 7: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.38 Realisation 8: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.39 Realisation 9: Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

157

Comparison of Dynamic and Static ASF Profiles

Figure 8.40 Realisation 10:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.41 Realisation 11:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3
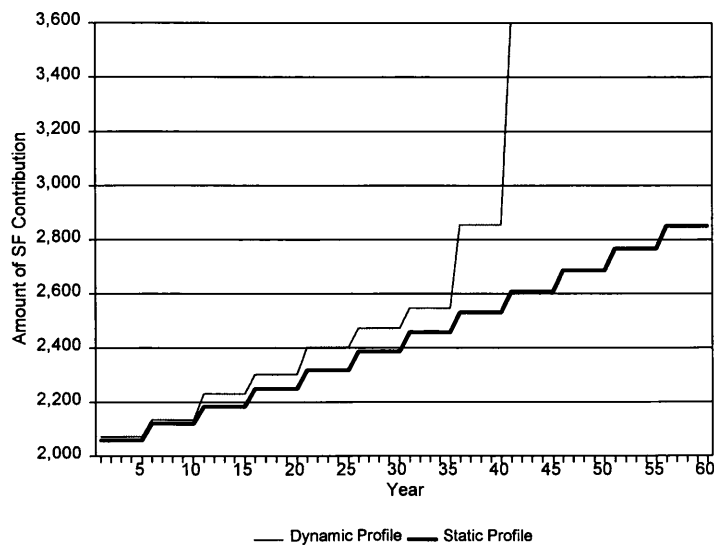

Figure 8.42 Realisation 12:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3
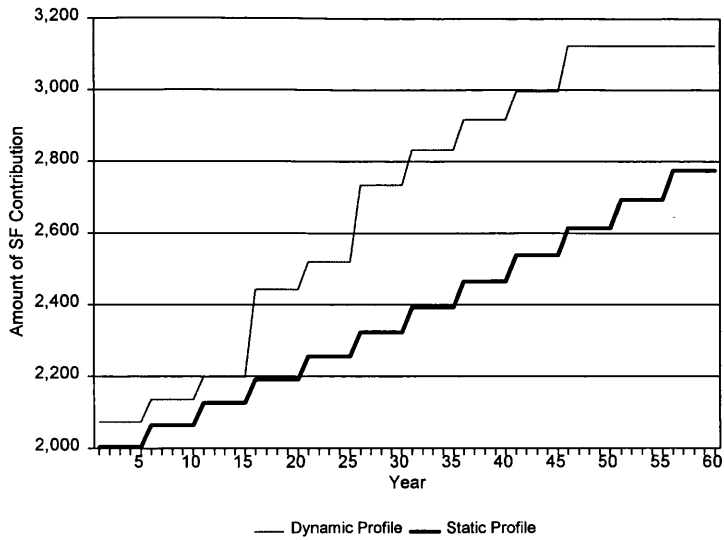
Comparison of Dynamic and Static ASF Profiles

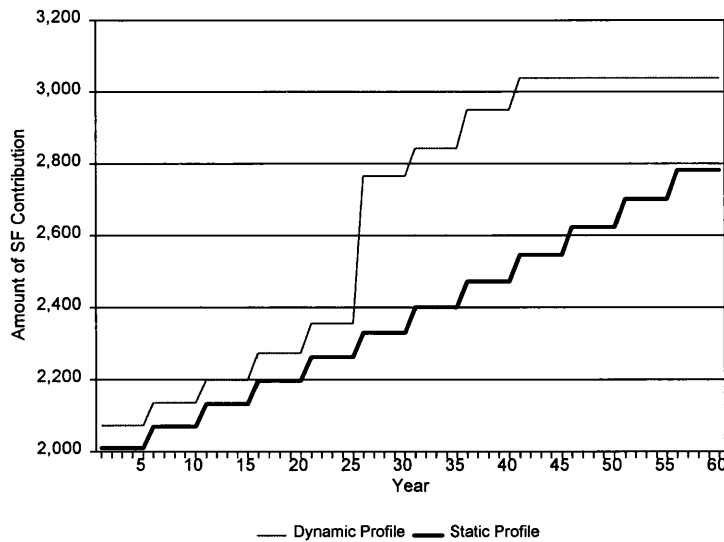Figure 8.43 Realisation 13:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

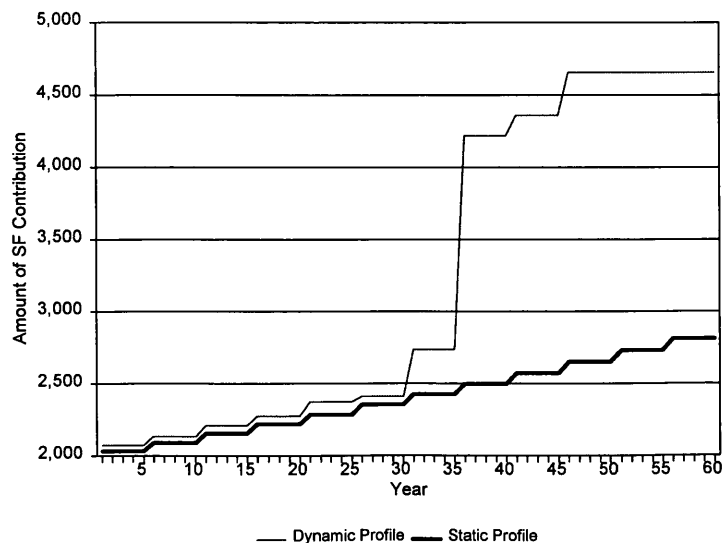Figure 8.44 Realisation 14:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.45 Realisation 15:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

159

Comparison of Dynamic and Static ASF Profiles

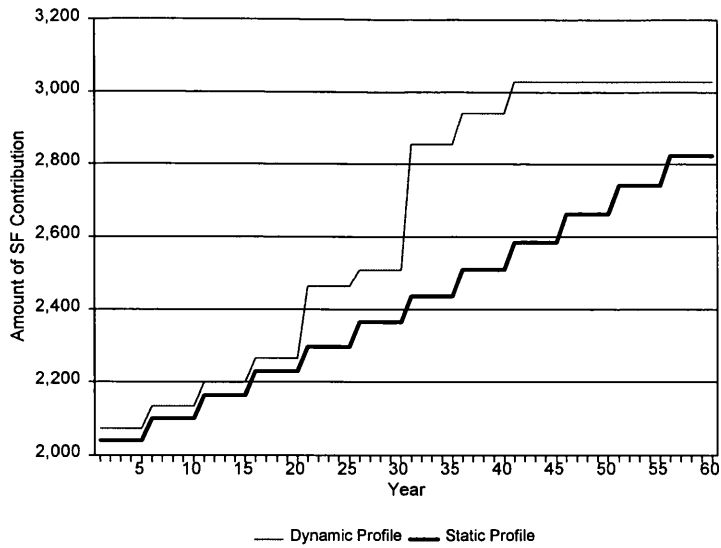Figure 8.46 Realisation 16:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.47 Realisation 17:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.48 Realisation 18:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

160

Comparison of Dynamic and Static ASF Profiles

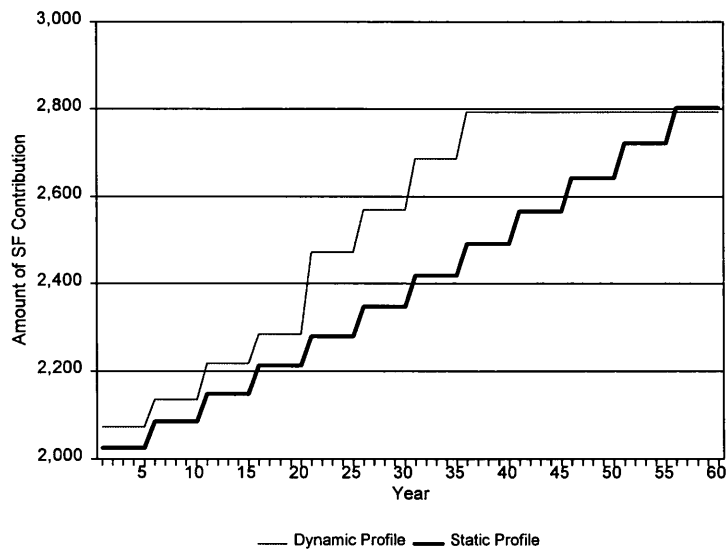Figure 8.49 Realisation 19:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.50 Realisation 20:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

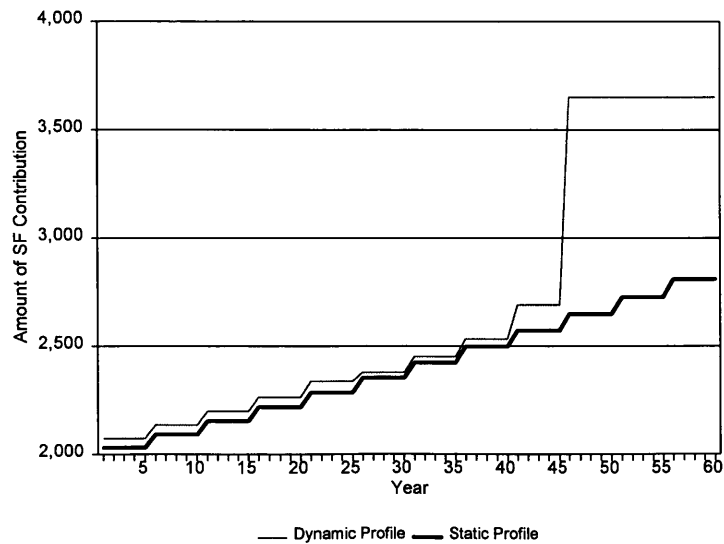Figure 8.51 Realisation 21:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Comparison of Dynamic and Static ASF Profiles

Figure 8.52 Realisation 22:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.53 Realisation 23:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Figure 8.54 Realisation 24:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

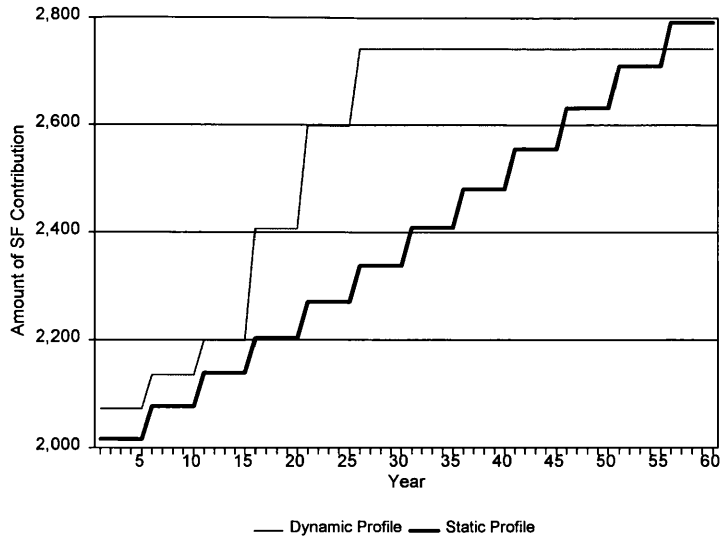# Comparison of Dynamic and Static ASF Profiles

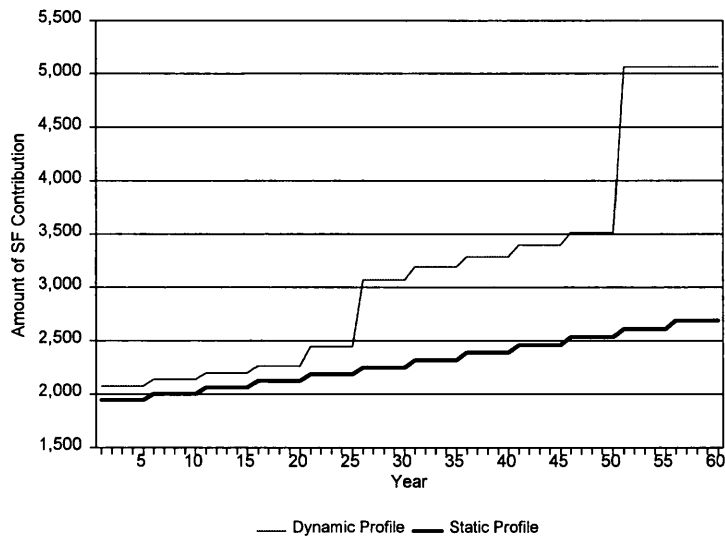Figure 8.55 Realisation 25:Dynamic and Static Profiles of ASF Contributions using Model A for SCHEME 3

Comparison of Dynamic and Static ASF Profiles

Figure 8.56 Realisation 1: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

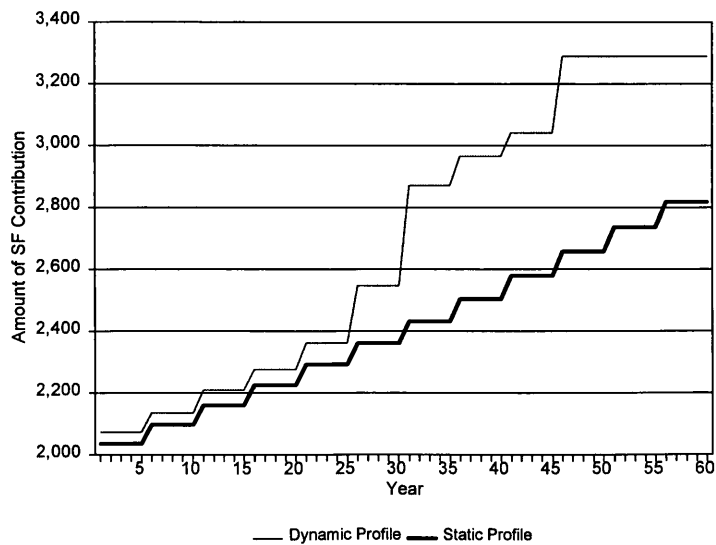Figure 8.57 Realisation 2: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.58 Realisation 3: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2
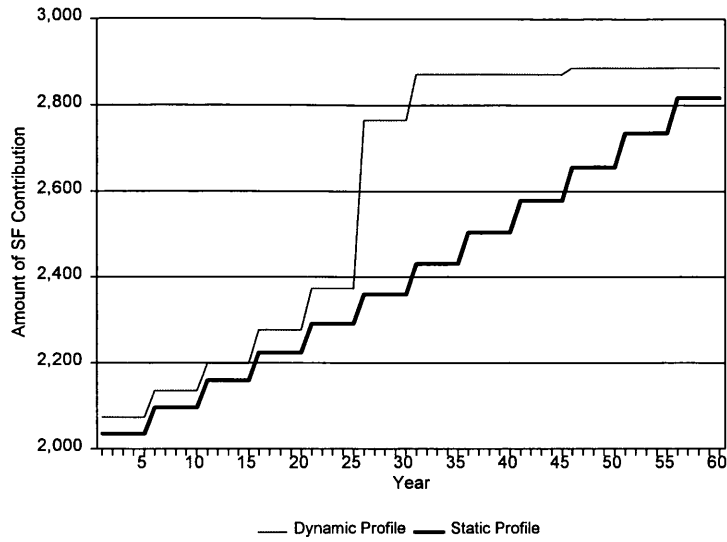
Comparison of Dynamic and Static ASF Profiles

Figure 8.59 Realisation 4: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.60 Realisation 5: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.61 Realisation 6: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

165

Comparison of Dynamic and Static ASF Profiles

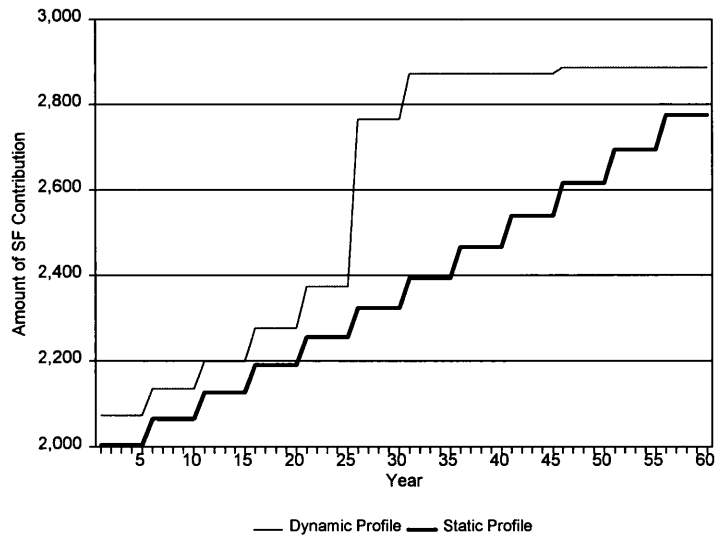Figure 8.62 Realisation 7: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.63 Realisation 8: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2
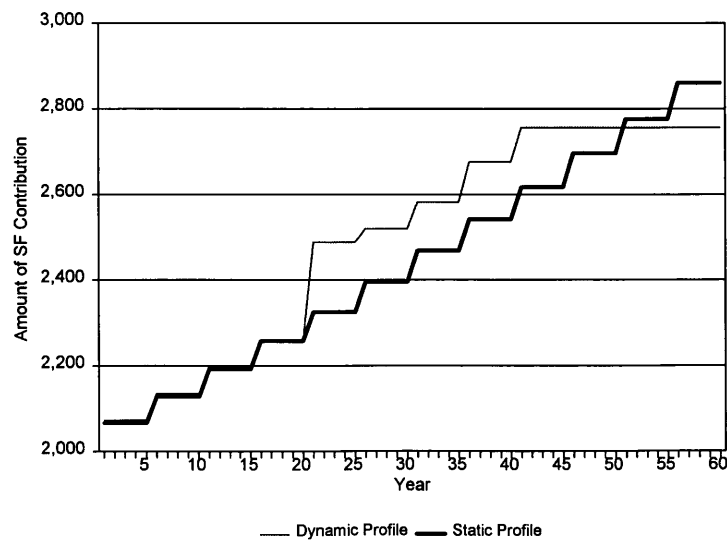

Figure 8.64 Realisation 9:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Comparison of Dynamic and Static ASF Profiles

Figure 8.65 Realisation 10:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.66 Realisation 11:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.67 Realisation 12:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

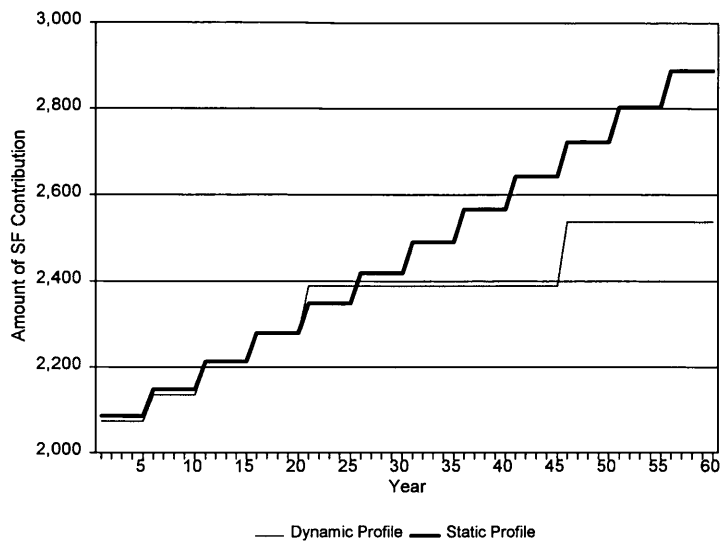## Comparison of Dynamic and Static ASF Profiles

Figure 8.68 Realisation 13:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2
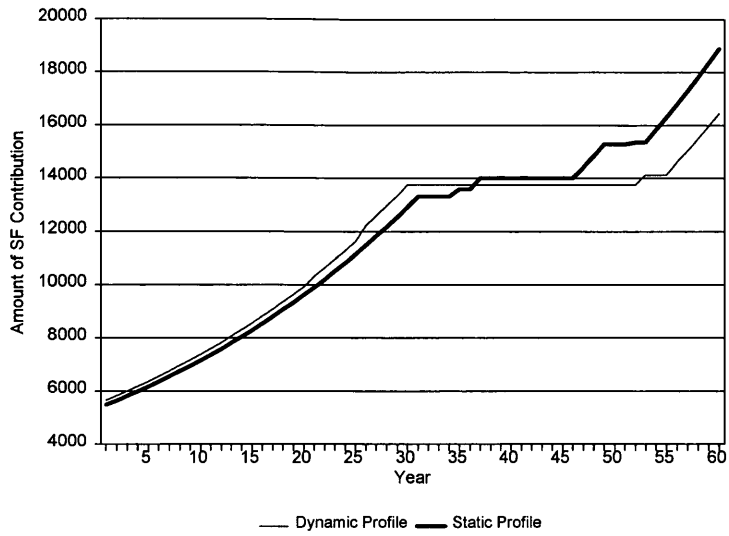

Figure 8.69 Realisation 14:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.70 Realisation 15:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

168

Comparison of Dynamic and Static ASF Profiles

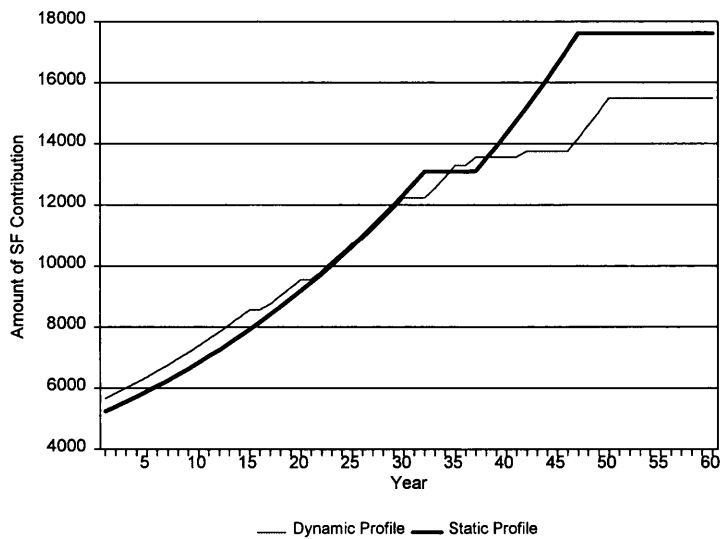Figure 8.71 Realisation 16:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

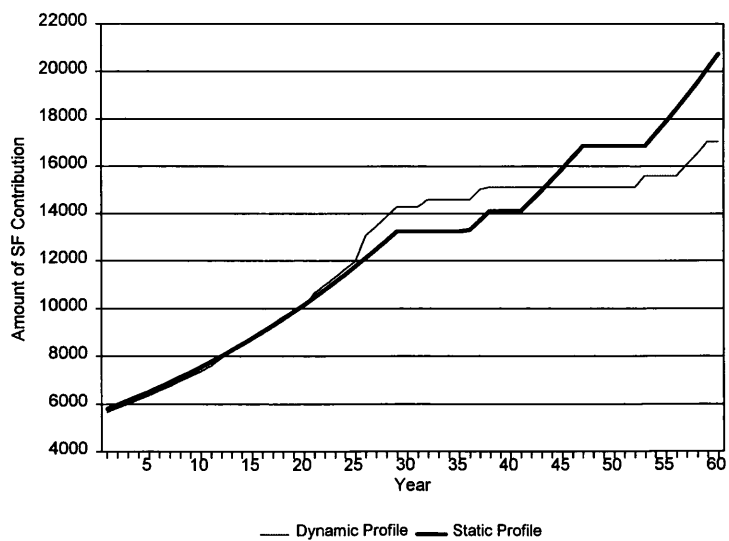Figure 8.72 Realisation 17:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Figure 8.73 Realisation 18:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Comparison of Dynamic and Static ASF Profiles

Figure 8.74 Realisation 19:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2
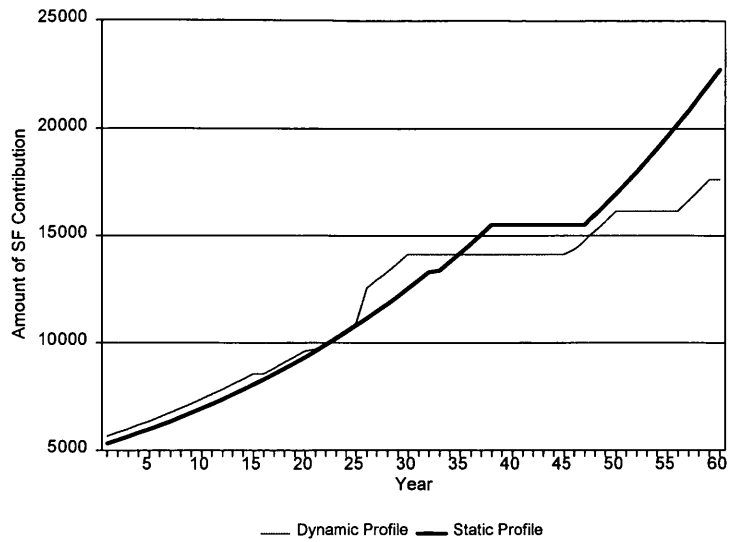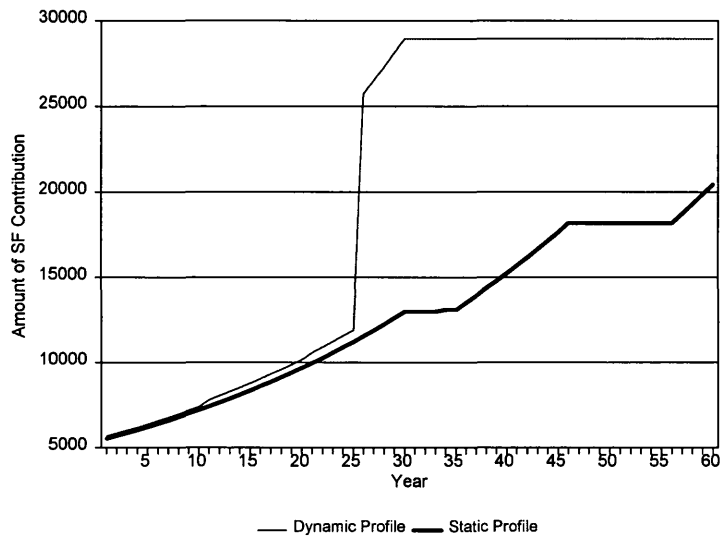

Figure 8.75 Realisation 20:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2
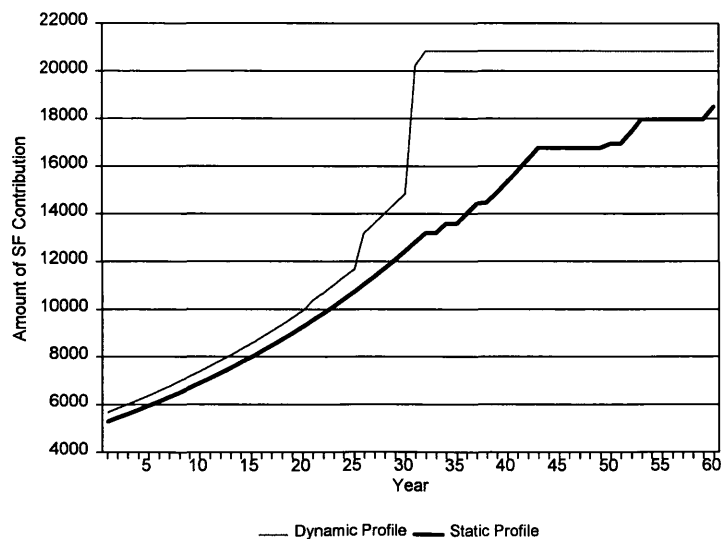
Figure 8.76 Realisation 21:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2

Comparison of Dynamic and Static ASF Profiles
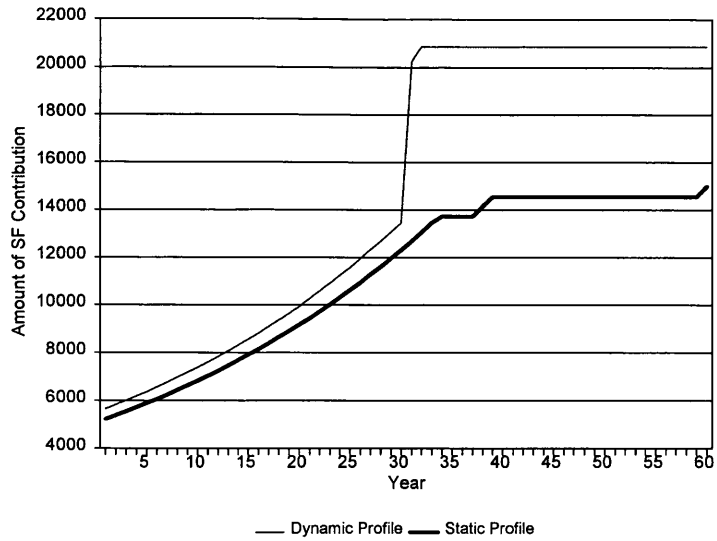
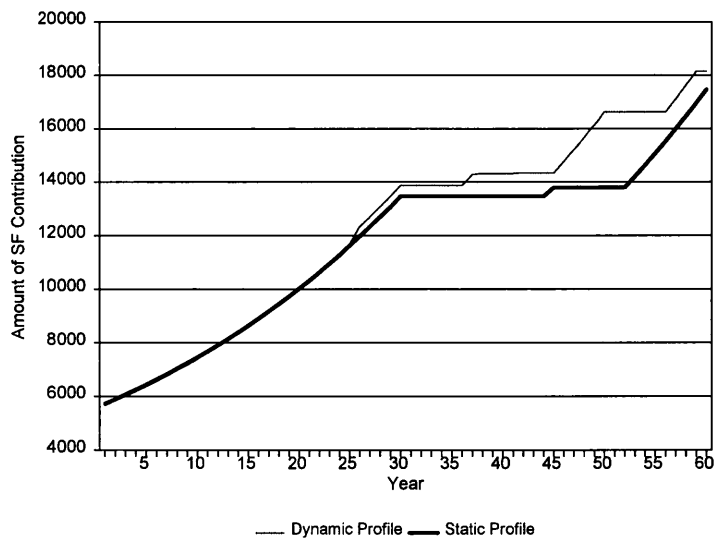Figure 8.77 Realisation 22:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2
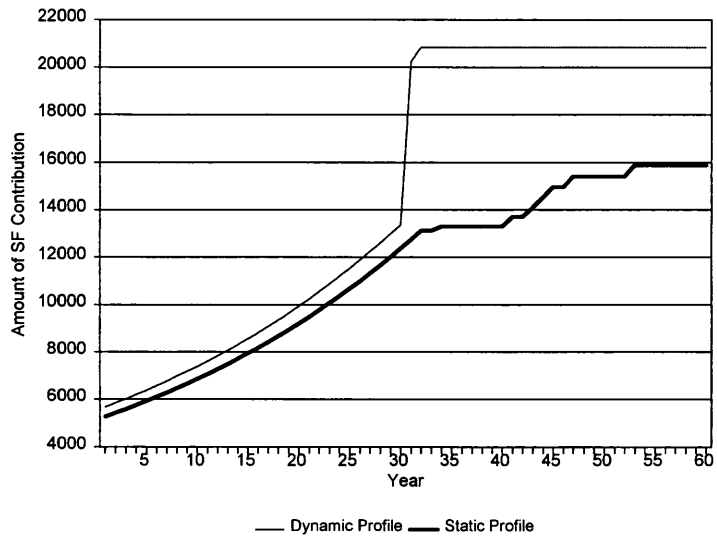
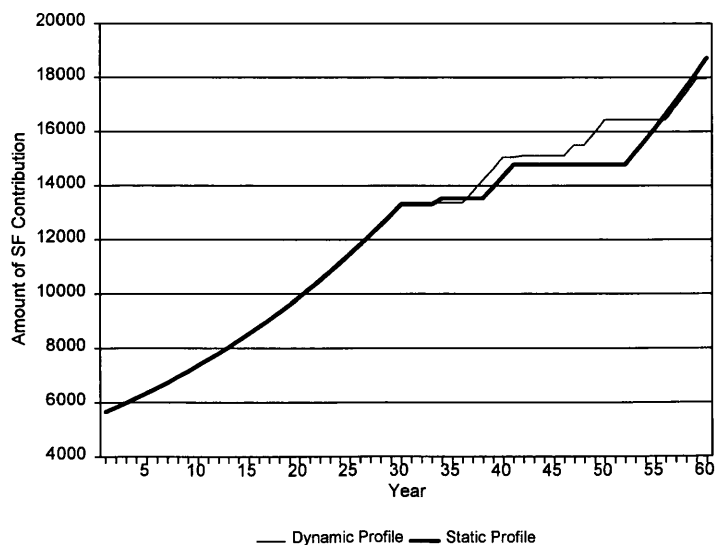Figure 8.78 Realisation 23:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 2
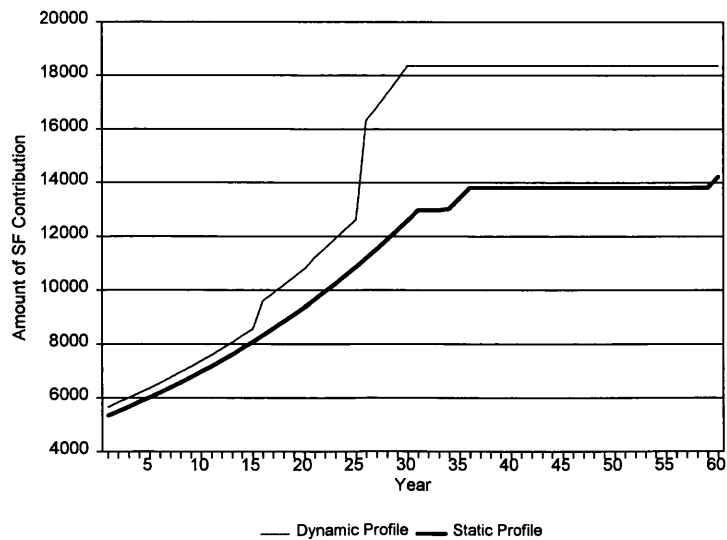
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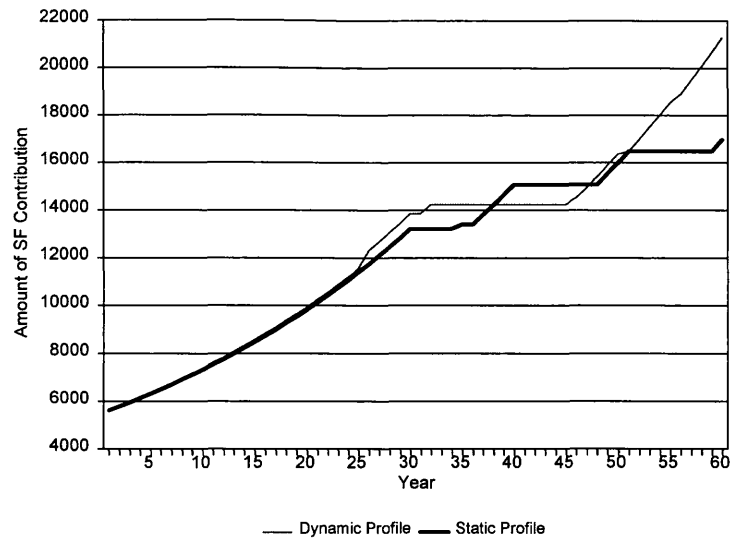
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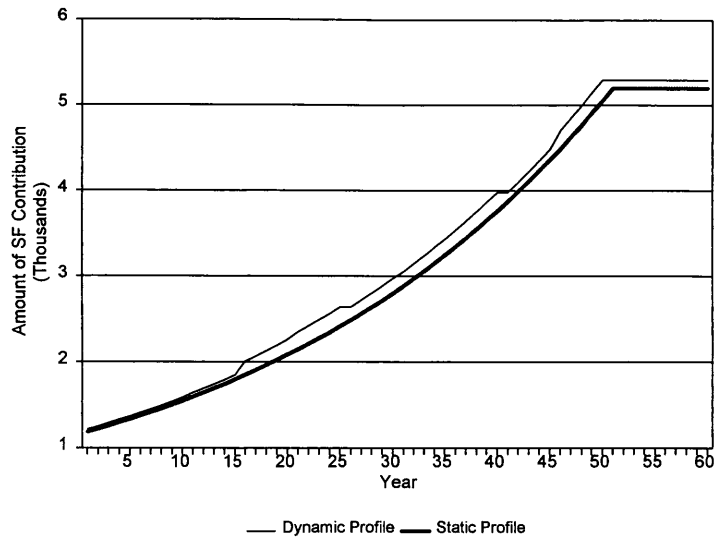
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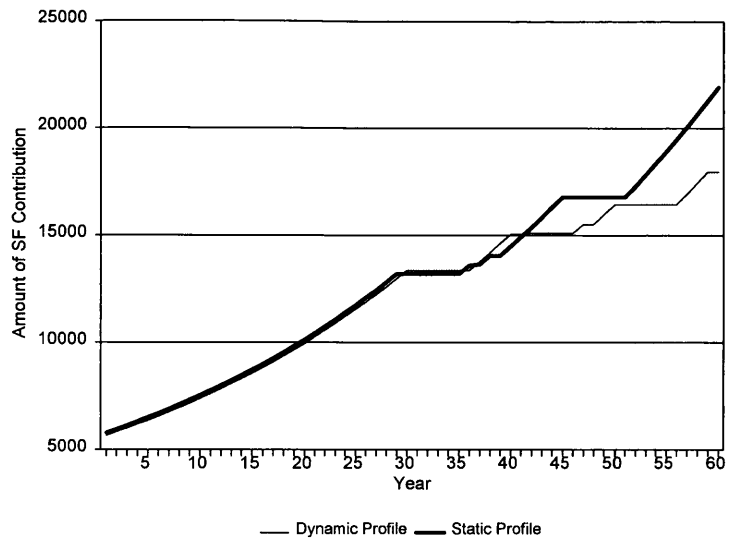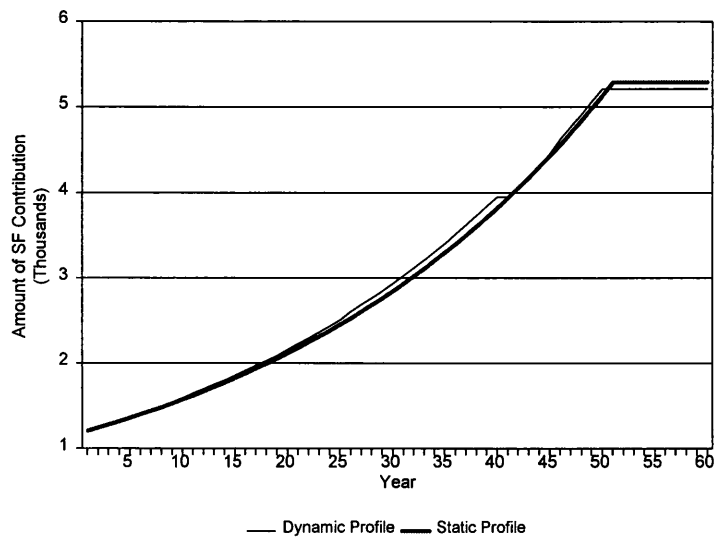

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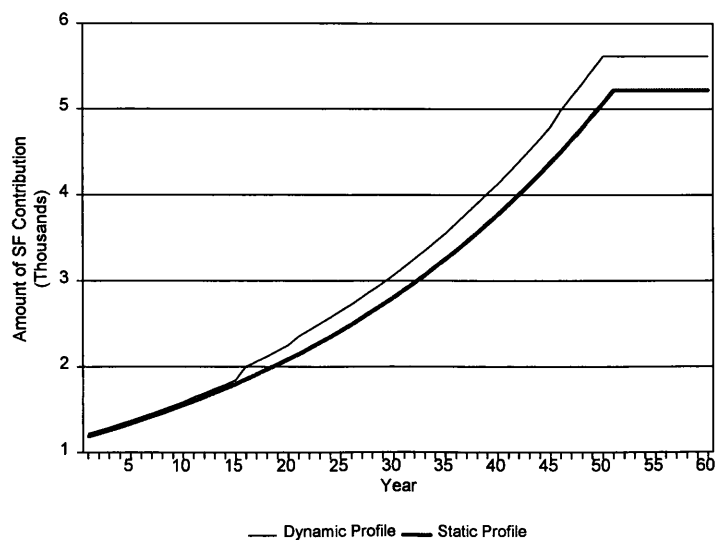
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173

Comparison of Dynamic and Static ASF Profiles
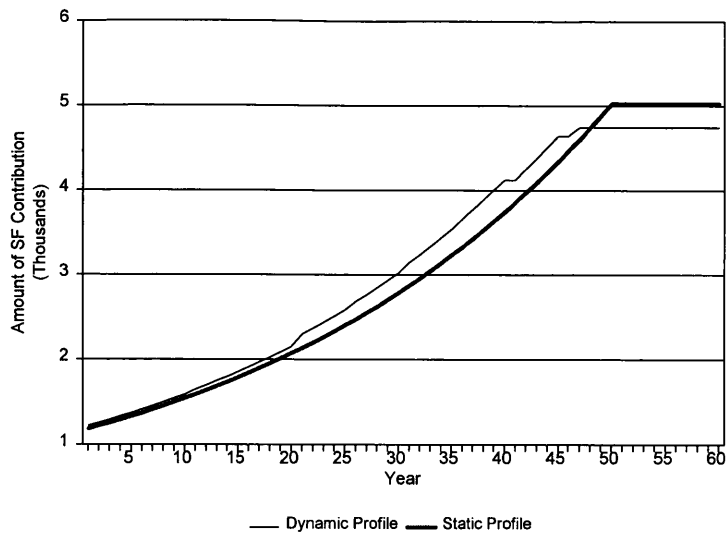
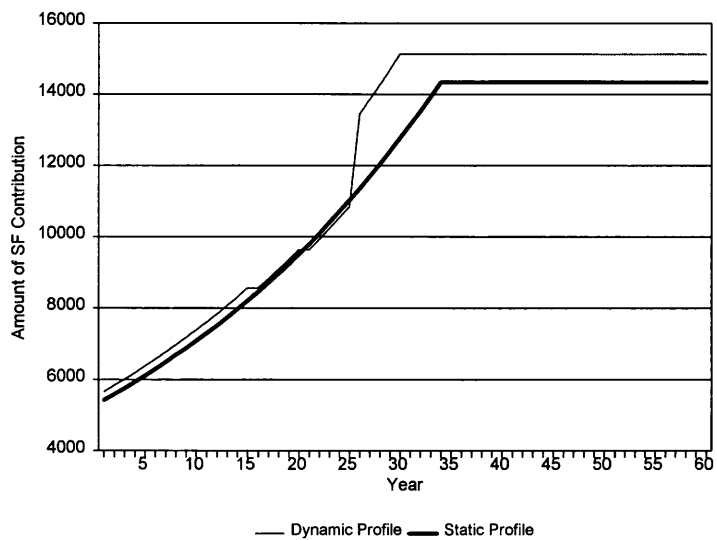Figure 8.84 Realisation 4: Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 3
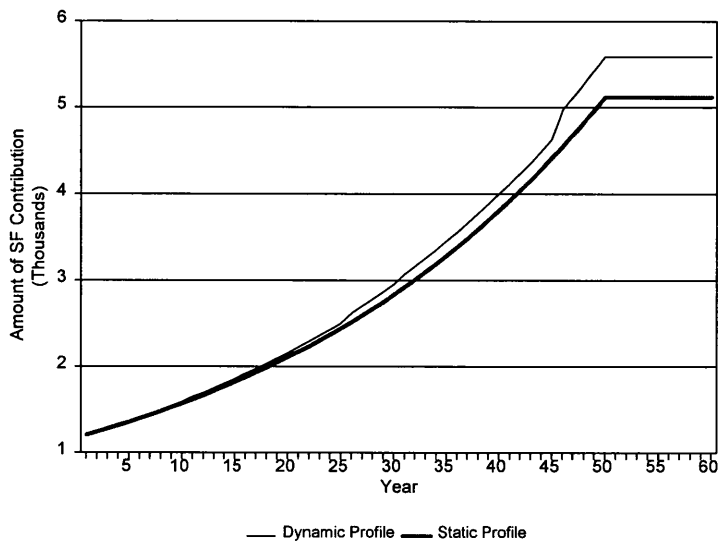
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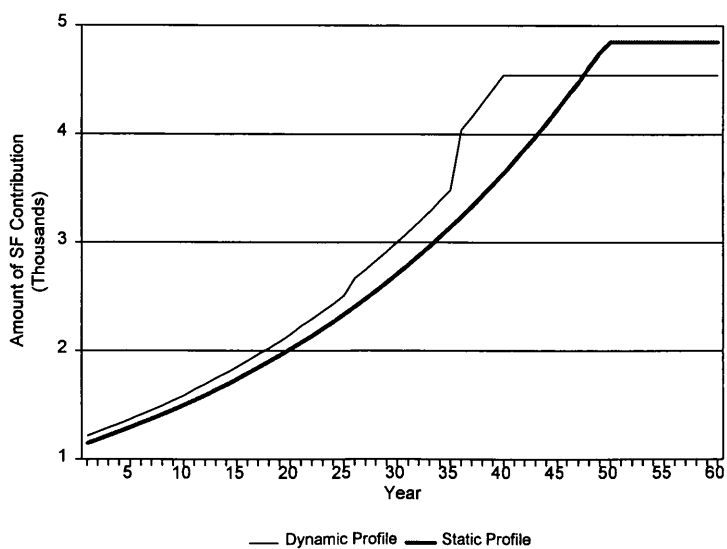
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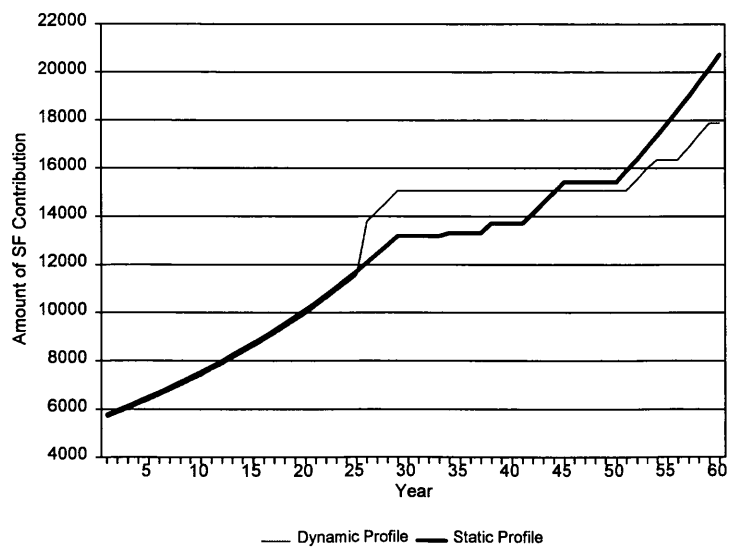
174

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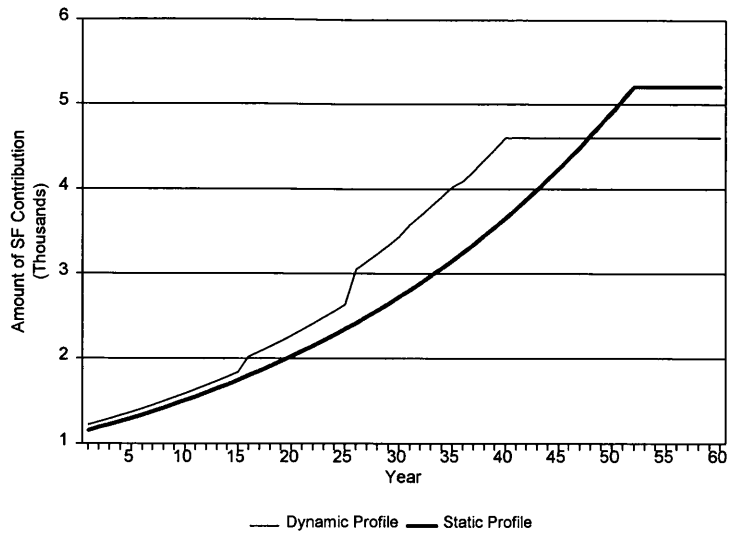
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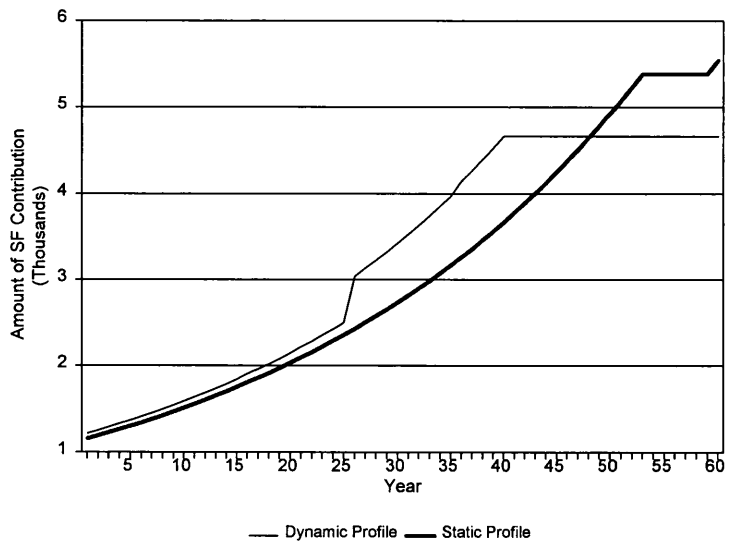
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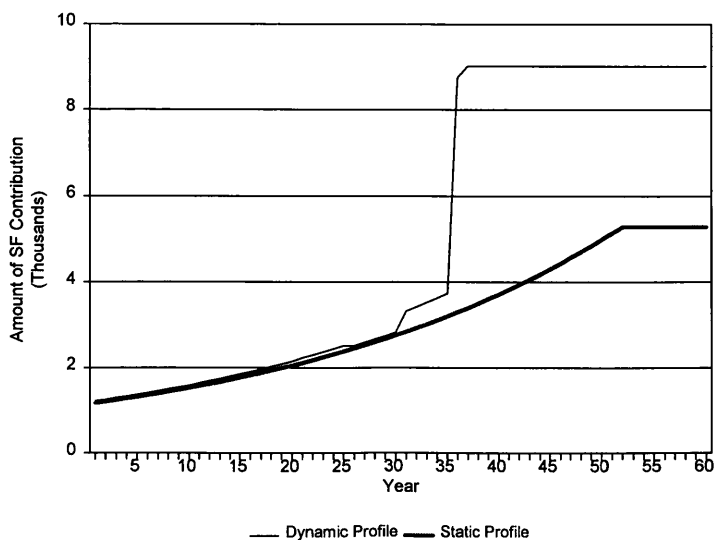
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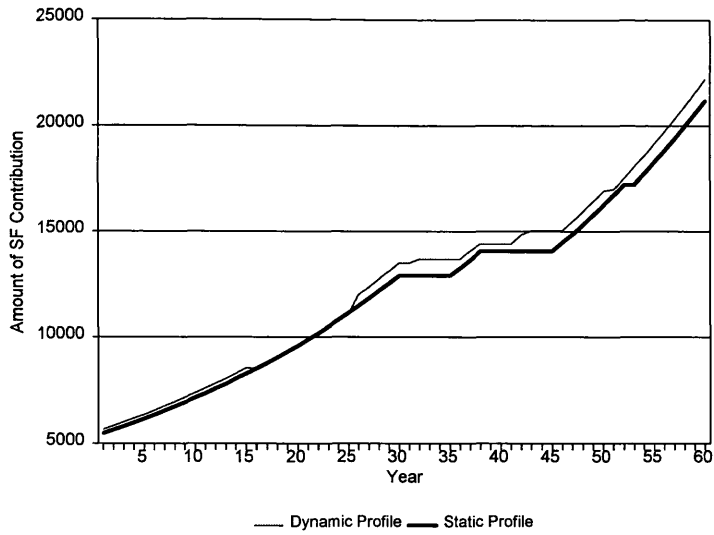## Comparison of Dynamic and Static ASF Profiles
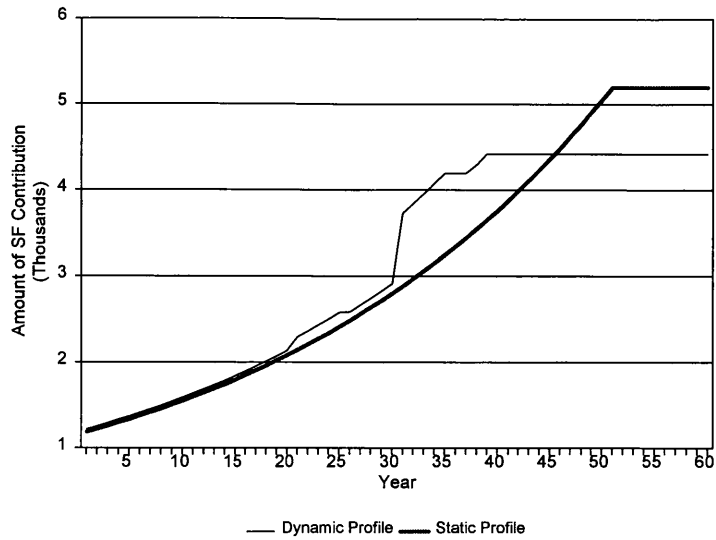
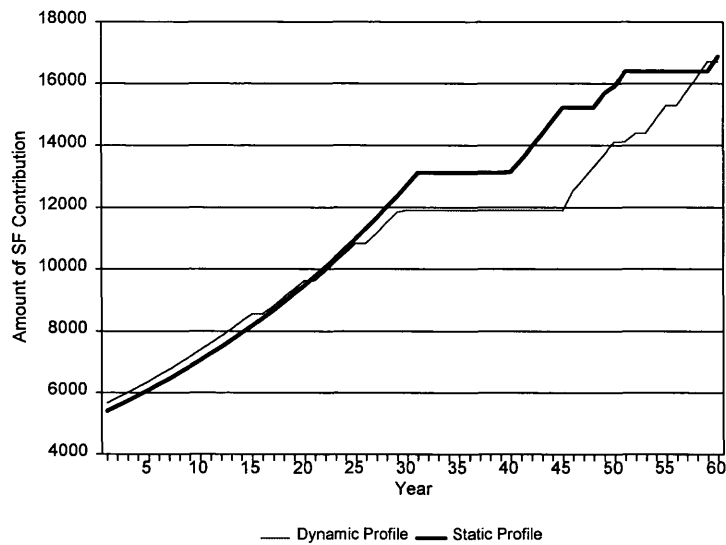Figure 8.90 Realisation 10: ynamic and Static Profiles of ASF Contributions using Model D for SCHEME 3
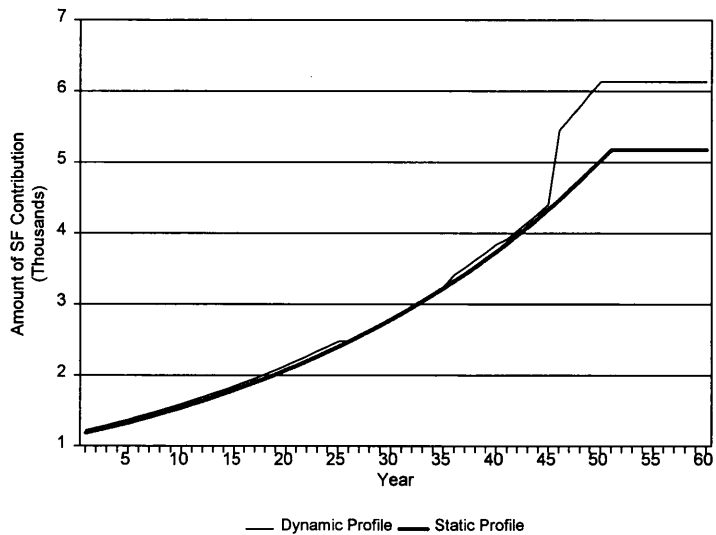
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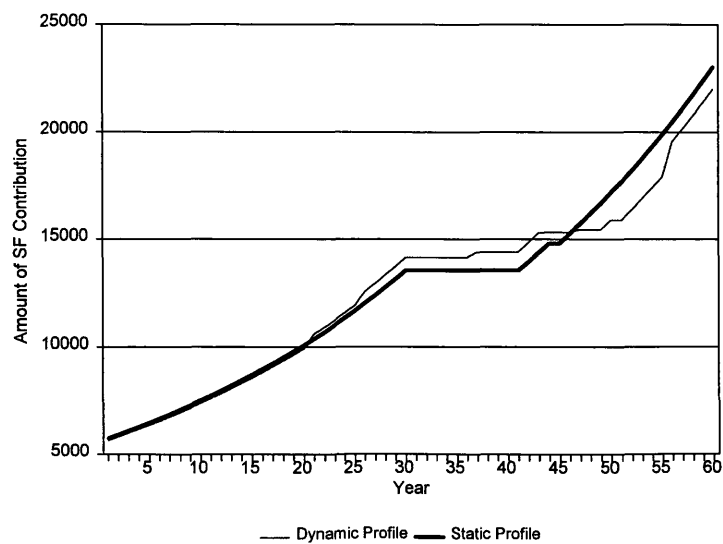

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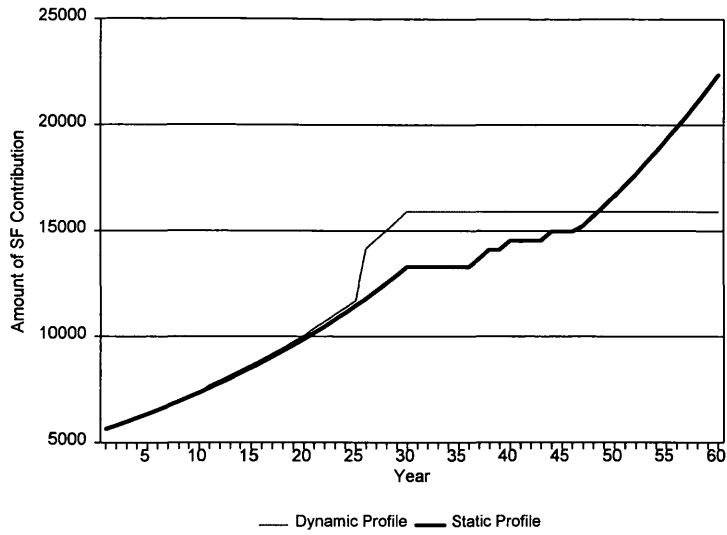# Comparison of Dynamic and Static ASF Profiles
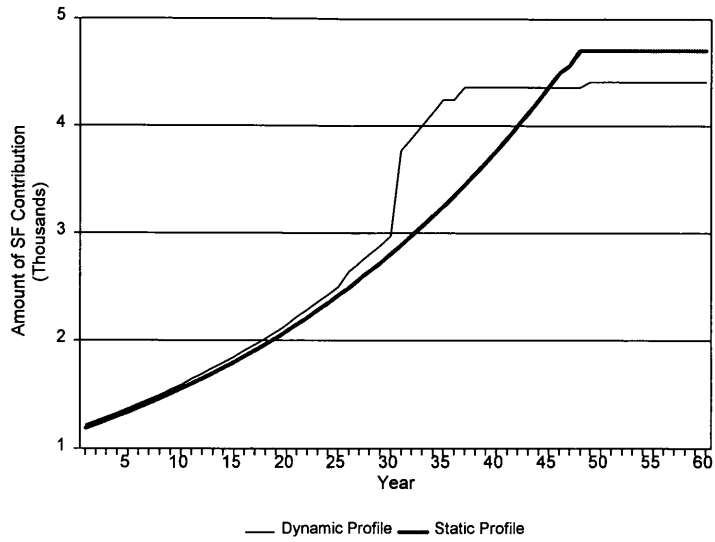
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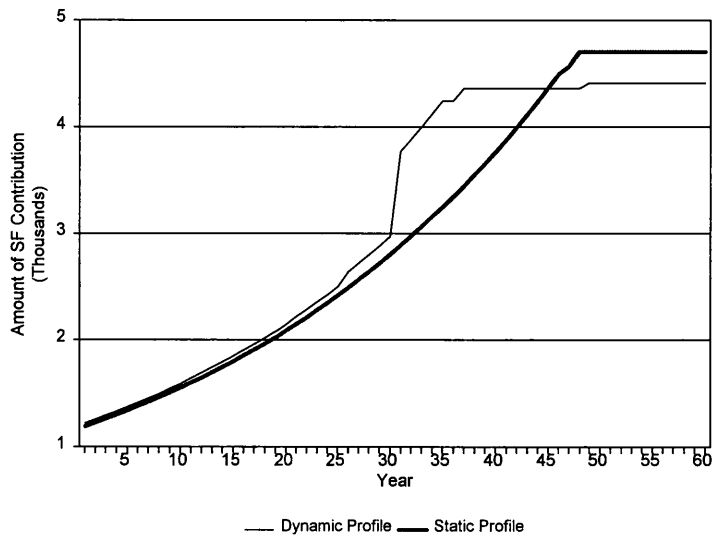
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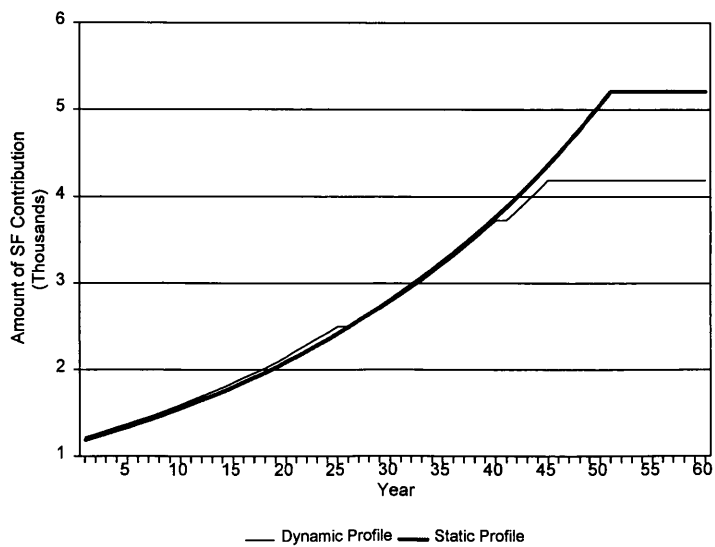
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Comparison of Dynamic and Static ASF Profiles
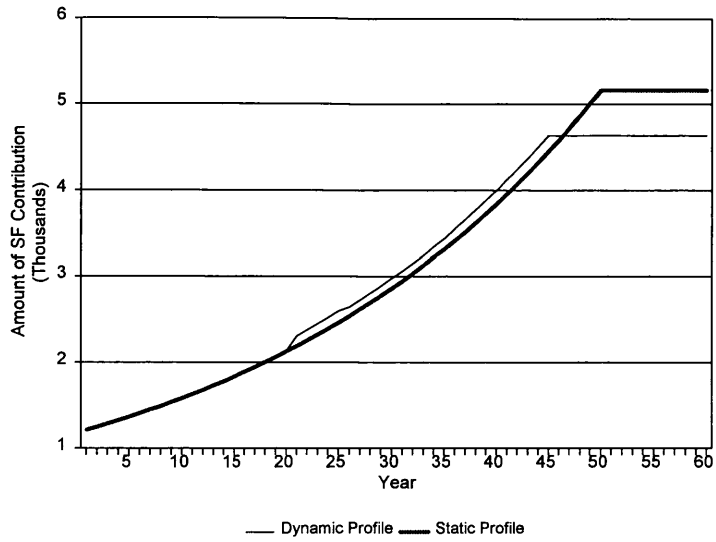
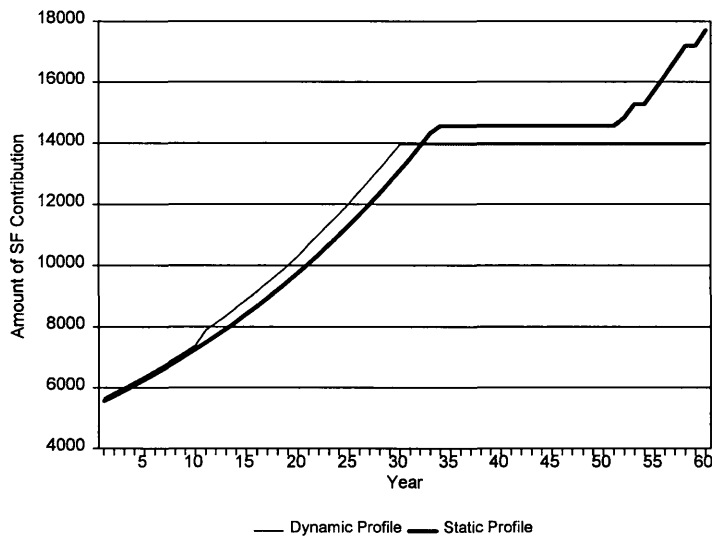Figure 8.96 Realisation 16:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 3
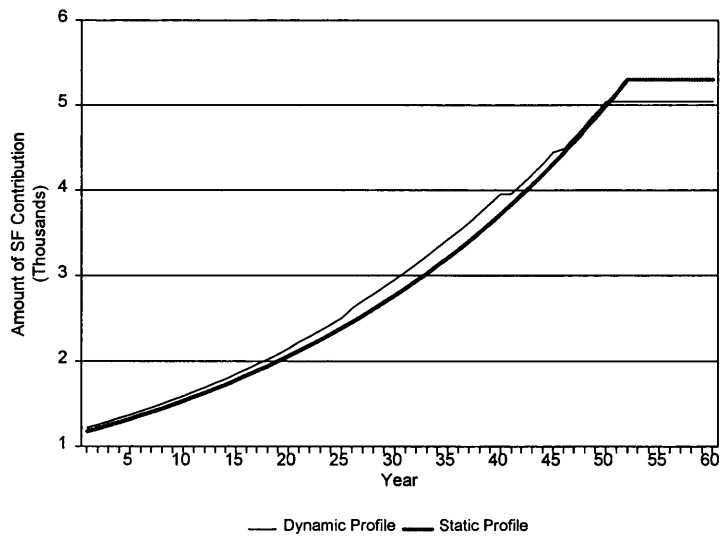
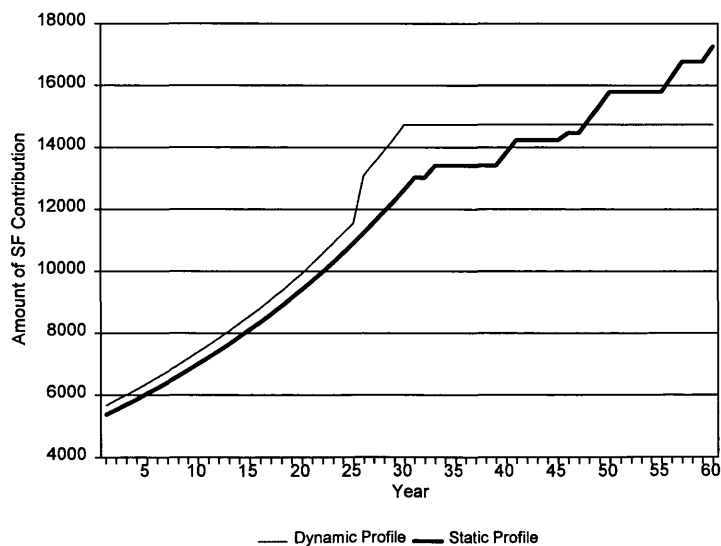Figure 8.97 Realisation 17:Dynamic and Static Profiles of ASF Contributions using Model D for SCHEME 3
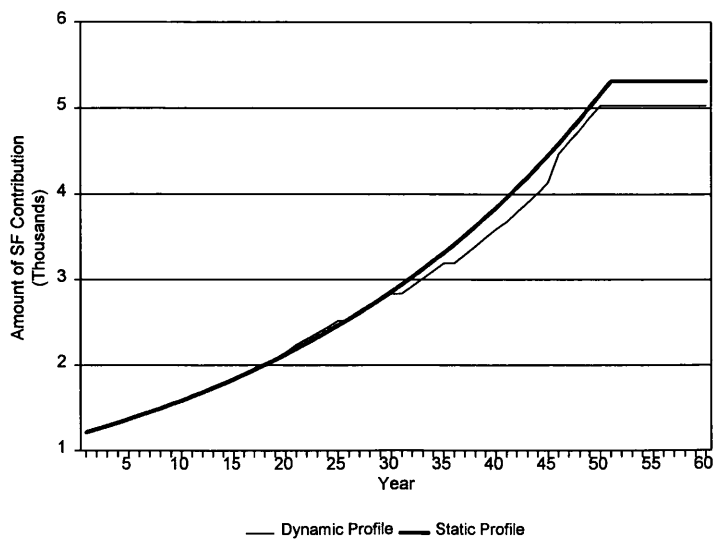
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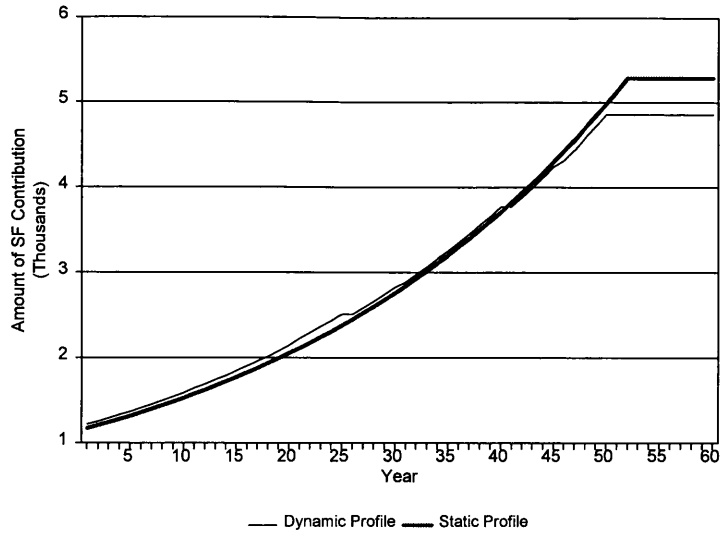
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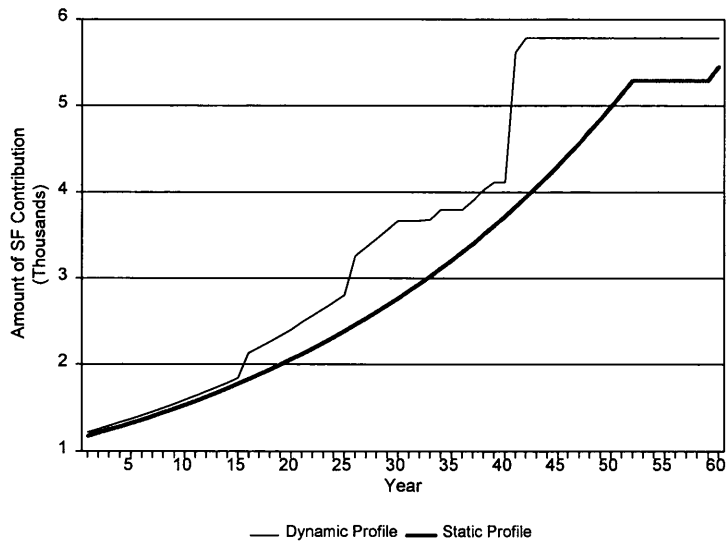
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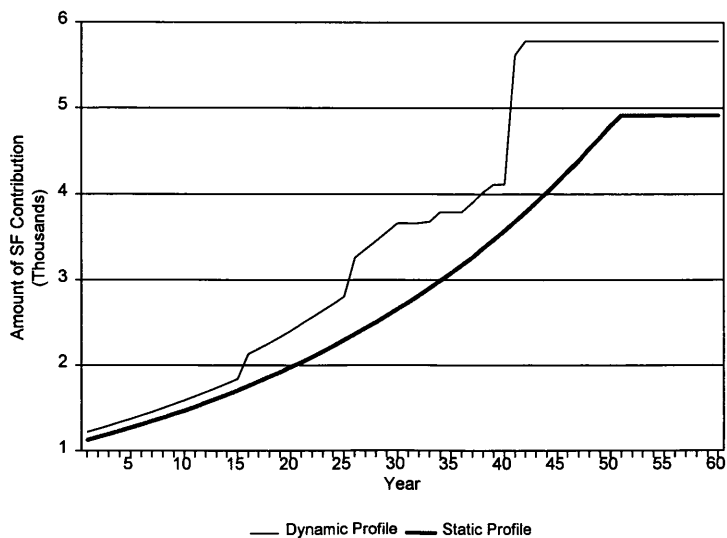
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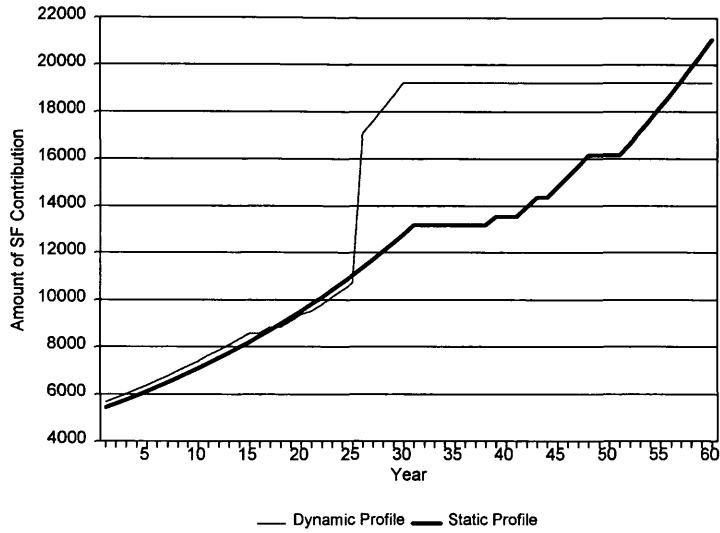
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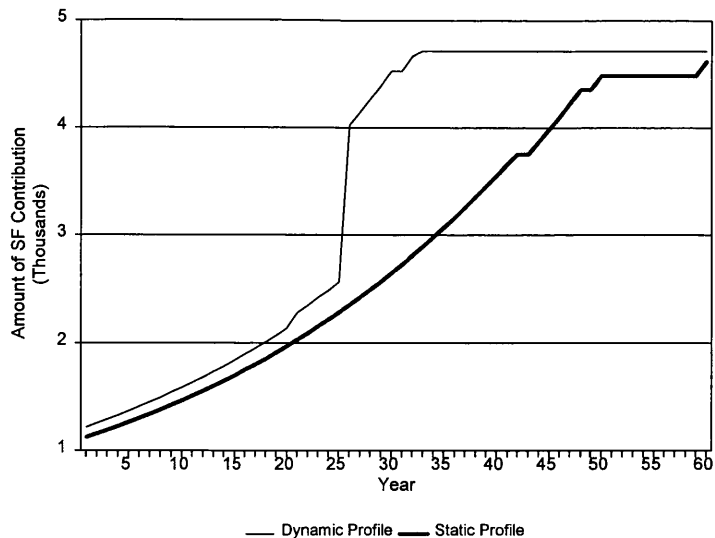
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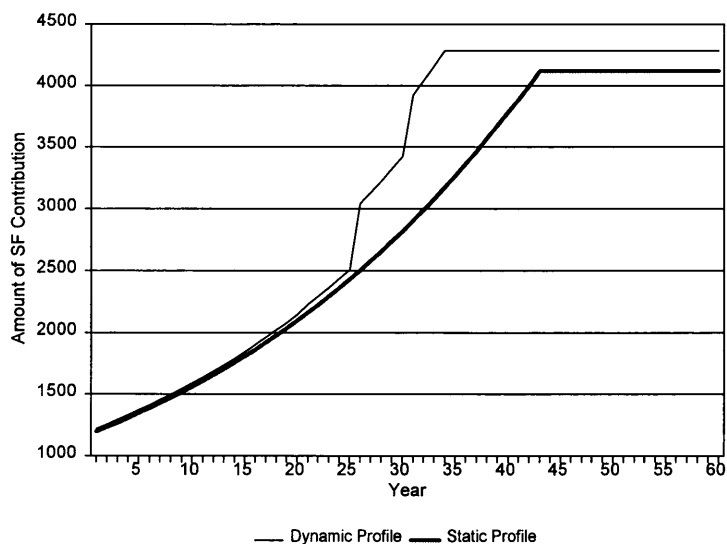
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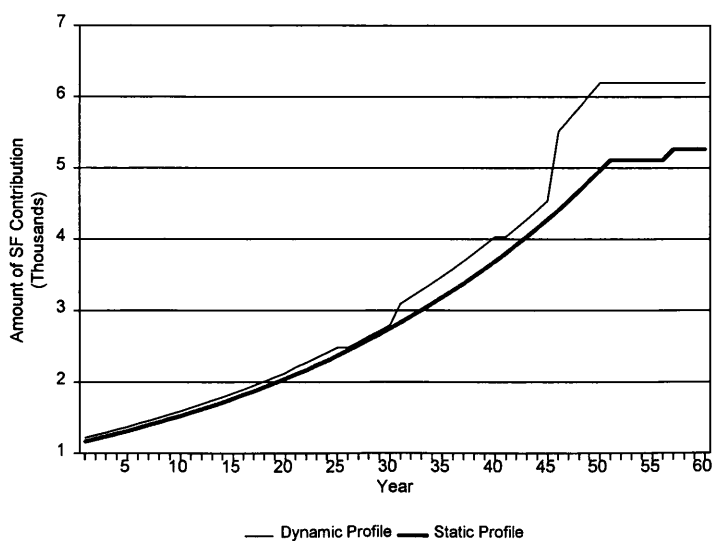
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Comparison of Dynamic and Static ASF Profiles

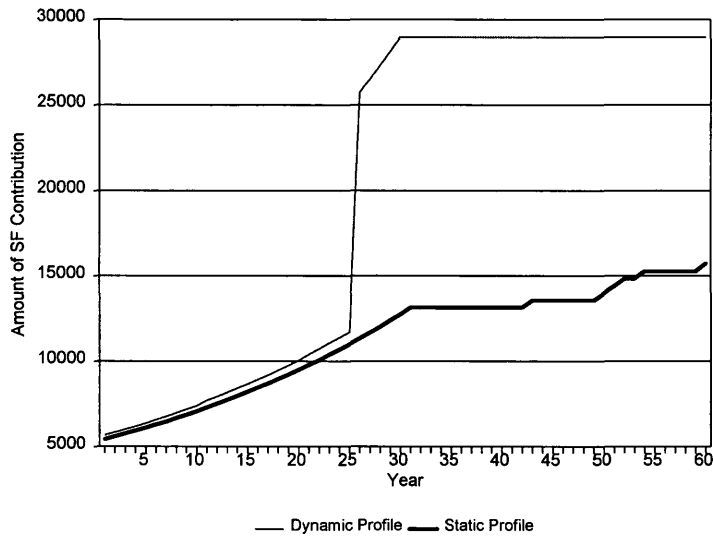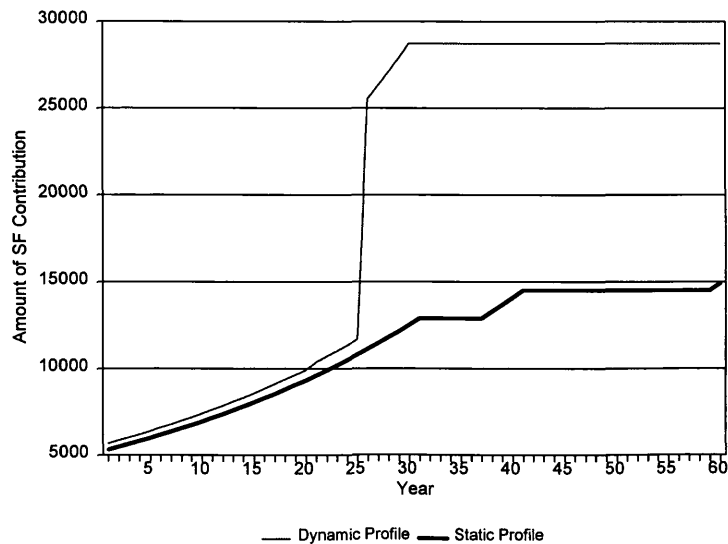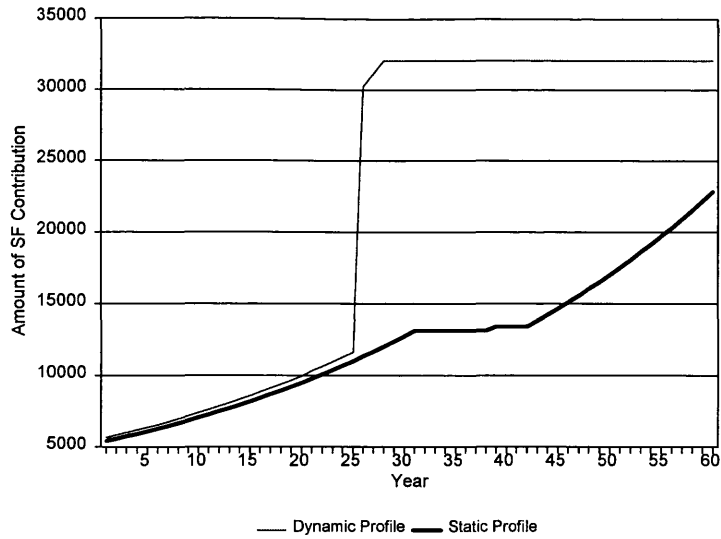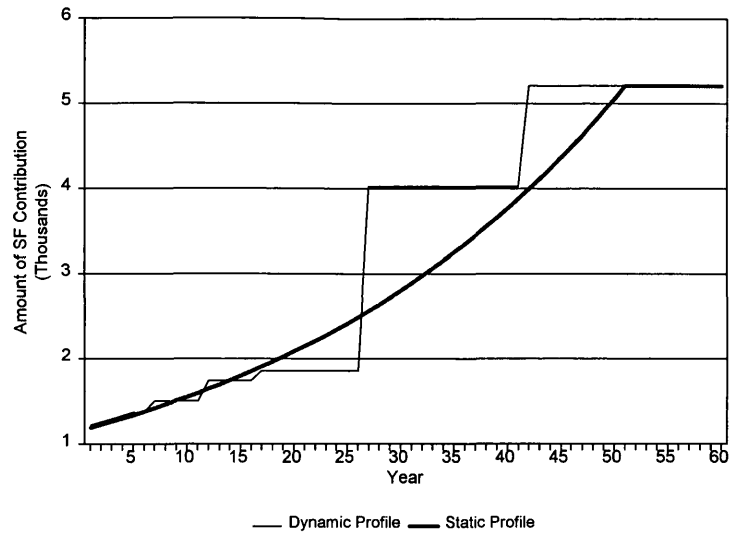Figure 8.105 Realisation 14:Dynamic and Static Profiles of ASF Contribs. using Model D for SCHEME 3

Comparison of Dynamic and Static Model Costs
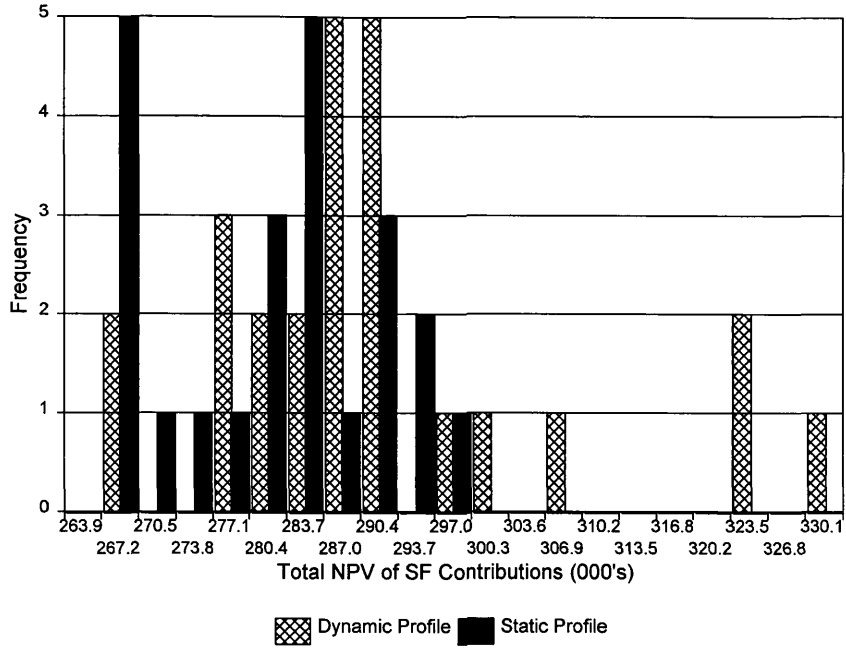
Figure 8.106 Frequency Distribution of Total SF Costs for SCHEME 2 using Model A Strategy
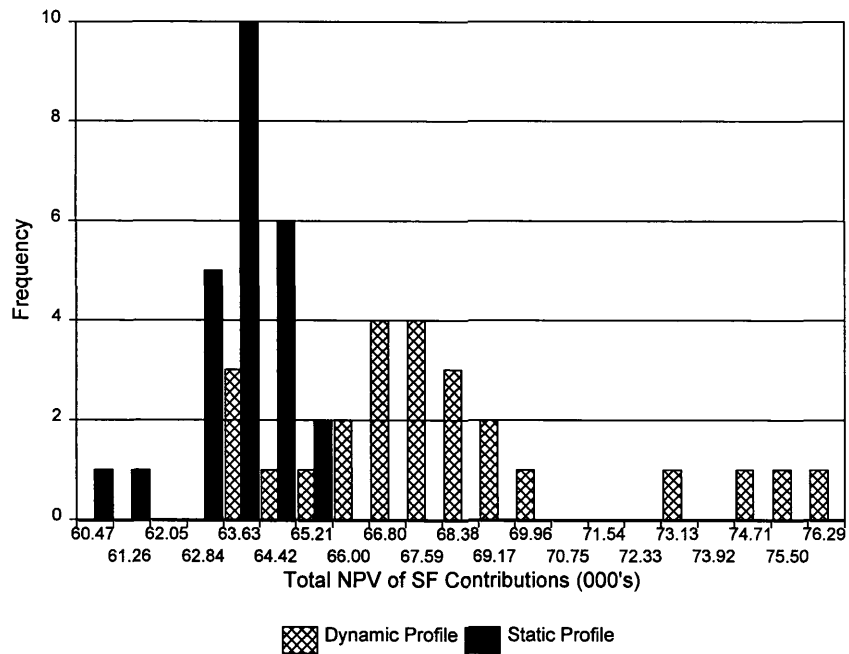
Figure 8.107 Frequency Distribution of Total SF Costs for SCHEME 3 using Model A Strategy

Comparison of Dynamic and Static Model Costs
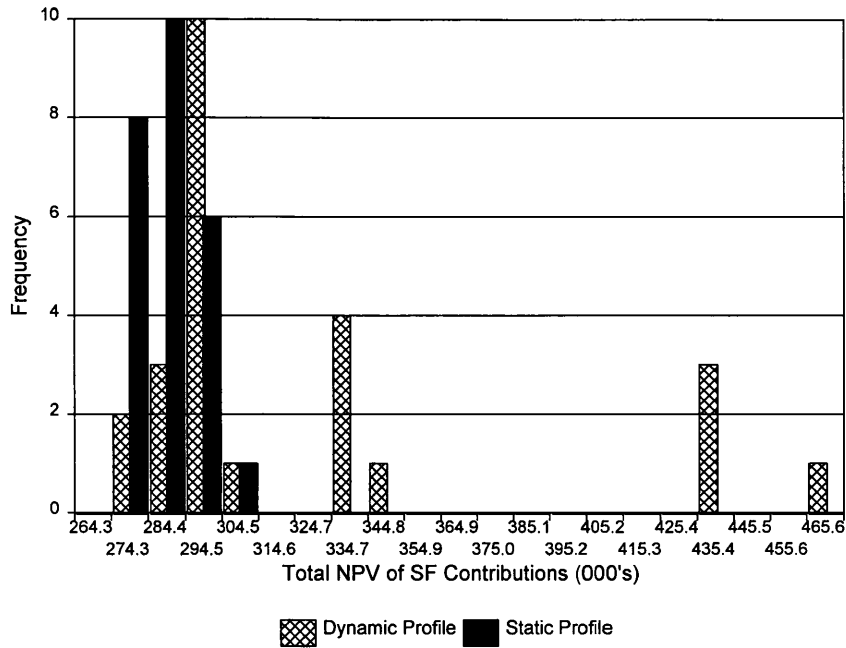
Figure 8.108 Frequency Distribution of Total SF Costs for SCHEME 2 using Model D Strategy
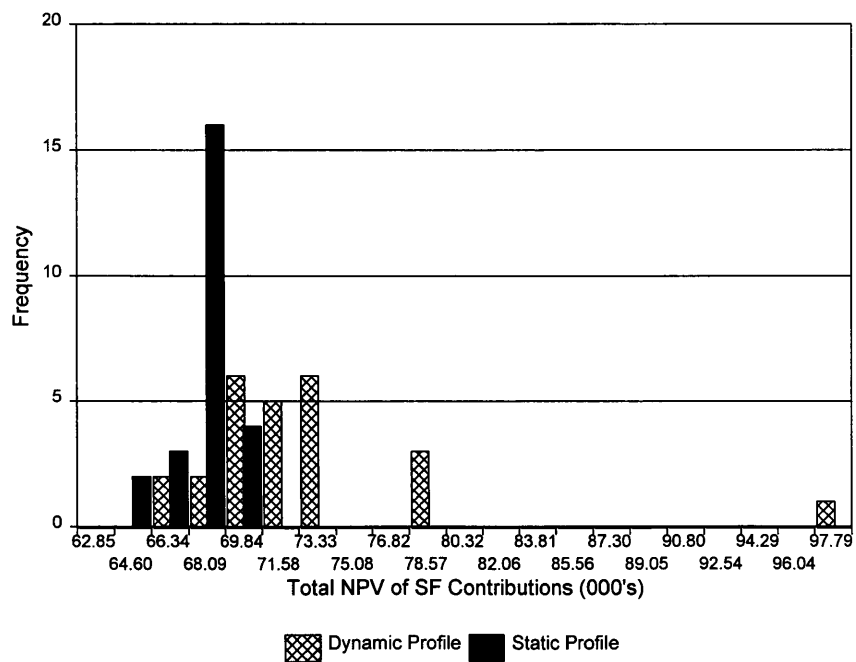
Figure 8.109 Frequency Distribution of Total SF Costs for SCHEME 3 using Model A Strategy

CHAPTER 9 Discussion

9.1 Introduction

This Chapter concludes the thesis with some general reflections on the research programme carried out. Specific findings are drawn from each of the Chapters, and the conclusions made from these are presented. Finally, some comments are made regarding future direction for the research.

9.2 Scope of the Research

The scope of the research work has not been founded within any narrow specialism, but a number of issues have been investigated drawing on literature from various disciplines. The work involved in modelling SF strategies and simulation can be described as OR and much of the literature consulted was in this field. OR is evident in many industries, but construction is one area where its impact has not been great. This position seems to be changing judging by the number of technical papers and journal articles now appearing, a welcome development given the sheer size of the construction industry and the scale of potential improvements in efficiency that could be made.

The nature of the research may be categorised as technological "push" rather than market "pull", in which the research assumes that if the knowledge is there a user will be found for it, rather than starting with the needs of a client. This is the nature of much research in construction management and one of the main reasons why greater success is not apparent in applying findings in practice. Being realistic, HAs are not about to adopt LP and other techniques themselves for sophisticated projection of SFs. This investigation can only hope to help highlight that there are alternatives to mechanistic calculation, and many widely different strategies can be implemented with the same overall cost implication.

Newton believes (106) that well-defined, universal theory is the mainstay of any science, but an accepted framework that would allow more ordered progress in construction management research is largely absent. Without this, a more discursive practice-oriented approach is needed. The potential contribution of LP for optimal decision making in construction (in the UK) was described as early as 1969 in a construction journal (107), but it was introduced in abstract theoretical terms using the language of MP in a way that has a slim chance of stimulating interest. There is little evidence of any practical application in construction management since then. Another consequence of having no defined paradigm is that research will lack focus and consequently progress will suffer. Runeson observed (108) that, of twenty papers on the subject

of building asset management at a CIB W70 conference, there is no instance of any reference appearing in more than one paper.

LCC is necessarily a significant part of the project, since any SF exercise is dependant on predictions of future maintenance. The discipline has existed for more than thirty years in construction, preoccupying much research effort and promoted by such professional bodies as the Royal Institution of Chartered Surveyors. Use in practice, though, appears to remain severely limited. Reasons why practitioners are reluctant to develop services and clients unwilling to commission them were summarised by Norman (109). The lack of data, as covered in this study and elsewhere is the most obvious. Secondly LCC calculations are perceived as inaccurate because they deal with the future, and are therefore inappropriate for decision making. Thirdly, the apparent precision of LCC calculations leave little scope for managerial discretion. The point that must be stressed though (as it frequently is in OR literature) is that techniques are only an aid to decision making, existing only to inform and not to be slavishly followed.

9.3 Placing the Investigation in Context

There is little published evidence of similar work being carried out on SFs. The mechanism of calculating a SF is quite simple and is probably dealt with in every text on valuation economics. It is experience of operating SFs in practice that is lacking, particularly on the scale now being required of housing associations. The various published expositions are limited to dealing with SFs in an exploratory way. Previous evidence of modelling a SF exists suggesting there is merit in investigating alternatives to the convention of calculating an annuity. The LP models developed herein are an extension to modelling by intuitive means, providing a formal method of modelling the SF and also optimising it according to some stated objective. The objectives in this study have been to minimise total costs and initial costs in the various SF models. However it has become apparent that HA reaction to SFs is wide and varied, and it would be naive to believe that an "off-the shelf" model could be prescribed for an organisation that would be relevant to its needs. Many more modelling objectives may become apparent over time, involving a number of personnel with differing objectives, and these would have to be explored before a truly optimal policy could be formulated.

It is expected that the author's own perceived limitations of the work must be shared by many others involved in research. Namely, the gulf that exists between theory and practice makes research seem a somewhat abstract pursuit at times. This is keenly felt since the success of OR is most widely measured by its implementation in practice, something which has not been achieved. The study has, by necessity, concentrated on the analytical aspects of SF models to highlight the properties of various ASF strategies, and provide a comparison with conventional methods. A developing theme in OR literature is that achieving success in practice requires strong will and

concerted effort on the part of the organisation. Such conditions were not present in the course of the research where the study was researcher led. OR is not a free activity, whether explicitly paid for or not. It absorbs resources, including time, and there is a paucity of resources in this field. The SF models do not define real problems as defined by individual associations, and the results could not be used to influence the SF management of individual associations, but to demonstrate how the application of new techniques compares with conventional methods. From the work presented and described it is hoped that the advantages of SF modelling are appreciated, and perhaps the basis for a more persuasive argument for their use is made. The approach will be of interest to larger associations grappling with treasury management.

Regarding predictive maintenance forecasting there is evidence of substantial research activity. Much of it would appear to owe a debt to work carried out by Damen and Botman in the early eighties, which used the now familiar normal distribution to represent probability of replacement of housing elements occurring at certain times. Following this Gaskell-Taylor (4) and Tucker and Rahilly (5) published work on predictive maintenance using distributions, the latter introducing the more flexible beta-distribution. These works have been based on profiling demand for resources across large stocks of housing. For this project simulation was used to predict resource need on single developments, in isolation of the remainder of the stock. The results, therefore, represent optimal solutions only to a part of the whole maintenance problem faced by HAs in the ongoing management of their entire stock. However, this is justified on the grounds that the kind of analysis carried out could only be done on individual developments. It is contended that predictive maintenance forecasting is where LCC research effort should be concentrated. The main criticism of deterministic forecasts is that there is simply not enough good data to support them, a situation that has not improved significantly in the last twenty years or so. Predictive maintenance forecasting at least recognises the uncertainty inherent in maintenance forecasting, and the data collection effort could be directed to refining the distributions that would be representative of likely lifespan.

At present, stock for which SFs are a necessity is still relatively new and trouble free, and the impact of a HAG-free financial regime is yet to make itself fully felt. Currently debate centres on the adequacy, or otherwise, of figures being proposed as necessary for the future maintenance of housing stock. It remains to be seen whether sophisticated modelling of SFs have validity in the uncertain political environment in which HAs must operate.

9.4 Summary of Findings

For certain profiles of maintenance it is possible to calculate a SF annuity in two ways using conventional financial calculations. Applying multiple ASF calculations for a projected profile of expenditure is always feasible, but the intermittent profile of expenditure results in an uneven, possibly undesirable, profile of SF annuities. Chapter 3 showed that simple manipulation of financial calculations could be used to derive a constant annuity over the whole of the planning horizon, but not for MR profiles showing a significant expenditure peak before the end of the projection.

Linear Programming models have shown that various diverse ASF strategies can be devised at optimal cost i.e. there are many degenerate optimal solutions. It is apparent then that there will be many strategies that can be modelled at optimal overall cost, it is only when constraints become unduly restrictive that the total NPV will rise. Of course minimising the overall cost is only one possible objective, but different objectives may also lead to degenerate optimal solutions as some of the models in Chapter 6 have shown. For some projected MR profiles the burden of expenditure occurs relatively early. Analysis has shown that a conventional SF, which is always in credit, is inefficient in such cases. A cheaper overall solution is possible if funds are obtained from other sources (such as borrowing) at times of peak expenditure, even where finance charges incurred are significant. Such information is of interest and value to all HAs, albeit the actual operations are more complicated than simply laying aside an annual payment.

For the given risk parameters, simulating the MR profile for a sixty year period (notional housing lifespan and SH required planning horizon) is more likely to result in lower estimates of projected expenditure compared to estimates based on average replacement cycles. Consequently, SF projections based on simulated data are more likely to be of lower cost than those based on deterministic data. It can be said that a projection based on fixed life cycles provides a conservative assumption for planning.

Changing assessments of component lifespan are inevitable over the life-cycle of a building and the SF will have to be amended accordingly. The analyses carried out in Chapters 6 and 7 treat the SF problem as a static one. i.e. all the strategies are based on single sixty year projections that do not take account of any changes that will inevitably have to be made in the light of changing information. The dynamic SF model has shown that making changes to SF strategy is very likely to have an adverse effect on overall cost i.e. a higher NPV of SF payments. It is clear, then, that more accurate projections of MR expenditure at the outset will reduce the need for significant changes having to be made to the SF, and therefore minimise its cost. However, the difficulty of making accurate long term component lifespan projections with the poor level of data that exists has been described. Indeed, it must be wondered if this situation will ever significantly improve. It may be that a decision approach to component lifespans by property

managers, of the type described by Holmes, provides the way forward for improving maintenance management. This would allow a SF strategy which is optimal at the outset to remain optimal. Such an approach would accord with that suggested by Meikle and Connaughton **(80)** who advocate a culture in housing maintenance management where components that are cheap to manufacture and install become the norm, and regular replacement is recognised as natural and desirable. Such an approach would be a significant step toward maintaining housing at a satisfactory level for far longer than current notional assumptions of housing lifespan.

9.5 Conclusions

It would appear that current guidelines on what constitutes an adequate level of ASF will not be sufficient to fund the MR needs of housing stock in the future. For the results presented only the most optimistic scenarios of high interest rates and prolonged component lifespans provided the conditions for a calculated annuity that fell below or equalled those contained in the guideline issued by SH **(2)**. The guideline, however, assumes the level of annual deposit is fixed throughout the planning horizon, ignoring the possibility of modelling the SF. Even using conventional financial calculations it is possible to project two different profiles as Chapters 3 and 6 showed. It is contended that a more objective measure of appropriate SF be adopted in favour of the current fixed proportion of works costs. This may be in the form of expressing an upper limit in terms of the total NPV of MRs or SF payments that are projected for a fixed period. Such an approach would emphasise the need for a long term planned major maintenance strategy from the outset rather than simply investing the guideline figure each year and assuming it to be adequate as HAs are reported to be doing **(110)**. This would accord with the SFHA view that MR funding requirements should be evaluated based on whole life-cycle costing i.e. HAs must take a needs rather than budget driven approach.

Chapter 8 has shown that the more a SF plan is changed the greater the cost implications. Therefore, once a strategy is developed it would be undesirable to deviate from it. However, it is recognised that HAs must be flexible given the many economic and political uncertainties they face.

On a more general level, it is an oft-repeated complaint by many maintenance professionals that the discipline has an unduly low status in the construction industry, lacking the glamour of new build work (the so called Cinderella profession). The most obvious consequence of this is that it is starved of cash. However statistics show **(111)** that the repair and maintenance sector of construction as a proportion of new-build has been growing steadily for a number of years. It is clear from the literature that, despite the year on year increase, expenditure is still below need. If the stock of buildings are to be maintained at an adequate level, avoiding some of the worst experiences of disrepair as reported by the AC, a cultural change is surely necessary. There is a

need to raise the level of professionalism in the maintenance industry and a greater use of IT tools is therefore advocated, for more sophisticated forecasting of maintenance need, and more effective presentation of the need for funds to senior management.

9.6 Suggestions for Further Research

The findings from the work carried out in this study have carried forward the investigation of SFs as a means of providing finance for the long term maintenance of housing. Further research proposals specific to the HA movement will only be able to be made when greater experience is gained in the field, and weaknesses in existing SF mechanisms for such large scale use can be identified from the feedback. The suggestions for further research are not confined therefore to the HA movement, but are aimed at improving the long term maintenance management of any built assets.

Conventional financial calculations offer little flexibility in the planning of a SF since it is not possible to model the distribution of its burden over time other than by trial and error. It is in the early years that a proportion of rental income can least be spared for the SF provision, yet the calculated annuity is never greater than at this time. The use of SFs will only become more attractive if annual contributions can be planned to suit the revenue stream of the organisation . This is the justification for further research on modelling (of which LP is one technique) in place of mechanistic calculation. Making the planning of a maintenance provision an integral function of asset management will reduce the likelihood of disrepair in the future through lack of planning and available funds. Various example strategies are offered, but to determine the needs of individual HAs a more comprehensive feedback exercise will be required detailing the adequacy of SF management being practised as stock ages. This will take some time, only becoming apparent as the condition of post 1989 stock deteriorates and the practicalities of SFs are more fully tested.

The studies herein are based on the SF cost implications of individual developments, in isolation of the remainder of the stock under HA management. Further study should consider the SF needs of the stock as a whole. The projected MR expenditure profile for all stock will give very different profiles to those derived in Chapter 6 for individual Schemes and an optimal SF strategy for the stock as a whole will not necessarily be the sum of optimal strategies for individual developments.

The accepted format of element and component lifespan data in LCC is for deterministic assessments or, at best, assessed lifespan range. All the current publications of data referred to in Chapter 5 are compiled in this way. If the emphasis of LCC is to move toward predictive maintenance forecasting, as is frequently advocated, then the available data will have to

reflect this. Sophisticated models, and the tools available to run them, are becoming ever more sophisticated, but no data would appear to exist to merit their serious use in practice. It is contended that the presentation of data be extended to include distribution parameter data at the heart of predictive maintenance forecasting, rather than merely single figure assessments. The beta distribution is shown to offer great flexibility in modelling the lifespan characteristics of building parts and requires only two parameters (in addition to expected minimum and maximum expected life) to fix its shape. Greater availability of more meaningful data, recognising the imprecision inherent in lifespan forecasting, would enhance the credibility of LCC and encourage practical use of the techniques that have largely been confined to theory.

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```
! APPENDIX 1 : MODEL TYPE 1

! XPRESS-MP Model file : MODEL A - Quinquennial increase of SF payments
! =====================================================================




DISKDATA -1
disc=maindat.wk3(k11..k11)
period=maindat.wk3(k12..k12)

LET horiz=period
LET INTCR=disc




TABLES
c(horiz)    ! Set up table for annual projected costs




DISKDATA -L
c=maindat.WK3(r15..r74)      ! Reads in cost data from spreadsheet file




VARIABLES
x(horiz)    ! One dim. array for annual SF contribs.
f(horiz)    ! One dim. value of fund each year




CONSTRAINTS
Initfund: x(1)=f(1)
levpay(YEAR=1:horiz-1|YEAR/5<>int(YEAR/5)):x(YEAR)=x(YEAR+1)
Incr(YEAR=1:horiz-1|YEAR/5=int(YEAR/5)):-INTCR*x(YEAR)+x(YEAR+1)=0
dec(YEAR=2:horiz):x(YEAR)-x(YEAR-1)>0
balance(YEAR=2:horiz):x(YEAR)+INTCR*f(YEAR-1)-f(YEAR)=c(YEAR)

Z: SUM(YEAR=1:horiz) 1/(1+INTCR)^YEAR*x(YEAR) $  !Objective function




GENERATE      ! Generate MPS file




TABLES
TAB(horiz,2)              ! Construct a 2 dim. array

ASSIGN
TAB(year=1:horiz,1)=x(year)
TAB(year=1:horiz,2)=f(year)   ! Fill array with solution values




diskdata -o

step.dat=TAB     !Write solution values to ASCII file.
```

```
!MODEL TYPE 1
! XPRESS-MP Model file : MODEL B - Expenditure linked increase in SF deposit
! =================================================================



DISKDATA -1
disc=maindat.wk3(g11..g11)
period=maindat.wk3(g12..g12)


LET horiz=period
LET INTCR=disc


TABLES
c(horiz)    ! Set up table for annual projected costs


DISKDATA -L
c=maindat.WK3(r15..r74)      ! Reads in cost data from spreadsheet file


VARIABLES
x(horiz)    ! One dim. array for annual SF contribs.
f(horiz)    ! One dim. value of fund each year


CONSTRAINTS
Initfund: x(1)=f(1)
levcon(YEAR=2:horiz|c(YEAR-1)=0):x(YEAR)=x(YEAR-1)
maxinc(YEAR=2:horiz|c(YEAR-1)>1):x(YEAR)=1.06*x(YEAR-1)
balance(YEAR=2:horiz):x(YEAR)+INTCR*f(YEAR-1)-f(YEAR)=c(YEAR)

Z: SUM(YEAR=1:horiz) 1/INTCR^YEAR*x(YEAR) $  !Objective function


GENERATE     ! Generate MPS file


TABLES
TAB(horiz,2)             ! Construct a 2 dim. array

ASSIGN
TAB(year=1:horiz,1)=x(year)
TAB(year=1:horiz,2)=f(year)   ! Fill array with solution values


diskdata -o

expinc.dat=TAB     !Write solution values to ASCII file.
```

```
!MODEL TYPE 1
! XPRESS-MP Model file :  MODEL C - Annual Increase in SF deposits
! ========================================================


DISKDATA -1
disc=maindat.wk3(g11..g11)
period=maindat.wk3(g12..g12)

LET horiz=period
LET INTCR=disc


TABLES
c(horiz)     ! Set up table for annual projected costs


DISKDATA -L
c=maindat.WK3(d15..d74)      ! Reads in cost data from spreadsheet file


VARIABLES
x(horiz)     ! One dim. array for annual SF contribs.
f(horiz)     ! One dim. value of fund each year


CONSTRAINTS
Initfund: x(1)=f(1)
increm(YEAR=1:horiz-1):-INTCR*x(YEAR)+x(YEAR+1)=0
balance(YEAR=2:horiz):x(YEAR)+INTCR*f(YEAR-1)-f(YEAR)=c(YEAR)

Z: SUM(YEAR=1:horiz) 1/INTCR^YEAR*x(YEAR) $  !Objective function


GENERATE     ! Generate MPS file


TABLES
TAB(horiz,2)               ! Construct a 2 dim. array

ASSIGN
TAB(year=1:horiz,1)=x(year)
TAB(year=1:horiz,2)=f(year)   ! Fill array with solution values


diskdata -o

fixinc.dat=TAB     !Write solution values to ASCII file.
```

```
!MODEL TYPE 1
! XPRESS-MP Model file : MODEL D - Minimise Initial SF deposit.
! ==============================================


DISKDATA -1
disc=maindat.wk3(g11..g11)
period=maindat.wk3(g12..g12)

LET horiz=period
LET INTCR=disc


TABLES
c(horiz)     ! Set up table for annual projected costs


DISKDATA -L
c=maindat.WK3(D15..D74)     ! Reads in cost data from spreadsheet file


VARIABLES
x(horiz)     ! One dim. array for annual SF contribs.
f(horiz)     ! One dim. value of fund each year


CONSTRAINTS

Initfund: x(1)=f(1)


balance(YEAR=2:horiz):x(YEAR)+INTCR*f(YEAR-1)-f(YEAR)=c(YEAR)
Upper(YEAR=1:horiz-1):-INTCR*x(YEAR)+x(YEAR+1)<0
lower(YEAR=1:horiz-1):-x(YEAR)+x(YEAR+1)>0

Z: x(1) $  !Objective function:Minimise initial contribution


GENERATE     ! Generate MPS file


TABLES
TAB(horiz,2)               ! Construct a 2 dim. array

ASSIGN
TAB(year=1:horiz,1)=x(year)
TAB(year=1:horiz,2)=f(year)   ! Fill array with solution values


diskdata -o

minyr1.dat=TAB     !Write solution values to ASCII file.
```

!**APPENDIX 2** : MODEL TYPE 2

!XPRESS-MP Model File : Model A - Quinquennial increase of SF payments
!===

LET HORIZ=60   !This will either be 30 or 60, depending on the horizon
LET INTCR=0.03
LET INTDR=0.15
LET INF=INTCR
LET m=0
LET M=182
LET DEF=-30

TABLES
COST(HORIZ)

DISKDATA -L

COST=maindat.wk3(d15..d74)

VARIABLES
x(HORIZ)
fund(HORIZ)
a(HORIZ)
a1(HORIZ)
a2(HORIZ)
b(HORIZ)
b1(HORIZ)
b2(HORIZ)

CONSTRAINTS
levpay(YEAR=1:HORIZ-1|YEAR/5<>int(YEAR/5)):x(YEAR)=x(YEAR+1)
incr(YEAR=1:HORIZ-1|YEAR/5=int(YEAR/5)):-(1+INTCR)*x(YEAR)+x(YEAR+1)=0
dec(YEAR=2:HORIZ):x(YEAR)-x(YEAR-1)>0

test(YEAR=2:10): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)=fund(YEAR)

int1(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
M*a1(YEAR)<fund(YEAR)+M
int2(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
m*a2(YEAR)>fund(YEAR)+m
indic1(YEAR=11:HORIZ): a1(YEAR)+a2(YEAR)=a(YEAR)+1

ch1(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
M*b1(YEAR)<fund(YEAR)+M
ch2(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
DEF*b2(YEAR)>fund(YEAR)+DEF
indic2(YEAR=11:HORIZ): b1(YEAR)+b2(YEAR)=b(YEAR)+1

cred1(YEAR=11:HORIZ): fund(YEAR-1)+DEF*a(YEAR)>DEF
cred2(YEAR=11:HORIZ): fund(YEAR-1)<M*a(YEAR)-0.000001
deb1(YEAR=11:HORIZ): fund(YEAR-1)>DEF*b(YEAR)
deb2(YEAR=11:HORIZ): fund(YEAR-1)+M*b(YEAR)<M-0.000001

Initial fund: x(1)=fund(1)
Optimise : SUM(YEAR=1:HORIZ) 1/(1+INTCR)^YEAR*x(YEAR) $

BOUNDS
fund(YEAR=1:HORIZ-1)>DEF
a(YEAR=11:HORIZ) .BV.
a1(YEAR=11:HORIZ) .BV.
a2(YEAR=11:HORIZ) .BV.
b(YEAR=11:HORIZ) .BV.
b1(YEAR=11:HORIZ) .BV.
b2(YEAR=11:HORIZ) .BV.

GENERATE

TABLES
TAB(HORIZ,2)

ASSIGN
TAB(YEAR=1:HORIZ,1)=x(YEAR)
TAB(YEAR=1:HORIZ,2)=fund(YEAR)

DISKDATA -O

OUTPT11.DAT=TAB

```
!MODEL TYPE 2
!XPRESS-MP Model File : MODEL B - Expenditure linked increase in SF deposits
!=======================================================================



LET HORIZ=60   !This will either be 30 or 60, depending on the horizon
LET INTCR=0.03
LET INTDR=0.15
LET INF=INTCR
LET m=0
LET M=182
LET DEF=-30

TABLES
COST(HORIZ)

DISKDATA -L

COST=maindat.wk3(d15..d74)

VARIABLES
x(HORIZ)
fund(HORIZ)
a(HORIZ)
a1(HORIZ)
a2(HORIZ)
b(HORIZ)
b1(HORIZ)
b2(HORIZ)


CONSTRAINTS
levcon(YEAR=2:HORIZ|COST(YEAR-1)=0):x(YEAR)=x(YEAR-1)
maxinc(YEAR=2:HORIZ|COST(YEAR-1)>1):x(YEAR)=1.06*x(YEAR-1)

test(YEAR=2:10): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)=fund(YEAR)

int1(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
 M*a1(YEAR)<fund(YEAR)+M
int2(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
 m*a2(YEAR)>fund(YEAR)+m
indic1(YEAR=11:HORIZ): a1(YEAR)+a2(YEAR)=a(YEAR)+1

ch1(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
 M*b1(YEAR)<fund(YEAR)+M
ch2(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+ &
 DEF*b2(YEAR)>fund(YEAR)+DEF
 indic2(YEAR=11:HORIZ): b1(YEAR)+b2(YEAR)=b(YEAR)+1
```

cred1(YEAR=11:HORIZ): fund(YEAR-1)+DEF*a(YEAR)>DEF
cred2(YEAR=11:HORIZ): fund(YEAR-1)<M*a(YEAR)-0.000001
deb1(YEAR=11:HORIZ): fund(YEAR-1)>DEF*b(YEAR)
deb2(YEAR=11:HORIZ): fund(YEAR-1)+M*b(YEAR)<M-0.000001

Initial fund: x(1)=fund(1)
Optimise : SUM(YEAR=1:HORIZ) 1/(1+INTCR)^YEAR*x(YEAR) $

BOUNDS
fund(YEAR=1:HORIZ-1)>DEF
a(YEAR=11:HORIZ) .BV.
a1(YEAR=11:HORIZ) .BV.
a2(YEAR=11:HORIZ) .BV.
b(YEAR=11:HORIZ) .BV.
b1(YEAR=11:HORIZ) .BV.
b2(YEAR=11:HORIZ) .BV.

GENERATE

TABLES
TAB(HORIZ,2)

ASSIGN
TAB(YEAR=1:HORIZ,1)=x(YEAR)
TAB(YEAR=1:HORIZ,2)=fund(YEAR)

DISKDATA -O

OUTPUT7.DAT=TAB

```
!MODEL TYPE 2
!XPRESS-MP Model File : MODEL C - Annual Increase in SF deposits
!=======================================================


LET HORIZ=60   !This will either be 30 or 60, depending on the horizon
LET INTCR=0.03
LET INTDR=0.15
LET INF=INTCR
LET m=0
LET M=450
LET DEF=-100

TABLES
COST(HORIZ)


DISKDATA -L

COST=maindat.wk3(h15..h74)


VARIABLES
x(HORIZ)
fund(HORIZ)
a(HORIZ)
a1(HORIZ)
a2(HORIZ)
b(HORIZ)
b1(HORIZ)
b2(HORIZ)


CONSTRAINTS
Increm(YEAR=1:HORIZ-1):-(1+INTCR)*x(YEAR)+x(YEAR+1)=0

test(YEAR=2:10): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)=fund(YEAR)

int1(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 M*a1(YEAR)<fund(YEAR)+M
int2(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 m*a2(YEAR)>fund(YEAR)+m
indic1(YEAR=11:HORIZ): a1(YEAR)+a2(YEAR)=a(YEAR)+1

ch1(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 M*b1(YEAR)<fund(YEAR)+M
ch2(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 DEF*b2(YEAR)>fund(YEAR)+DEF
 indic2(YEAR=11:HORIZ): b1(YEAR)+b2(YEAR)=b(YEAR)+1
```

cred1(YEAR=11:HORIZ): fund(YEAR-1)+DEF*a(YEAR)>DEF
cred2(YEAR=11:HORIZ): fund(YEAR-1)<M*a(YEAR)-0.000001
deb1(YEAR=11:HORIZ): fund(YEAR-1)>DEF*b(YEAR)
deb2(YEAR=11:HORIZ): fund(YEAR-1)+M*b(YEAR)<M-0.000001

Initial fund: x(1)=fund(1)
Optimise : SUM(YEAR=1:HORIZ) 1/(1+INTCR)^YEAR*x(YEAR) $

BOUNDS
fund(YEAR=1:HORIZ-1)>DEF
a(YEAR=11:HORIZ) .BV.
a1(YEAR=11:HORIZ) .BV.
a2(YEAR=11:HORIZ) .BV.
b(YEAR=11:HORIZ) .BV.
b1(YEAR=11:HORIZ) .BV.
b2(YEAR=11:HORIZ) .BV.

GENERATE

TABLES
TAB(HORIZ,2)

ASSIGN
TAB(YEAR=1:HORIZ,1)=x(YEAR)
TAB(YEAR=1:HORIZ,2)=fund(YEAR)

DISKDATA -O

OUTPUT3.DAT=TAB

```
!MODEL TYPE 2
!XPRESS-MP Model File : MODEL D - Minimise Initial SF deposit
!=================================================


LET HORIZ=60   !This will either be 30 or 60, depending on the horizon
LET INTCR=0.03
LET INTDR=0.15
LET INF=INTCR
LET m=0
LET M=450
LET DEF=-100

TABLES
COST(HORIZ)


DISKDATA -L

COST=maindat.wk3(h15..h74)


VARIABLES
x(HORIZ)
fund(HORIZ)
a(HORIZ)
a1(HORIZ)
a2(HORIZ)
b(HORIZ)
b1(HORIZ)
b2(HORIZ)


CONSTRAINTS
upper(YEAR=1:HORIZ-1):(-1-INF)*x(YEAR)+x(YEAR+1)<0
lower(YEAR=1:HORIZ-1):-x(YEAR)+x(YEAR+1)>0

test(YEAR=2:10): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)=fund(YEAR)

int1(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 M*a1(YEAR)<fund(YEAR)+M
int2(YEAR=11:HORIZ): (1+INTCR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 m*a2(YEAR)>fund(YEAR)+m
indic1(YEAR=11:HORIZ): a1(YEAR)+a2(YEAR)=a(YEAR)+1

ch1(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 M*b1(YEAR)<fund(YEAR)+M
ch2(YEAR=11:HORIZ): (1+INTDR)*fund(YEAR-1)+x(YEAR)-COST(YEAR)+  &
 DEF*b2(YEAR)>fund(YEAR)+DEF
 indic2(YEAR=11:HORIZ): b1(YEAR)+b2(YEAR)=b(YEAR)+1
```

cred1(YEAR=11:HORIZ): fund(YEAR-1)+DEF*a(YEAR)>DEF
cred2(YEAR=11:HORIZ): fund(YEAR-1)<M*a(YEAR)-0.000001
deb1(YEAR=11:HORIZ): fund(YEAR-1)>DEF*b(YEAR)
deb2(YEAR=11:HORIZ): fund(YEAR-1)+M*b(YEAR)<M-0.000001

Initial fund: x(1)=fund(1)
Optimise : x(1) $

BOUNDS
fund(YEAR=1:HORIZ-1)>DEF
a(YEAR=11:HORIZ) .BV.
a1(YEAR=11:HORIZ) .BV.
a2(YEAR=11:HORIZ) .BV.
b(YEAR=11:HORIZ) .BV.
b1(YEAR=11:HORIZ) .BV.
b2(YEAR=11:HORIZ) .BV.

GENERATE

TABLES
TAB(HORIZ,2)

ASSIGN
TAB(YEAR=1:HORIZ,1)=x(YEAR)
TAB(YEAR=1:HORIZ,2)=fund(YEAR)

DISKDATA -O

OUTPUT1.DAT=TAB

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref : SCHEME 1

Num. of Units : 18

Tender Date Jun 90

Tender value £ 548700

REAL INT. 3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £ 5,769

as % of reconst. cost 1.05 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	SLATE	60	4032	25
	TILE	35	18006	298
EXT.WALLS	RENDER	60	9161	56
	CLADDING	30	747	16
WINDOWS	S/W UNITS	30	38325	806
EXT.DOORS	DOOR	25	7302	200
	IRONMONG.	25	2556	70
CEILINGS	P/B&PLAS	30	5973	126
FLOORS	GRANO	50	461	4
	VINYL	25	2881	79
INT.DOORS	DOOR	40	23862	316
	IRONMONG.	40	10701	142
FITTINGS	K.U's	15	25743	1384
SANI.WARE	W.C	35	4068	67
	BATH/SINK	35	7600	126
WATER SUPP.	H&C.SUPP	50	5904	52
	STORAGE	25	10815	297
DRAINAGE	WASTE	25	8593	236
	RAINWATER	25	1647	45
HEATING	ELECTRIC	25	10811	297
ELECT.	MAINS	25	30652	841
	EQUIPMENT	25	3833	105
COMMUNI.	ENTRY.	15	2329	125
	TV/PHONE	25	2089	57

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref :   SCHEME 2
Num. of Units :   32
Tender Date Jun 91
Tender value   £ 1108438

REAL INT.   3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £   11,013
as % of reconst. cost   0.99 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	SLATE	60	82785	348
	TILE	35	5816	79
EXT.WALLS	RENDER	60	29455	124
	CLADDING	30	3291	59
WINDOWS	S/W UNITS	30	70946	1265
EXT.DOORS	DOOR	25	17090	410
	IRONMONG.	25	6633	159
CEILINGS	P/B&PLAS	30	4991	89
FLOORS	GRANO	50	436	3
	VINYL	25	9328	224
INT.DOORS	DOOR	40	51746	545
	IRONMONG.	40	20062	211
FITTINGS	K.U's	15	41672	2081
SANI.WARE	W.C	35	7665	104
	BATH/SINK	35	10492	142
WATER SUPP.	H&C.SUPP	50	9823	64
	STORAGE	25	18368	441
DRAINAGE	WASTE	25	6180	148
	RAINWATER	25	2952	71
HEATING	ELECTRIC	25	27693	665
ELECT.	MAINS	25	71513	1717
	EQUIPMENT	25	2830	68
COMMUNI.	ENTRY.	15	7623	381
	TV/PHONE	25	5179	124

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref : SCHEME 3
Num. of Units : 10
Tender Date Nov 89
Tender value £ 324332

REAL INT. 3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £ 2,454
as % of reconst. cost 0.76 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	TILE	35	19256	318
EXT.WALLS	B/W REPOINTING	50	4687	42
WINDOWS	H/W UNITS	40	12562	167
EXT.DOORS	DOOR	25	4653	128
	IRONMONG.	25	1023	28
CEILINGS	P/B&PLAS	30	4180	88
FLOORS	VINYL	25	0	0
INT.DOORS	DOOR SETS	40	5896	78
	IRONMONG.	40	2046	27
FITTINGS	K.U's	15	3751	202
SANI.WARE	V.C GOODS	35	2607	43
	S/STEEL GOODS	35	2321	38
WATER	H&C.SUPP	50	4730	42
	C.W STORAGE	25	1386	38
	H.W STORAGE	20	2079	77
	INSUL.	20	2409	90
DRAINAGE	WASTE	25	1918	53
	RAINWATER	25	1661	46
HEATING	ELECTRIC	25	7205	198
ELECT.	MAINS	25	4260	117
	LIGHTING	25	4926	135
COMM.	ALARM SYSTEM	15	4843	260
	TV/PHONE	25	991	27
EXT.WORKS	FENCING/GATES	25	7769	213

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref : SCHEME 4

Num. of Units : 12

Tender Date Dec 89

Tender value £ 348081

REAL INT. 3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £ 2,513

as % of reconst. cost 0.72 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	SLATE	60	19443	119
EXT.WALLS	RENDER	60	7068	43
WINDOWS	S/W UNITS	30	8143	171
EXT.DOORS	DOOR	25	3599	99
	IRONMONG.	25	2228	61
CEILINGS	P/B&PLAS	30	0	0
FLOORS	VINYL	30	2932	62
INT.DOORS	DOOR SETS	40	4301	57
	IRONMONG.	50	2228	20
FITTINGS	K.U's	15	7931	426
SANI.WARE	V.C GOODS	35	1802	30
	S/STEEL GOODS	35	3593	59
WATER	H&C.SUPP	50	3593	32
	C.W STORAGE	25	1188	33
	H.W STORAGE	20	1854	69
	INSUL.	20	3010	112
DRAINAGE	WASTE	25	1836	50
	RAINWATER	25	1428	39
HEATING	ELECTRIC	25	9378	257
ELECT.	MAINS	25	5540	152
	EQUIPMENT	25	6798	186
COMM.	ALARM SYSTEM	15	4331	233
	TV/PHONE	25	979	27
EXT.WORKS	FENCING/GATES	25	6376	175

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref :   SCHEME 5 (BCIS Analysis)
Num. of Units :   28
Tender Date Apr 88
Tender value   £   784630

REAL INT.   3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £   8,476
as % of reconst. cost   1.08 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	TILE	35	37364	618
EXT.WALLS	B/W REPOINTING	50	0	0
WINDOWS	H/W UNITS	40	50952	676
EXT.DOORS	DOOR	25	12738	349
CEILINGS	P/B&PLAS	30	33649	707
FLOORS	VINYL	30	34078	716
INT.DOORS	DOOR SETS	40	25724	341
FITTINGS	K.U's	15	19109	1027
SANI.WARE	Various	35	19401	321
WATER	H&C.SUPP	50	8818	78
DRAINAGE	WASTE	25	16348	448
HEATING	GAS	25	50393	1382
ELECT.	POWER&LIGHT	25	66032	1811

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref :   SCHEME 6 (BCIS Analysis)

Num. of Units :   12

Tender Date Feb 91

Tender value   £ 359276

REAL INT.   3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £   2,411

as % of reconst. cost   0.67 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	TILED	35	13628	225
EXT.WALLS	B/W REPOINTING	50	0	0
WINDOWS	H/WOOD	40	18868	250
EXT.DOORS	DOOR	30	6289	132
CEILINGS	P/B&PLAS	30	3352	70
FLOORS	---	30	7897	166
INT.DOORS	DOOR SETS	40	15520	206
FITTINGS	K.U's	15	8203	441
SANI.WARE	Various	35	7563	125
WATER	H&C WATER	50	4956	44
DRAINAGE	WASTE	25	3830	105
HEATING	ELEC.	25	11987	329
ELECT.	POWER&LIGHT	25	11546	317

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref :   SCHEME 7 (BCIS Analysis)

Num. of Units :   16

Tender Date Aug 91

Tender value   £ 604732

REAL INT.   3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £   5,700

as % of reconst. cost   0.94 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	TILED	35	19224	318
EXT.WALLS	B/W REPOINTING	50	0	0
WINDOWS	UPVC	40	21533	286
EXT.DOORS	DOOR	30	7178	151
CEILINGS	P/B&PLAS	30	11824	249
FLOORS		30	19575	411
INT.DOORS	DOOR SETS	40	19796	263
FITTINGS	K.U's	15	18384	988
SANI.WARE	Various	35	8978	148
WATER	elsewhere	50	0	0
DRAINAGE	WASTE	25	4039	111
HEATING	ELEC.	25	44028	1208
ELECT.	POWER&LIGHT	25	44079	1209
PROT.INST	DOOR ENTRY	15	6666	358

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref : SCHEME 8 (BCIS Analysis)

Num. of Units : 12

Tender Date Jun 91

Tender value £ 387304

REAL INT. 3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £ 3,264

as % of reconst. cost 0.84 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	SLATE	60	15784	97
EXT.WALLS	B/W REPOINTING	50	0	0
WINDOWS	S/W UNITS	30	16480	346
EXT.DOORS	DOOR	25	5493	151
CEILINGS	P/B&PLAS	30	6246	131
FLOORS	VINYL	30	14418	303
INT.DOORS	DOOR SETS	40	17700	235
FITTINGS	K.U's	15	8490	456
SANI.WARE	Various	35	8432	139
WATER	H&C.SUPP	50	11127	99
DRAINAGE	WASTE	25	16348	448
HEATING	ELEC.	25	12509	343
ELECT.	POWER&LIGHT	25	18764	515

SINKING FUND ANALYSIS
NEW BUILD PROPERTY

Scheme Ref :   SCHEME 9 (BCIS Analysis)

Num. of Units :   8

Tender Date Jan 91

Tender value   £ 306263

REAL INT.   3.00 %

SUMMARY INFORMATION

INITIAL DEPOSIT £   2,395

as % of reconst. cost   0.78 %

ELEMENT	SUB-ELEMENT	LIFE SPAN	RENEWAL COSTS	A.S.F
ROOF	SLATE	60	19439	119
EXT.WALLS	B/W REPOINTING	50	0	0
WINDOWS	S/W UNITS	30	12246	257
EXT.DOORS	DOOR	25	4082	112
CEILINGS	P/B&PLAS	30	5757	121
FLOORS	VINYL	30	6116	129
INT.DOORS	DOOR SETS	40	7743	103
FITTINGS	K.U's	15	6678	359
SANI.WARE	Various	35	19401	321
WATER	H&C.SUPP	50	8781	78
DRAINAGE	WASTE	25	2066	57
HEATING	ELECTRIC	25	9613	264
ELECT.	POWER&LIGHT	25	17358	476

APPENDIX 4

Stochastic Parameters: **SCHEME 2**

NUMBER OF ITERATIONS   240

	AVG	MIN	MAX	ALPHA	BETA	REP. COST
SLATE	60	60	60	3	3	82785
TILE	35	30	40	3	3	5816
RENDER	60	60	60	3	3	29455
CLADDING	30	20	40	3	3	3291
S/W UNITS	30	25	35	3	3	70946
DOOR	25	20	30	3	3	17090
IRONMONG.	25	20	30	3	3	6633
P/B&PLAS	30	25	35	3	3	4991
GRANO	50	45	55	3	3	436
VINYL	25	20	30	3	3	9328
DOOR	40	35	45	3	3	51746
IRONMONG.	40	35	45	3	3	20062
K.U's	15	10	20	3	3	41672
W.C	35	30	40	3	3	7665
BATH/SINK	35	30	40	3	3	10492
H&C.SUPP	50	40	60	3	3	9823
STORAGE	25	20	30	3	3	18368
WASTE	25	20	30	3	3	6180
RAINWATER	25	20	30	3	3	2952
ELECTRIC	25	20	30	3	3	27693
MAINS	25	20	30	3	3	71513
EQUIPMENT	25	20	30	3	3	2830
ENTRY.	15	10	20	3	3	7623
TV/PHONE	25	20	30	3	3	5179

APPENDIX 5

Stochastic Parameters: **SCHEME 3**

NUMBER OF ITERATIONS   240

	AVG	MIN	MAX	ALPHA	BETA	REP. COST
TILE	35	30	40	3	3	19256
B/W REPOINTIN	50	40	60	3	3	4687
H/W UNITS	40	35	45	3	3	12562
DOOR	25	20	30	3	3	4653
IRONMONG.	25	20	30	3	3	1023
P/B&PLAS	30	25	35	3	3	4180
VINYL	25	20	30	3	3	0
DOOR SETS	40	35	45	3	3	5896
IRONMONG.	50	45	55	3	3	2046
K.U's	15	10	20	3	3	3751
V.C GOODS	35	30	40	3	3	2607
S/STEEL GOODS	35	25	45	3	3	2321
H&C.SUPP	50	40	60	3	3	4730
C.W STORAGE	25	20	30	3	3	1386
H.W STORAGE	20	15	25	3	3	2079
INSUL.	20	15	25	3	3	2409
WASTE	25	20	30	3	3	1918
RAINWATER	25	20	30	3	3	1661
ELECTRIC	25	20	30	3	3	7205
MAINS	25	20	30	3	3	4260
LIGHTING	25	20	30	3	3	4926
ALARM SYSTEM	15	10	20	3	3	4843
TV/PHONE	25	20	30	3	3	991
FENCING/GATES	25	20	30	3	3	7769

APPENDIX 6:   SIMULATION MACRO

```
\s          {let COUNT,1}{blank ITER}
            {}
loop        {}
            {blank MAINT}{let ELEM,0}{let TOTAL,0}
            {}
data_in     {if ELEM>23}{branch PROFILE}
            {}
            {goto}data~
            {down ELEM}
            {let MIN,@cellpointer("contents")}
            {right 1}{let MAX,@cellpointer("contents")}
            {right 1}{let ALPHA,@cellpointer("contents")}
            {right 1}{let BETA,@cellpointer("contents")}
            {right 1}{let COST,@cellpointer("contents")}
            {branch sim}


sim         {let TOTAL,0}
            {}
            {}
johnks      {let RAN1,@rand}{let RAN2,@rand}
            {if RAN1^(1/ALPHA)+RAN2^(1/BETA)<=1}{branch johnks}
            {let X,RAN1^(1/ALPHA)/(RAN1^(1/ALPHA)+RAN2^(1/BETA))}
            {let Y,MIN+(MAX-MIN)*X}
            {}
            {let TOTAL,TOTAL+Y}
            {if TOTAL>60}{let ELEM,ELEM+1}{BRANCH data_in}
            {put MAINT,ELEM,@ROUND(TOTAL-1,0),(1+INF)^@round(TOTAL-1,0)*COST}
            {branch johnks}


profile     {goto}ITER~{right COUNT-1}{menu}evANNDEM~~
            {let COUNT,COUNT+1}
            {if COUNT>REAL}{quit}
            {branch LOOP}
```

APPENDIX 7: DYNAMIC SCHEDULING MACRO

```
          {blank SCHED}{let ELCOUNT,-1}
          {}
          {}
\s        {let ELCOUNT,ELCOUNT+1}
          {/ Block;Values}~~
          {}
NEXTEL    {let AVE,@index(ELDATA,ELCOUNT,0)}
          {if AVE=0}{quit}
          {let REV,0}{let REVCOUNT,0}
          {let REPCOUNT,0}{let REMAIN,AVE+5}
          {}
          {let REP,@index(ELDATA,ELCOUNT,REPCOUNT+2)}
          {}
DATIN     {if REVCOUNT>12}{/ Block;Values}~~{branch NEXTEL}
          {/ Block;Values}SCHED~SCHED~{goto}SCHED~
          {right ELCOUNT}{down REVCOUNT}
FORCAS    {if REMAIN>60-(REV-5)}{branch NEXTEL}~
          @if(REP-REV>5,REMAIN-5,REP-REV)~
          {let REMAIN,@cellpointer("contents")}
          {if REMAIN<=5#and#(REP-REV)>5}{branch PROLONG}
          {if REMAIN<=5}{branch REPLACE}
          {}
          {let REV,REV+5}{let REVCOUNT,REVCOUNT+1}{branch FORCAST

          {if +AVE-(5-REMAIN)>60-REV}{branch NEXTEL}
          {down 1}
          +AVE-(5-REMAIN)~
REPLAC    {let REMAIN,@cellpointer("contents")}
          {}
          {let REV,REV+10}{let REVCOUNT,REVCOUNT+2}
          {let REPCOUNT,REPCOUNT+1}
          {/ Block;Values}SCHED~SCHED~
          {branch DATIN}


          {}
          +5~
          {if +REMAIN-5>60-REV}{branch NEXTEL}
PROLON    {down 1}+REP-REV-5~
          {let REMAIN,@cellpointer("contents")}
          {let REVCOUNT,REVCOUNT+1}{;branch REPLACE}
          {if +AVE-(5-REMAIN)>60-REV}{branch NEXTEL}
          {down 1}
          {}
```

```
+AVE-(5-REMAIN)~
{let REMAIN,@cellpointer("contents")}
{}
{let REV,REV+15}{let REVCOUNT,REVCOUNT+2}
{let REPCOUNT,REPCOUNT+1}
{/ Block;Values}SCHED~SCHED~
{branch DATIN}
```

APPENDIX 8 DATA PROCESSING MACRO

\S   {blank DATSET}{let SETCOUNT,0}
                 {for ZCOUNT,60,5,-5,ZERO}
                 {let SETCOUNT,-1}
                 {}
                 {for PROGNUM,0,55,5,LOOP}

LOOP   {}
                 {let SETCOUNT,SETCOUNT+1}
                 {}
                 {for X,0,23,1,YCOUNT}

YCOUNT   {let COST,@index(COSTDAT,X,0)}
                 {for Y,0,3,1,OUTPUT}

OUTPUT   {let PROJ,@index(PROG,X,Y+PROGNUM)}
                 {}
                 {if PROJ>0}{put DATSET,SETCOUNT,PROJ,@index(DATSET,SETCOUNT,PROJ)+COST}

ZERO   {goto}DATSET~{down 1}{right SETCOUNT}
                 +0~{/ Block;Copy}~{down 1}.{down ZCOUNT-2}~
                 {let SETCOUNT,SETCOUNT+1}