UNIVERSITY OF STRATHCLYDE

DEPARTMENT OF MANAGEMENT SCIENCE

MODELLING RESPONSE BUILDING MAINTENANCE PROBLEMS WITH A LOCAL AUTHORITY

VOLUME 1

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GLASGOW

I keep six honest serving-men
    (They taught me all I knew),
Their names are What and Why and When
    And How and Where and Who.
I send them over land and sea,
    I send them east and west;
But after they have worked for me,
    I give them all a rest.

I let them rest from nine till five,
    For I am busy then,
As well as breakfast, lunch, and tea,
    For they are hungry men.
But different folk have different views;
    I know a person small -
She keeps ten million serving-men,
    Who get no rest at all!
She sends 'em abroad on her own affairs,
    From the second she opens her eyes -
One million Hows, two million Wheres,
    And seven million Whys!

The Elephant's Child

Rudyard Kipling
from the Just So Stories

ABSTRACT

Over the past decade the traditional role of local government has been challenged and systematically dismantled by waves of legislation. The main thrust of the legislation being aimed at changing the traditional range of functions undertaken by local authorities, enforcing new working practices and methods of raising revenue.

The changes have created a revolution which is currently shaking the foundations of local authorities and may continue well into this decade. An express intention of the legislation is to create and polarise distinct Client (enabler) and Contractor (provider) functions and force both of these organisations outwith the protective umbrella of authorites into a fully competitive, commercial environment.

The aim of this investigation is to expose the nature of response building maintenance problems within the current legislative framework and produce quantitative computer aided techniques and simulations which may assist client and contractor departments to more effectively manage the delivery of the repairs services in the future.

We believe that it is necessary to clarify and quantify the contents of response maintenance and to attempt to ring fence this problematic element of building maintenance. Until this is achieved the disorder inherent within this repair category will drive the system, obscuring the potential for flexible packaging of functional works contracts.

The techniques developed enable the scale of a variety of contracts to be estimated in terms of cost and manpower requirements. The fluctuating nature of response maintenance is identified and combined with variable target response times to highlight management problems created for contractors.

Flexible working among trades is the subject of an analysis and the capacity to create flexible contracts in terms of size, based on individual trades or combination of trades is demonstrated.

Finally the potential to introduce an inspection system is analysed. An inspection model is developed and tested within the response maintenance envelope.

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"There is nothing permanent except change"

Heraclitus (540 - 475 BC?) The central theme of his philosophy

CHAPTER ONE

A REVIEW OF THE MAINTENANCE SYSTEM AND RELEVANT LITERATURE

PAGE

NUMBERING

AS ORIGINAL

1.1 INTRODUCTION

The aim of this chapter is to identify key factors which interface, interact and integrate to comprise the whole building maintenance system in an attempt to expose the scale and nature of system components, together with the complexity of the interactions of the criteria which influence maintenance policy formulation. Quantified solutions need to be attempted if credible outcomes are to be achieved in view of the need to control money, manpower, materials, mechanisation and of course, time, all within a complex framework of subjective and objective variables.

Over the past decade the introduction of numerous Acts of Parliament has sought to change the structure of Local Government in many fundamental ways. Over fifty pieces of legislation have been imposed which impinge to a greater or lesser extent on local government procedures and practices and these legislative changes have impacted on the delivery of a wide range of local authority services.

The extent to which the more significant Acts and regulations therein have changed or attempted to change the form and size of public sector housing and the associated management/delivery of an acceptable repairs service is aired more fully in Chapter Two.

Essentially the successive legislative demands have sought to:

(a) Deregulate private sector maintenance contractors

(b) Privatise council housing

(c) Dismantle local authority and any associated direct labour organisation relationships (DLO)

(d) Prevent restrictive practices and dissolve monopolies

(e) Introduce full compulsory competitive tendering (CCT)

(f) Enforce quality management.

Worthy of note is that, during and after the implementation of these changes DLO's or DSO's as they are now known, have been forced to seek contracts for work within a confined commercial market place, well defined by legislation.

Within local authorities a division between the DLO (the Contractor) and the Housing maintenance department (the Client), which represents the Tenant (the Customer), is demanded with clear identification and separation of Client and Contractor functions. It is therefore important that we investigate the impact of the legislative changes on the modus operandi of Client and Contractor departments regardless of the contractor having a public or a private sector origin. The consequential effects on the entire repair service ensuing as a result of the implementation of legislation must be exposed and the scale and complexity of any problems generated must be acknowledged.

It is therefore not an intention of this investigation to debate whether the Public Sector or the Private Sector is the more effective deliverer of a building maintenance service either in the capacity of enablers or providers of the repairs service. The main thrust of this investigation is targeted at selected aspects of the service with particular emphasis being placed on the vexing problem of managing the RESPONSE repairs element of the maintenance system. This is considered of great importance since it is the intractable nature of this component of the maintenance service which is the hub of the building maintenance manager's problems. Whichever maintenance contractor, public or private, tenders for and wins a Response maintenance contract, the conundra of how to cope with widely fluctuating and variable repair demands will exist to confound either.

In this highly charged, fully competitive commercial market place, it is increasingly more essential that the true *nature* and *scale* of a functional works (maintenance) contract(s) is exposed and understood otherwise the wrong people will find themselves doing the wrong thing.

1.1.1 The Research Objectives

In view of the nature and timescale of this investigation the research objectives largely evolved as distinct from being planned. However the initial objective was to attempt to ascertain the feasibility of superimposing a cost effective inspection system onto an already existing purely reactive repairs services. This was originally proposed by Christer and is developed in Chapter 5. The main considerations are the cost of providing an inspection system and any potential to reduce the cost of repairs thereby identified and clustered for future repair.

The initial intention was to tackle the problem within two or more Authorities. However this proved to be too daunting and overambitious proving too time consuming for hard pressed maintenance personnel. It was therefore within only one Local Authority (Strathkelvin District Council) that the investigation proceeded. The problems encountered in this phase of the research are discussed in Chapter 5. The outcome of this initial study was reasonably meaningful. However securing robust data proved difficult and results were not as convincing as hoped for.

Attention was turned to the housing maintenance system in general and was directed at both *enabler* and *provider* aspects of the service.

Progress was slow and hindered by many changes in the various departments comprising the repairs services. The changes included, accommodation, reorganisation and restructuring, new system routines, computerisation and so on.

During this phase of the investigation several Audit Commission Reports aimed at improved performance in Local Authority building maintenance were published. The impact of changes in Legislation being introduced or being proposed by Central Government were already beginning to cause tremours under the foundations of many Local Authorities. Existing working practices across a wide range of services were to be challenged and changed. It became clear that not only would changes occur in the style of management within the housing maintenance sector but also that logistics problems involving manpower deployment and packaging of functional work contracts could ensue.

It was therefore with a firm focus on proposed changes in Legislation, especially changes to the Local Government Act and The Local Government Planning and Land Act that the rest of the research objectives transpired.

The objectives were expanded to include modelling response maintenance manpower problems occasioned by fluctuating work loads, the creation of flexible functional works contracts and to create computer aided support for effective organisation and management of problems generated in changing housing maintenance environments. These are more fully explained in Chapters 3 and 4. The ideas and analytical techniques developed were of course framed within the envisaged new autonomous regimes enforced by the Legislation aimed at creating distinct *Client* and *Contractor* departments servicing Local Authority housing maintenance.

Chapter I sets the scene, Section 1.3 to 1.7 being a broad discussion of building maintenance in general with reference to specific housing maintenance characteristics, while Section 1.8 reviews the literature including OR literature in the area.

1.1.2 The Context

The sheer number of council houses managed by some authorities is awesome enough; the largest in Scotland having over 155,000 houses under its control with an annual revenue repairs budget of approximately 47.5 million pounds. Even with very much smaller authorities many variables compound to produce complex management problems, fraught with uncertainty and ambiguity.

During these transitional legislative times the locus for this investigation was within a medium sized District Council. Many fundamental structural and organisational changes took place since the inception of this study and their significance is discussed in Chapter Two. Exhibit 1.1 shows the trends in spending by the Council since 1982, the year of the implementation of the Planning and Land Act which for the purposes of this investigation is considered to be the most significant piece of legislation affecting the delivery of the repairs service. Annual spending on Revenue repairs, Capital programmed maintenance and new building works is shown together with the changing profile of the number of council houses managed by Strathkelvin District Council, which houses constitute the system to be maintained in this investigation. Exhibit 1.1 will be referred to as and when appropriate. General statistics for local authorities are published by the convention of Scottish local authorities via Glasgow District Council Housing Department.

No attempt has been made to reduce costs to a base year and values shown represent actual amounts committed.

1.2 THE INCIDENCE OF DEFECTS IN BUILDINGS

Very many facets of building maintenance problems have been researched, notably causes and effects. Consequently it will not be an aim of this investigation to till over the design, detailing and workmanship relationships, vexing as they are, for in spite of current awareness of such problems, "the masterpiece leaks" ; Building Research Digest No 176.

Therefore the loci from which this study stems are the assumptions that;

(a) Defects exist, many of which will worsen with age.

(b) New defects will arise with the passing of time.

(c) Defects will occur at random in time, type and location.

(d) The demand for the repair of defects will be randomly generated in time, type and location.

(e) Randomness forces reactive management solutions which influences the logistics of providing a maintenance service.

DATE / YEAR	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92
No of Houses	10,913	10,693	10,447	10,293	9,937	9,695	9,252	9,027*	8,801	-
Repairs Completed	31,243	27,991	33,505	26,745	36,542	28,427	41,000	51,000*	48,584	-
Revenue Costs	1,498,351	1,509,764	1,966,819	1,340,706	2,485,813	2,039,612	2,331,419	2,820,000	2,768,000	-
Capitalised Repairs Costs	-	-	-	-	-	-	1,035,165	110,000	276,252	-
Ave. Cost of Repair (Contractor)	£51.06	£51.96	£58.97	£52.33	£67.67	£69.32	£45.07	-	£48.85	-
Ave. Cost of Repair (CMS)	£35.86	£56.39	£57.67	£50.51	£67.55	£71.72	£45.87	-	£54.85	-
Proportion of Work to CHS	29%	39%	36%	56%	37%	44%	53%	-	76%	100%

* Estimates

Exhibit 1.1

Annual Spending Trends and Total Council Houses

Strathkelvin District
CMS (Community Maintenance Services) DLO

Exhibit 1.2 shows some of the variables which interact to influence the incidence of defect occurrence and illustrates how the phenomenon of randomness associated with building defects originates.

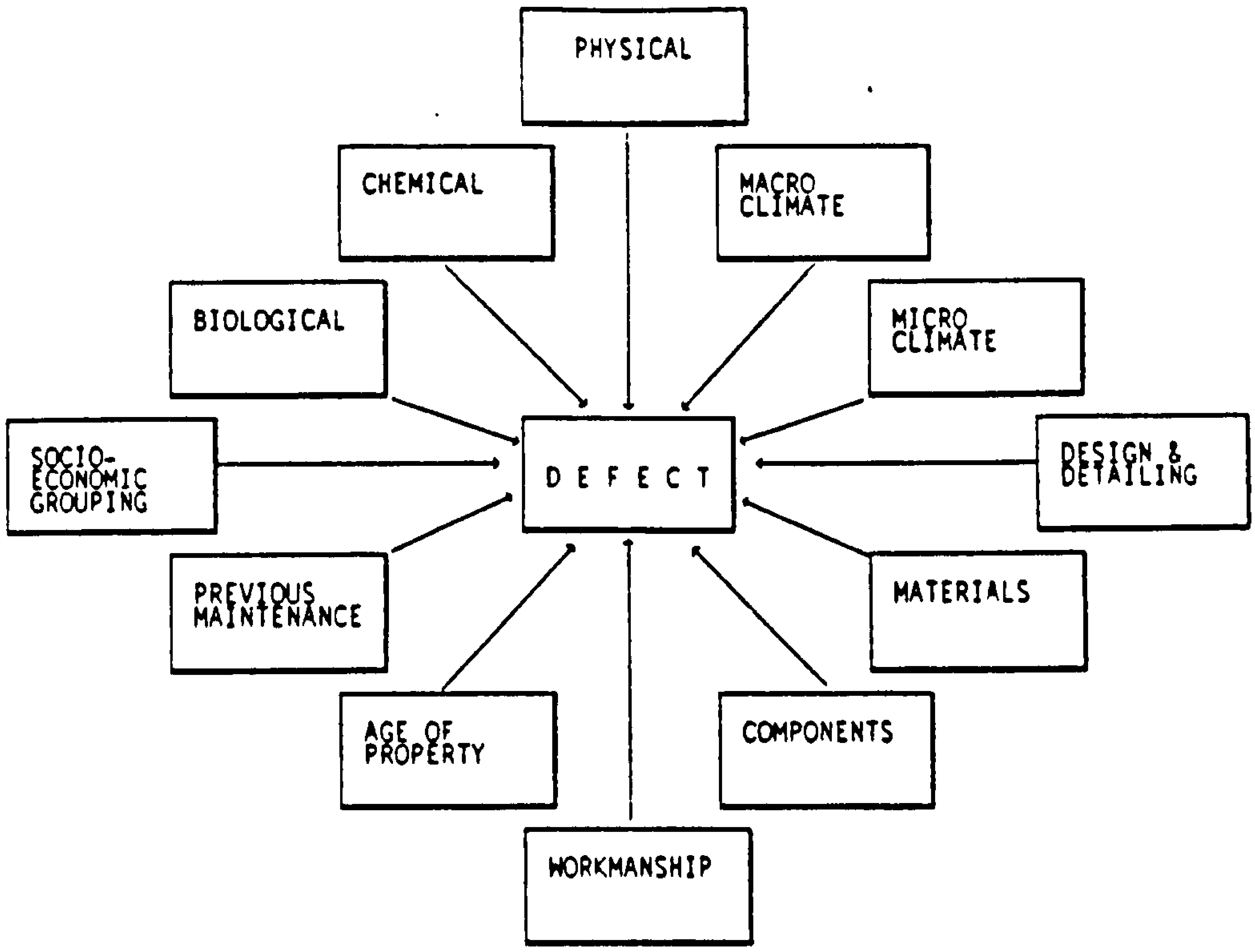


Exhibit 1.2

Agencies Influencing the Incidence of Building Defects

This inherent randomness, sufficient in itself to create logistics problems during the defect repair process, is exacerbated by the manner by which defects are identified, reported and classified into a priority order as discussed later.

During an investigation of a Council Housing repairs service, Christer[1] acknowledges the randomness of defect occurrence and reporting by the building user, each reported event being considered as an independent random variable. Obviously this is not likely to be true for all defects since some degree of dependency must exist. However, approximately 85% of jobs were reported to be single trade repairs. Skinner[2] likewise acknowledges the randomness of job occurrence in terms of time, type and location, with so called day to day repairs accounting for approximately 90% of jobs which were mainly of a small scale nature.

The classification of defects in terms of which to repair and when is a perplexing issue. The aim of both Client and Contractor departments should be to preserve the functional utility of public sector dwellings to a level that satisfies the needs of the Tenants (customers).

Some defects may simply be cosmetically unacceptable whilst others seriously impair the function of an element of the building and the building as a unit, possibly even endangering "life and limb". The procedures for identifying defects and classifying them into priority order for repair are the keys to the managers problem. The subjective nature of decision making as to when a defect has entered into a LIMIT STATE of unacceptability is a major contributor to maintenance management problems.

Accepting that the "Gasman Cometh"[(3)(4)] syndrome survives to an extent; that is, the occurrence of a defect is a consequence of a preceding one, we proceed to investigate the variety of maintenance management problems caused by building defects which arise independently of each other and are repaired on a day to day basis.

1.3 MAINTENANCE STRATEGIES

The scale and complexity of the repairs required to keep a housing stock up to a suitably maintained standard will require that repairs are classified to permit effective management of the repairs service.

General definitions for the various forms of maintenance strategies are given in BS 3811. The strategies are illustrated in Exhibit 1.3 and are developed to embrace building maintenance strategies for council house repairs. Two broad classifications exist, namely Planned Maintenance and Unplanned Maintenance. Although we are focussing on so called day to day maintenance it would be imprudent not to consider problems generated within the complete maintenance framework.

(1) Planned Maintenance

(a) Planned Preventive Maintenance

(i) Preventive Running Maintenance

Work in this category includes contract maintenance eg. by gas boards where certain elements of equipment are replaced or serviced at specific time intervals as agreed at the outset of the contract to install say central heating. Cyclic Maintenance is also in this category and this refers to pre paint maintenance and painting contracts on a cyclical basis say every five years.

(ii) Preventive Shutdown Maintenance

This does not apply to the maintenance of council housing stock to any great extent and is more applicable for large industrial mechanical processing plants.

(b) Planned Corrective Maintenance

(i) Planned Corrective Shutdown Maintenance

This may be considered as applying to rehabilitation and refurbishment of buildings. The extent of any shutdown or DOWNTIME of premises varies with the scale of the proposed programs. Some forms of construction require major improvements to the external envelope with roof replacement and structural strengthening of walls with enhanced thermal and sound insulation provided. Other programs may require modest refurbishments (modernisation), eg central heating, sinks, wc's, baths and washbasins, or possibly combinations of rehabilitation and refurbishment programs including environmental improvements. During such programs Tenants are decanted into temporary accommodation.

(ii) Planned Corrective Breakdown Maintenance

We group this area of so called planned maintenance with unplanned maintenance to form a combined category as shown in Exhibit 1.3 and discussed below.

(2) Unplanned Maintenance

Exhibit 1.3 identifies a hybrid classification referred to as RESPONSE maintenance. This is necessary since not all unplanned maintenance is in the EMERGENCY category. The situation is further confused by the welter of terminology used to define the same category of work. Unplanned maintenance is variously described as demand, day to day, reactive, routine, jobbing, contingency and responsive maintenance.

Hence a Response Maintenance strategy is identified which is subdivided in the following classes

(i) Unplanned Response Maintenance. Into this definition are grouped all repairs which have little or no potential to be organised into packages of work which could be executed on a "planned" response basis.

(ii) Zonal Response Maintenance. Potential exists to plan a proportion of the daily demands for the repair of defects. Many repairs could be delayed for as long as a six weeks, say, from the receipt of the repair request by the maintenance organisation or the contractor responsible for effecting the repair. Both of these sections of the maintenance system could benefit from such a planned approach in terms of budget control or improved logistics.

(iii) Void Maintenance. This refers to the repairs deemed necessary when a council house becomes vacant during a change in Tenancy. Such repairs do, usually, require to be executed quickly to avoid downtime, causing inconvenience to Tenants and loss of revenue through rents. Voids are therefore usually, as was the case in this investigation, repairs within the definition of Response Maintenance.

(iv) Minor Works. These may be larger scale jobs identified under response maintenance system and requiring that tenders be invited for a minor works contract with the repairs being delayed for an extended period.

All of the work within the Response Maintenance mode is referred to as Functional Work and is funded out of a Revenue Budget which may be exclusively generated out of housing rent.

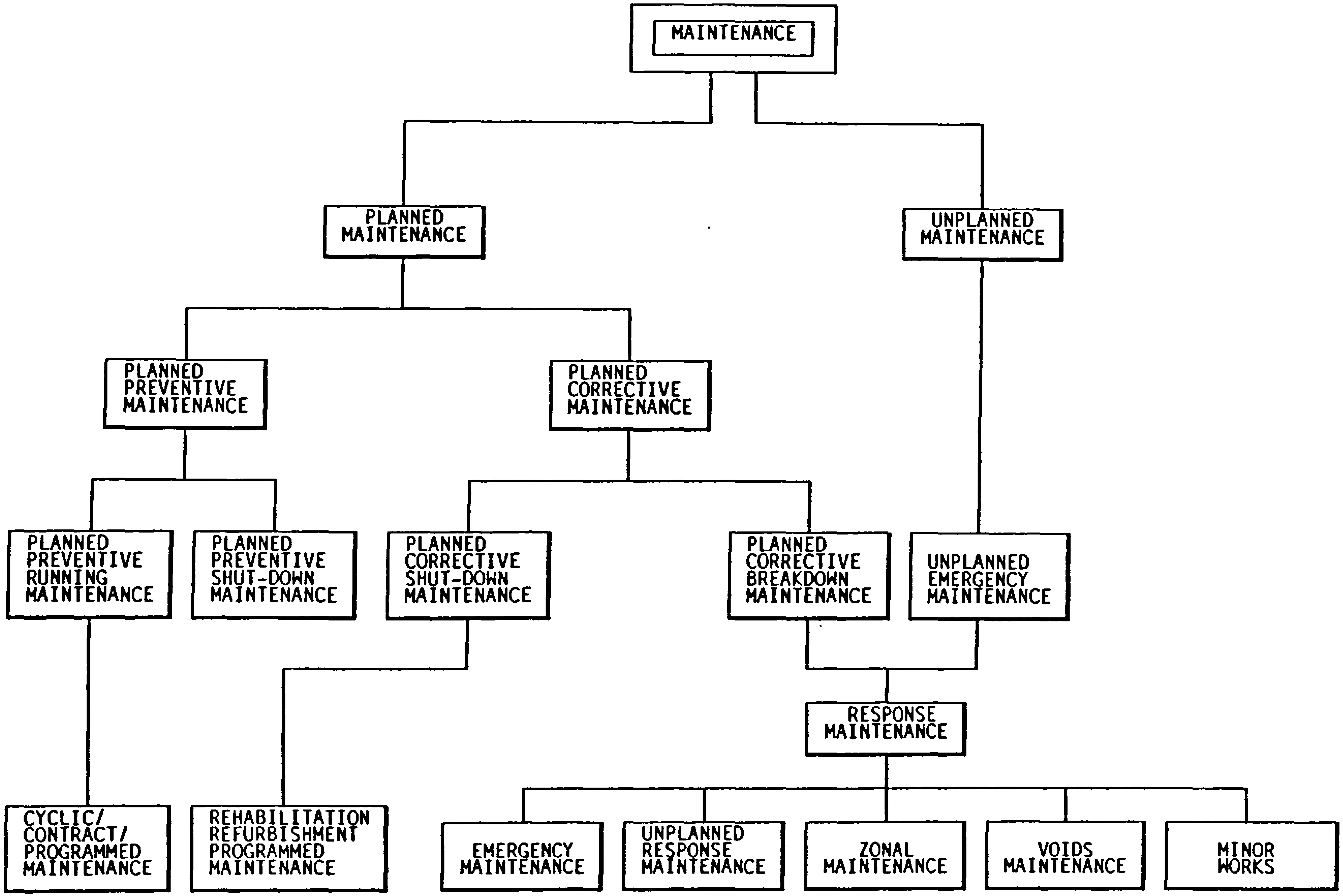
1.4 MAINTENANCE STRATEGIES AND PRINCIPAL VARIABLES

A main objective of both the Client and Contractor divisions of the Maintenance System should be to attempt to manage repair demands in terms of time, type and location.

The Client Department may wish to devise a program of work based on planned maintenance strategies which have developed from a knowledge of the state of the housing stock. The Contractor Department may attempt to optimise resources by adopting a Zonal approach to as many response repairs as possible, consistent with meeting service level demands.

To attempt to clarify the nature of the previously defined strategies each variable may be considered as either controllable or uncontrollable and combinations of the three variables grouped to correspond with these maintenance strategies.

Table 1.4 shows how the strategies discussed in Section 1.3 may be represented by applying restraint or otherwise on each variable. It is worth noting that the variable "type" of repair refers not only to the variable nature of each repair but also the variable trade specialism from which it emerges.



MAINTENANCE STRATEGIES

EXHIBIT 1.3

GROUPING I		GROUPING II		GROUPING III	
VARIABLE	DEGREE OF RESTRAINT	VARIABLE	DEGREE OF RESTRAINT	VARIABLE	DEGREE OF RESTRAINT
TIME	UNCONTROLL ABLE	TIME	CONTROLL ABLE	TIME	CONTROLL ABLE
TYPE	UNCONTROLL ABLE	TYPE	UNCONTROLL ABLE	TYPE	CONTROLL ABLE
LOCATION	UNCONTROLL ABLE	LOCATION	CONTROLL ABLE	LOCATION	CONTROLL ABLE
UNPLANNED RESPONSE MAINTENANCE		ZONAL/VOID/CYCLIC MAINTENANCE		PLANNED MAINTENANCE REHAB/REFURBISH/ MINOR WORKS	

Degrees of restraint on the variables:
time, type and location and maintenance strategies

Table 1.4

Grouping 1

This corresponds to unplanned response maintenance where breakdown of function has occurred in opinion of the Tenant who reports the defect to Client Department which in turn transfers the repair demand to the Contractor Department, both operating in a pure reactive mode. The extent of repair demands will vary from Authority to Authority. In the case of the investigation by Skinner[(2)] they amounted to 90% of jobs and accounted for 50% of maintenance costs.

Grouping 2

This represents a Zonal system where repairs are clustered after repair requests have been generated within a Response maintenance system. The repairs are grouped in say geographical areas as a result of a delay tactic initiated by the Contractor for logistical reasons or by the Client Department based on some economic rationale.

Repairs are then tackled systematically area by area (zone) by mixed trade gangs or autonomous groups of trades, depending on frequency of repair type.

This strategy applies to cyclic maintenance programs also, in that repairs are generated as a result of an inspection system. Although only fabric repairs may be identified they will still be sensibly random in type.

The maintenance of Voids is similarly described, albeit that individual voids may occur randomly in location the likelihood is that each void will yield several independent random repairs.

Grouping 3

This corresponds to a totally planned maintenance strategy likely to be adopted for:

(i) modernisation programs

(ii) rehabilitation projects

(iii) the planned maintenance of specific elements of a building either on a repair and or replacement basis

Other programs may be recognisable, however the examples listed thus far suffice to home in on any scope for derandomisation. For large scale housing complexes the randomness thus far identified will exist and how it influences the management of the maintenance system needs to be addressed together with ways of tackling any problems generated.

1.5 MAINTENANCE POLICY FORMULATION

The Maintenance Policy formulated will vary with the size and complexity of the system to be maintained, available cash and other resources and the consequences of lack of maintenance. The policy thus established may range from a basic unplanned response system, ie. the tenants report defects and the maintenance organisation respond by initiating means of repair; to a complex mixture of elements of both planned and unplanned strategies. The question now is which policy and what is the rationale for selection?

A planned preventive or planned corrective maintenance strategy may be formulated by considering the elements of the system to be maintained, based on either the age or the condition of a property and the individual elements which comprise it.

(a) Age-based policies

Here the idea of replacing or repairing trade element components based on service age is considered. This maintenance technique or strategy is complicated by age not necessarily being a function of real time and a requirement that data relating to 'time to failure' or the 'reliability function' for the components is available. Such a policy may well yield benefits with certain types or groups of buildings, eg. hospitals, high rise office blocks, or dwellings, hotel, factories where mechanical, electrical or plumbing services and sophisticated and controlled environments are essential. Much work has been done in this area including that by Christer[5] and Jardine[6].

(b) Condition-based Policies

The decision to repair or replace components of a property is here based on the condition or state of repair. Obviously the 'condition' of the property needs to be observed, therefore some form of inspection is implied. Given that an inspection takes place, the decision of what to repair or replace and when could be influenced by:

(i) previous maintenance and/or any programmed planned maintenance

(ii) current budgets and budget boundaries

(iii) implications for the Tenants

(iv) implications for the rest of the property

Inspection Systems

The possible need for an 'Inspection System' in some form is thus recognised and this requires the following problems associated with inspection systems to be addressed:

(i) Are inspections feasible; if so, how many?

(ii) At what intervals should inspections take place?

(iii) Which components or properties or groups of properties are to be inspected?

(iv) What information is collected at inspections and what use is made of the data collected?

(v) Are inspections pre-repairs, post-repairs, or both?

(vi) Who makes the inspections and how well qualified and versatile are the inspectors?

(vii) Is access feasible and are inspections perfect?

(viii) What is the cost of inspections and are resources available for their execution?

(ix) Are there cost or other benefits accruing from inspection?

Once again, randomness and geographical spread of properties compound the complexity of potential inspection routines.

1.6 THE MAINTENANCE SYSTEM: DEFINING KEY FACTORS

With large scale building complexes the randomness thus far assumed will exist and needs to be considered conjointly with other key factors which influence the organisational routines leading to the effective remedy of building defects.

Christer[1] identified the elements which interact with each other to constitute the maintenance system which controls the repair of building defects to varying degrees of complexity. These are gathered into three main groups as - Tenant, Property and Maintenance organisations and are considered to interact as shown in Exhibit 1.6 in the current context.

The requirement for a distinct Client/Contractor department split is again recognised here and considered in more detail in subsequent chapters.

The individual components of each are listed here, being expanded and modified where necessary, so that the complexity of organisational decision-making can be appreciated.

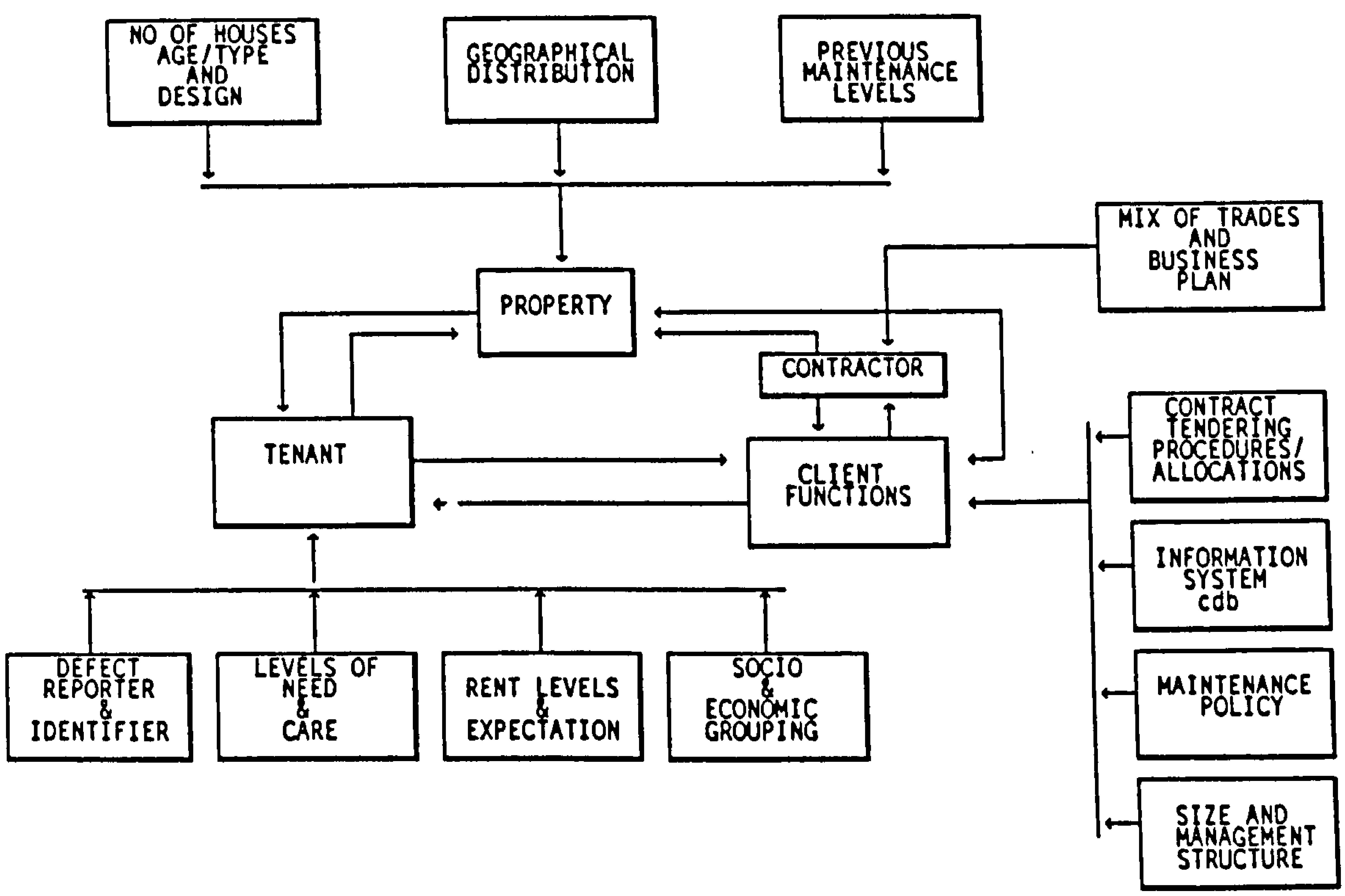


Exhibit 1.6

The Maintenance System

1.6.1 The Property

Most of the property variables have been highlighted under origin of defects in Exhibit 1.2. However, additionally and relating specifically to organisation logistics there are:

(a) the number of properties and their geographical distributions;

(b) Types of properties, for example - four in a block, high rise, tenements and so on.

(c) Previous and future maintenance programmes, for example, modernisation and rehabilitation or specialised elemental programmes, eg. window or external plumbing replacement or repair.

1.6.2 The Maintenance Organisation

The key factors identified in this group include

(a) The size of the Client Department

This may be classified as:

(i) Small ie < 7500 houses

(ii) Medium ie ≥ 7500 < 15000 houses

(iii) Large ie ≥ 15000 houses

The staffing complement and duties undertaken could be directly related to departmental size(7), although current findings suggests that medium size authorities cope on average with a higher ratio of properties per staff member than either small or large authorities.

(b) The Client Department Management Structure

(i) The variety of functions within a Housing Department, including Letting, voids and maintenance, unplanned and planned maintenance including contract maintenance programmes, demands an intricate and efficient communications system.

(ii) The degree of decentralisation of autonomous groups within the department and attendant extension of lines of communications.

(iii) The existence or otherwise of a DLO group.

(c) The Mix of Trades

It is necessary to consider the structure and resourcing potential of the DLO, eg. the mix of difference trades available and the number of tradesmen and labourers per trade, and the variety of private contractors available to service the Local Authority.

(d) Location of Depots

Consideration needs to be given to centralisation or decentralisation of depots and the effects on travelling time, mode of transport, and maintenance strategy.

(e) Information Recording, Retrieval and Analysis System

Contemporary systems should be almost entirely computer based, mainframe and micros, with the extensive use of applications packages, a system which should have far reaching benefits for system control.

(f) Cash Constraints

One of the principal factors is that the maintenance system is able to provide an acceptable repair service within a fixed budget. Constraints on rates of spending and rigid budgetary boundary conditions can influence not only the overall maintenance policy but also the maintenance standards and strategies which could vary from a modified emergency service to a minimum letting standard internally plus pre-paint maintenance standard externally and upwards.

(g) Target Service Level

Arguably, one estimate of the efficiency of the maintenance process is the time interval between the receipt of the repair request and completion of repair. Target times are set arbitarily and variably by different authorities for a range of repair types. It is likely also that political influence could set maximum target times which would prove counter-productive to cost effective management.

(h) Access to Property

Obtaining access to a property is a critical aspect of the repair service. Access may be necessary to carry out repairs or to perform pre-repair and post-repair inspections. This calls for clear lines of communication between Client, Contractor and Tenant.

(i) Job Satisfaction, Level of Payment and Bonus Systems

Improving efficiency by the maintenance contractor leading to an increase in the number of man jobs/day will most likely affect the bonus system of payment and could lead to a contentious and delicate management problem. This can produce knock-on effects and influence scope for changes in the maintenance planning.

(j) Methods of Calculating Job Costs

There are two methods used to determine the cost of repairs

(i) A Schedule of Rates. This is employed by most local authorities and DLO's. The schedule may be Priced or Unpriced and may vary in content from Authority to Authority.

Most maintenance tasks will be covered by the schedule which specifies the nature and the scale of each repair type and usually the associated cost.

(ii) Dayworks. Work done is charged for by the hour plus materials costs and is referred to in the trade as 'time and lime'. Private contractors and Development Bodies eg housing associations largely used this method of charging.

Response maintenance contracts within local authorities will most likely be costed based on a Schedule of Rates with some work being separately charged for on a Dayworks basis depending on the scale and detail of the schedule.

An Audit Report (8) acknowledges the difficulty of comparing these two methods of pricing work in terms of value for money.

(k) The Contractors Business Plan

Careful consideration must be given to the range and scale of contracts that the contractor, DLO or private, is providing services for, or is able to offer. In the maintenance context commercial survival may depend on choosing the right balance of work.

1.6.3 The Tenant

(a) Defect Reporting and Maintenance Department's Expectations

The method of identifying and reporting defects and the extent of the tenant's involvement are important elements of the maintenance policy. It is quite possible that repair requests will be almost completely tenant-generated. The pivotal role conferred upon the tenant has serious control ramifications on overall maintenance department performance, since rates and types and descriptions of defects produced rests with this (the Tenant) untrained, unskilled, unpaid building inspector.

(b) Tenants' Demands or Expectations

There is likely to be a large variance in the levels of need among tenants in view of age, health, infirmities, general abilities and so on, and unless clustered into definable groups, the haphazard demand for repairs will certainly add to the inherent randomness of defect occurrence.

(c) Socio-economic Grouping

Unless clustering of tenants into socio-economic groups is introduced, there is likely to be a wide variation in the level of tenant awareness of how defects are initiated and develop together with varying degrees of care as exercised by the Tenant, while the property is in service. Likewise, it is possible that a wide difference in the financial resources available exists from Tenant to Tenant, ranging from the unemployed; pensioners, to several wage earners per household; and it is conceivable that this too could create a variety of demands on the repair service.

(d) Level of Rent and Rates

A meaningful correlation may exist between the level of rent/poll tax or alternative and repair demand, or possibly a relationship with acceptable total repair completion times. However, no attempt is made to establish such relationships which are mentioned here simply to point out possible variable Tenant responses.

1.7 The Maintenance System Control and Performance Measures

Christer[9] suggests the need to select control variables in terms of level, type and value; and also to select system performance measures which are available directly, or after data analysis and which can subsequently be deployed to determine changes in the control variables. This process is shown in simplistic form in Fig 1.7.

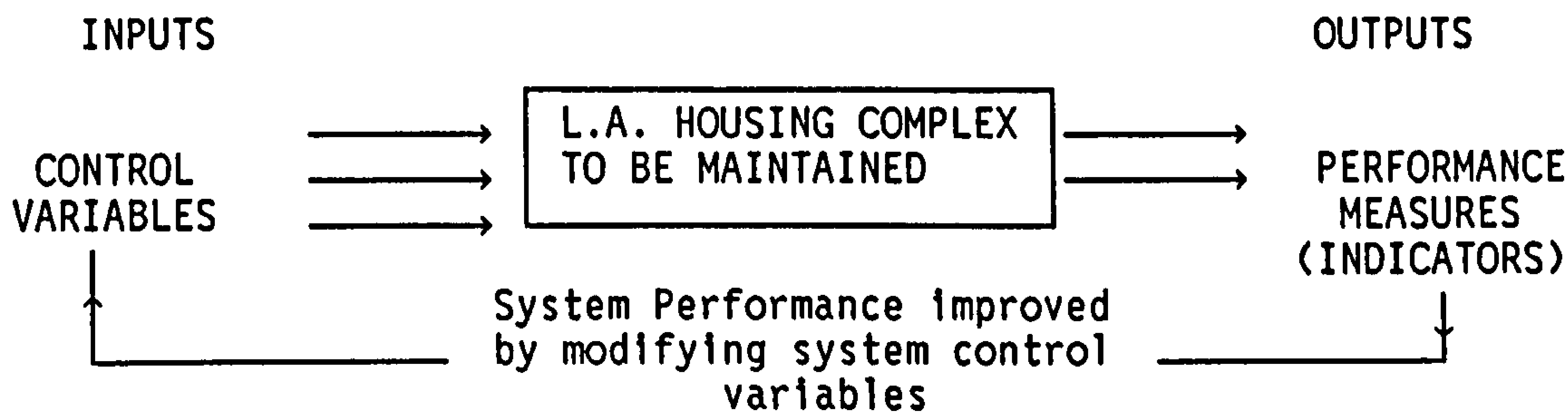


Fig 1.7

Obviously the interaction of the system variables is more complex than Fig 1.7 conveys, with changes in one or more of the decision variables producing a variety of responses within the system and subsequent influences on performance, all of which can be affected by chance events.

As a consequence of the Client and Contractor department split enforced by Legislative demands, each department requires to be modelled separately to establish a Quality Management based system, with clearly defined functions and duties set within the framework of system control variables and performance indicators. This idea will be further developed in Chapter Two.

Randomness in varying forms, the complex interaction of decision variables and the system maintained, together with the requirement to optimise resources within unavoidable cash limits and a commitment to monitor and modify system performance, clearly present major organisational problems. It would therefore seem that reasonable, primary maintenance management objectives ought to be to:

(a) Manage the randomness of the variables, time, type and location as discussed earlier.

(b) Develop reactive management responses in both Client and Contractor Departments.

(c) Control costs or downtime.

(d) Limit tenant hardship and inconvenience.

(e) Improve repair quality and maintenance system control and performance.

An aim of the investigation will be to attempt to establish feasible means of achieving these stated objectives, within the context of a District Council Housing Maintenance System.

1.8 Literature Review

It must be made quite clear from the outset that this investigation specifically focuses on the delivery of a Response housing repairs service and does so within legal constraints that dichotomise traditional Local Authority organisational and management structures. Substantially this study hinges on the implementation of the Local Government Act 1988[10], and amendments to the Local Government Planning and Land Act up to April 1991[26] which specifically target the packaging of Functional Works Contracts (Response Repairs Contracts) in a competitive commercial environment. Consequently the ideas subsequently evolved are relatively new, and are dedicated to solving current and future response maintenance problems.

Problem analysis is by the application of management science (Operational Research) methodology. Section 1.8.6 discusses the specifically OR contributions to the study of maintenance problems.

In the field of Local Authority Housing maintenance management much of the previous work published has been overtaken by changing events over the past ten years and especially by impact of the relevant legislation over the past three years. This literature review is curtailed to maintain a sharp focus on the problems tackled by this research. This study seeks to keep pace with the rapid, legislation led changes required within Local Authority housing maintenance organisations. It is this legislation, together with Audit Reports, selected housing maintenance publications and relevant research projects which form the hub of the knowledge, necessary to underpin an understanding of the contents of this research. It is anticipated that the reader will be familiar with Local Authority, or other similar organisations' housing maintenance practices and will realise the obvious distinction between managing and delivering a response service and programmable maintenance as an element of a planned maintenance scheme. It is quite reasonable to analyse response maintenance as identified in this study in isolation from any concurrent planned maintenance system or indeed from any research in that field, whether it is preventative maintenance as part of say a five year cyclical program, or rehabilitation or refurbishment work. Planned maintenance is the result of systematic surveying of the housing stock, identifying defects, large or small, itemising, prioritising and scheduling these for subsequent repair.

In ideal circumstances a planned maintenance program, hybridised with the *ubiquitous* response repair service is more effective in preserving the condition of the housing stock. Every manager knows that it makes sense to inspect and monitor the condition of the housing stock in an attempt to preserve the capital value of this asset. However many of these managers may not have the resources to do so and some may even be reluctant to open up some kind of Pandora's box. To direct the unfamiliar reader to the wider; though not for this study appropriate; aspects of housing maintenance we include some references to planned maintenance systems. Until such times when concrete evidence is available which proves a correlation between response and planned systems in terms of reduced demands and lower costs the arguments for and against will rage on.

1.8.1 The Legislation

At this point no attempt is made to discuss the contents, implications and timing of relevant pieces of legislation. Instead the reader is referred to Chapter 2 for a legislative review and a discussion of knock-on effects created for Client and Contractor Departments. A brief reference worth making here is the Tenants Right of Repair by Jan Luba[27]. This is a very extensive, indepth explanation of Tenants Rights and in general does not have much impact on this study. However the implications of Right to Repair for response maintenance profiles need to be aired since in the event of a Landlord being in breach of obligation to effect repairs within a reasonable time scale a Tenant may withhold rent and use it to pay for repairs the value of which may be between £20 - £200. However as explained in Chapter 4 part 2(a) of Right to Repair, before taking such action the Tenant should follow the following preliminary steps carefully:

(a) inform the Landlord of the intention to take this form of action if repairs are not carried out;

(b) allow a further reasonable period for the Landlord to comply with repair obligations;

(c) obtain three estimates for the cost of carrying out the remedial work and submit copies of these to the Landlord with a "final warning";

(d) engage the contractor at the lowest tender and have the work carried out;

(e) submit a copy of the contractor's invoice to the Landlord and request reimbursement;

(f) if no money is forthcoming, recoup the cost by deducting from future rent.

As reported later in Chapter 2 this is not an option which Tenants in Local Authority care have taken up: possibly because the process is complicated and cumbersome for Tenants to handle, or possibly because it is unnecessary and authorities were delivering an acceptable repairs service.

1.8.2 Defect Identification and Repair: Traditional and Non Traditional Construction

Details of management functions including planning, specifications, costing and corrective design/repair feedback data which interact to create the Scottish Local Authority Maintenance Management system are well documented in the Scottish Local Authorities Special Housing Group (SLASH)[28] publications numbered 1 to 10. Every aspect of planning, specification, costs and feedback are covered by these detailed and extensive, yet succint documents. The contents cover all aspects of external and internal maintenance work on traditionally constructed dwellings and a range of non-traditional constructions. Each booklet contains details of repair types and remedial treatments which are derived by combining knowledge based on research, largely by the Building Research Establishment[29], and feedback from practical experiences in the maintenance field. These publications make a significant contribution to education and training across the spectrum of managers and operatives in Local Authority Housing maintenance and elsewhere.

A more exhaustive study of defects and repair techniques for non-traditional housing has been undertaken by the Birmingham TERN project on Non Traditional housing Defects and Repairs[30]. TERN stands for Training for the Evaluation and Repair of Non-Traditional buildings. This category of construction includes structures built using concrete, timber, steel-frame, insitu-reinforced framed structures with a variety of cladding panels and covers low, medium and high rise buildings. Information on the maintenance of such building is reported to be sparse. Although a great deal of excellent work has been produced by Establishments such as the Building Research Establishment, the Housing Defects Division of the DOE, the Construction Industry Research and Information Association as well as the former Cement and Concrete Association, which all address the problem of defects in non-traditional buildings in terms of cause and effect, the TERN Project reports too little advice on the following areas:

(i) Evaluation of a suitable repair type;

(ii) Selection of effective repair techniques and materials;

(iii) Effective methods of executing repairs and ensuring quality assurance.

The project plugs this knowledge gap with a series of videos and handbooks based on a synthesis of research and knowledge pooled from a spectrum of specialists in this field of work.

What yet remains to be established is a definitive framework for assessing the performance of the variety of repair techniques which may be employed in attempts to solve more vexing maintenance problems, eg highrise blocks. Rates of deterioration need arresting and less palliative and more long term solutions must be found. Computer aided databased condition surveys have been undertaken and a system for judging the maintenance problems against a matrix of assessment criteria is utilised after which a loose hierarchical action plan can be developed. During decision making it is necessary to take account of any future use and lifespan of the building and this involves inputs from a large team of integrated specialists including the Tenant. The use of value engineering and life cycle costing techniques should be utilised when reaching a repair/reinstatement decision.

Figs (1) and (2) show the repair/reinstatement cycle and assessment criteria matrix proposed by TERN.

Repair/reinstatement cycle

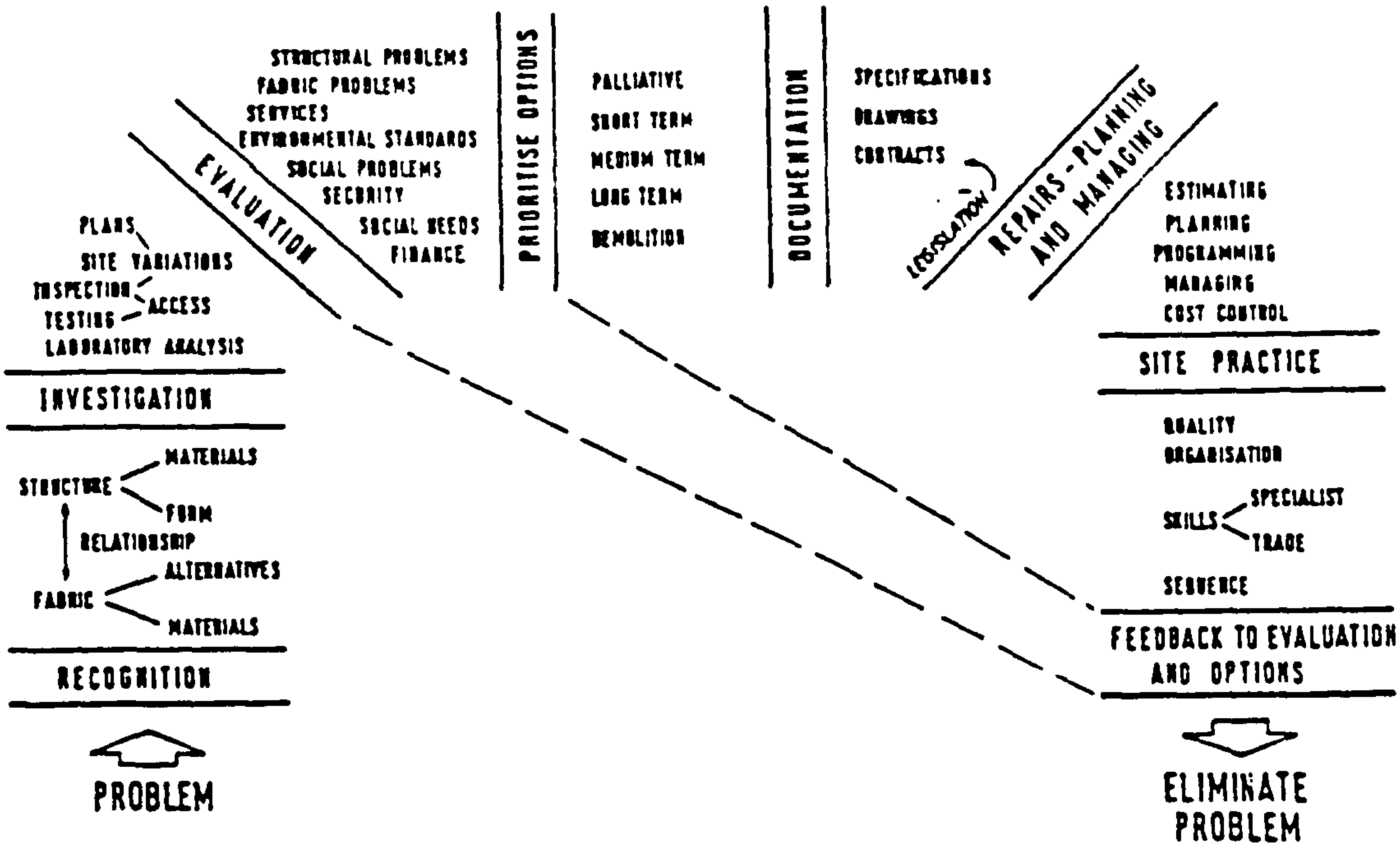


Fig 1

Structural Survey

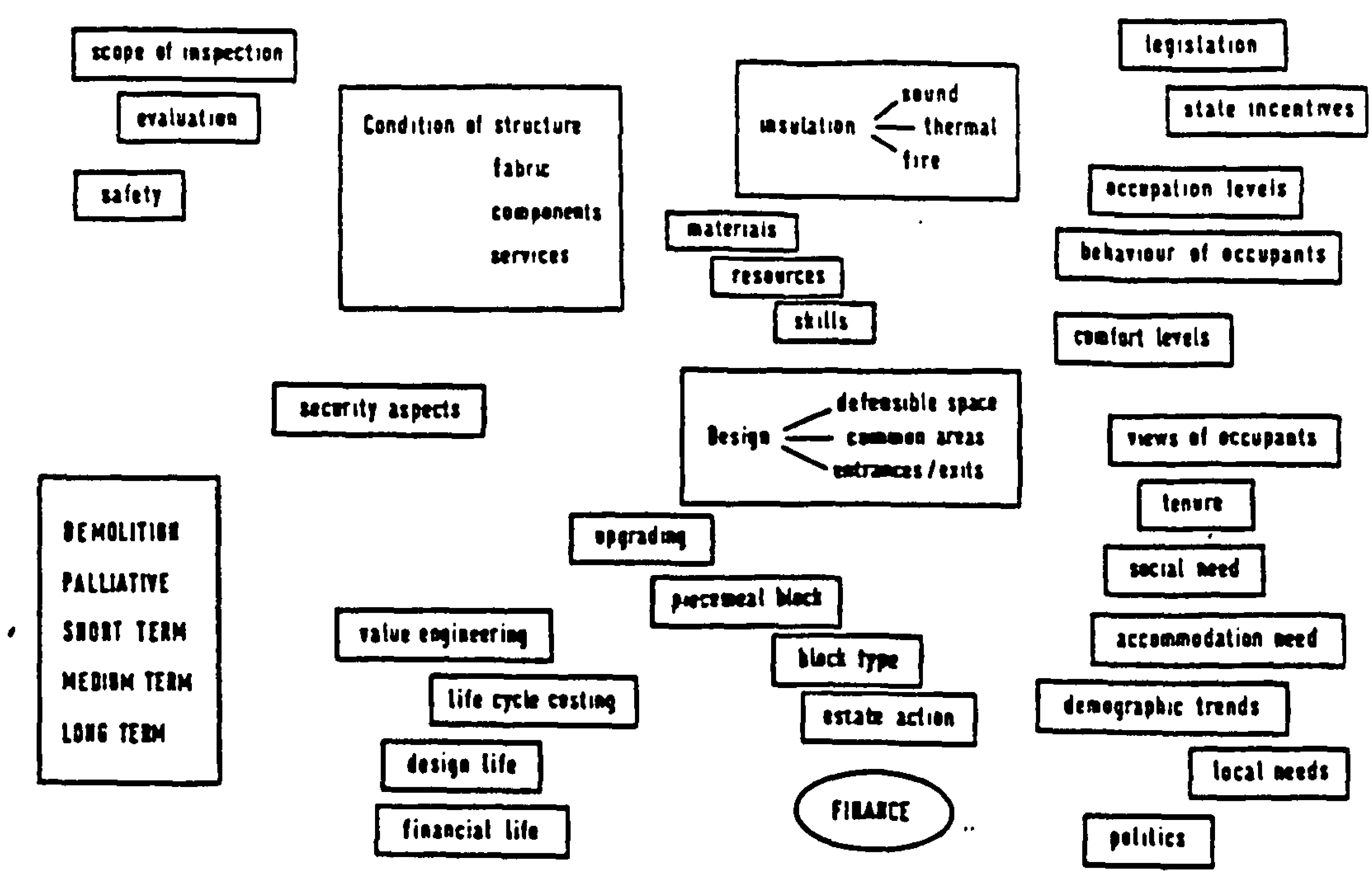


Fig 2

1.8.3 National House Condition Surveys

It is not the intention to list and review house surveys or consider the statistics generated - that is outwith the scope of this study. What is more important however is that any lessons that can be learned from such surveys are exposed.

Condition surveys of public sector housing stock initiated by Central Government have been ongoing since 1967. Since 1971 a survey has been conducted every 5 years, the most recent being 1986. The development of the English House Condition Survey is reported by O'Dell[31]. Initially the purpose of the survey was to identify houses "unfit for human habitation". Over the years the survey has grown with several changes in content, policy and presentation.

The first survey used random sampling techniques to select dwellings for inspection and cataloguing and until recently survey data was analysed using simple statistical methods. The most recent surveys have been expanded to include interviews which illuminate several issues including social, economic and financial matters which influence the changing nature of the state of repair of the housing stock. Local Authority questionnaires were utilised which establish their contribution to repair/improvement of Local Authority stock together with a survey of property values.

Much more interest is currently being directed towards better presentation of results including computer modelling for examining strategic issues.

Prior to the 1986 survey previous data collection and reporting procedures were critically examined and evaluated with a view to enhancing existing physical survey techniques. This more sophisticated study revealed certain fundamental limitations in previous surveys which inhibited the measurement of small changes in the condition of the stock over relatively short periods of time. Significant modifications to previous survey proformas and strategies were therefore implemented for the 1986 survey.

The design of the sample for the 1986 survey was amended and the survey has four main phases;

(a) A physical inspection of 30,000 dwellings;

(b) Interviews with 8,000 occupants selected following the physical inspection of the sample;

(c) An enquiry to relevant Local Authorities regarding approximately 12,000 of the dwellings sampled.

(d) A valuation survey of approximately 5,000 houses;

Other improvements implemented were the replacement of random samples by stratified samples which enable buildings of interest to be targetted. Cross-sectional samples were replaced by longitudinal samples which allow individual dwellings to be monitored through time.

The Amended Physical Survey Methodology.

A new survey proforma was devised for the 1986 survey as shown in Fig 3. This form is highly structured so that the judgements of individual inspectors were less at variance than in previous surveys therefore producing more precise data, and did not place too much burden on the memory of inspectors who were all trained building surveyors. This however did not prevent differences in value judgements occurring among inspectors during preliminary trial training periods.

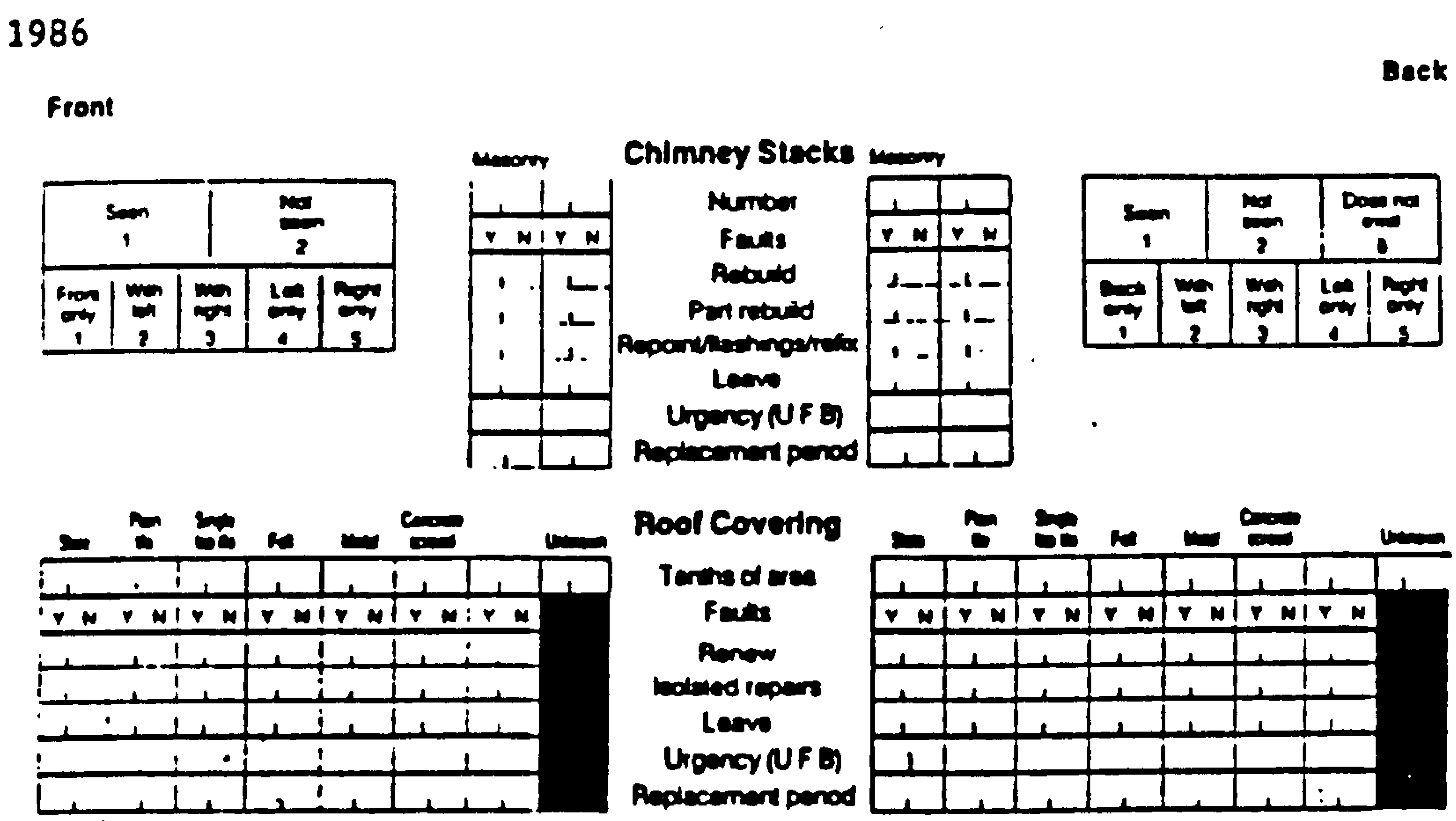
Surveyor Variability in Estimating Repair Costs

Careful attention was given to the training of inspectors prior to the survey. This involved field tests and video film simulations to compare individual responses to defect reparation and costs. Of interest was the finding that in general surveyors agreed closely in identifying and describing the observed defect, disagreed more in the diagnosis of the defect and much more in the remedial treatment. This is to an extent consistent with the TERN[30] observations and highlights a possible deficiency in training and education programs. The recommendation therefore is that interpretation and analysis of the defect is left until a standard ruling can be applied. However these initial inconsistencies were smoothed out by the inclusion of a time scale and an urgency classification in the pro-forma for certain types of repairs, see Fig 3.

Figs 4 and 5 show the impact of surveyor variability on estimating repair costs. The results were derived from a large number of surveyors examining the same very poor condition dwelling. Results show that one third of inspectors estimated cost which differed from the mean cost by more than 30%. Surveyor variability also has a distorting effect on the overall distribution of repair costs with too many dwellings being recorded as having very high or very low repair costs as shown in Fig 5.

Estimating deterioration rates is currently the subject of an investigation since this is not a simple or straightforward problem and simulation techniques are being developed to assist better understanding of this topic.

Some important issues have therefore been identified and although these developments arise from a national condition survey the same or similar lessons should be considered by any Authority mounting a conditioned based survey of its stock.



Extracts from survey form 1986

Fig 3

Summary of Results of The Survey

The results of the English House Condition Survey 1986[32], which applies to all tenures reveals a grim picture showing almost no improvement in condition being achieved over results of previous surveys. It is acknowledged that results were more difficult to compare in view of the changes in survey procedures.

In summary the situation is

(a) 5% of the housing stock is unfit for human habitation;

(b) additionally 2.4 million dwellings are in poor repair;

(c) 15% of the housing stock is in poor condition;

(d) 543000 dwellings lack basic amenities.

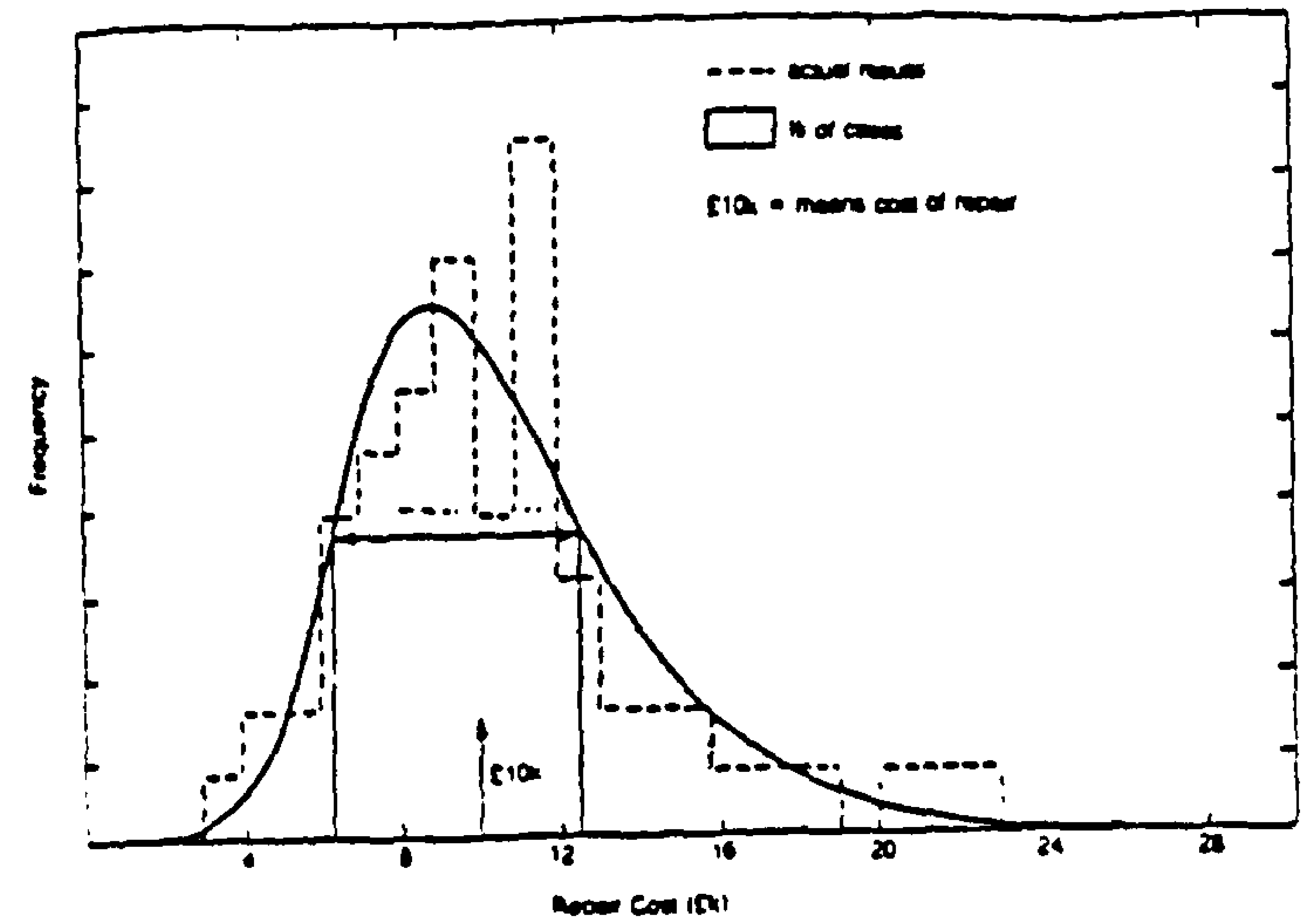
Luba[27] further reports that the latest projection (1989) from the Association of District Councils is that £38 billion is required for repairs to dilapidated buildings with a total of £50 billion needed to tackle disrepair. Glasgow council housing alone requires £1.6 billion (1985) to repair defects.

In these circumstances it is unlikely that the response repairs maintenance problem is likely to diminish.

An inquiry into housing in Glasgow 1986[33] examines a wide range of problems and recommends solutions, financial, organisational and administrative in an attempt to avert a major crisis by arresting a steady decline in housing standards. The provision of good quality low cost housing which matches the requirements of the community is the aim.

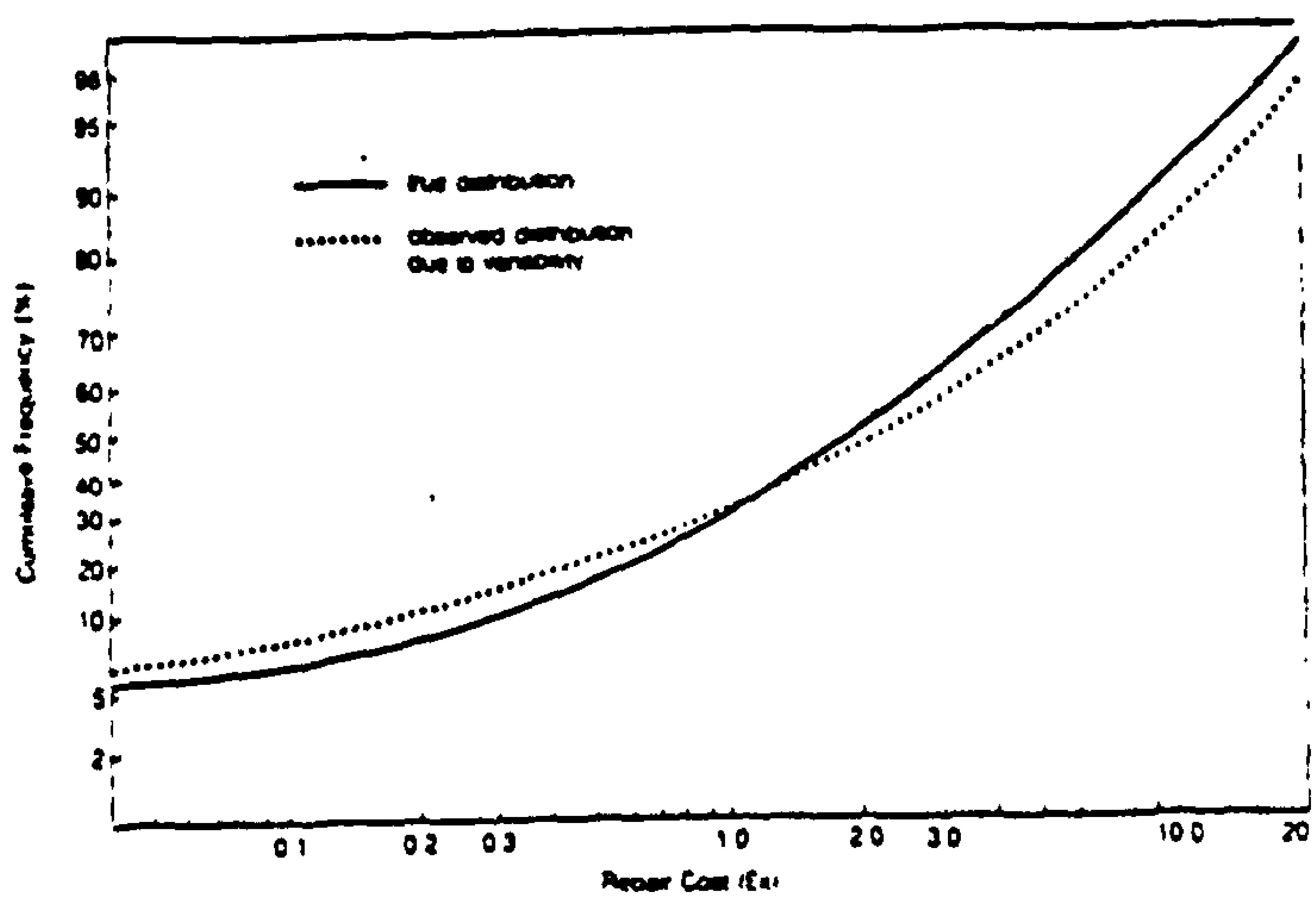
The extent of disrepair and backlogs are identified and the levels of funding necessary to reinstate to tolerable standards is quantified.

A variety of schemes for managing the maintenance problems are proposed and discussed. Decentralisation of the administration of the repairs service is advocated and the role of the private sector is considered.



Surveyor variability in a measurement of repair cost

Fig 4



Distortion in the repair cost distribution caused by surveyor variability

Fig 5

1.8.4 Planned Maintenance

The literature on planned maintenance is extensive and although varying in style and emphasises most of the papers are similar to one another in approach and content. Here we discuss three references which serve to illustrate the categories of planned maintenance and the rationale for implementing such strategies.

Maintenance as a Total Concept

A maintenance philosophy based on a "Total Concept" which embraces, running, jobbing, planned and long term planned maintenance is described in a Planning Exchange Occasional Paper, "SSHA Maintenance: Developments and Directions", by Colston and Ross[34]. The strategies developed are aimed at not only preserving the stock but also adapting the stock to changing user requirements leading to longer lettable life spans of up to one hundred years.

The housing stock totalling 90,000 dwellings and valued at £2.25 billion is divided into 1,500 schemes and supervised by building inspectors each with a responsibility for between 3,000 and 7,000 dwellings. Each inspector is allocated up to 3 assistants, making each inspector responsible for approximately 1,500 - 2,000 houses. The stock is further banded by age and form of construction which is classified as either traditional or non-traditional.

The procedure is to examine the age profile of the components comprising each dwelling or groups of dwellings thereby permitting probable age based replacement strategies to be developed.

A five year cyclical inspection program is compiled listed under ten inspection headings which allows 1/5 of the total stock to be painted each year. The inspection headings numbered 1 to 10 are grouped in pairs and staggered with two inspections each year in the five year cycle, eg inspection heading, 1-6, 2-7, 3-8, 4-9 and 5-10. The procedures are obviously elaborate and are illustrated by a series of charts, tables and diagrams too large to reproduce here and with the exception of two exemplaries given later the reader is referred to the actual text for details.

Based on inspections a condition profile of the stock is generated which defines some twenty elements of construction which are grouped as External fabric, Internal fabric and External (environmental) works which are presented against a time scale in years 0 - 100, in 5 yearly increments. A line representing the end of life expectancy is plotted against each element of construction together with the history of previous completed work. For each scheme of houses examples of performance profiles are presented in tabular form showing, composition (size), usage (Tenant statistics) and performance eg. insulation, condensation etc.

An important aspect of long term maintenance planning is that it makes long term forecasts of funding necessary to ensure the prolonged lettable life of the housing stock.

In summary the advantages of a profile system are stated to be:

(a) The condition and performance of each scheme is shown;

(b) The condition can be compared with cash invested to arrive at a "value for money" judgement;

(c) It provides the basis to predict component life and improve relationships between first and second costs;

(d) It provides the means to plan work, estimate costs and judge priorities within and between schemes against an agreed strategy;

(e) By aggregation it is possible to obtain an accurate statement of condition and cash needs across the whole stock.

The contents of the above Planning Exchange Occasional Paper was published by the Scottish Special Housing Association SSHA[35]. The presentation is broadly similar and additionally an appendix which presents an expanded inspection check list is given. Fig 6 shows an extract from the publication which illustrates the Association's information systems and how they relate to Whole Life Maintenance philosophy. Fig 7 shows an example of the staggered inspection cycles discussed above over a ten year cyclical inspection period.

A housing maintenance kit produced by the Scottish Office: Scottish Homes for Housing Associations[36] provides a step by step guide to the care and maintenance of housing stock. Since most of the Housing Associations' stock in Scotland was either completed or rehabilitated in the 1980's, the guide provides a maintenance strategy not dissimilar in philosophy from that of the SSHA, and aims at maintaining the stock to a high level from the outset thereby preventing out of control deterioration to occur. Fig 8 is an extract which shows the stages in the step by step approach.

The benefits of such planned maintenance strategies are defended by Colston[37][38] against the alternative argument that response maintenance is more cost effective within the context of Local Authority funding[39]. It is not the intention of the study to become emboiled in tis, tisn't arguments which fail to quantify advantages and disadvantages in hard cash terms. It suffices to say that long term or short term condition surveys, programmed repairs and replacement strategies which sustain the utility and value of the housing stock are highly commendable and worthy of funding, if funds are available. If not, the manager has the unenviable task of optimising use of resources within a maintenance system which is likely to be highly reactive in nature.

Those wishing to pursue the arguments on the benefits of planned maintenance are referred to Holmes[62], the Changing Nature of Building Management. Therein Holmes asserts that there is little evidence to support an increase in planned maintenance or programmed maintenance which are seen by many "as the way forward to an efficient and cost effective strategy" asserting that "planned maintenance is beneficial and cost effective if the failure of the elements or components results in high consequential cost, but this is not so for housing". Scottish Office Report[7] 1986 reports that apart from external painting and obviously associated prepaint repairs, *planned maintenance hardly featured at all in Scottish Authorities.* It therefore makes much sense to examine, analyse and model response maintenance as achieved by this thesis whether there is a planned system for effecting repairs or not.

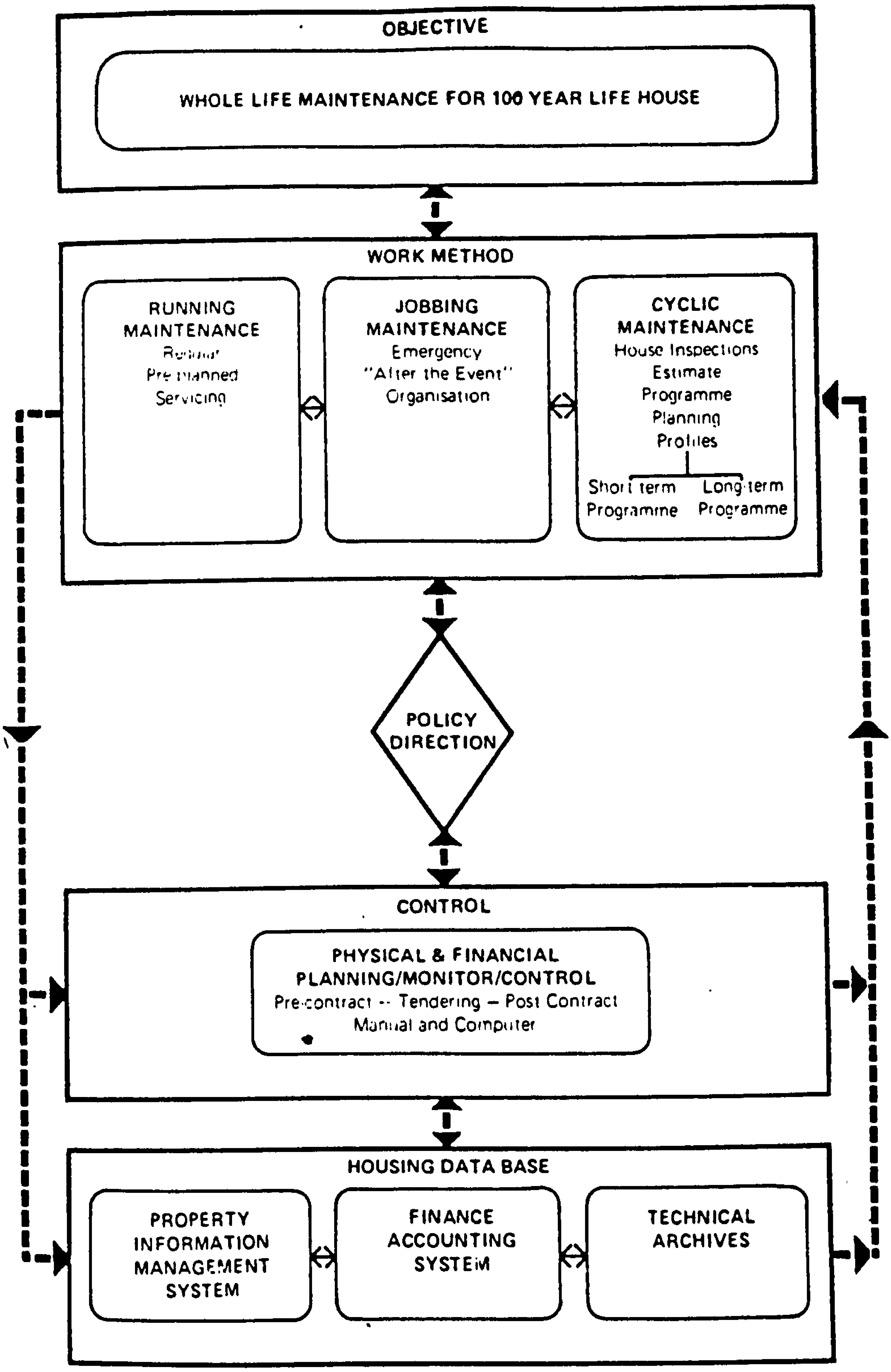
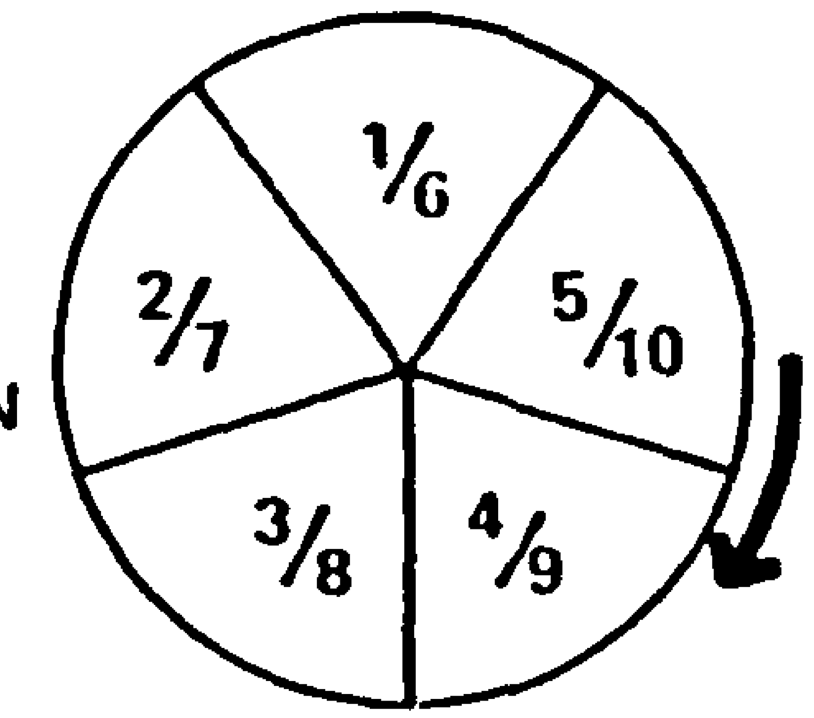


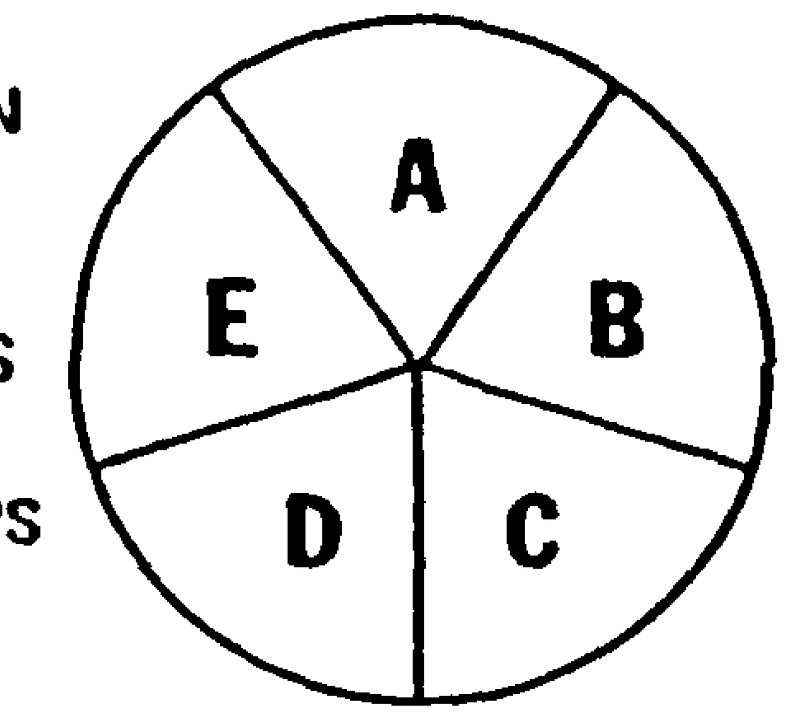
Fig 6

Source : Scottish Special Housing Association[35]

5 YEAR COMBINED INSPECTION AND SUPERVISION CYCLE AS AT 1983



SUB-DIVISION OF BUILDING INSPECTOR'S AREA INTO 5 SUB-GROUPS OF HOUSES

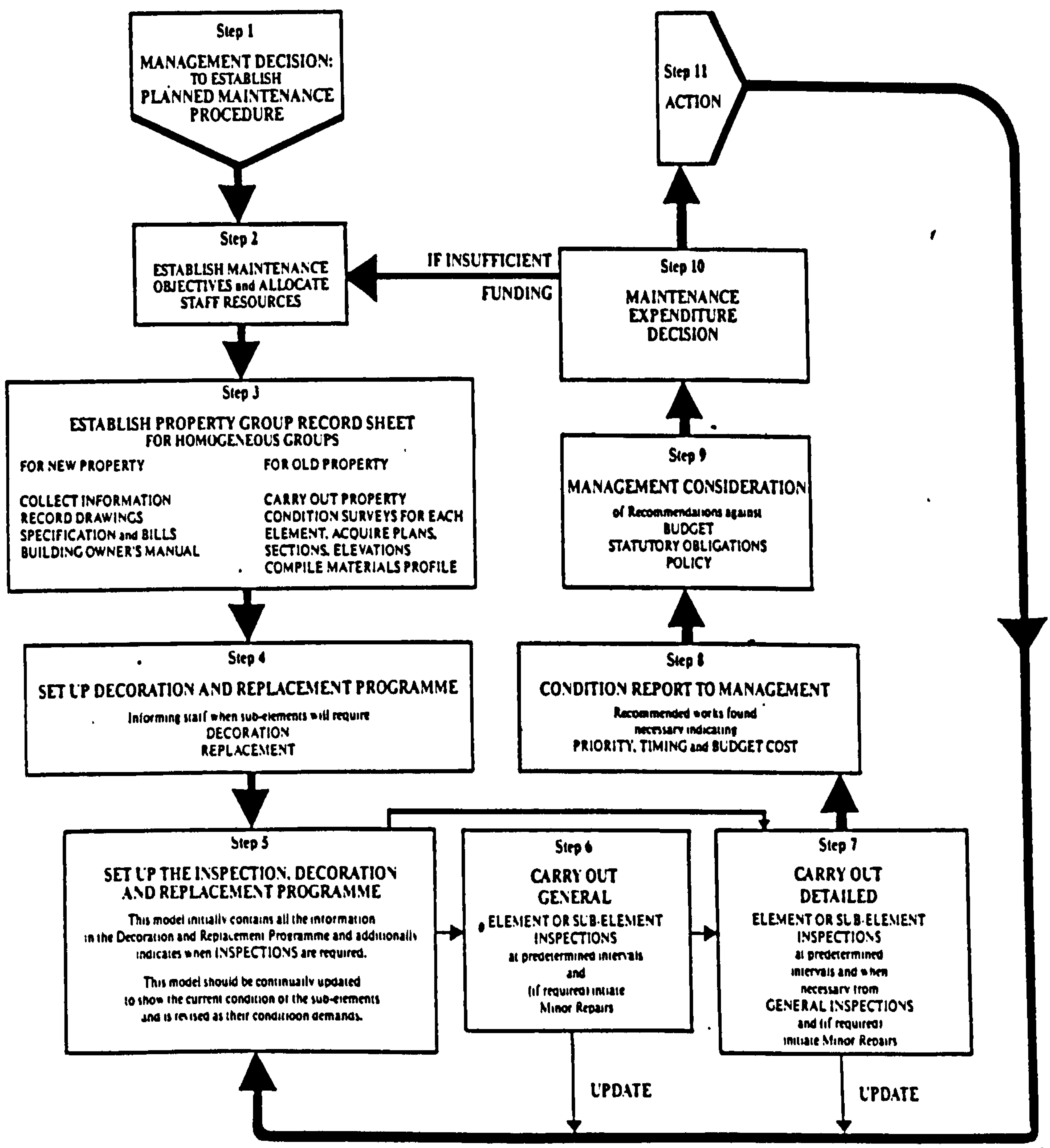


INSPECT'N NUMBER	INSPECTION STAGE	SUPERVISION STAGE	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92
4 & 9	FABRIC AND MAIN STRUCTURE	*Contract Work – Electric, Gas and Heating Defects Liability – Mechanical and Special Services*	C	D	E	A	B	C	D	E	A	B
5 & 10	PRE-PAINTING EXTERNAL WORKS LANDSCAPING	*Contract Work – Fabric and Main Structure Defect Liability – Electric, Gas and Heating*	B	C	D	E	A	B	C	D	E	A
1 & 6	PLUMBING AND SANITARY FITTINGS	*Contract Work – Painting External Works Landscaping Defects Liability – Fabric and Main Structure*	A	B	C	D	E	A	B	C	D	E
2 & 7	MECHANICAL AND SPECIAL SERVICES	*Contract Work – Plumbing and Sanitary Fittings Defects Liability – Painting External Works, Landscaping*	E	A	B	C	D	E	A	B	C	D
3 & 8	ELECTRIC, GAS AND HEATING	*Contract Work – Mechanical and Special Services Defects Liability -- Plumbing and Sanitary Fittings*	D	E	A	B	C	D	E	A	B	C

Fig 7

Source : Scottish Special Housing Association[35]

MODEL CYCLICAL MAINTENANCE PROGRAMME



SOURCE: BUILDINGS INVESTIGATION CENTRE

Fig 8

Source: Housing Maintenance Kit[36]
Scottish Homes/Scottish Office

Planning Non Urgent Response Repairs

The Planning Exchange occasional Paper by Fogg, 1984[40] explains how after reorganisation in 1974 Renfrew District Council set out to amalgamate the five former housing authorities into a single unit. A housing stock comprising 40,000 dwellings with a replacement value then of £1 billion was thereby created. The maintenance standards of the previous constituent authorities had been distinctly different and a lack of detailed knowledge about existing stock together with an obvious need for extensive repairs to external timbers and plumber work made it desirable to develop alternative maintenance strategies.

The maintenance budget during 83/84 had *risen* to £9.71 million since reorganisation, and expenditure on planned maintenance had risen to 44% of total expenditure. The council therefore adopted a policy aimed at increasing the planned maintenance component of expenditure to 60% of the maintenance budget in the *long term.* To achieve this a 5 yearly inspection and prepaint repairs program was introduced to reinstate external timber and plumber work to a state of "good repair". Additionally a cyclical maintenance system was introduced for "routine" type repairs which were delayed or queued for up to thirteen weeks, with all such work up to the first eleven weeks executed by teams of tradesmen either from the DLO or private contractor or mixture of both over a single or two week period. The strategy is referred in Chapter 4 of this study as zonal maintenance and the limitations on using mixed or separate DLO and private contractor workforces imposed by recent legislation and CCT are highlighted there. Such a cyclical maintenance system claims several advantages including reduced travelling time, reduced access problems and using pre-inspections which reduce abortive calls.

By introducing a pre paint repairs system more communication was necessary between the housing maintenance repairs service section and the Technical Services Department which controls, organises and commissions planned maintenance programs, in order to avoid duplication of effort. To improve information storage and retrieval and improve control and communication a computer aided database system for property records was introduced.

Prior to the *investment* in planned repairs, deterioration was out-running rectification, and although unsubstantiated, this trend was being arrested and the housing stock was at 83/84 in a more stable state of repair and hopefully the council objectives would, in the future be achieved. There is a need for planning and "the management of long life high value assets with predictable rates of deterioration should always have been subject to a systematic approach instead of adopting ad hoc hand to mouth methods".

Response repairs are still necessary and account for a substantial proportion of the maintenance budget.

Capital Maintenance

It should be made clear from the outset that the types of maintenance contracts devised within the capital programme require organisation and planning techniques which are analogues to those applied to new build projects. The contract is definable in nature and work content in advance of the start date and this allows forward planning. The type of projects funded by the capital budget include say, rehabilitation, refurbishment, rewiring and so on. Start and finish dates can be targetted and the works carried out in sequence and or in parallel. A variety of computer project Planning Packages are available which use network analysis from which bar charts are prepared to assist managers to keep the projects on scheduled completion times. Also manpower requirements and cost evaluation predictions can be forecast. The process is therefore quite distinct from that required to manage a response repairs service.

However the problems involved in developing a 5 year rolling capital programme valued at £750 million are discussed in the Planning Exchange occasional paper by Nichol[41]. A variety of projects within Glasgow District Council which include, new build, rehabilitation, refurbishment, planned repairs, rewiring, insulation, extraordinary repairs and so on are discussed with respect to a restructuring of the system for managing the Council's housing stock.

The management of such a wide range of projects was complicated by a decentralisation policy which created eight District housing programs, each district containing between 16,000 and 25,000 dwellings. This created approximately 1,300 individual projects all at different stages of developments. This gives some indication of the scale of both the capital programme and the response maintenance system which runs in parallel with it.

It was found necessary to identify a core program of priority work which initiated the 5 year rolling program together with other projects of lower priority which could be commissioned contingent on available funding. All of the projects in the overall capital program were monitored within the remit of the Council's Housing Programme.

The complexity of the envisaged 83/84 capital programme enforced the need to change from a manual control system to computer aided programming techniques and after consultation a system call Artemis which had been currently used by the then Building and Works Departments was employed. The decision to change to this system of control was fashioned by consideration of possible further decentralisation, Council and Committee procedures and Tenant participation schemes.

The actual operational aspects of the programmes were not developed, however the above comments serve to highlight issues to consider in possible future application of computer based analysis.

Athough the funding mechanisms for Local Authorities and Housing Associations are different, the development of the discussions in "Making The Most of Your Money, a guide produced by the National Federation of Housing Associations 1991"[(42)] would be of interest to managers of Local Authority Client Departments. The guide explains very clearly how Housing Associations generate funding necessary to complete response repairs and capital works and makes recommendations on how Associations should make the most effective use of budgets. Various types of accounts are discussed and the role of the Housing Corporation under the provisions of the Housing Associations Act of 1985 is clearly explained. A section on overspending on day-to-day (response) maintenance considers the implications of seasonality on budget demands. This is an area which is targeted for modelling in Chapter 4 of this study.

In general the housing stock controlled by Housing Associations is relatively new and does not at this time constitute the same major repairs backlog and ageing stock problems faced by Local Authorities, however the possible effects of ageing of Housing Association stock is considered in the National Federation of Housing Associations publication long-term maintenance[(43)].

1.8.5 Audit Commission, Association of Metropolitan Authorities, DOE and National Federation of Housing Associations Reports.

(a) Audit Reports

Over the past six years several Audit Reports have been published on subject areas relating to or specifically directed towards housing maintenance management. Such Reports cover a wide range of issues which are contextually set within sample Local Authorities in England and Wales. An aim of these Reports is to highlight problem areas and offer sound advice on ways and means of addressing problematic issues. In view of the extent of Audit Commission researches and the number of Authorities studied a wide range of working practices is identified. Consequently the advice offered is to an extent general in nature and requires to be adapted to each Authority's specific requirements.

The following is a resume of relevant Audit Reports in chronological order. Any issues raised by these reports which are germane and supportive or otherwise to this investigation are referred to within the text and in the context of response maintenance management.

The Scale of the Problem

The results of a two year investigation of 400 Authorities in England and Wales are given in Managing The Crisis in Council Housing 1986[(44)], which analyses the Authorities performance as managers of the 4.8 million dwellings under their control.

The report covers a wide range of housing management and makes recommendations to client departments on how more effective use of resources may be achieved. However the report is not intended to focus on the delivery of the repairs services.

Client Department Initiatives

Effective management within Client Departments is targeted by the Audit Report on Improving Council House Maintenance 1986[8].

This general report, eighty pages long, advises client departments on a range of issues requiring analysis and which lead to improved management of the maintenance effort. Substantial savings are possible, amounting to as much as thirty per cent improvement in maintenance value (ie more repairs completed for the same cost) is said to be achievable; this being equivalent to approximately £700 million pounds per year.

The problem of backlogs in repairs is quantified and the need for longer term planning and funding strategies considered. Condition based surveys are highlighted with more programmed repairs (ie less response repairs) recommended together with tighter control over emergency work. More *competition* is advocated with *work put out to tender in ways that permit small firms to make bids.* This is indeed what current Legislation enforces and what this research tackles in Chapter 4. Wide variations in tender prices received are identified and discussed. Cyclic maintenance and a window replacement strategy are considered.

Estate based management of the repairs service is recommended with more zonal maintenance and the establishment and monitoring of realistic service standards. Five key factors viz systems, strategy, structure, staffing and style, which the client department must consider are discussed.

The appendices comprise, (i) future expenditure and age profiles of existing stock, (ii) a five year maintenance plan, (iii) procedures for monitoring repairs and performance within a local authority and (iv) comparative prices for response repairs.

Squaring up to a Competitive Environment

The need for Councils to prepare for a competitive tendering environment is discussed in The Competitive Council 1988[14]. This twelve page reports aims to act as an initiator of debate which will lead to the introduction of strong management into local authorities where this is lacking. Eight key points are identified in the summary which all well managed authorities must respond to. These are:

(a) understand customers
(b) respond to the electorate
(c) set and pursue consistent achievable objectives
(d) assign clear management responsibilities
(e) train and motivate people
(f) communicate effectively
(g) monitor results
(h) adapt quickly to change

Authorities should analyse management routines and philosophies and measure these against targets set within the report. An organisation's style, culture and competitiveness are the pivotal attributes discussed and around which recommendations revolve.

The Delivery of the Repairs Service

Operational routines and areas of management affecting the delivery of the repairs services by Direct Labour Organisations are analysed in A Management Handbook for Building Maintenance Direct Labour Organisations 1989[13].

The aim of this report is to advise managers of DLOs on how to improve the efficiency and the effectiveness of the activities undertaken at the contractor end of the repair service. Achieving better quality repairs, better value for money and a requirement to be more competitive are primary aims.

The report is seventy pages long, general in nature and is the complement of a report written for the client departments. Legislation in effect at the time of publication is reviewed and possible changes in prospect identified. The general performance of DLOs is reviewed and the share of the market achieved by DLOs is analysed.

The remainder of the report sets out six main steps towards improving the performance of DLOs and the following area of management concern are discussed in detail.

(a) Better materials management
(b) Controlling overheads
(c) Increased working time

(d) Improved rate of work
(e) Aggregate management information
(f) Increased effectiveness

A model for a business plan is then discussed. The appendices comprise, a work model; a cost model and a review of incentive bonus schemes.

Although overtaken by events and publications resulting from recent legislation and a report published by the former Audit Commission, Direct Labour Organisations Maintenance 1982[45] led the field in attempting to identify how DLOs should be organised to meet the challenges imposed by the Local Government Planning and Land Act 1980[46].

The report, one hundred and ninety pages long, examines the full range of management practices and operational procedures and identifies working practice which should enable DLOs to face a variety of challenges by being more adaptable to future demands.

(b) **Other Relevant Reports**

The Association of Metropolitan Authorities publication, Repairing for the Future, 1988[47] advises authorities of good management practices from both the client and contractor standpoints. Housing standards, repair quality and customer satisfaction are targeted.

The report straddles the audit reports above and although less precise and quantitative, it is a comprehensive review of problem areas and identifies how these should be tackled.

The need for clearer definition of repair types is identified and types of response and programmed maintenance discussed. The text is, in general, similar in content and philosophy to that of audit reports. The range of client and contractor functions and related performance indicators are given detailed consideration.

Section six provides a check list of good management practices against which authorities' performance should be measured. This report, which predates audit reports, forms a basis for quality management and is meaningfully relevant within a contemporary legislative formwork.

In the same mould as Audit Reports and a forerunner to these is the DOE Report by the Housing Services Advisory Group titled Organising an Effective Repairs and Maintenance Service System 1981[48]. This report covers very much the same ground as Audit Reports and is therefore subsumed to a large extend. Nevertheless the publication is enlightening and is framed around specific case studies of management practices in several Local Authorities. Of specific interest is the detailed storage and analysis of job type and frequency undertaken by Peterborough Development Corporation since as far back as 1973. These records were used to ascertain the amount of monies required to repair various types of defects on an estate basis. Likewise these procedures could lead to identifying potential problem areas which may influence the delivery of the service. Every item of jobbing repair was recorded and stored on computer enabling a complete maintenance history to be assembled. This tactic could permit feedback on design problems associated with a high incidence of the same type of defect leading to a possible preventative maintenance strategy. Some details of this system are produced in Computer Aids to Housing Maintenance Management by Pettitt 1979[49] where a repair coding system is also identified.

In 1980 a computer aided system of programming, non-urgent day to day repairs was introduced by the GLC[50]. Approximately 15,000 houses were managed by zoning into geographical areas each containing 2000 dwellings. This is the cyclical maintenance system operated by some Authorities for non urgent response repairs with target response times up to as much as say twelve weeks. This is discussed in Chapter 4 of this study and referred to there as zonal maintenance. The procedure is that the computer is used to store and retrieve information on outstanding and completed work moving outstanding work forward in a queuing system. Mobile gangs of autonomous tradesmen execute work clustered in daily or weekly workloads.

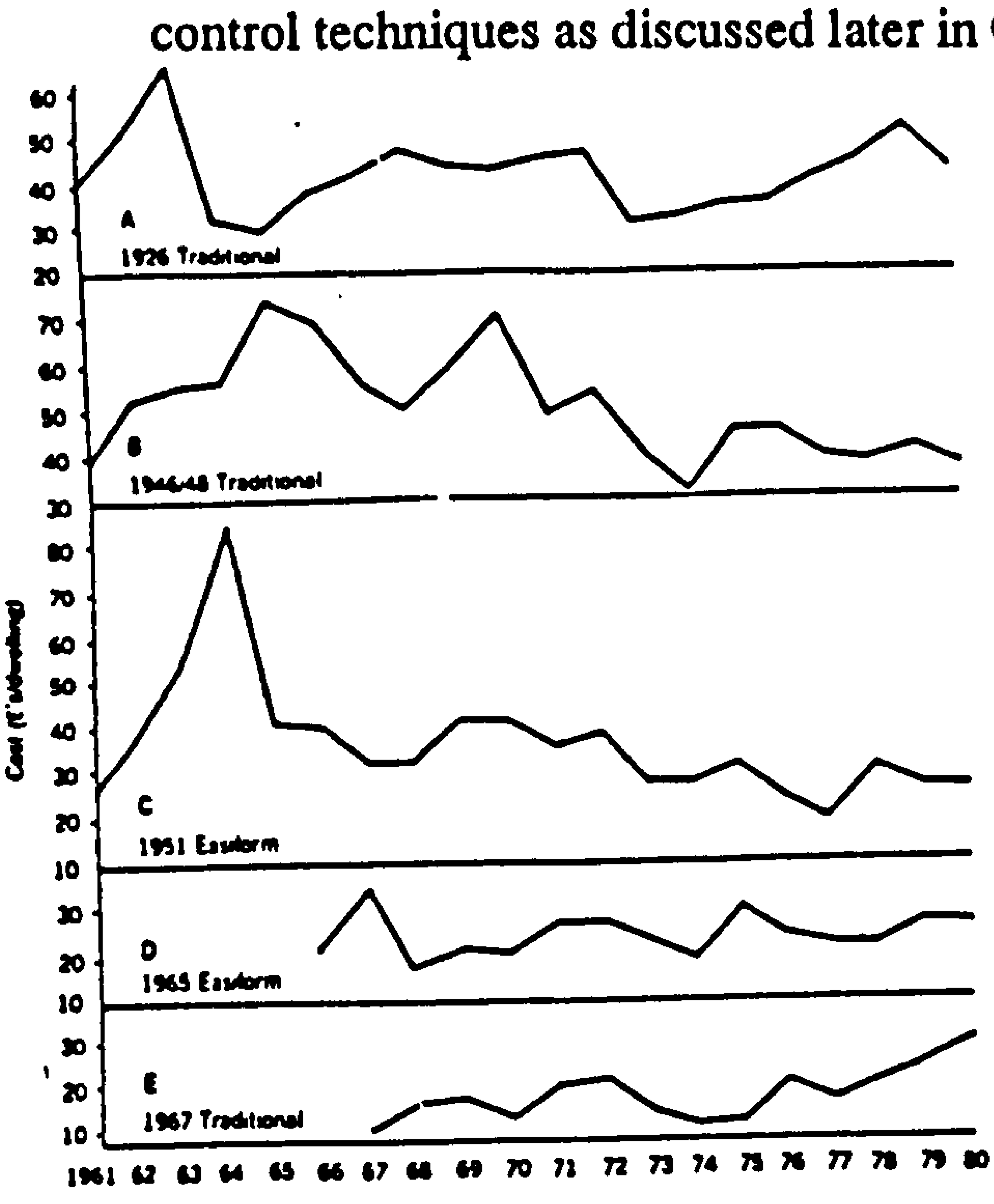
The National Federation of Housing Associations publication, Standards for Housing Management 1987[11] is primarily intended as a guide for housing associations, housing co-operatives and similar organisations. The contents are however relevant to any organisation concerned with maintenance from a Client perspective. Although unquantitative in nature and wide ranging in topics details, the document serves as a management control and service delivery reference frame to ensure customers rights and satisfaction are the main focus for management.

The following eight topics are discussed in detail:

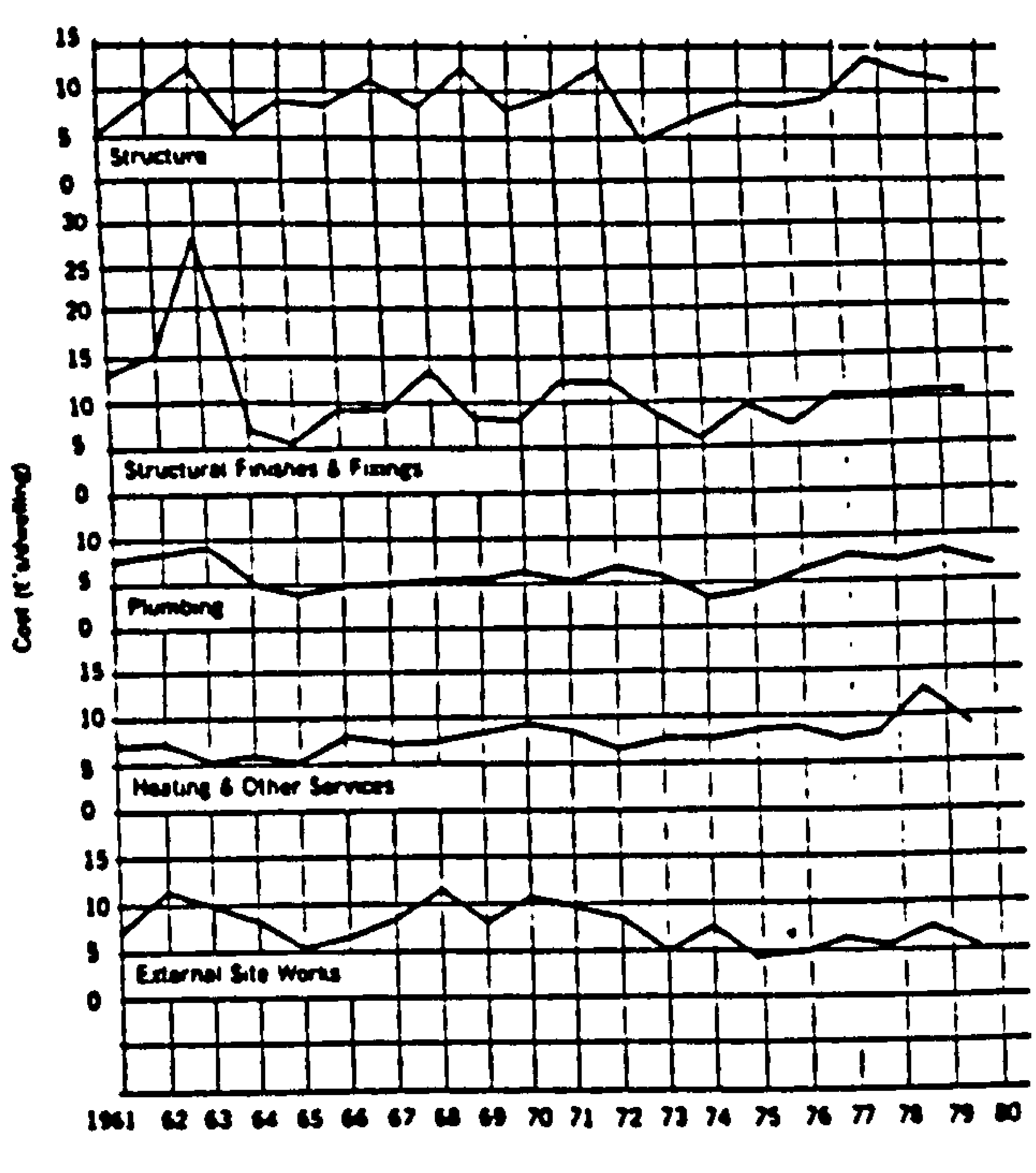
(1) selection and allocation
(2) transfers, mutual exchanges and reciprocal letting
(3) tenant involvement and access to services
(4) tenancy agreements, licences and tenants rights
(5) rents, rates and licencees' charges
(6) Services paid for by services charges
(7) Repairs and maintenance
(8) Housing management and development

With respect to this investigation topics seven and eight are of most relevance.

The installation of maintenance coding systems are pivotal to the successful monitoring of trends in response maintenance activities, and are essential if any developments as proposed in this study are to succeed. An example of a maintenance coding system and how this is used to monitor cost trends with time is presented by Holms and Mellor, 1985[51]. Fig 9 shows an example of cost trends in contingency (response) maintenance taken from the case studies presented. Although to an extent unrelated to the techniques developed in Chapter 4 of this study the system shows potential to be adapted to produce the computer generated data necessary to enable the analysis of alternative situations and to devise system control techniques as discussed later in Chapter 4.



Contingency maintenance cost by year ending March 19- House-types A-E



Contingency maintenance costs at Level 1 by year

Fig 9

Similarly a variety of issues including examples of schedules of rates, housing repair detail codes and maintenance contracts are given in Computer Maintenance Management in A Housing Authority by Saville, 1990[52]. Response contracts are discussed and tendered for based on a sum £(x) allocated per property multiplied by the number of properties to be maintained. A summary of previous years work is provided for contractors to aid calculations. The main thrust of the paper is directed at selecting a computer program/package to assist the general management of the maintenance system including databases, costing and planned maintenance. Clearly the application of computer aided management has become more sophisticated. However, Holmes[62] reports that a review of various information systems in Authorities involved with housing maintenance shows that much of the data is "stored data" rather than "used data".

Careful thought is required prior to and during the preparation of an effective database and a structured approach to this is presented by Tong, Wilson and Ellis[53] in Information Needs of Housing Management 1986. The different levels of information for line management are discussed in the categories; operational, management and strategic. It is suggested that "a long term aim, now being examined by many Authorities is to develop *common data bases*". This is aimed at providing greater interchange of data across dedicated banks of information. An example of the levels of information specific to repairs which is considered necessary for effective management is reproduced in Table I. It is information systems of this type coupled with a specific repairs coding system which could be adapted to produce the data necessary to test the response maintenance modelling processes developed later in Chapter 4.

Table 1. Different levels of information for line management

REPAIRS

Operational	**Management**	**Strategic**
• Address • Type of repair • Priority status of repair • Date reported • Progress • Date completed • Cost of repair	• Number & cost of repairs in each neighbourhood for: — all repairs — each type of repair — each type of property • Average completion time for repairs in each neighbourhood for: — all repairs — each type of repair • Number of repairs reported for each priority rating	• Comparison between neighbourhood offices of: — average number of repairs per dwelling (for each type of repair and property) — average cost of repair per dwelling — completion times — priority ratings • Comparisons between maintenance contractors/DLO depots of: — average cost of each type of repair — completion times • The effects of changes in policy and procedure relevant to repairs

Table I

The most recent Housing Research Bulletin[54] 1990 issued by the Scottish Development Department does not; with the exception of references[7][36]; contain any publications which are of immediate value to this study. However those involved in or contemplating Condition Surveys may be interested in the Manual of Guidance on Local Housing Condition Surveys produced by the SDD. None of the work in progress in the Department's research programme has any distinct bearing on the research work of the study.

The Scottish Office Report, The Delivery of the Repair Services in Public Sector Housing In Scotland 1986[7] makes a significant contribution to the understanding of the nature of Response (contingency) maintenance and its management over the full range of service delivery requirements. The Report exposes the range of working practices adopted by Authorities to tackle this problem and analyses how effective Authorities are in doing so. With respect to the issues raised by this thesis the Report acknowledges and illustrates seasonal variations in repair demands but pursues this phenomenon no further. The Report is especially critical of the lack of proper data based recording systems for monitoring costs and general maintenance information. This information was generally throughout Authorities either "not collected at all, or it is not collected in the correct manner, or is stored in the wrong place, or is not kept up to date". These *"chaotic"* recording systems made it impossible for Authorities to *"monitor their own performance"*. The Report suggests that there can be little hope of improved standards in such circumstances. This thesis seeks to highlight the need for establishing and updating efficient data recording and retrieval systems and to recommend potential ways and means of improving maintenance system control and performance measurement which are fashioned to cope with the competitive environment of the nineties. In these highly politically charged times its is possible that both internal and external assessments will be made to establish how effectively Authorities are discharging their duties.

1.8.6 Management Science (OR) Contributions

Prior to reviewing Management Science (OR) contributions to maintenance and specifically that which is applicable to building maintenance we must make the point that housing maintenance and its management is a field of study which has potential for the application of operational research techniques. Analytical techniques such as statistical analysis, simulation, queuing theory, maintenance theory, project network analysis and linear programming may be potentially usable in tackling problems which arise or which perhaps enable a clearer understanding of problems extant.

Much more OR effort needs to be channelled in this direction however difficult it is to unearth the roots of a problem and identify a solution.

To appreciate the difficulties in finding OR applications in this field we believe it necessary to focus on the principal factors which fashion the complex character of Local Authority Housing Maintenance. This we do by contrasting this maintenance problem with certain maintenance OR work in other applications. The additional areas where OR has been meaningfully applied to building maintenance are subsequently summarised.

We recall that Local Authority Housing Maintenance as a whole comprises Response (day to day) repairs plus Rehabilitation/Refurbishment projects. Large Rehabilitation projects being analogous to replacement of the building as whole which is considered as only a rare or remote possibility.

Response repairs are predominantely generated by the Tenants expressing some degree of dissatisfaction with the state of repair of the property which they pay rent to occupy. The repair demands made on the repairs services will vary or fluctuate among groups of tenants and among houses grouped together to form say Estates. Such repairs will be paid for out of a Revenue Account funded by rent monies and the management of this aspect of the maintenance service will be the responsibility of the Housing Maintenance Section within the Client Department. Rehabilitation/Refurbishment or new build projects are on the other hand funded separately from a capital budget and managed by Technical Services Section of the Client Department.

It is worth noting the points listed below, which in summary focus on the nature of housing maintenance and factors influencing strategic decision making.

i) The timescale between repair demands per house per year may be months. McLennan[7] and Skinner[2] report an average of 2.3 and 2.4 repairs per year respectively.

ii) The average cost of a response repair is relatively low say £50.00; see Section 1.2

iii) Repairs are randomly generated in time, type, location and trade and possibly scattered over a large geographical area. Within Local Authorities the maintenance systems to be managed are generally large and subdivided into subsets of say 2000 - 3000 dwellings possibly of a variety of constructional types.

iv) The time interval between Rehabilitation/Refurbishment programmes may be decades and the lettable life span of the dwellings may be 80 - 100 years, during which time the Building Regulations change, housing standards, health and safety and environmental standards improve.

v) Rehabilitation/Refurbishment costs vary depending on the scale of the proposed *improvements*, but are likely to be tens of thousands of pounds.

vi) Replacement costs are relatively high say £50,000 or higher.

vii) The system maintained does not require to be in perfect working order.

viii) The decision as to what to repair or improve and when will be conditioned based.

The scale of the rehabilitation/refurbishment projects, which group of houses and when improvements are to be done will be a group decision possibly involving the Director General, Technical Services personnel, council members, with inputs from environmental health officers, social workers and so on and will be part of a long term prioritised improvement program.

With respect to (vi) above we must consider the influence of response type defects on the building and its user(s). With the exception of emergency repairs, the definition of which has been recently changed, other defects are to varying degrees tolerable and do not constitute failure of the building as a habitable system. The defects are unlikely to cause downtime in the system (except in the case of Rehab./Refurb. projects) in that the dwelling will be closed with the tenant decanted and temporarily relocated. Nor will any consequential costs be incurred by the landlord since the tenant continues to pay rent even when repairs are outstanding.

It is however worth recalling that the system to be maintained could be subdivided in a variety of smaller units or perhaps certain clusters of dwellings which generate excessive maintenance problems and could be targetted for alternative maintenance strategies.

The bulk of OR literature on maintenance applies modelling techniques to maintenance systems which differ significantly from the housing response maintenance system pursued later in Chapters 2 to 5. Frequently the issues of interest are WHEN to action repairs and WHAT to repair or replace. The types of maintenance systems generally analysed by OR methodology are more "gaged" in that the repairs or inspections are performed in a relatively confined environment. Consequently there is not the same requirement to consider how to organise the "WHATS" that need doing. It is the organisation of the WHATS that need doing that is central to this study and the analytical applications which seek to achieve this are exposed in Chapter 4.

Typical of the maintenance systems studied, are, vehicle fleets, military or production systems where certain defect occurance cannot be *tolerated*. Failure in one or more components may disable the system to some extent causing danger to life and limb on a small or large scale, endangering national security or commercial survival, creating downtime and consequential loss of trade or profit, excessive deviation from target quality production standards and so on. Frequently repair and replacement of the system are considered together. In short the systems are maintained to a level which reduce the frequency of random failures and do so at the most economical running costs and minimise downtime.

An additional difference between most, but not all, building and other maintenance systems is that most OR methodologies tackle problems using the premise of age based repair/replacement strategies with age not necessarily being a function of real time. On the other hand housing :repair/rehabilitation maintenance decisions are nearly always conditioned based with the subjective assessments of what's tolerable being variable. Other areas of building maintenance could be investigated and the ideas of age, downtime, costs and inspection systems tested. Indeed Christer(9) in a general paper outlines how this may be tackled for hospital complexes and recent research has been done in this field by Christer the results of which are currently being prepared. Similarly the sophisticated services and environmental control systems within specialised buildings could be targetted for reliability type theory applications.

It was therefore as a result of the problem of finding applications for the available OR maintenance theory within housing maintenance that this investigation was channelled towards how to organise WHAT it is that needs to be put right and doing so within the acceptable time limits.

A paper entitled "Operational Research can do more for managers than they think!" by Fortuin, Van Beek and Van Wassenhove(69), reviews how OR can contribute to more effective and efficient management. In general terms they describe how OR can support management problem solving. This is achieved by a systematic and structured analysis, mainly based on interviews with personnel within the Companies which need assistance. A three phase step by step problem solving model is described. The elemental strategies being, a preliminary analysis, working out the proposed solution and finally implementation. The various characteristics of OR are explained and areas of application described in simple general terms. The role of computer software is highlighted and caution is recommended in anticipating results as this may lead to too high an expectation and possibly disappointment. It is noted that it takes time to make things happen.

With respect to Housing, a descriptive paper entitled Housing in the Dearne Valley: Doing Community OR with the Thurnscoe Tenants Housing Cooperative by Thurhurst, Ritchie, Friend and Booker(70) explains how OR activities are assisting the housing cooperative. General areas of interest are discussed and although the repairs service is discussed there is no attempt in this first paper to identify and solve any problems which may arise in this area. The ideas of *hard* and *soft* OR applications are briefly discussed and the point is made that although there is a perception that classical OR tools "are only suited to problems set in a *mechanical - unitary*" context and are unlikely to be most important from the point of view of community research; the authors have been able to apply a wide range of OR techniques during their investigations.

The text of the Blackett Memorial Lecture by D.R. Cox[71] is entitled "Quality and Reliability: Some Recent Developments and a Historical Perspective". The contents of the lecture are statistically non technical and present an historical development of the concepts of Quality and Reliability from the late eighteenth century through to modern times. Even from the very early days statistical analysis and the careful study of empirical data are identified. With respect to the development of new methods, Cox supports the unifying role of "theory" and especially "mathematical theory" and warns of sterility in OR approaches which are not underpinned by longer term theory. Cox advises that it takes time to translate academic exercises into things meaningfully practical or useful and "blessed, for example, by the ultimate seal of approval: simple software, not too user hostile". On the role of OR, Cox, believes that the contribution of OR to *quality* and *reliability* has so far not been as great as would be expected and that quality as a theme is given too little attention. On the definition of quality and its appropriate level Cox considers the level at which to aim thus. In some very specific industrial contexts, especially in the role of subcontractor - quality consists of meeting a specification. In other contexts the other answer "keep the customer happy" may be quite a useful first formulation. We believe this study contributes to both these areas of concern. By analysing the maintenance system we can help contractors to be more reliable (a slightly different connotation of "reliability" than in most OR maintenance problems) thereby ensuring greater customer satisfaction.

An example of an age based replacement, repair model is that by Makis and Jardine[72] entitled "Optimal Replacement Policy for a General Model with Imperfect Repair". The paper considers "a general replacement/repair model in which the system can be replaced at any time at a cost Co and at a nth repair the system can be replaced at cost Co or can undergo a repair" at a particular cost with cost being dependent on *age*. These explicit assumptions for modelling the system render such a modelling process inappropriate for housing response maintenance scenarios. As stated earlier, replacement is unusual and at any rate would be at very high cost, rehabilitation as an alternative solution would be a separate strategic decision, repairs are generally low in cost, infrequent on average, have a much more scattered geographical distribution, are not necessarily age dependent and do not reinstate the property to an as good as new condition, although the repair itself may be a small scale replacement eg a door handle etc. Additionally repair and replacement or rehabilitation time scales are vastly different. Repairs are not usually counted since a single count of different kinds of repairs would not be very helpful. Of central interest to this research work is the scheduling of work to effect response type repairs and this is an issue not tackled by Makis and Jardine which has as its criterion minimising cost per unit time and replacement as a key option.

A paper by Jack[73] entitled "Costing a Finite Minimal Repair Replacement Policy" is on a similar topic to that of Makis and Jardine and has cost in use as a criterion. Replacement is a key option and again organisation of the repairs that need to be done is not an issue. OR Papers which target maintenance replacement/repair problems as above have no bearing on the work of this research. Whether such ideas can be utilised in building components of a relatively large scale eg. flat roofs or wooden windows replaced by plastic windows remains to be established and is outwith the scope of this research.

At any rate large scale replacements are likely to be condition based. This is not to say that age is discounted in maintenance policy formulation. Indeed Life Expectancies of Building Components and Materials[23] are well catalogued. Age considerations are usually based on empirical data resulting from long term exposure testing; or otherwise; of materials. However durability is a vexing problem with a wide range of climatic conditions and exposures possible, together with accidental damage and wilful vandalism, compounding to confuse the issue. While age may be an indicator of unfitness, condition based assessment surely is.

The factors influencing the occurrence of building defects are treated generally in Section 1.2 and the causes of defects inspected are given in Chapter 5.

Some OR work on deterioration rates has been surveyed by Raafat[74] in a "Survey of Literature or Continuously Deteriorating Inventory Models". This is not regarded as having any significance for this study although managers of DLOs may well need to consider the implications of perishable items held in stores. However Christer[58] does use a rate of deterioration function for timber when investigating painting cycles and the influence of rotting window sills.

A Management Science Paper by Ahmad, Gross and Miller[75] entitled "Control Variate Models for Estimating Transient Performance Measures in Repairable Item Systems" presents a queueing model with units either in use, awaiting or under repair, or waiting for use and the model assumes a fixed number of units. This model is not regarded as relevant to work of this research. Although houses are repairable items and we are interested in transient performance measures in that of central interest to this study is the establishment of the labour requirement to match fluctuations in repair demands, such repairs are carried out while the houses are occupied. The response repairs system was originally considered as a queueing problem but this idea was subsequently abandoned in view of the considerable amount of subjective, preemptive prioritisation which takes place within both Client and Contractor departments. This accounts for the style of Chapter 3. Even considering a series of rehabilitation projects as a queueing model the time scale between planning and commencing individual projects could be many years. The reality is that the number of houses in the model would change (right to buy policy) and even the Authority overseeing the project could change during planning stages. We should also recall that the rationale for prioritising such projects may be conditioned by environmental problems tempered with "member" influence.

Jardine and Hassounah[76] investigate "An Optimal Vehicle Fleet Inspection Schedule" for a fleet of 2000 buses which are repaired/inspected by eight garages each bus being assigned to a particular garage. The inspection policy adopted by the Transit Commission was to inspect buses at intervals of 5,000, 10,000, 20,000 and 30,000 kilometres, different levels of inspection being applied at successive intervals. Bus breakdowns are assumed to occur according to the negative exponential distribution as are inspection times and repair times. Each garage was found to be operating different inspection policies. The reason for this variation was unknown and it was assumed that buses were inspected at random intervals. Examples of the variations in inspection frequencies are shown in the following page.

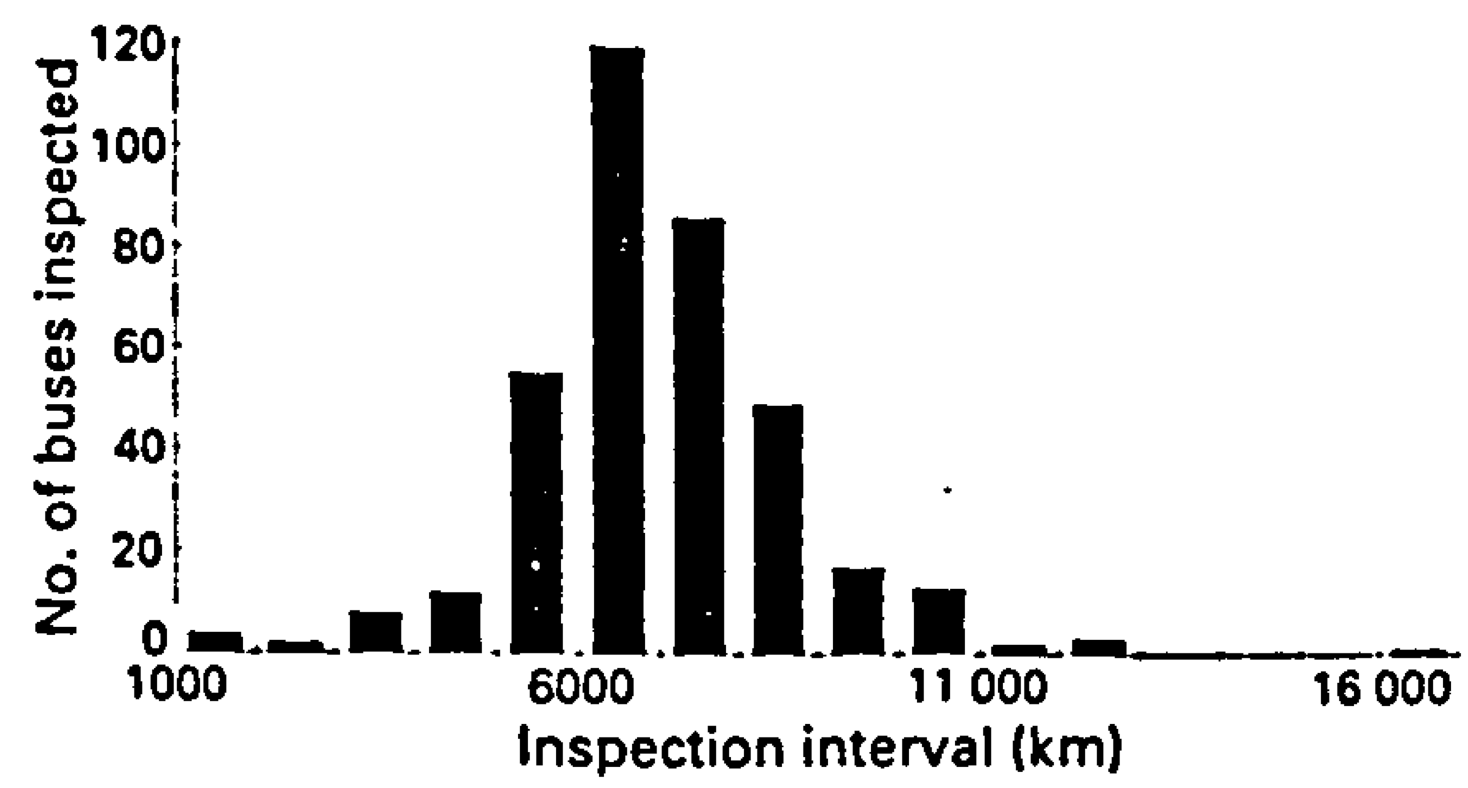


FIG. 5. *Inspection frequency distribution (Namur garage).*

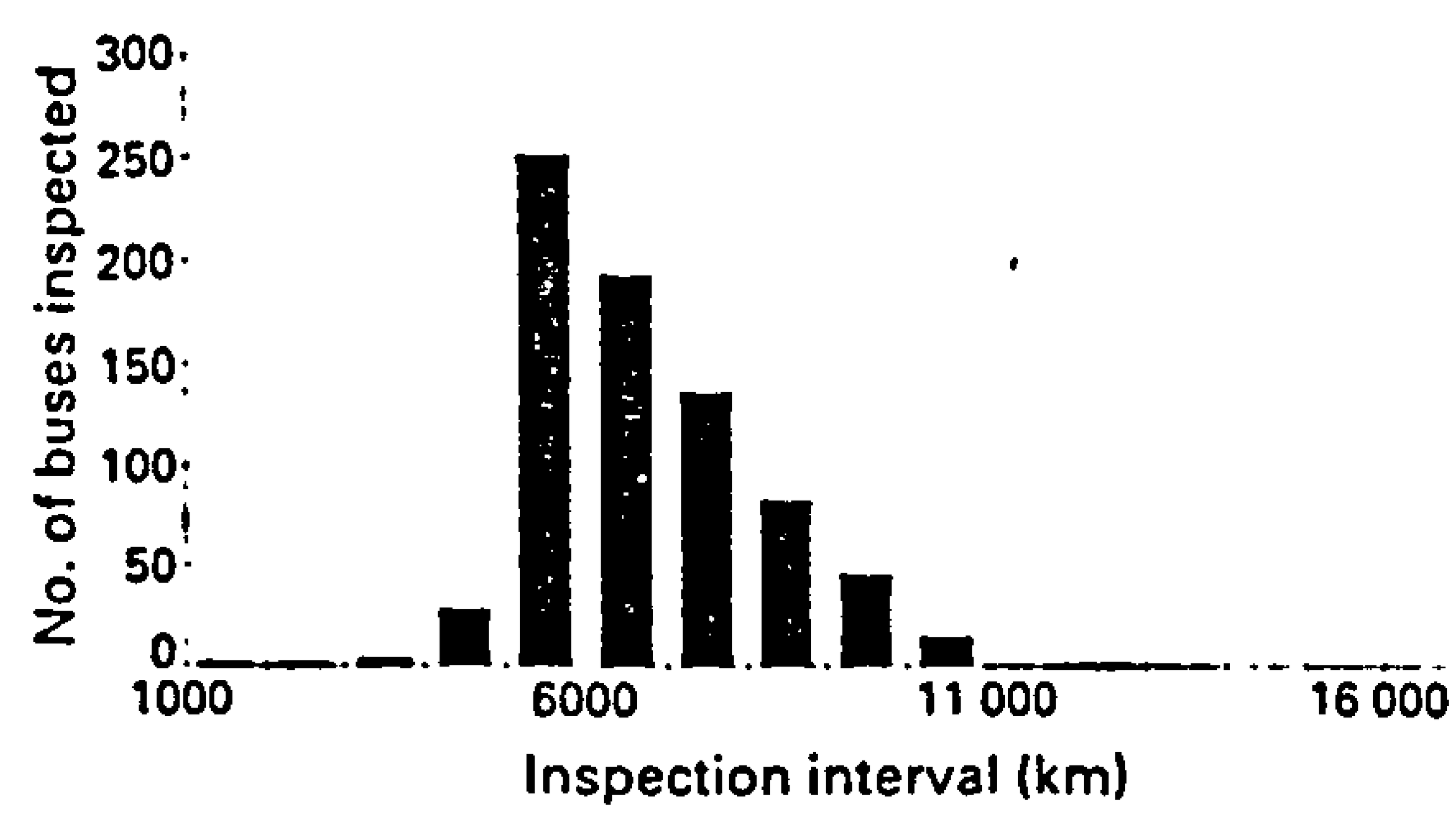


FIG. 6. *Inspection frequency distribution (St Henri garage).*

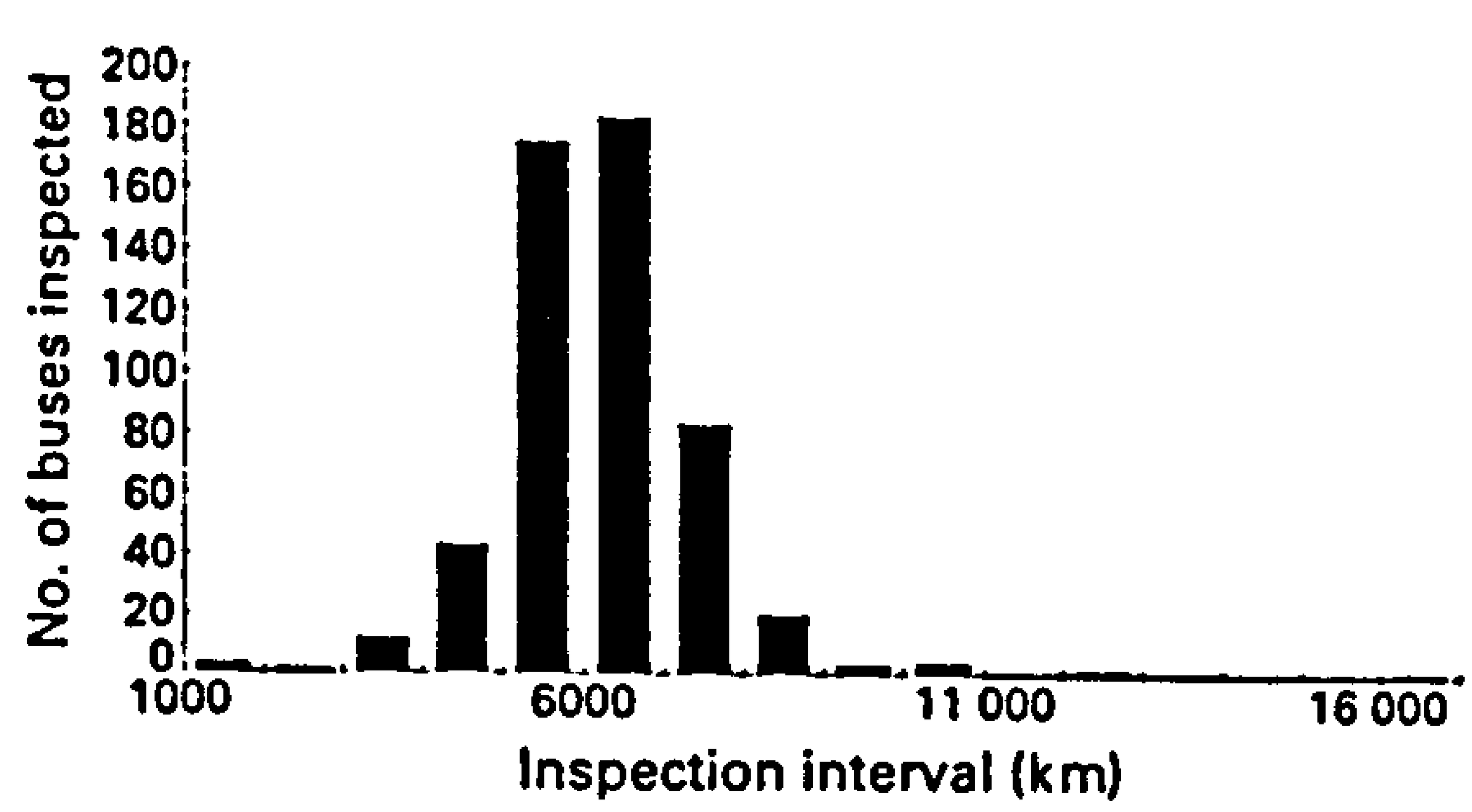


FIG. 7. *Inspection frequency distribution (Frontenac garage).*

The modelling process thereafter developed is concerned with the relationship between mean arrival rate of breakdowns and inspection frequency and also with minimising downtime or conversely increasing availability; success is identified by significant cost savings. The modelling process as suggested by Christer and Waller[57] based on *"delay time"* as discussed in Chapter 5 of this investigation is suggested as a possible alternative approach to modelling such a problem. This may be applicable if a tight inspection policy is adopted which was not the case as discussed by Jardine. It is worth noting that the use of a *delay time* approach requires an estimate of the probability density function f(h) of delay time h, "which in practice may be a difficult task". This was indeed the case as encountered for the building application of *delay time* attempted in Chapter 5. Whether this idea as presented by Jardine, with the exclusion of *downtime* (which is not as applicable in housing response maintenance) can be utilised in building maintenance situations where inspection systems are in operation and consequential variations in the arrival rate of repair demands can be identified remains to be tested and, in another forum.

For some specialised building types planned preventive maintenance may be an important aspect of the overall maintenance strategy. However we believe that it does not have a significant role to play in housing maintenance in general. One application for p.p.m would of course be central heating boilers where regular servicing is carried out as part of a maintenance contract with say, the Gas Board, as was the case with the Local Authority studied by this investigation. Whether or not p.p.m is worthwhile as a measure for preventing or reducing random *failure* of appliances is the subject of an OR paper by Baker[77] entitled "Testing the Efficiency of Preventive Maintenance". The objective of the paper is to "find out from data whether p.p.m's are having any effect, and to do so using only objective data likely to be available". The idea is to find out something about the existing p.p.m before changing it. This is distinct from determining the optimal interval between p.p.m's as by say Jardine[6]. Baker asserts that this approach is rarely taken in reliability literature and that statistical literature does not provide many "clues" as to how it may be tackled. Baker suggests two alternative null hypothesis which could be tested, one being that p.p.m had no effect at all. The requirements of the *test* are listed and the idea of partial likelihood explained. Data from various systems are tested including diesel engines in submarines, and medical equipment including two types of infusion pumps and ECG machines. The test thus devised proved to be fairly easy to use and to give results consistent with other conclusions drawn. Such approaches may be useful in checking the efficiency of p.p.m's on sophisticated service systems in complex specialised intelligent buildings. This yet remains to be tested.

Chapter 4 of this investigation uses a simulation technique to model among other things manpower requirements when faced with fluctuating demands for service. Simulation techniques are quite common in OR applications. Although unrelated to the issues addressed by this research an example of an OR simulation is "A System Dynamics Model of Submarine Operations and Maintenance Schedules", by Coyle and Gardiner[78]. This is of course a different kind of maintenance and scheduling from that attempted by this study, nevertheless the ideas and methodology may spark of other ideas since we believe there is potential for further simulation applications, yet to be developed, in building maintenance systems as a whole and in establishing interactions in general. There is a need to consider the maintenance and dependencies within the housing maintenance context and this idea is further developed in Chapter 2 of this study. A schematic influence diagram for the submarine maintenance and replacement scheduling is shown below.

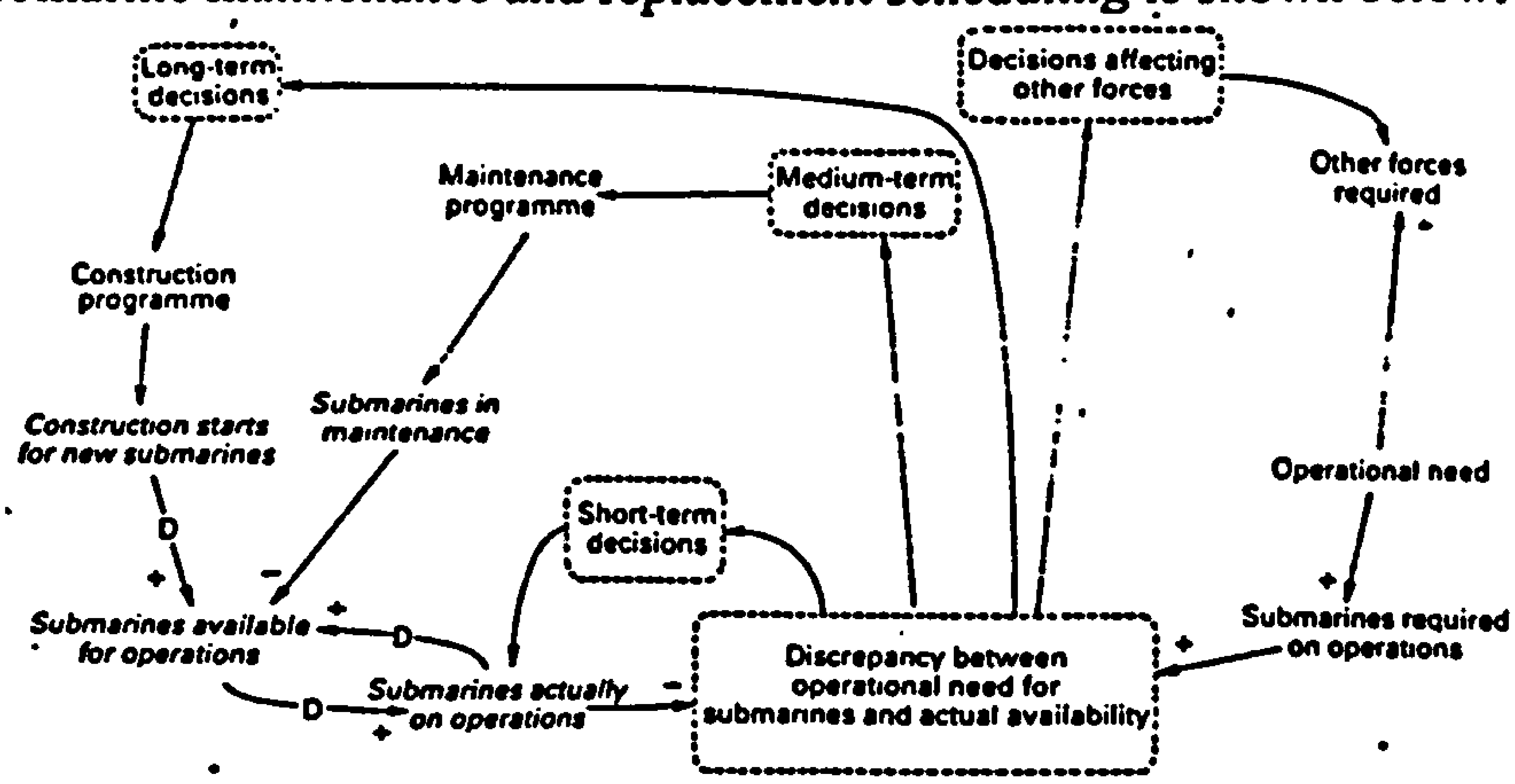


FIG. 1. Schematic influence diagram for the problem.

An inspection model for production plant ie a "Machine Dominant Manufacturing Process" is given in a paper by Lee and Park[81] entitled "Joint Determination of Production Cycle and Inspection Intervals in a Deteriorating Production System". The technique involves minimising the expected total cost of producing items for sale which have been manufactured by a deteriorating production system. The system at some point ceases to operate effectively and in an "out of control state" manufactures a number of defective items until this is noticed at an inspection sometime during the production run. The costs incurred arise from setting up, inventory holdings, inspections, restoring plant, selling defective items (warranty) and reworking defective items not sold. Although the idea of minimising expected costs as a function of the inspection interval, as reproduced below is similar to that adopted in Chapter 5 of this investigation the problem is set within a mechanical unitary context and is a different type of problem to that tackled within a building response maintenance context in Chapter 5.

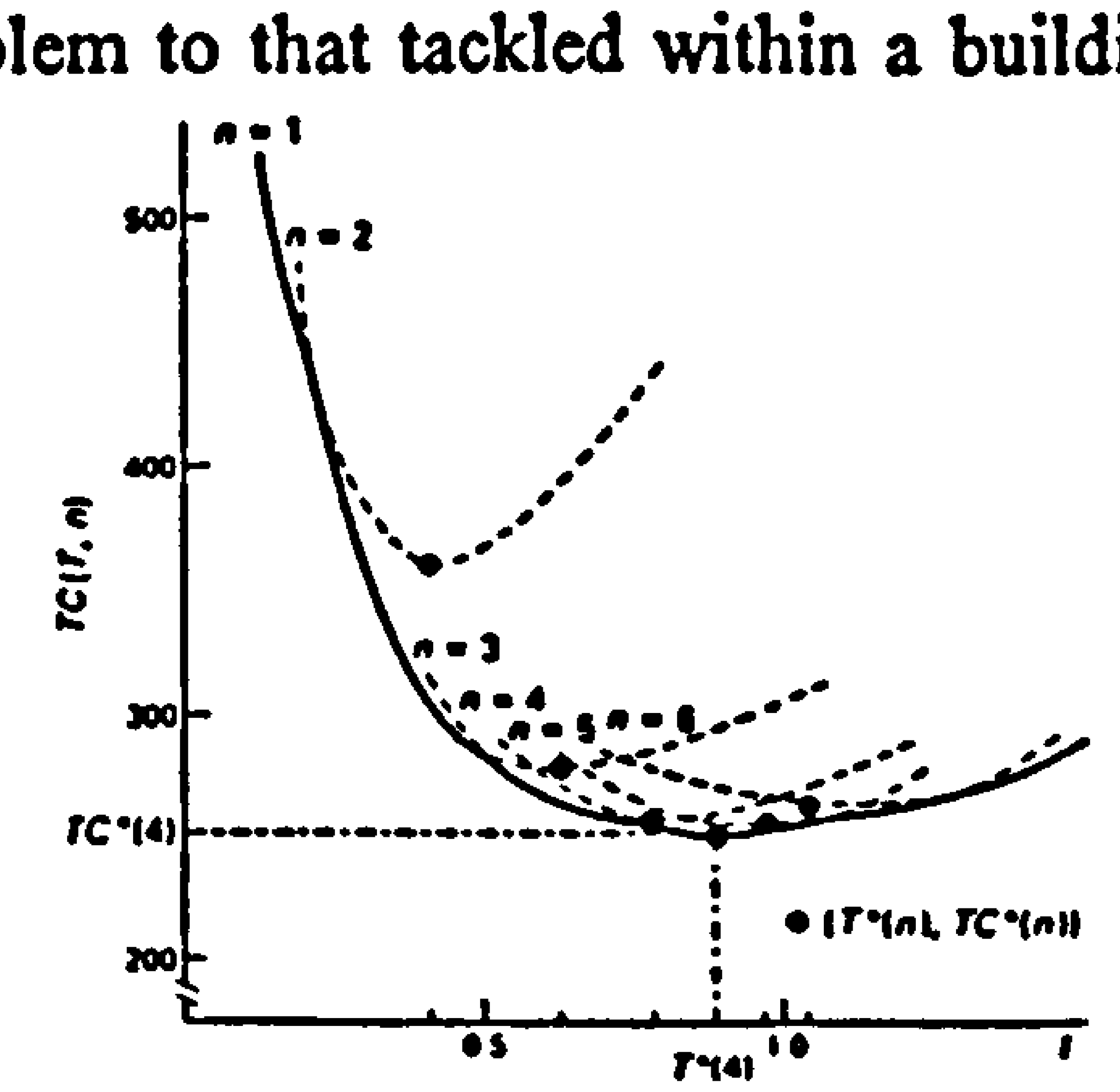


FIG. 1. Expected annual variable costs as a function of n and T.

The following are OR type contributions which have been directly or indirectly applied to building maintenance problems.

Two of the aspects of Planned Maintenance discussed earlier have been the subject of mathematical modelling by Christer[1][4]. The first involved a study of the economic and behavioural benefits accruing from purposefully delaying maintenance work. This involves clustering requests for service made by Tenants under a response repairs system into areas of higher geographical density for subsequent repair at some fixed point in time. This strategy was discussed earlier and described as cyclical maintenance and is further discussed in Chapter 4 of this study there referred to as zonal maintenance. The idea is to accumulate non-urgent repair requests then distribute these to tradesmen in selected bundles which reduce travelling time between individual jobs. Christer[1] uses a probability tree type analysis to derive percentage time savings achievable by reductions in travelling time between jobs. The numerical computations and analysis of this field study are presented by. Kavilondo in a thesis titled Modelling Resource Allocation For Building Maintenance[55]. The time savings derived above are referred to in Chapter 4 of this study where the potential to use probabilistic simulations to forecast likely bundles of work in the non-urgent category is discussed.

The second aspect of planned maintenance tackled by Christer[4] is the problematic issue of determining an optimal inspection cycle which minimises costs. The technique proposed by Christer requires that subjective estimates of the life span of defects can be made and to an extent is anologous to screening humans for cancer. The idea is to superimpose an inspection system upon an existing response maintenance system which enables defects to be identified for subsequent reparation ie either by planning the timing of repairs or by initiating preventive maintenance. Inspection cycles are investigated in this study and the reader is referred to Chapter 5 for a more exhaustive discussion.

Christer and Waller[56][57] apply the ideas discussed above to a delay time analysis and snapshot modelling to model the downtime consequences of a high speed production line maintained under an inspection system. A basic model of inspection maintenance applied to industrial plant is presented and the models for inspection maintenance problems are developed based on the downtime of plant and any economic consequences. The ideas presented there are adapted for application to building maintenance inspection systems in Chapter 5 of this investigation.

Painting cycles are also mathematically analysed by Christer[58] and a range of options are identified for housing and Local Authority Schools. Authorities are reported to have subjective assessments of painting cycles ranging from 3 to 14 years. As reported earlier the usual interval adopted (where possible) is a 5 yearly inspection, pre-paint repairs cycle.

The contribution by Ward[21] was instrumental in prompting the simulation of manpower demands created by fluctuating response maintenance demands developed in Chapter 4 of this study. Ward's efforts to resolve this issue are more fully discussed in Chapters 3 and 4 of this investigation.

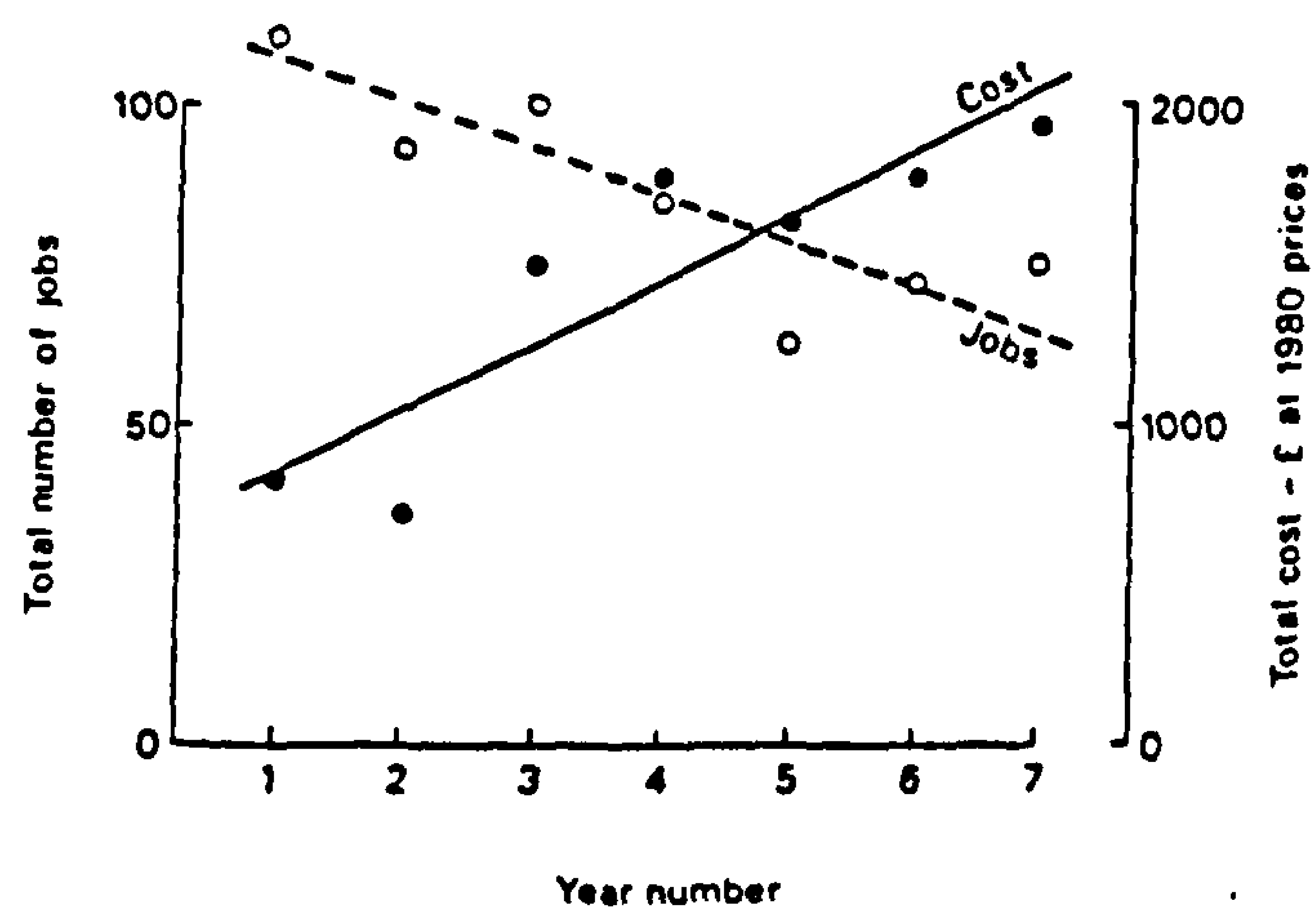
The Matching of Planning Systems To The Maintenance Work That is Actually Done by Skinner[2] suggests that the improvement of working methods on day to day repairs is *difficult* but the *potential is high.* The reliable appraisal of possible improvements depends on having details of repairs by time, type and place. As ever the focus is placed on planned maintenance however emphasis is placed on the need to ring fence and quantify day to day repairs and embrace these within a planned maintenance framework. Optimism is expressed for the potential to forecast specific kinds of work.

Skinner further suggests that planning systems are unlikely to be successful unless they are related to information on work actually done on buildings. Information, however, was lacking about work done by organisations making it difficult to assess the suitability of proposed planning systems. Princes Risborough Laboratory (PRL) had built up maintenance details of housing and schools and these showed that day to day repairs accounted for *more* than 50% of costs and 90% of jobs. These were small jobs completed mostly at short notice in response to what in practice are random failures by time, type and place. To facilitate a planning system which encompasses such jobs needs the application of computer technology. It is further suggested that this would enable the efficient execution of day to day repairs in the short term and provide management information on which to base reliable decisions about changes in strategies over the longer term. It is this possibility which this study tackles in a quantified way by using computer simulations developed in Chapter 4.

An analysis of how past experience of housing maintenance defects and their repair can be fed back to improve maintenance procedures and the design and construction of new buildings is presented by Skinner[59] of PRL. Five years of historical maintenance data were analysed by computer and used to forecast costs, number of jobs and replacement times of immersion heaters and outside door leaves during the next ie. sixth year. One hundred houses in each of three estates comprising roughly two thirds traditional and one third non-traditional forms of construction, were examined.

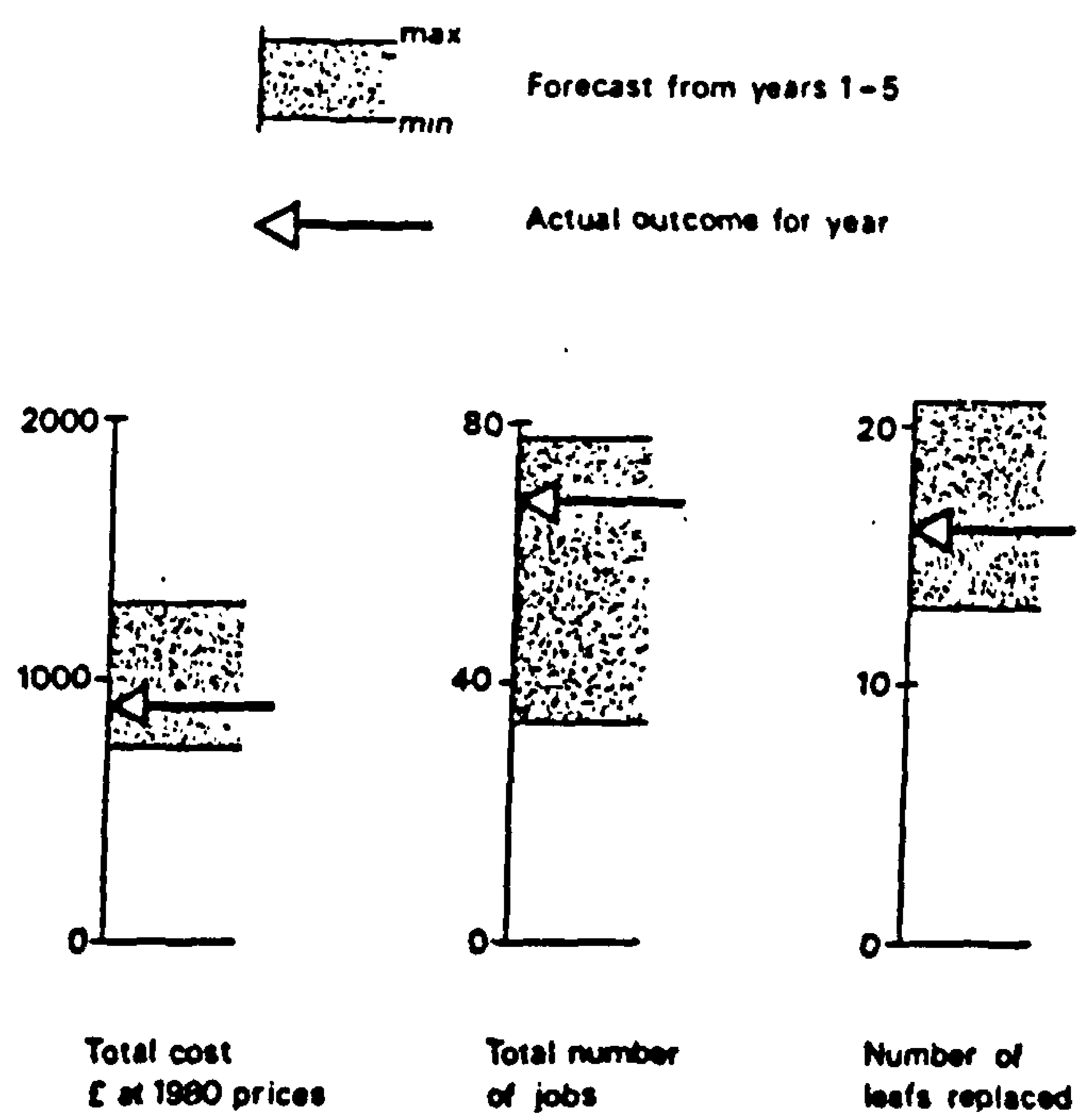
A coding system assigned to components, permitted a range of components to be analysed in terms of frequency and intervals between jobs. Age based replacement strategies for immersion heaters and external door leaves are identified as being forecastable. Fig 10 shows the results of trends with time for number of jobs and job costs for external doors. Fig 11 illustrates the estimated forecasts and actual outcomes for year six also for external doors. Skinner concludes that based on a growing databank of information on defects that the feedback from such data can "provide a quantified aid to better management and building design, and that it could provide a stimulus to better component design and lower life cycle costs".

Although outwith the scope of this study the decision on whether to renovate dwellings or demolish and rebuild is an issue now receiving attention by Management Science. The decision to renovate public sector housing in America at high cost without considering the option to demolish and rebuild is questioned by Gleeson[60]. The American Congress has authorised a large scale modernisation program of public sector housing beginning in 1992 and currently guidelines permit the cost of such projects to be as high as 60% of the cost of new build, which is an option not considered. Gleeson has developed a mathematical model based on reliability theory (the survivor function) which allows a comparison of the cost effectiveness of renovation programmes with that of the cost of new build.



All doors in estates 1 and 3 — trends with time

Fig 10



Estates 1 and 3 doors — forecasts for year 6 versus outcomes

Fig 11

The most recent International conference on building maintenance was held in Singapore in 1990. The proceedings of this symposium on Property Maintenance and Management are collated in Building Maintenance and Modernisation 1990[61] A wide range of maintenance issues are tackled with contributions from nearly seventy world wide specialists in the field.

With the exception of two papers by Christer[1][4] discussed earlier, none of the topics discussed, specifically target response maintenance for quantitative treatment, although Holmes[62] does make signficant comment on coding systems, computer applications, planned and response maintenance and the limited contribution of life cycle costing during the past ten years.

Various other management science or OR type of contributions are made towards the improvement of maintenance effort and although these are not germane to this investigation they may be of interest elsewhere. Briggs[64] applies renewal theory and spreadsheets to predict optimum replacement strategies for components of buildings and building systems and the method is based on the "survivor function". However rehabilitation and newbuild are not compared as by Gleeson[60]. A theoretical decision model for building renewals based on the physical and functional condition of a building is presented by Coskunoglu and Moore[64] which minimises the cost function based on the physical and functional conditions of the building. Pugh[65] demonstrates an alternative approach to economic modelling to establishing costs and benefits of rehabilitating buildings. Many authorities will have flat or low pitch roofed housing which are likely to be replaced during major refurbishment programs. However several optimal replacement strategies have been developed including that by Bailey and Brotherson[66] using a programme called Roofer. Two alternative theoretical decision models for flat roof replacement are given by James and Green[67] together with an inspection model for gulleys; maintenance policies for internal decoration and a tap washer replacement strategy. In the same publication, Recent Developments in Building Maintenance edited by Gibson[68] much useful research and a range of topics is presented, including, Effect of Design on Maintenance, Durability of Materials and the Use of Decorative and Protective Coatings. The reader is referred to the text for details.

A review of building maintenance literature in general between 1970 and 1984 is presented in the Chartered Institute of Building[79] booklet which summarises 825 contributions to building maintenance research and developments. This serves to indicate the vast amount of work undertaken in this field.

The search for Local Authority housing maintenance publications some of which were referred to earlier was conducted using the "ICONDA" (1976 - March 1992) system, used by the William Harley Library at Glasgow Polytechnic.

A *final plea* by Britton[80] in Management Research Needs - Maintenance 1990 is "Please do not give up research in maintenance management - we do need it even though we often appear too busy to listen. You will have difficulty in obtaining information from the harassed staff but we do need your help in the future".

Although much has been achieved more applied management science based research and developments are necessary especially in the areas identified by this research study.

1.9 Summary of the contents of the Rest of The Thesis

Chapter 2 examines how the changing Legislative framework of the eighties and the early nineties impact on the management and operational procedures of both Client and Contractor departments which are responsible for managing and delivering a response repairs service. The separation and isolation of Local Authority Client functions and former "inhouse" DLOs acting as contractors as enforced by the Legislation and any constraints on working practices are reviewed. The commercial survival options open to DLOs in a competitive environment are considered and the changing management structures during the late eighties adopted by the Authority which was the locus of this study are described. There is an account of the intricate information flow and decision making routines in operation during the course of this investigation.

The methods of allocating work to the DLO and locally based private contractors, prior to the introduction of the amendments to the Local Government Planning and Land Act in 1991 are reviewed, and their joint service delivery capacity is highlighted. As is necessary for the nineties Quality Schemes are identified and a set of performance indicators and performance consequences are suggested set against maintenance system control variables for both Client and Contractor Departments.

In Chapter 3 the maintenance repair service is described as a queuing system framed within target delivery response times. The significance of job arrivals, how these are prioritised and possibly queued is then explained. The data requirements for proposed modelling purposes and a data collection exercise which was undertaken to unearth the information necessary to construct models of response maintenance problems are described. Any limitations and difficulties encountered during this exercise are then critically reviewed.

The geographical division of the District under study is illustrated on an Estate by Estate, Ward by Ward basis giving the distribution of the housing stock within each. This is to enable combinations of various groups of dwellings to be achieved so that the impact of doing so is reflected in the incidence of repair requests. The seasonal fluctuations in jobs issued to contractors for three principal trades viz, Joinerwork, Plumberwork and Electricalwork are graphically presented and tabulated in spreadsheet format to illustrate arbitrarily selected combinations of estates.

Techniques available for compounding discrete empirical distributions as will be necessary to model the envisaged problems are discussed and a simulation method of doing so is identified. A previous effort at forecasting man job hours of work arriving is discussed and the rationale for an alternative, flexible and more robust approach to modelling these arrivals is explained. This is done using defined terminology consistent with Audit Commission usage.

Chapter 4 exposes a range of response maintenance problems which are analysed by simulating scenarios which create difficulties for managers of both Client and Contractor Departments. Computer programs are developed which permit, using random numbers, sampling from defined distributions to produce results which assist managers with dynamic decision making. In the first instance the number of jobs arriving per day, how long they are likely to take to complete, where they are likely to occur and which response category they are in are forecast. These outputs are then utilised to consider a statistical effect of grouping individual trades into a variety of trade amalgams. Time savings due to fewer access problems, inaccurate job description and specifications and travelling time between jobs are considered.

Manpower resourcing problems at contractor level caused by the fluctuations in daily bundles of work is specifically targetted as an area from which contractors' logistics problems stem. This situation is modelled in a way that enables contractors to begin to consider how to plan the deployment of the maintenance workforce and the idea is extended to accommodate the possibility of employing theoretical distributions in the event of future research proving their existence. The basic concepts are further developed by adapting the initial computer program for the purposes of controlling cost and predicting more statistically accurate costs of functional works contracts of variable sizes as enforced by Legislation.

The contentious issue of inspection intervals is tackled in Chapter 5. Knowing when or what to inspect or even if we should inspect are the subjects of much debate. This invariably boils down to the maintenance organisations commitment to inspect or not to inspect property for the purposes of introducing some planned repairs system. This has already been discussed in Section 1.8. The main concern is likely to be; are inspections cost effective, ie give value for money spent or do they simply provide information about the housing stock at a price. The thrust of Chapter 5 is direct towards testing a model to determine an optimal inspection cycle which minimised costs by savings which accrue from clustering identified defects for subsequent repair under a planned repairs scheme. The model is tested within what was at the time of the investigation, a purely response maintenance system and in times of strife. The results of this investigation although less convincing than hoped for do not rule out the potential for such analytical approaches to the problem of determining optimal inspection intervals.

Finally Chapter 6 draws conclusions and makes recommendation regarding future research based on the experience and learning accumulated from this study.

CHAPTER TWO

ADAPTING TO LEGISLATIVE REQUIREMENTS

2 THE CHANGING LEGISLATIVE FRAMEWORK AND SERVICE DELIVERY IMPLICATIONS

2.1 BRIEF HISTORICAL DEVELOPMENT

THE LOCAL GOVERNMENT PLANNING AND LAND ACT 1980 (THE ACT). Since the enforcement of the Act on 1st April 1982 and all other subsequent amendments up to 1st April 1991, legislative frames have been established within which Local Authorities and associated Direct Labour Organisations (DLOs) were required to discharge their respective duties. It is not the intention here to review in detail the impact of all successive amendments to the Act on the modus operandi of the delivery of the building maintenance service. It suffices to say that successive regulations tightened and reduced the operational reference frame within which Local Authorities were permitted to deliver the service. However it is important to examine how the maintenance system performance and maintenance management structures have been influenced by the introduction of the most recent amendments to the Act which for Local Authorities took effect on 1st October 1990 and for Development Bodies, for example Housing Associations, on 1st April 1991. To appreciate the scale and nature of any enforced changes in operational procedures we must of course also examine the Legislative framework immediately revoked by the regulations enforced from 1st October 1990.

In broad terms the implementation of successive regulations sought to achieve a phased in approach to a fully competitive, commercial environment which ensured that local authority DLOs and private contractors contested the right to execute building maintenance contracts by open competitive tendering for such contracts.

The clear aim of the Legislation was to attempt to ensure greater public accountability on the part of the Local Authority, and improved operational efficiency on the part of DLOs, out of which should emerge a more efficient and cost effective building maintenance service. It should be noted that similar Legislation was introduced in England and Wales on 1st April 1989.

2.2 LEGISLATIVE SUMMARY

2.2.1 Pre 1st October 1990

The salient features of the Act revoked by the 1990 regulations were as follows:

(a) DLOs with a workforce of THIRTY or less (referred to as the de minimis) in the preceding year who were employed for the purposes of effecting repairs, were exempt from the conditions of the Act.

(b) DLOs with a workforce greater than THIRTY were entitled to a competition free allowance of 40% of total revenue job costs.

(c) In addition to the competition free allowance; DLOs were entitled to all emergency work free from competition.

2.2.2 Current Legislation

The following Statutory Instruments revoke specific previous regulations within the Act.

(a) The Local Government (Direct Labour Organisations) (Competition) (Scotland) Regulations 1990, No 1782 (S.169).

(b) As above; (Specified Number of Employed Persons) (Scotland) Order 1990 No 1783 (S.170).

The significant changes contained within the above statutory instruments which have swingeing implications for Local Authorities and their associated DLOs, are:

(a) THE REMOVAL OF THE FORTY PER CENT COMPETITION FREE ALLOWANCE. This demands that, with the exception of REAL emergency work all response maintenance work must be won by submitting a tender in open competition.

(b) EMERGENCY WORK IS REDEFINED IN VERY STRICT TERMS. This prevents or inhibits any generous interpretation of what constitutes an emergency repair, thereby excluding a DLO from receiving many competition free repairs.

(c) The de minimis is reduced to a maintenance workforce of FIFTEEN from a previous limit of THIRTY. This obviously forces smaller DLOs into the competitive environment which previously were exempt from the conditions of the Act. This clearly reinforces the intention of the legislation bearing in mind that during the draft stages of the regulations the de minimis was at one stage reduced to FIVE.

(d) The number of contractors submitting tenders for contracts for maintenance work must include three other persons who are not Local Authorities or Development Bodies.
This inhibits, say, Local Authorities competing against each other, a situation which could culminate in the locus of a contract being arranged.
Additionally contractors cannot be excluded from the Tender list for non-commercial reasons.

(e) Local Authorities are prohibited from renewing maintenance contracts with their DLOs without first going out to tender.

In stipulating such specific tendering procedures the Act obviously seeks to prevent any practices which may restrict or distort in any way an open commercial, competitive environment.

(f) It is required that a separate revenue account be set up for the DLO.

Scottish Development Department circular No 22/90 paragraphs five and six broadly refer to the financial and Local Authority manpower implication ensuing from the implementation of the Act. The expectation is that increased competition leads to cost savings by:

(a) A private contractor winning contracts by submitting the lowest tender.

(b) Any contract won by a DLO has been a consequence of improved efficiency and competitiveness.

(c) A reduction in the DLO workforce may ensue with an increase in administration staff required to cope with increased tendering procedures.

(d) Savings should outweigh costs.

No rationale is however given which substantiates these expectations.

2.2.3 The Local Government (Scotland) Act 1988

Direct Labour Organisations (DLOs) Section 32 and Schedule 6

These parts of the above Act make amendments to Part III of the Local Government, Planning and Land Act 1980, which specifically relate to construction and maintenance work undertaken by DLOs.

Paragraph 3 amends Section 9 of the 1980 Act which regulates the power of local authorities to undertake Functional Work.

Paragraph 3(3) prohibits 'ANTI-COMPETITIVE BEHAVIOUR' when a contractor is being selected to undertake functional work which has been subject to competitive tendering procedures. The same paragraph also empowers the Secretary of State to regulate the contents of and procedures for handling maintenance contracts before and after Tenders for contracts have been invited. Section 7 of the Act defines how authorities must publish competition requirements and invite tenders for work to be undertaken. The Local Government Act also requires that detailed specifications are made available with a lead time commencing between three and six months before the actual formal tendering date.

Department of the Environment circular 19/88[10] and Scottish Development Department circular No 18/1988 note that competition on a large scale for "defined activities" eg functional work, which in this context is Response maintenance contracts; will be a new experience for both Client departments within defined authorities and maintenance contractors, DLO or otherwise. Additionally contractors should have adequate time to analyse the SCALE and the NATURE of maintenance work on offer before making the decision to bid for any Functional Works contract.

Sections 8(2), (4), (5) and (6) empowers the Secretary of State to regulate the manner in which tenders submitted from both private contractors and DLOs are handled and requires the publication of tender appraisals before the decision to whom the maintenance contract is to be awarded.

2.2.4 Anti-Competitive Behaviour

The Local Government Act does not define anti-competitive behaviour in any detail, however circulars 19/88 and 18/1988 suggests that it is for individual Authorities (client departments) to decide how to, package work; invite tenders; appraise competitive bids and mediate on other relevant matters subject to prevailing conditions, in such a way that prohibits anti-competitive acts.

Authorities behaving in the following ways could be deemed to be unfair and anti-competitive

(a) Packaging maintenance work in such large parcels which prohibits or inhibits small scale contractors from submitting a tender. It is worth noting that large or small scale building Response maintenance contracts will require to be executed by several different trades, the range of which may also vary with work packaging procedures.

(b) Giving new or less experienced maintenance contractors too little time in which to respond to tender invitations.

(c) Rejecting lower tenders from private contractors in favour of the "in house" DSO without good cause.

(d) Requesting detailed and sensitive information about private contractors which exceeds the data required to assess the competence of the contractor to successfully complete the maintenance work within fixed time targets.

(e) Requiring private contractors to carry excessive Performance bonds.

(f) Keeping work "in house" by using redundancy costs to offset lower tenders by private contractors during the second round of maintenance contract tendering.

Authorities indulging in such anti-competitive practices risk being sanctioned by the Secretary of State under Sections 13 and 14 of the Act and this could lead to the closure of the DSO in whole or part.

The Scottish Office; Environment Department Circular 6/1991 replaces some advice given in circular 18/1988. Of specific interest, in paragraphs 25-30 is the reference to the size of contracts and the requirement to consider *smaller work packages.*

Work falling below the de minimis cost threshold

Work carried out 'in house' during the previous financial year and not exceeding a gross cost of £100,000, need not be treated as a 'defined activity'.

2.2.5 Performance Indicators

One of the purposes of the Local Government Act is to make authorities set out clearly in specifications which are available for inspection by anybody with any interest, exactly what the authority intends to achieve by way of enhancement of any services which are subject to competitive tendering.

In the near future the Government's White Paper[20], "The Citizens Charter" may introduce the concept of Performance Indicators and require Local Authorities to furnish Tenants (customers) with sufficient information to enable the Client departments performance as housing managers to be judged. For building maintenance this information could include:*

(a) Housing Revenue Account (HRA) Utilisation

- i the number of dwellings benefiting from programmed maintenance funded from the HRA and the mean costs of repairs for these dwellings, together with a description of the scale and nature of the maintenance programs.
- ii the mean cost of response maintenance repairs which are funded from the HRA, together with data on size of housing stock and the duration of time repairs are taking to process and complete.

* From a paper by J Higham, IMBM Conference, Warwick University, April 1991

(b) Establishing procedures to assess and measure the level of Tenant satisfaction with the repairs service, making results available, and also submit the assessment model for inspection.

This list may be easily extended and the idea is further developed later in this Chapter.

2.2.6 Additional Legislative Frameworks

Many Acts of Parliament apply to Housing Management in general, some of which impinge to a greater or lesser extent on the delivery of the repairs service. Here we restrict attention to those Acts and sections within which may have the most significant bearing on the repairs service and for simplicity highlighting in general terms the meaning of the relevant sections of each Act.

Those wishing to investigate relevant Legislation in general should refer in the first instance to the reasonable summary given in the National Federation of Housing Association's publication[11].

(a) The Local Authorities (Goods and Services) Act 1970

To further compound the DLO managers' problem of attempting to achieve commercial survival and match the legislative demands the situation is exacerbated by the restrictive market opportunities imposed by the Goods and Services Act. This Act prohibits DLOs from seeking maintenance contracts outwith the Public sector unlike their competitors from the Private sector who continue to benefit considerably by having the flexible capacity to bid for and capture maintenance work from both the Public and Private sector markets.

(b) Defective Premises Act 1972

This Act requires that repairs are effected in a professional manner using proper materials. Likewise tenants must be protected from personal injury and also care and safety must be maintained.

Landlord and Tenant Act 1985

This Act imposes on any Landlord the requirement to keep the structure of premises properly maintained and ensure that all installations are in proper working order. With respect to such repairs Tenants should be made aware of the necessity for reporting defective elements as they arise and any procedures for doing so.

Housing Act 1985

This Act offers Tenants a "right to repair" scheme whereby Tenants may authorise the repair of a defect which is the Landlords responsibility. The Tenants may subsequently demand reimbursement from the Landlord.

Tenants are also given the right to choose a landlord and either buy outright or rent their council house.

We are unaware of any national statistic which would lead to the conclusion that the Tenants right to repair has a significant effect on the management of the repairs service. Indeed at local level within Strathkelvin it is an option which has had very little take up on the part of the Council Tenants(12). Likewise; within Strathkelvin; to date there is no sign that council Tenants are inclined to move outwith the Factorial control of the Local Authority, similarly Audit Report(8) indicates that this option has not been taken up by council tenants in England and Wales to any significant extent.

The statistics shown earlier in Section (1.12) Exhibit (1.1) indicate a significant constant increase in the sale of council houses. The significance of the reduction (of approximately 15%) in the housing stock since the implementation of the right to buy option on the delivery of the repairs service has not been tested. However the likelihood is that better properties are being sold, with a possible shift in the profile of council tenants in terms of, say, socioeconomic grouping. Exhibit (1.1) indicates that in spite of a reduction in the number of council houses, the number of repairs is increasing. This could by symptomatic of aging stock and or a policy to effect certain types of repairs within the revenue budget. It should be noted that a right to buy option was available within Strathkelvin before the enforcement of the relevant Act.

It is therefore possible to conclude that the existence of the Housing Act does not in any significant way affect the overall management of the maintenance system or the logistical procedures, devised at contractor level, which are aimed at the provision of an effective repairs service.

Obviously each individual authority requires to analyse the scale of any impact that legislative demands make on their maintenance system.

2.3 NEW HORIZONS OR BUSINESS AS USUAL?

2.3.1 Commercial Decisions

For some authorities the legislative changes in the Act of October 1990 may have an awesome effect on the modus operandi of all parties within a local authority involved in the delivery of building maintenance services. The requirement for a clear identification of separate client and contractor functions is obvious, with each having well defined duties and responsibilities.

The client department (landlord) must represent the tenants' needs and carefully balance the available revenue and capital budgets against the quality of the housing stock. Additionally the client department is required to devise contracts for both revenue and capital projects and associated tendering procedures which are accurate and which should be offered for bids in an open, fair and competitive way.

The contractor departments (DLOs) will need to absorb the full brunt of the legislation to survive within the local authority umbrella. Alternatively an existing DLO may seek to survive outwith the local authority and local government structures. Such decisions may be conditioned by political influences or state of art thinking and forward planning by some DLOs who may have anticipated the inevitability; that the legislation cometh; and are honed up for the challenges in advance. The course of action taken by a local authority and its DLO will be influenced by its perceived survival rating after an exhaustive analysis of the entire maintenance system set against the framework of The Audit Commission Reports(8)(13)(14). Report(13) is aimed at improved DLO performance where

Business Plans and Quality Schemes are well described. It is not the intention of this investigation to attempt to offer worldly advise on such complex business matters and those interested should refer initially to Jackson[15] and Dockray[16] for a discussion on the Audit Commission Reports and the possible options for a way forward open to a Local Authority and its DLO. These include:

(a) Stop trading forthwith: thus creating redundancies
(b) Phased run down of the DLO
(c) Accept redundancies and start again
(d) Sell out to trade buyers
(e) Arrange a Management Buy Out (MBO) by a management team
(f) Form a Local Authority Company; a half-way stage to an MBO
(g) Or business are usual; bigger business possibly, but business as usual

Management Buy Outs are the subject of an Audit Report.

Whichever avenue is chosen there will be a clear need for a Business Plan and clearer focussing on business opportunities available within or outwith the confines of the Goods and Services Act 1970.

Given that option (g) is selected, which was the case for the Authority which was the locus for this investigation, the procedures which define the Client and Contractor Department division must be initiated. A communication and committee structure is required which ensures that the integrity of Client function is preserved being reasonably free from elected member influences, but which is charged with managing the repairs system effectively and profitably.

Such a scenario does not alter the trading position of the Local Authority DLO which is still bounded by the legislative requirement to show a Rate of Return of 5% per annum. Failure to do so for three consecutive years could result in the Secretary of State stopping the operation of the DLO.

We therefore proceed on the premise that large response maintenance contracts for Local Authority housing will continue to be available for some considerable time to come and regardless of the maintenance contractor being from a Public or Private sector base. The influence of the current legislation on selected aspects of work planning and logistics is given primary consideration.

Exhibit (2.3.1) shows in summary the relationship existing between the parties and influences involved in the maintenance process and identifies the boundary conditions existing between each indicating the areas of conflict and empathy.

2.3.2 DLO New Initiatives

In attempting to face up to the challenges of the nineties, DLOs may require a reappraisal of current working practices and management philosophies.

A more commercial business approach may need to be adopted in terms of both competing for maintenance work packages and in delivering the service speedily and satisfactorily. Organisational procedures may be streamlined, leading to improved tendering strategies, seeking work from wider public sector sources, reviewing workforce deployment strategies and careful balancing of the mix of trades or alternative schemes.

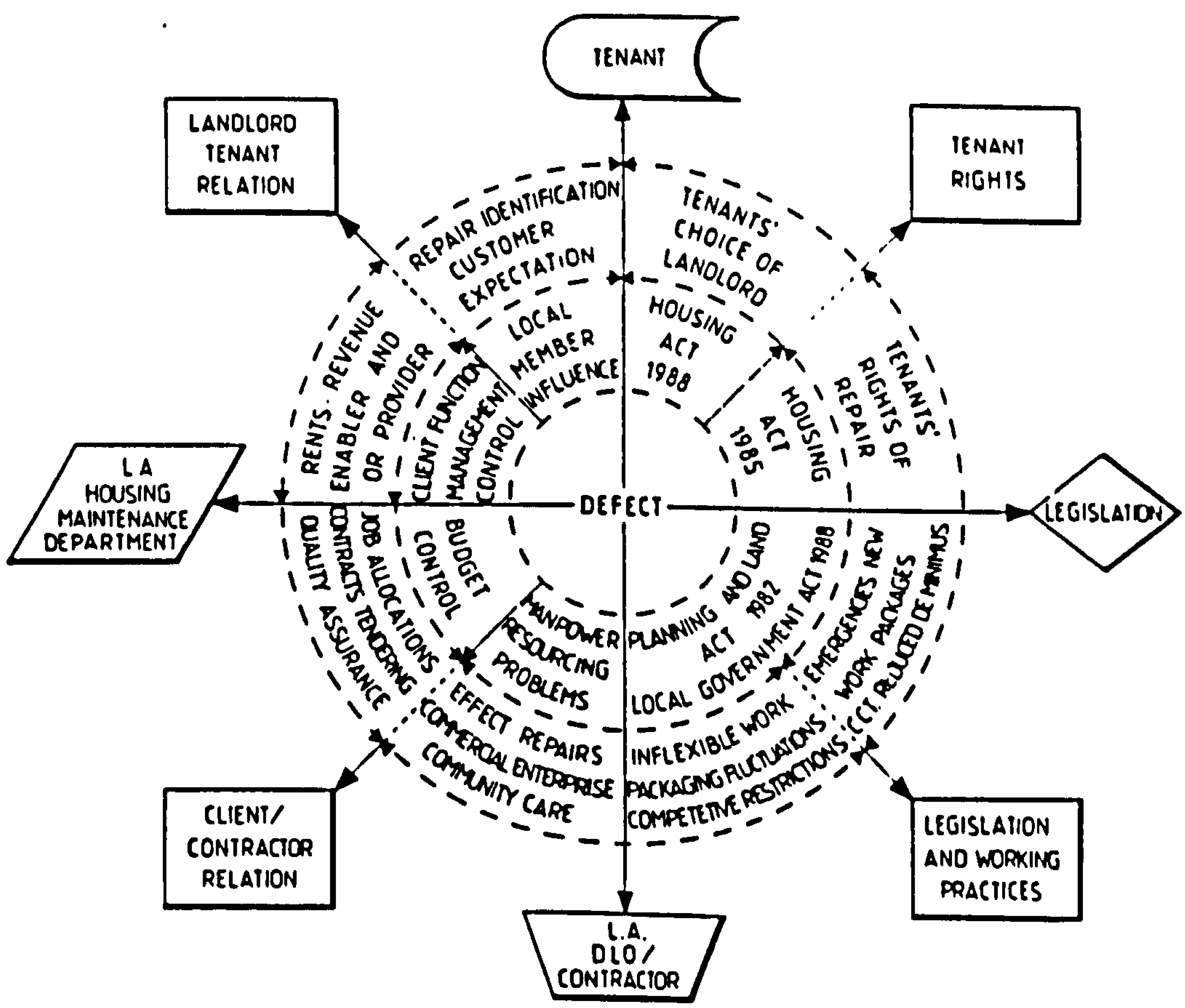


EXHIBIT 2.3.1

The Audit Report[13] provides a comprehensive review and analysis of operational procedures leading to more effective management of the service at contractor level. However, here in summary in view of the range of topics and extensive coverage given elsewhere we identify some of the areas of management concern which may impinge on the response maintenance problem and for which revised organisational strategies may be derived:

(a) Depot and or sub depot locations and management
(b) Transportation
(c) Area or Estate based teams and Zonal repairs
(d) Multitrade gangs and balance of Trades
(e) Multiskilled workforce
(f) Mobile units
(g) Work study and bonus schemes
(h) Monitoring response times
(i) Target completion times
(j) Post repair inspection systems
(k) Corporate image (style) and client satisfaction
(l) Job security and training schemes
(m) Stores and inventory policies

The list may be extended and it is prudent to acknowledge that private contractors aiming to compete with DLOs for response maintenance contracts may well benefit from a reappraisal of their current practices.

2.3.3 Local Authority Housing Management Initiatives

The strategic role of the housing maintenance management team must be clearly and carefully defined. Charged with the responsibility of delivering a near criticism free repairs service the maintenance management has an unenviable task, since the quality of the service is invariably judged by the tenants' perceptions backed possibly by those of elected members. That system performance should be totally judged by such criteria remains questionable. The question of whether to raise rent levels to finance revenue budgets may lead to an upward spiralling of tenant expectation which could result in increasing demands being made for a quality repairs service.

The lowering of the de minimis to fifteen forces more Client Departments to alter relationships with DLOs. Once again Local Authority maintenance management structures, the development of adequate organisational routines and attitudes to competition are well documented in Audit Commission Reports[8][13][14]. The problems of backlogs of repairs, house condition surveys and the anticipated turmoil occasioned by the requirements of compulsory competitive tendering have been exposed in England and Wales. At present no such surveys are completed for Scotland and the full scale of the maintenance problem is yet to be revealed.

The housing maintenance manager will be responsible for enforcement of policies and strategies devised by the Client Department which must ensure an effective and efficient maintenance service right from the time of receipt of a repair demand or the need for a repair is recognised; to time of the completion of that repair. The managers systems control regime for response repairs may include:

(a) Deployment of neighbourhood or Estate based management teams.
(b) Devising work packages to be put out to tender.
(c) Establish a schedule of rates and mediate on same.
(d) Selecting the maintenance contractor(s).
(e) Establish minimum service level requirements and monitor contractor performance.
(f) Introduce a penalty scheme and enforce same.
(g) Formulate response maintenance repair criteria.
(h) Enforce emergency repairs criteria.
(i) Initiate pre and post repair inspection policies.
(j) Monitor competition and tendering procedures.
(k) Control expenditure.
(l) Control the issuing of repairs to contractor(s).
(m) Set up Tenant/Client liaison routines.

There will of course be other control devices for planned maintenance, minor works and possibly (although unlikely) new building. Likewise other aspects such as rent collection, rent arrears and social problems etc come within the organisational remit. However this investigation is concerned with the Response Maintenance problem and only those aspects of the system which directly interface.

2.4 MANAGING THE CHANGE

2.4.1 Historical Development

Within Strathkelvin District the management structure of the building maintenance department has, over the years since the enforcement of The Act undergone two major changes, each aimed at meeting the challenges imposed by the legislation.

2.4.2 The First Significant Change

The first of these restructuring exercises was initiated in 1984 on the recommendation of a management consultancy group. Prior to this both the Housing maintenance department and the direct works department (DLO) existed as autonomous groups which functioned under the control of the Director of Technical Services under whose aegis the Department of Technical Services was also controlled.

A new Department of Housing (Maintenance Services) was created under the control of a Chief Officer which amalgamated the Housing Maintenance Department and the DLO. Such a structure is widely referred to in the public sector as a single hatted organisation, that is, the Client and the DLO (contractor) departments are combined under a single Director. It is easy to say in retrospect that this structure clearly failed to anticipate the subsequent legislative demands for a distinct Client/Contractor division.

Exhibit (2.4.2) is a simplified representation of the above structure.

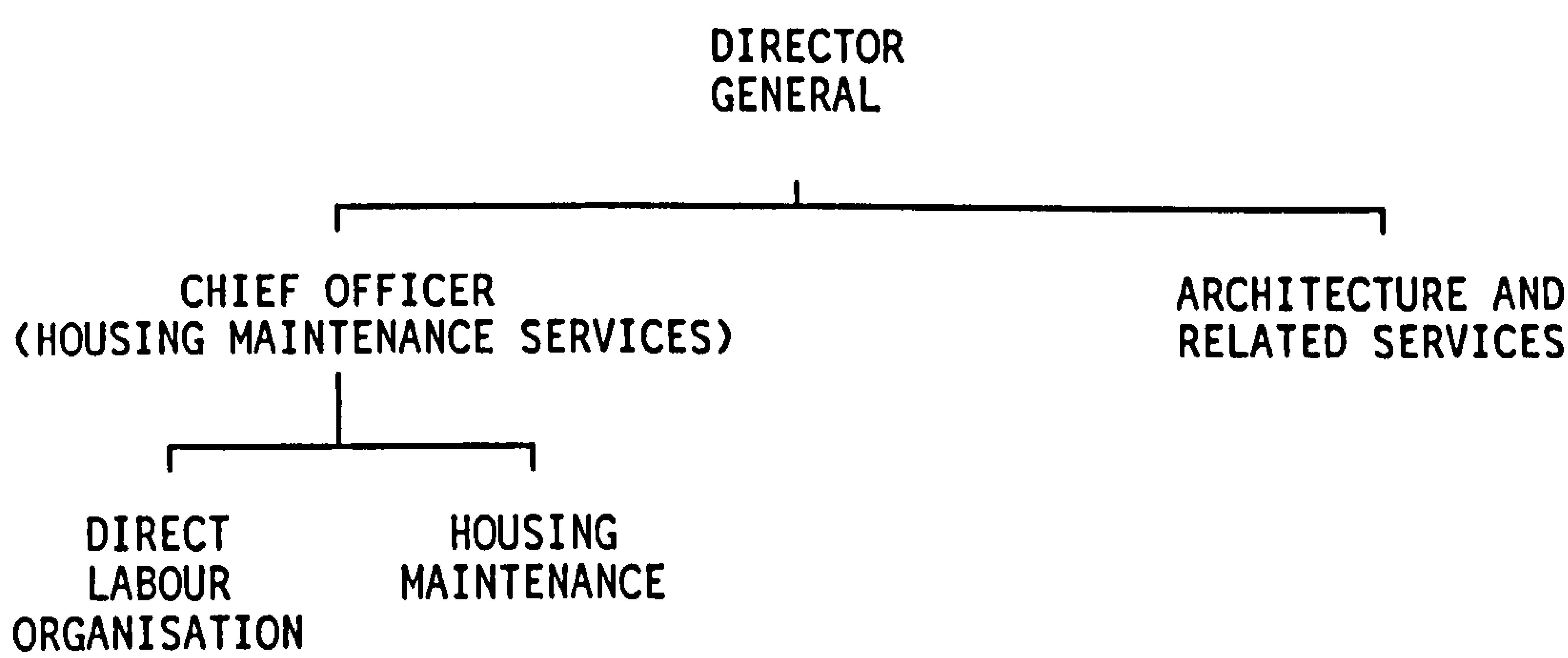


Exhibit (2.4.2)

Reports by the Chief Officer[17] described the historical modus operandi of both elements of the new department as "demand" led and referred to problems created by the "sheer volume" of work to be executed. In fact the real problem was an externally enforced policy that **all** repairs should be completed within seven (then shortly afterwards reduced to three) days.

The Chief Officer acknowledged the regulations of the Act at that time and made recommendations for changes to the inherited structure shown in Fig (1) Appendix (1). Significant among the proposed innovations were

(a) Enhancement of the existing, limited, computer systems.

(b) The introduction of a planned maintenance strategy to supplement the existing if modest cyclical maintenance program.

(c) New cost control procedures and tendering and specification capacities.

(d) Improved communications and radio controls.

(e) Introduction of work study techniques.

(f) Stores and inventory control procedures.

Although a division is shown between Housing and the DLO, in Fig (1), there is only one department.

At this time the District housing stock was for management purposes divided into eleven areas each controlled by a maintenance supervisor. These areas and the housing stock therein are given in Table 1, Appendix (1) together with Exhibits (1) and (2) which illustrate the information flow and decision making routines for both sections of the Housing Department. The pivotal role of the maintenance clerk is highlighted, since the degree of urgency or otherwise of the repair will to an extent rest with the clerk's interpretation of the Tenants' description of the defect.

It is worth noting that the DLO, Housing and the Local Authority Accounts sections all occupied different, and in the case of Housing, temporary accommodation, with the Architecture and Related Services being administered some five miles away.

There followed a period, during which the management of the new department could be described as traumatic and is therefore not considered suitable for discussion or contributory to progress.

2.4.3 The Second Significant Change

The second restructuring was proposed by mid 1985 following the appointment of a new Director of Housing and Architecture[18]. This approximately coincided with the completion of new Council premises in which was centralised all aspects of housing management, including maintenance, accounts, computing, architecture and related services and social welfare; thereby providing a "one door" approach to housing services.

Significant among the changes proposed in the organisational structure were;

(a) A return to a two hatted organisation with a distinct Client/Contractor split.

(b) The Establishment of Estate based management teams; five estates in total.

(c) The introduction of a development department within the Architecture department linked to the repairs services through the individual estate teams.

(d) A rationalisation of the Maintenance supervisors' duties.

(e) A clear focusing on the Tenant/Client department relationship and philosophy with the aim of providing a comprehensive servicing capacity.

(f) The establishment of specialist Accounts and Allocations sections, servicing all Estate teams in parallel.

A simplified version of the above "two hatted" or "three hatted" structure is shown in Exhibit (2.4.3)

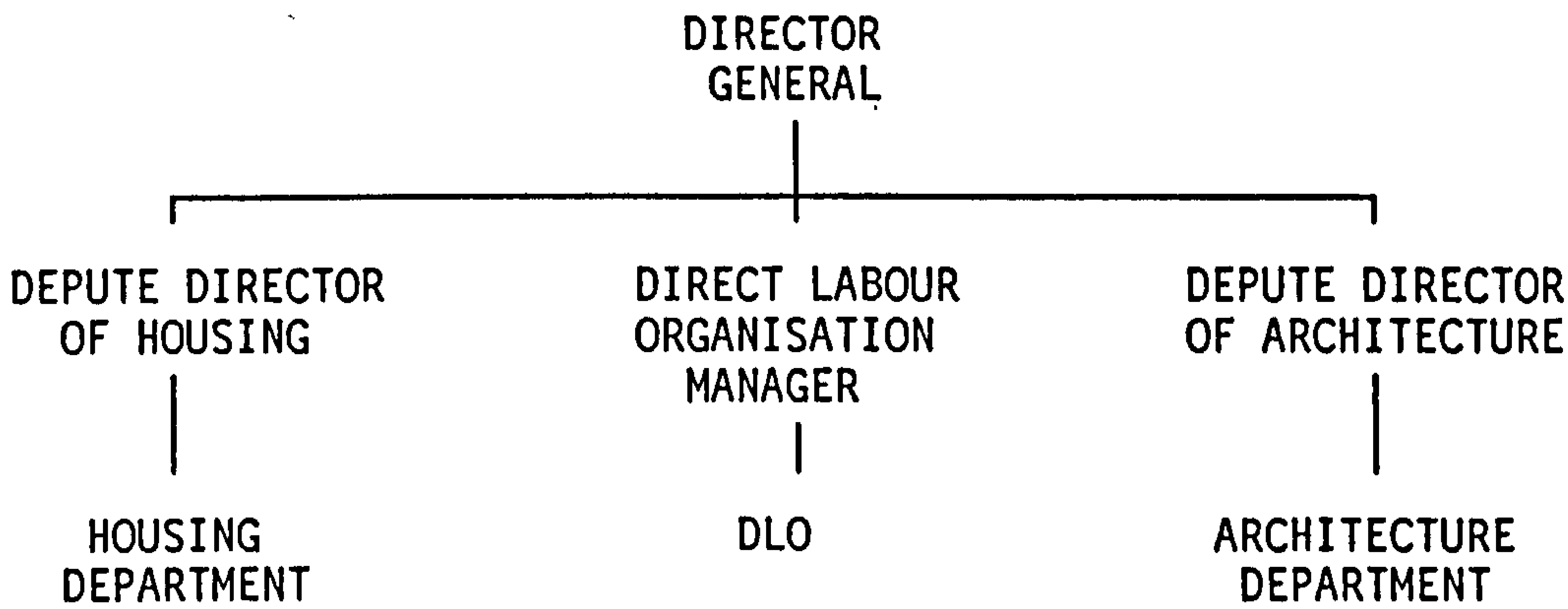


Exhibit (2.4.3)

The full new departmental structure is reproduced in Appendix (1) together with a summary of the functions of the Housing and Architecture departments subsections.

2.4.4 Restructuring the DLO (Community Maintenance Services)

The restructuring of the DLO was the subject of a separate report[19] which identified the District Council's commitment to preserve a community owned building maintenance services division which would meet any demands for competitiveness and provide an efficient and cost effective service. It also additionally recommended that the DLO be renamed "Community Maintenance Services" (CMS).

From the contents of report[19] the following notable recommendations are highlighted.

(a) A restructuring of the productive workforce to produce a balance of trades which more accurately reflected the perceived housing maintenance needs.

(b) The introduction of a more clearly defined stores and inventory policy to establish holding and ordering levels and best purchasing prices.

(c) A reviewing of the bonus scheme with the anticipated introduction of a schedule of rates, comprehensive job descriptions and associated minute value elements.

(d) The contractor services to be "tuned" to the needs of the Client Department.

(e) A requirement to win work by competitive tendering and the possible expansion of the current work loads.

(f) A need to translate work study findings into working practices.

(g) The current centralised location of CMS depot and resources to be retained.

(h) The enhancement of existing computer aided management systems.

(i) The introduction of a twenty four hour emergency housing repairs services.

2.4.5 Maintenance Workforce Operational Structure

The operational structure of the Community Maintenance Services (DLO) at August 1985 was as shown reproduced in Fig (2.4.5).

2.4.6 Installing the New Department of Housing and Architecture

This department was larger than previous organisational structures, involving the amalgamation and centralisation of all elemental services to provide a unified community oriented service.

As a consequence of this there followed a bedding in period, during which progress on this investigation was impeded, hardly surprising in view of the scale of the changes within the new premises; including setting up the Estated based Structure, staffing compliments and redesignations, communication systems, accounting procedures and woven throughout a computer based repairs and accounting system. Much time was therefore consumed re-entering the maintenance organisation and being aquainted with staff and operational procedures. However the following objectives were achieved

Direct Labour Organisation

Current operational structure August 1985

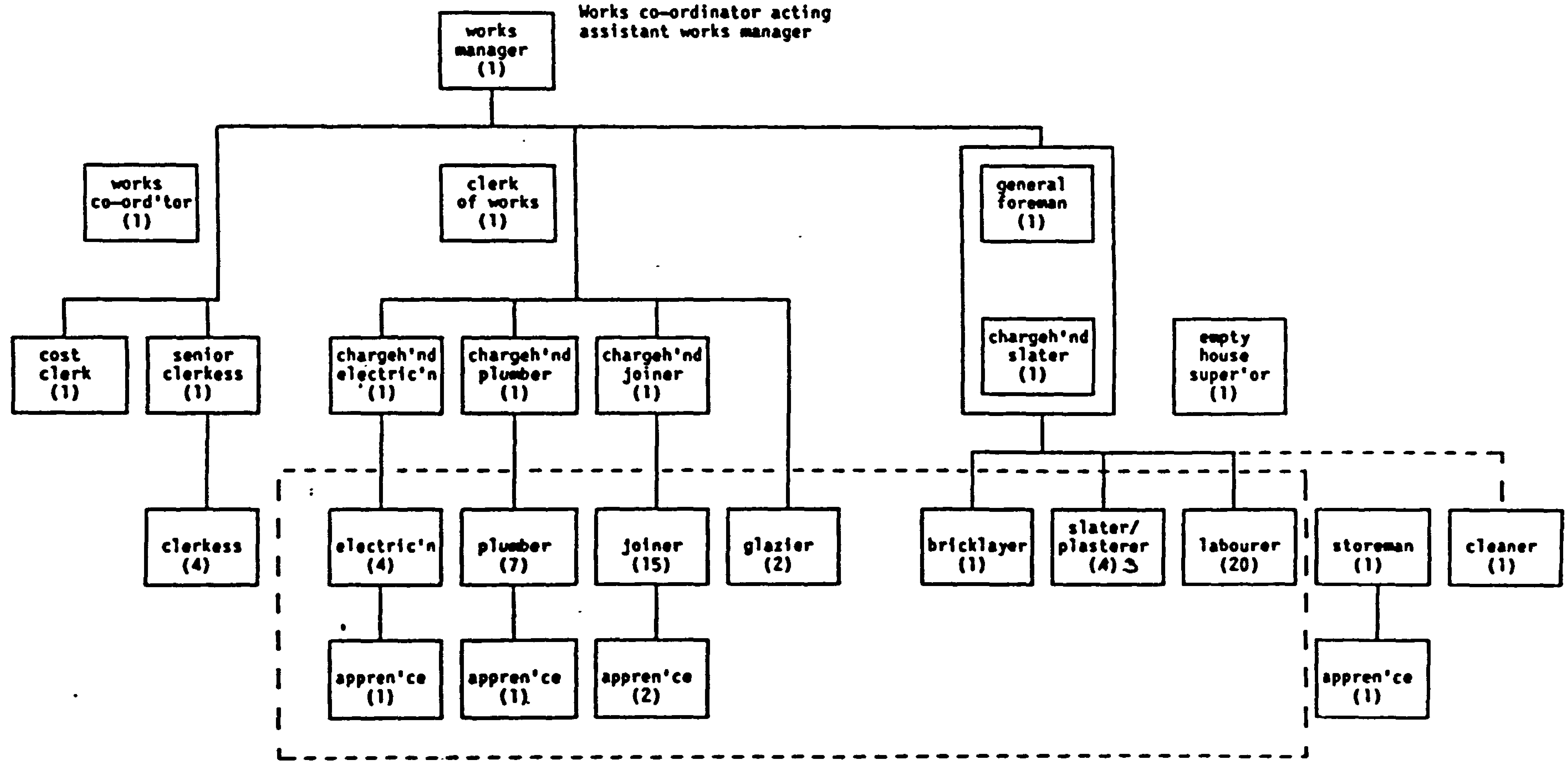


FIG 2.4.5

(a) An analysis of the new system routines from which was produced an information flow and decision making diagram. Such a diagram illustrates how Client functions of the repairs service interface with the CMS department; private contractors and the Development Unit of the Architecture Department.

(b) A review of the computer generated repairs service, data formatting, storage and retrieval procedures.

2.4.7 Information Flow and Decision Making Routines

The information flow diagram as shown in Exhibit (3) Appendix (1) applies to each individual Estate and traces the possible paths taken by a Tenant generated response repair request from receipt by the maintenance clerk right through to the completion of the repair by a contractor, CMS or Private. The routes then proceed to the various budget accounts.

The decision routines defined apply to the period during which the forty percent competition free allowance for CMS was in vogue and a large pool of private contractors was available to effect the remainder of repairs. The most recent regulations envoked by the Act (1990) will not significantly alter these routines given that it is quite conceivable that more than one contractor could be sharing response repairs budget. It is acknowledged that alternative methods of representing the decision variables may be devised and tailored to an individual organisations requirements. What is important is that effective management exists, communication is swift and that decisions follow the proper consultative process. In this respect the role of the maintenance clerks and maintenance supervisors will remain relatively unchanged and as outlined for the previous organisational structure shown and discussed in Appendix (1).

Exhibit (3) identifies the following three budgets used for accounting procedures.

(a) Revenue: this budget is used to fund repairs in the Response category.

(b) Capital: allocated for the funding of New Build, Planned maintenance, minor works, or as illustrated in Exhibit (3) large scale repairs deflected out of the response category by maintenance supervisors and the Development Unit.

(c) Capital Quota: this is a sum of money allocated from the capital budget to fund the replacement of selected defective items identified through the response repairs system. An example of this would be the replacement of wash hand basins, wc's and baths.

The above comments are necessarily brief since it is not the intention here to discuss the intricacies of accounting procedures or methods of raising money to finance maintenance operations.

2.4.8 CMS and Private Contractor Response Capacities

The response repairs service represented by Exhibit (3) is fairly flexible and with the total workforce capacity available there should be no difficulty in accommodating variable repair demands. The ability to do so is of course contingent on the provision of adequate funds and also that the contractors are allowed to phase work loads within prescribed time limits.

Repairs may be deflected to the most suitable contractor selected from say locally based private contractors depending on trade specialisations and location of repair or from the local DLO for the same reasons.

Within the recently imposed legislative framework, this degree of flexibility is severely restricted since the possibility exists that a single contractor could win an entire response maintenance contract, which contractor would require to be able to provide a range of trade skills at a manpower level which can match the demand for services. The service delivery boundaries are therefore more rigid and that a single contractor can overcome the ensuing challenges is largely untested.

The existing CMS department posesses a multi disciplinary trade workforce and organisational routines as may be defined by Exhibit (3) and any subsequent updates.

Within Strathkelvin private contractors were largely single trade firms with a few exceptions where a limited range of trade amalgams were available. This is fairly typical of the building industry in general where the sub contracting of work is widespread even for very large contracts. Therefore that private contracts can provide an autonomous repair delivery service is likewise to be proved convincingly.

2.5 THE MAINTENANCE SYSTEM

2.5.1 Defining System Response Times

The organisational and heirarchical decision making routines for individual repairs are fully described in (Appendix 1) are, where relevant, referred to here. Exhibit 2.5 shows a simplified schematic flow diagram of the maintenance system illustrating how the Client and Contractor departments interface. Only one contractor is identified since in the compulsory, competitive, tendering environment there should be no distinction between a public sector contractor (DLO) and a private contractor, although a distinction may be drawn between each, contingent on the impact that legislative changes may have.

The system discussed is referred to as a multicapacity repairs service in that all commonly required trades are available to effect repairs and that the repairs demand is such as to require several tradesmen within each individual trade. However it is acknowledged that very small authorities may cope with maintenance demands using only a few selected tradesmen.

For convenience in Exhibit 2.5 the epochs, T_A, T_R, T_S and T_C are identified and these are reproduced in Exhibit 2.5a.

THE CLIENT DELAY TIME (CDT) = $(T_R - T_A)$. This is the time lapsed before the contractor receives the order to execute a repair.

THE CONTRACTOR WAITING TIME (CWT) = $(T_S - T_R)$. This is the time taken by the contractor to issue the order to the tradesman to effect a repair.

THE SERVICING TIME (ST) = (T_C - T_S). This is the time allocated by the contractor to the tradesman within which the repair must be effected, and includes the job completion time.

THE CONTRACTOR RESPONSE TIME (CRT) = (T_R - T_C). This is the time taken by the Contractor department to process, prioritise and effect the repair.

THE SYSTEM RESPONSE TIME (SRT) = (T_A - T_C). This is the total time a repair request remains in the system.

It is important to carefully identify and distinguish between these "system times". In the event of customer complaints it may be necessary to determine which Department was principally responsible for any delay in delivering the service.

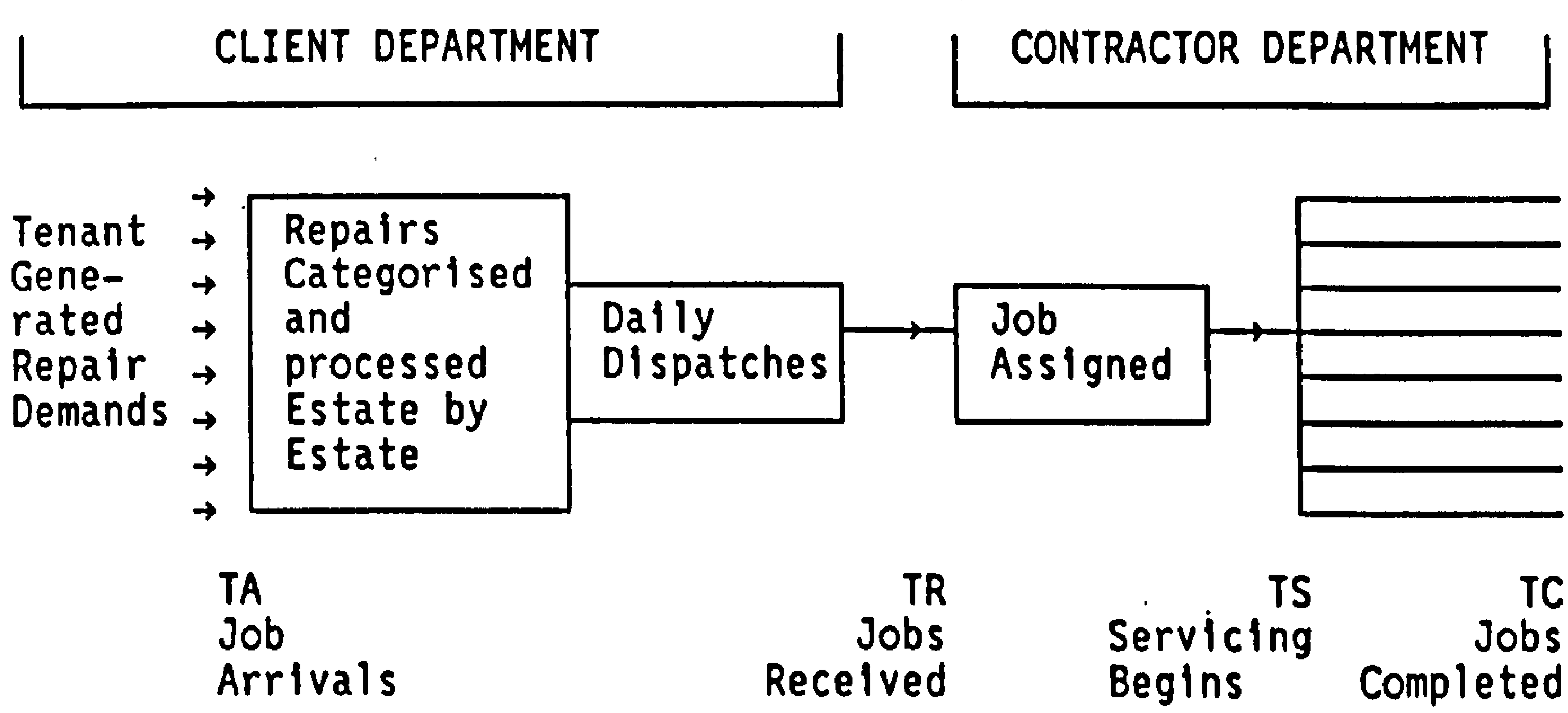


Exhibit 2.5

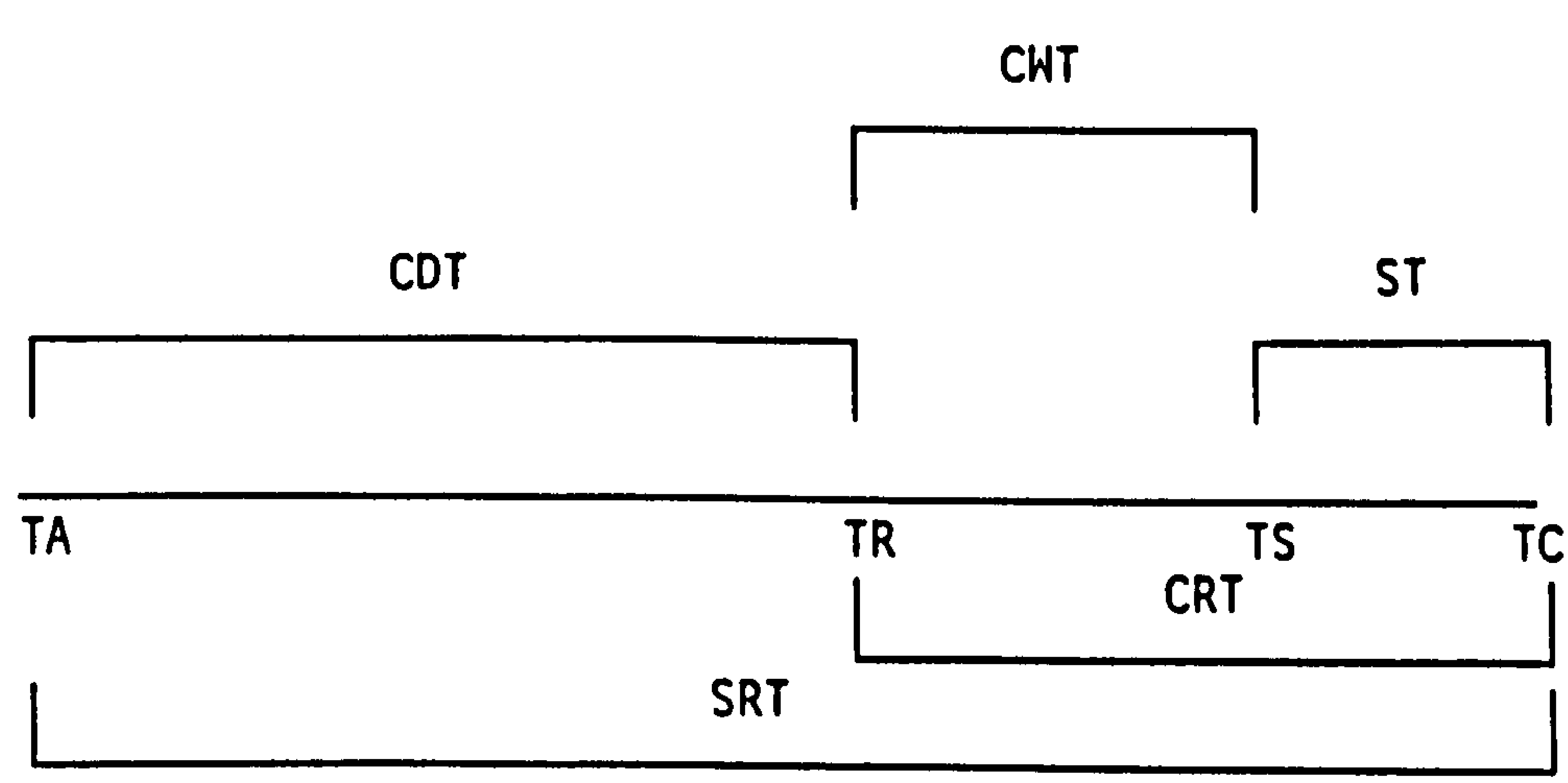


Exhibit 2.5a
The Maintenance System Simplified

2.5.2 Defining Roles

Both the client and contractor departments are required to execute their respective functions within certain time constraints and each must ensure that certain duties are fulfilled, principal among which are the following:

CLIENT DEPARTMENT DUTIES

(a) CONTROLLING the SYSTEM RESPONSE TIME of individual repairs
(b) ASSIGNING realistic TARGET RESPONSE TIMES
(c) MONITORING contractors actual RESPONSE TIMES
(d) MONITORING the QUALITY of completed repair and attendant service
(e) CONTROLLING monthly and annual budget EXPENDITURE
(f) ENSURING customer CARE and SATISFACTION

CONTRACTOR DEPARTMENT DUTIES

(a) MATCHING the TARGET RESPONSE TIMES allocated by the client department
(b) COMPLYING with the terms of specifications and schedules of rates
(c) MONITORING jobs costs, bonus schemes and profit margins
(d) ENSURING an even flow and DISTRIBUTION of work across a range of trades and skills
(e) PROVIDE an EFFICIENT and EFFECTIVE service at a competitive price

Now from Exhibits 2.5 and 2.5a it is possible to identify where two distinct queues in series may develop.

The first potential queue which occurs during the client delay time may be created by the Client department which may purposefully withhold the issuing of certain categories of repairs to the contractor for reasons which the Client department may perceive good cause.

The second queue which may occur is within the contractor response time. The Contractor department may be swamped by a surfeit of demands for repairs and may also be forced to consider a phased allocation of workload, while still attempting to work within prescribed time limits and retain commercial viability.

It is therefore evident that the Client and Contractor Departments are required to execute their respective functions faced with the difficult problem of harmonising unique and conflicting demands, with the likelihood of their respective roles being unsympathetic towards each other.

2.6 QUALITY ASSURANCE BS 5750

2.6.1 Quality Schemes and Building Maintenance

The idea of Quality Assurance schemes is nothing new. Certain forms of system building in the mid sixties were the subject of such a scheme which was never implemented and the production and delivery of Ready Mixed Concrete has arguably been controlled effectively by a Quality Scheme since the very early seventies.

Government initiatives led to the publication of a British Standard for Quality Assurance (BS 5750) in 1987. Within the construction industry in general progress on quality schemes is, arguably, slow. The establishment of a quality scheme for Local Authority housing maintenance services is at the moment formative and not even in draft form. Many elements which could be combined to produce a Quality Assurance Scheme for Local Authorities (QSLA) appear to be contained within say Audit Commission Reports and guidelines could be drafted to create a competence based reference frame to which Local Authority housing maintenance departments should comply to achieve accredited membership*. Obviously there is little point establishing such schemes without the monitoring and inspection processes necessary to ensure compliance or otherwise. It is not the aim here to attempt to initiate such schemes, but simply to acknowledge such a possibility.

Tentatively however, compliance clauses for a quality scheme could be framed around the following elements of the global management organisation.

(a) The management structure and lines of communication.
(b) Information flow and decision making routines.
(c) Processing orders and response times.

* Since writing, this idea has been underpinned by the possible future introduction of CHARTERMARK approved authorities[20].

(d) Information data bases/storaging and retrieval.

(e) Accounting system and data bases.

(f) Stock condition and attribute data bases.

(g) Work tendering procedures.

(h) Quality control checks.

(i) Research and Development.

(j) Supervision and Inspection levels.

(k) Technical and Administrative training schemes.

(l) Tenant Liasion schemes.

(m) Maintenance Strategies.

(n) Schedule of Rates.

The introduction of a quality scheme would not disallow individual approaches by authorities to solving problems since each may well experience situations which are unique. Instead the idea would be to attempt to develop progressive attitudes stemming from recommended uniform standards of behaviour.

2.6.2 Quality Systems

It is not an intention to attempt to devise a quality system for say large scale, low cost housing building maintenance organisations. To do so would require a full scale study by formally constituted committees representing the range of expertise required from a variety of parties within maintenance organisations and characterising the spectrum of Authorities, Development Bodies and other groups involve in such activities.

However establishing a quality system requires that an organisation's philosophies, policies and procedures are fully documented and set out to demonstrate, clearly, how it is to function to ensure a quality service is assured at a competitive price. It is therefore considered necessary to extend the aforegoing organisational/ management routines to include the concept of system control variables and performance measures (indicators) as touched on in Chapter 1.

Sound management routines may very well already exist within authorities and at best may only require to be exposed and clarified.

At worst the existing arrangements would be scrapped and possibly replaced. Many client departments will currently be organised on well grounded principles, however, for the interim, it is the DLOs which will suffer most hardship under the new legislative rules. Similarly private contractors embarking on major response maintenance contracts may well find the going tough and will require to adopt more sophisticated routines to survive not only the rigors of competition; but also the uncertainty of response maintenance workloads. It is therefore important that any contractor winning a response contract is able to demonstrate that it is procedurally competent to undertake and satisfactorily match any contractural requirements.

It is to be the responsibility of the client department to assess such capabilities which can best be evaluated within a structured organisational statement pivotal in which will be system performance measures (indicators). That client departments should blindly accept lowest tenders as a limiting criteria for contractor selection could be a prescription for chaos and quality denudification. The building industry is notorious for harbouring more than its fair share of 'cowboys' and even well meaning contractors may find difficulty in recruiting the right standard of tradesmen; whom it must be stressed; deal directly with the Tenants (customers) and therefore require to be versed in more than trade tool skills.

Arguably the nuclear elements of Quality System exposed in this investigation already exist as given in Appendix (1). For example the information flow and decision making routines etc and also by defining the System Response Times in Exhibit (2.5a). The idea is further extended by expanding the concept of system control variables and performance measures raised in Chapter 1, Fig (1.7) to accommodate the contemporary requirement for separate client and contractor departments. Each department still requires to interface and interact to greater or lesser extends contingent on the relationships between the authority and its DLO or any private contractor. There will be a need to monitor and modify performance with the likelihood that departments may work together to solve any problems or misunderstandings created by the new and enforced operational modes.

Exhibit (2.6.1) and (2.6.2) show the principal decision or control variables, perfomance indicators and possible consequences ensuing as a result of a lack of management control, or otherwise, for both Client and Contractor departments respectively. It is worth noting that Client departments, could, in the not too distant future, be forced to compete to win a contract to continue to be engaged as the enablers and managers of the housing maintenance service[20].

These structures are not advanced as definitive and are simply presented to indicate some problems which may arise and their origins. Indeed some performance indicators may be quite alien, notably job arrival frequencies and target time completion frequencies. However these will be the subject of more rigorous analysis in Chapter 4.

The interrelations and interactions of all of the variables is much more complex than these exhibits attempt to convey. Nevertheless it is important to formally expose and condense the maintenance systems before attempting to produce solutions; however embryonic; for what are very vexing management problems.

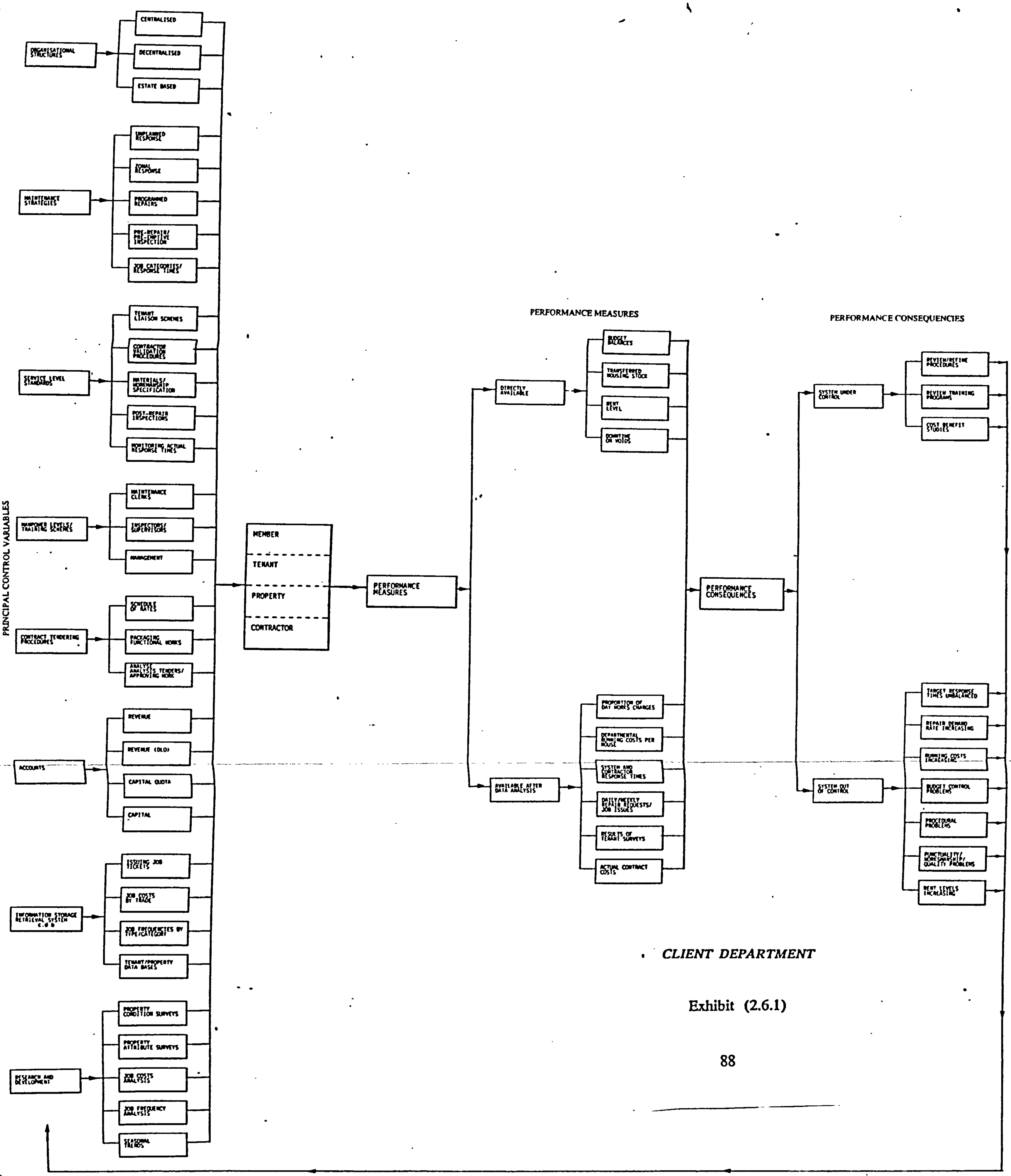
2.7 Summary: What This Chapter Does

This Chapter reviewes the various, relevant pieces of legislation implemented over the past ten years. Reference is made to relevant Statutory Instruments which explain how the legislation may be interpreted and the possible consequences which may ensure for Client and Contractor departments in the event of intervention by the Secretary of State. The possibility of a multitude of changes to traditional working practices is thus identified. Variable packaging of maintenance work, contract sizes, and anti-competitive behaviour are recognised as contentious issues.

The mechanisms which seek to polarise and create autonomous Client and Contractor departments are focussed on and a list of alternative commercial decision and initiatives which Authorities may pursue are reviewed.

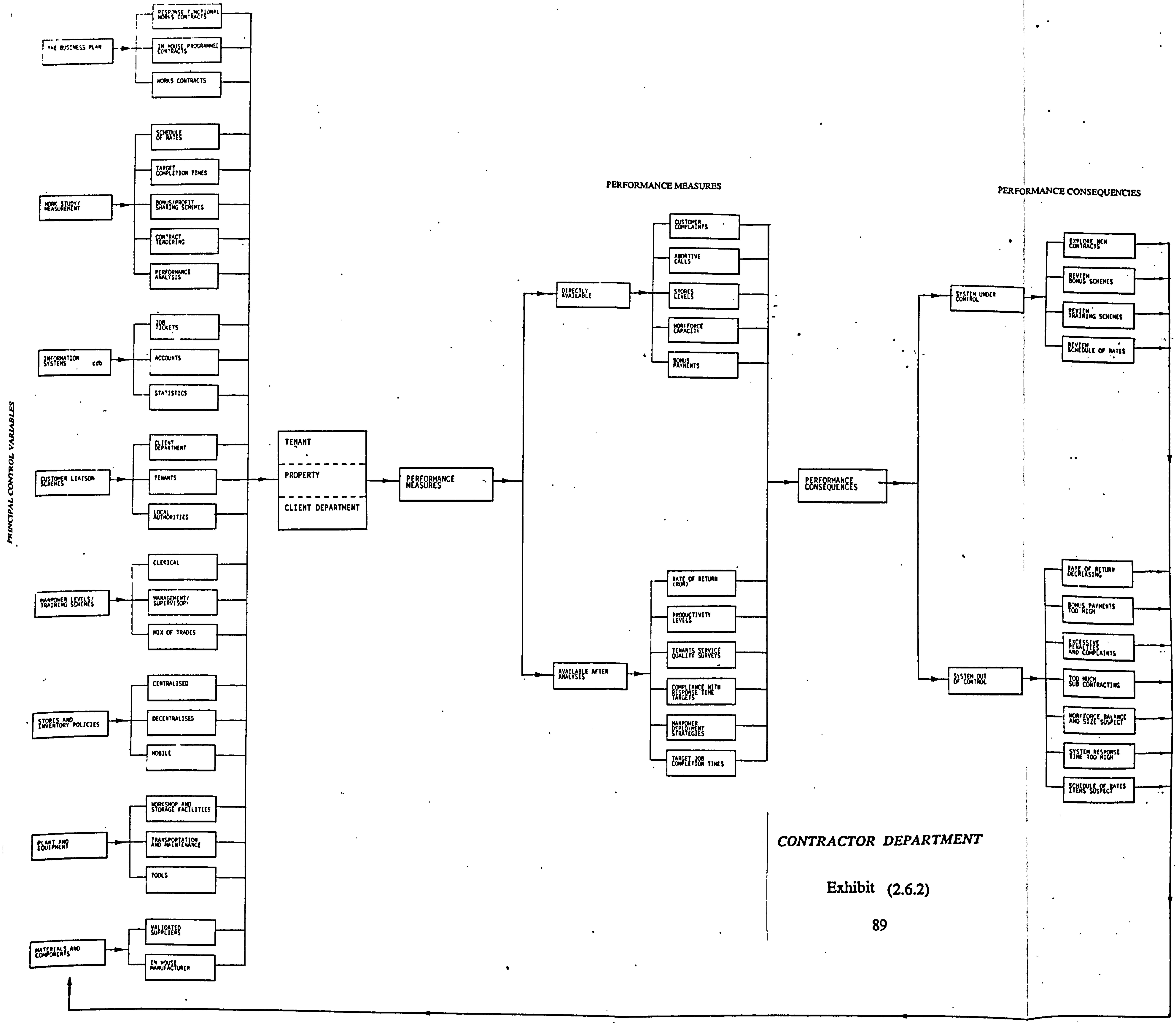
The changing management structures and modus operandi of the Local Authority which provided the data for this investigation are described and information flow and decision making routines formulated, up to a point in time prior to the enforcement of the 1990 Local Government Legislation.

Quality Assurance and Quality Schemes are considered and lists of possible Departmental functions and Performance Criteria for both Client and Contractor departments operating within current legislative requirements are proposed.



CLIENT DEPARTMENT

Exhibit (2.6.1)



CONTRACTOR DEPARTMENT

Exhibit (2.6.2)

CHAPTER THREE

A MODEL OF RESPONSE MAINTENANCE

AND

DATA COLLECTION

3.1 INTRODUCTION

This chapter prepares the background for the modelling processes developed in Chapter 4. Service level reference frames are discussed, job arrival patterns and service delivery characteristics are presented as a queuing model.

Data collection exercises and the problems inherent in obtaining relevant data and ensuing censoring problems are identified. Weekly job arrival patterns for three principal trades, namely joiner, plumber and electrical work are presented and flexible packaging of job arrival by Estates is demonstrated.

To provide solutions it is necessary to compound frequency distributions for independent random variables and techniques for achieving this are briefly discussed.

An historical modelling process developed by Ward[21] is reviewed and the need to produce more flexible and dynamic solutions is explained together with the range of frequency distributions necessary to construct a quantitative model. A time scale over which to test the model is also stipulated.

Finally target job completion times and how they are influenced by bonus schemes is discussed, so as to provide a standardised definition used in the modelling processes in Chapter Four.

3.2 RESPONSE TIMES AND JOB CATEGORIES

Each local authority will require to establish a reference-frame providing categories of work on a trade by trade basis against which realistic Target Response Times are set. Such a reference frame requires to be unequivocal thereby providing a benchmark for the evaluation of performance standards.

It would be counter-productive to select a frame which was arbitrary and was not set against a background of local experience. Published Target Response Times and categorisation of individual job types must be realistic and achievable and any penalty imposed on contractors for non-compliance with Target Response Times carefully and fairly measured.

The Target Response Time reference frame not only provides sieves to arrest unreasonable demand repair requests, it is the instrument used by the Client Department to exercise management control and also provides the motivation for the Contractor to maintain or improve efficacy.

On receipt of a repair request each job is identified by Estate and assigned a job priority coding. The priority classification system used may vary from Authority to Authority and in this study the classification is alphabetical with Target Response Times as shown in Table 3.2.1.

Table 3.2.1

JOB CATEGORY	PRIORITY RATING	TARGET RESPONSE TIME WITHIN/WORKING DAYS
A	Emergency	1
B	Urgent	2
C	Quite Urgent	5
D	Non-urgent (Routine)	20

The Audit Commission Report[8] suggests a classification system and Target Response Times as a model and this is shown in Table 3.2.2.

It should be noted that the emergency classification in Tables 3.2.1 and 3.2.2 are as defined prior to the introduction of recent legislation, see Chapter Two, Section 2.2.2.

Table 3.2.2

JOB CATEGORY	PRIORITY RATING	TARGET RESPONSE TIME WITHIN
E	Emergency	24 hrs
A	Urgent	7 days
B	Non-urgent	3 to 6 weeks

Examples of the types of repairs which fall into the categories given in Table 3.2.2 are also suggested in the above report. Each authority will have available its own published version of job types and respective categories for the guidance of the maintenance clerks.

3.3 JOB ARRIVAL PATTERNS

The job arrival pattern provides both the average rate of arrival of demand for repairs and the statistical distribution of job arrivals. In the maintenance system discussed here queues may develop in series each with different characteristic arrival patterns (refer to Section 2.5 in Chapter Two).

A demand to execute a repair, in the response maintenance situation is usually TENANT led and the frequency of individual job arrivals is influenced by many factors including, season, nature of the defect; socio-economic group; council member influences, extreme climatic conditions and so on.

Individual repair requests as received by the Client Department are generally acknowledged to be independent events which are almost completely random in time, type and location as discussed in Chapter 1. The arrivals are then grouped by the Client Department by Trade and Estate and then issued to the appropriate contractor. However, individual jobs arriving at each contractor are still taken to be random in type and location. When fully processed, at the end of each day jobs are dispatched to the contractor and for simplicity we assume as individual daily bundles. Obviously in view of their nature emergency and very urgent jobs will be dispatched in the course of each day in advance of urgent and non-urgent work, however collectively they constitute a daily consignment. The situation now is that jobs arrive at the Contractor Department in aggregated groups of varying sizes in a series of arrival intervals one day apart, producing a group size frequency distribution of jobs which are considered to be independent random variables.

At this stage it should be noted that the arrival rate of jobs at and the departure rate of jobs from the Client Department need not be even approximately equal. The Client Department may elect to MODIFY the rate at which jobs reach the Contractor Department by RETAINING certain job types and categories for subsequent release. This delay mechanism may be enforced on the Client Department by financial constraints caused by excessive maintenance demands, overspending of monthly budgets or timing in the financial year. In the near future client departments may be forced by examine repair allocation procedures to ensure a more even distribution of work to contractors. This is discussed more fully in Chapter 4.

Two important overall measures of the efficiency and effectiveness of the Client Department are the Client Delay Time and the System Response Time (as defined previously) both of which are directly influenced by the aforementioned arrival rates Other individual and no less important performance measures/indicators were discussed in Chapter Two.

3.4 THE SERVICE MECHANISM

We now consider using general phraseology the servicing mechanism and three aspects of this are, the service time, service capacity and service availability, each of which is discussed below.

(i) THE SERVICE TIME: This is the length of time required to service individual jobs for each particular trade and in this investigation six separate trades are considered, namely; joinery, plumbing, electrical, builderwork, slating: plastering and glazing. Joinery and glazing could be taken as one trade but for the moment they are considered separately.

The service times for individual jobs within each trade are assumed to be independent random variables all with the same service time distribution, with each trade having its own unique service time distribution.

Service time usually means a consolidated completion time allocated to a variety of maintenance tasks usually linked with a schedule of rates and a bonus related incentive scheme with travelling time allowances. Contractors having more advanced operational experience will likely express the service time in standard minute values (smv's), however, the schedule of rates may not be sophisticated enough to enable all of the myriad of maintenance tasks to be allocated specific smv's in this way.

(ii) THE SERVICE CAPACITY: This may be defined as the maximum number of MAN JOB HOURS which are available on a day to day or week to week basis. Within individual trades the service capacity may range from one "server" to several tradepersons in a multiple server system and the obvious question begging an answer is how large a workforce is required to provide the level of service demanded by the Client Department in terms of Target Response Times.

To simplify the analysis it is assumed here that the system service capacity will not significantly influence the actual service time values. However it is acknowledged that during possible slack or peak periods of working, variations in mean service times may occur. Likewise, for zoned repairs, scale advantages may accrue with subsequent savings in service times. In such circumstances it is likely that a negotiated bonus scheme would generate agreed service times with specific smv's allocated to schedule of rates items where existing. Thereafter all such service times can be amalgamated in the general service time distribution for each trade.

It must be noted that the system capacity will influence the variable of real interest, namely the Contractor Response Time.

(iii) THE SERVICE AVAILABILITY: This describes not only when and where service can be provided but also any conditions which limit the number of response maintenance jobs that may be executed in parallel. For instance, a workforce may always be present, but, the spectrum of work undertaken by the Contractor may include contracts for, planned maintenance, minor or major building works, and response maintenance within one or more local authorities. The balance of such work will change from time to time producing additional conflicting contractual demands which will influence the availability of the deployable workforce.

To enable flexibility within the system capacity and to attempt to ensure an available workforce which can cope with the fluctuating demands of response maintenance, it may be necessary to modify the system by introducing one or more of the following measures:

(a) overtime working
(b) transfer of workforce between contracts
(c) employment of temporary casual labour
(d) subcontracting of work between contractors; public or private sector.

Although such measures will temporarily relieve congestion and possibly reduce backlogs of work they must be regarded as undesirable and it is difficult to justify such expensive, reactive solutions to a problem that may be more effectively controlled.

3.5 THE QUEUE DISCIPLINE

This final descriptor of a queuing system specifies the rationale by which individual jobs are selected from the pool of jobs arriving at a queuing point.

At this stage discussion is restricted to the possibility of congestion within the Contractor Department, where jobs arrive in daily bundles of varying sizes. The maintenance controller may then group jobs by Trade and Job type on an Estate by Estate basis. Jobs are then allocated to the workforce contingent on availability and the priority rating of the repairs. Procedures may vary from one authority to another with workloads being issued on a daily or weekly basis.

Under the terms of the recently revoked legislation a DLO could be operating with a workforce capable of coping with emergency work and a competition free allowance of about 40% of all other response maintenance work. In these circumstances the maintenance controller was able to operate a STOP-GO POLICY, such that during slack periods, additional work may be requested from the Client Department or the maintenance controller could call for a reduction in job arrivals when periods of congestion are on the near horizon. In other words the controller could to some extent influence the rate of job arrivals.

Current legislative proposals implemented on October 1st 1990, demand the removal of the competition free allowance; a new category for real emergency work; a reduction in the de-minimis to fifteen and under the terms of compulsory competitive tendering that DLOs tender for all response maintenance contracts. Tenders for such contracts may be on an Estate by Estate basis, or possibly for ALL response maintenance work within a local authority housing stock. This being the case, a likely senario is that a DLO maintenance controller will not know the new overall arrival rates or other related aspects of the response maintenance profile.

This argument is equally true for any private contractor who had tendered for and won such a contract. In short, the contractor will have no influence over job arrival rates and the likelihood is that the contractor will have no previous experience of the overall response maintenance profile. This situation will, in the very near future, require much clearer specification.

Clearly the controller's task is unenviable, being charged with maintaining an even flow and distribution of work; manipulating, possibly four priority work categories; purposefully organising a queue of jobs with a facility for pre-emptive prioritisation and delivering the repairs service within target response times when failure to do so could involve a penalty.

3.6 DATA COLLECTION EXERCISES

Obtaining data in the form necessary to derive accurate frequency distribution as envisaged necessary for modelling purposes proved to be a daunting task.

The main function of the Client department computer division with respect to the repairs service was to store, collate and reproduce data printouts which could be used as information and management control tools. The hardcopy printout requirements of the client department and the DLO were at variance with those required for this investigation. Initial discussions with computer and accounts personnel and the DLO failed to yield any positive results. The requirement that job arrivals per day; by trade and category on a Ward by Ward basis was outwith the scheme of client department needs. Subsequently however, computer printouts were produced, which although less than ideal did provide information which, when sifted and censored manually enabled the generation of the raw data used in this investigation.

3.6.1 Job Arrival Data

Job arrivals were not grouped by trade and appeared on the printouts haphazardly as originally input. Establishing order proved to be time consuming and tedious. The data included all repairs and ancillary activities, for example, plant hire and reimbursement payments to tenants.

No distinction was made between true response repairs funded from a revenue account and those funded by a captialised repairs budget. It was therefore necessary to interprete the data and make value judgements to differentiate between these repair classifications to establish, as accurately as possible a true response maintenance profile.

The original data required to be cleaned up and filtered and to do so required that a decision reference frame was established. This frame was focussed on for two main reasons.

(a) To acknowledge the inexact nature of the input data used to demonstrate subsequent analytical techniques.

(b) To identify the aspects of any future data collection which would facilitate greater accuracy and less subjectivity.

The coding system used to classify repairs by trade or type is given in Appendix (2).

3.6.2 The Reference Frame

The following types of maintenance work were identified and deleted to produce input data

(a) Any obvious large scale planned work (capital quota account); for example large window replacement schemes. Isolated one off replacements being retained.

(b) Contract maintenance, for example, gas board cyclical maintenance.

(c) Tenant reimbursements for say, redecoration allowances or plant hire eg. dehumidifiers.

(d) Call outs eg. emergencies outwith normal working hours, but including any subsequent follow up "call out" repairs.

(e) Programmed painterwork and prepaint repairs where identifiable eg cyclical maintenance.

(f) Central heating installations.

(g) Any repair judged to be in the programmed category.

The following types of repairs were in some way possibly modified

(a) Repairs to voids; ie. housing undergoing a change in tenancy. Such repairs were included in the response category and were allocated to the DLO under the forty per cent competition free allowance rule.

Often several trades were involved in making good defects in one house. DLO repairs tended to be very itemised with each elemental activity being assigned a code number. These required to be grouped as necessary to form a single repair. Care was exercised in attempting to avoid any duplication.

(b) Bricklaying occasionally included repairs which were not strictly in this trade category. However these were retained in the input data.

(c) Glazierwork was separated out as a single trade, as would be the case for the DLO or specialised glazing private contractors. However general private contractors eg joiner and glaziers could very well be considered as the same trade and could therefore have created minor discrepancies.

Although an earnest attempt was made to filter the raw data this may not have been achieved with the degree of accuracy hoped for. Therefore data inputs to the modelling processes are not regarded as exact. However we believe these inputs to be sufficiently accurate to meaningfully demonstrate any analytical techniques devised.

3.6.3 Job Completion Time Data; Job and Materials Costs

Estimates for job durations were obtained from a breakdown of private contractors accounts, supplied by the accounts section. Material costs were deducted from total costs to yield labour costs. Dividing labour costs by the labour rate per hour gave a completion time eg

$$\text{Job duration} = \frac{\text{Labour Cost}}{\text{Labour Rate/hr.}}$$

The data as provided rendered it impossible to determine any separate charges for labourers or apprentices. It is therefore possible that the same labour costs included a levy for an apprentice or a labourer. Similarly it is conceivable that certain types of repairs could be completed by an apprentice or a labourer, both of whom could have different labour rates.

The accuracy of the job duration times is thus basically flawed. However once again we believe that data inputs are sufficiently accurate to illustrate the techniques exposed in Chapter Four.

3.6.4 Duration of Data Collection

The data received and derived above were obtained from selected private contractors accounts and comprised all accounts over the period January to August 1988 which straddled the four week period selected for detailed analysis given later in this Chapter.

3.7 WORKFORCE RESOURCING REQUIREMENTS

Let us now consider in more detail the occurrence of repair requests and the issuing of orders to execute, in the response maintenance category, in terms of time, repair type and location of repair.

For the purposes of organising non-urgent (category D) repairs the Audit Commission Report[13] recommends zoning of council house stock using the main

DLO depot as the locus about which zones are defined. The Report acknowledges no universal best practice but suggests local experience of volumes of repairs generated; density of housing stock and distance from the main depot as the principal factors to be analysed. The report further suggests that 3000-4000 houses within a one mile radius might yield sufficient work for fifteen to twenty operatives and be within walking distance. The report also discusses the requirement to offset transportation costs against increased productivity.

The district which was the subject of the investigation covers an area of roughly 64.5 square miles and contains approximately 9,000 council dwellings. The district is divided into fifteen Wards which provide the electoral boundaries and for administrative convenience the Wards are grouped together to form Five Estates each having an estate management team. The management structure and operational procedures were as discussed in detail in Chapter 2.

Exhibit 3.7.1 is a plan of the District showing Estate boundaries, prior to the data collection exercise. The number of council housing stock in each Ward and Estate is given as is the location of the Community Maintenance Depot (DLO). Estate boundaries indicated are clearly not aligned with all ward boundaries. A consequence of this was that several council members could have an interest in the management of the repairs service in different Estates.

A rationalisation of Estate boundaries was implemented with new Estate boundaries fixed to coincide with Ward boundaries. At the time of the data collection exercise Estates one to five were as shown in Exhibit 3.7.12 together with amended council housing totals to be managed by each Estate team. This policy decision is highlighted to focus attention on the changing proportions of housing stock in each Estate since we must consider any impact this may have on the repairs service.

The Five Estates used in this investigation comprise the following combinations of Wards as given in Table 3.7.

Note Ward 8 is omitted, since there were no district council houses in this Ward.

ESTATE	WARDS
1	1 + 15
2	2 + 11
3	12 + 13
4	3 + 4 + 5 + 14
5	6 + 7 + 9 + 10

Table 3.7

Response maintenance includes all four categories of work discussed previously. However for the purposes of modelling the response maintenance profile we group categories A, B and C together and define the group as Unplanned Response Maintenance with all categories having target response times equal to or less than five working days. Category D type repairs which could have a target response time of three-six weeks are now defined as Zoned Response Maintenance with a potential for planning such repairs and executing work on a cyclical basis.

Exhibits 3.7.13 to 3.7.16 shows the weekly variations in jobs issued by the Client Department to the Contractors, for all response maintenance for three trades; joinerwork, plumberwork and electrical work, over a period of thirty five weeks. Using a spreadsheet computer package similar patterns may be plotted for individual estates or the sum of any combinations of Estates, or similarly for Wards. The numerical values for these weekly job arrivals are given in Appendix 2.

Fluctuating weekly arrival rates are obvious with some abnormally high occurrences in all trades noteably weeks 3 and 34 for joinerwork and for plumberwork. These peaks appear to be produced by a high incidence of category D repairs issued by the Client Department; for example in week 3 over 170 category D joinery repairs were identified. The reason for these peaks could be that the Client Department delayed issuing these repairs for reasons discussed earlier. However, it must be noted that at the time of data collection, work was being issued to numerous contractors selected from a pool of private contractors and also the DLO which was entitled to a 40%

competition free allowance. Such delay strategies by the Client Department were not necessarily placing an undue burden on any one contractor, however, within the framework of recent legislative changes, such swingeing variations in workload will pose difficult resource management problems for any contractor who has won a major response maintenance contract. Such potential to create difficulties for contractors needs to be addressed immediately.

Exhibits 3.7.13 to 3.7.16 give no indication of variations in daily arrival rates of jobs or of any shifts in the proportions of work within each category comprising unplanned response maintenance. Likewise the balance of work in unplanned and zoned response maintenance groups is not evident. Nevertheless this initial presentation of the job arrival patterns serves as a preliminary demonstration of the nature of the Contractors' resource management problem.

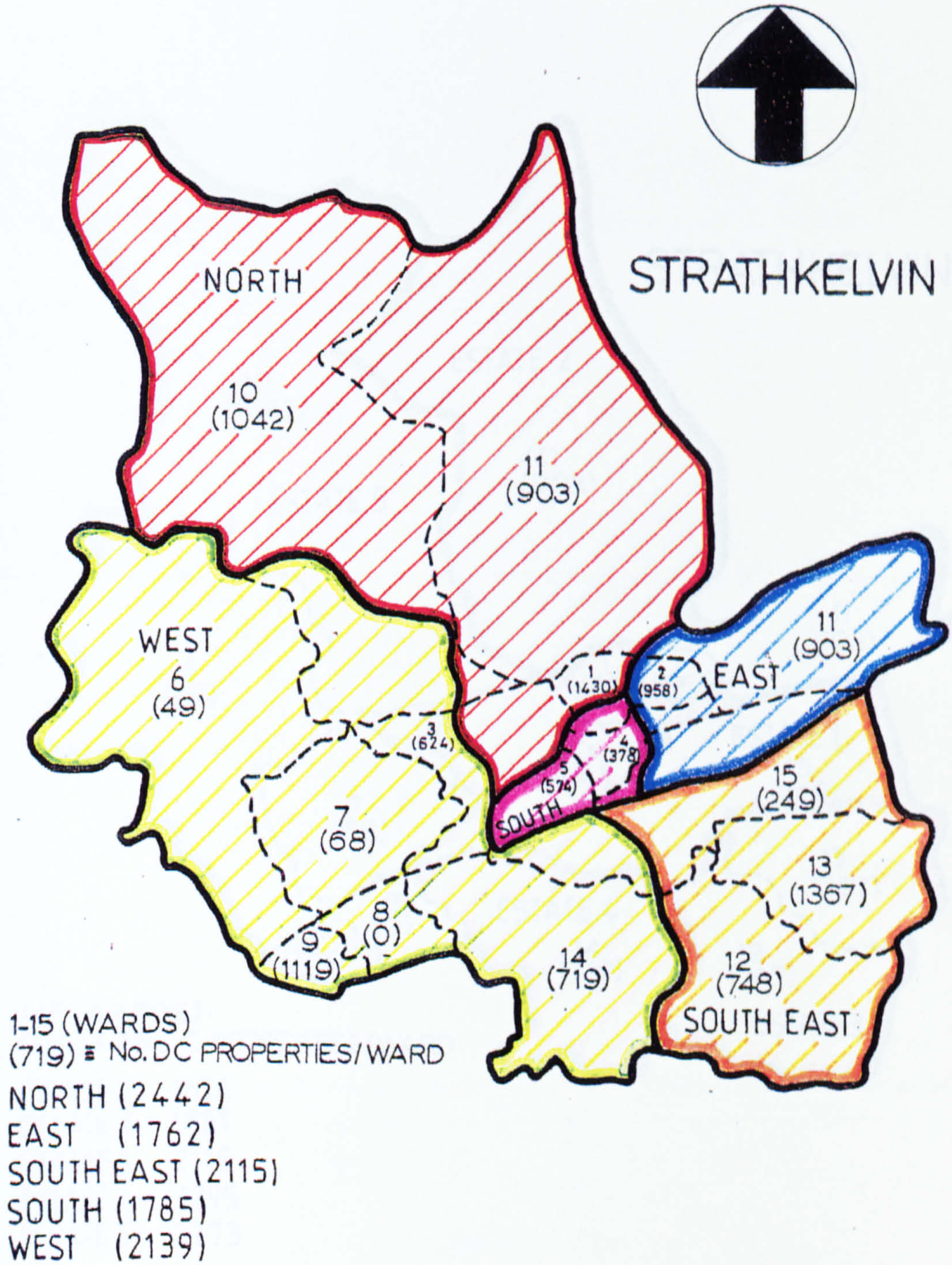


Exhibit 3.7.1

Original Estate Boundaries

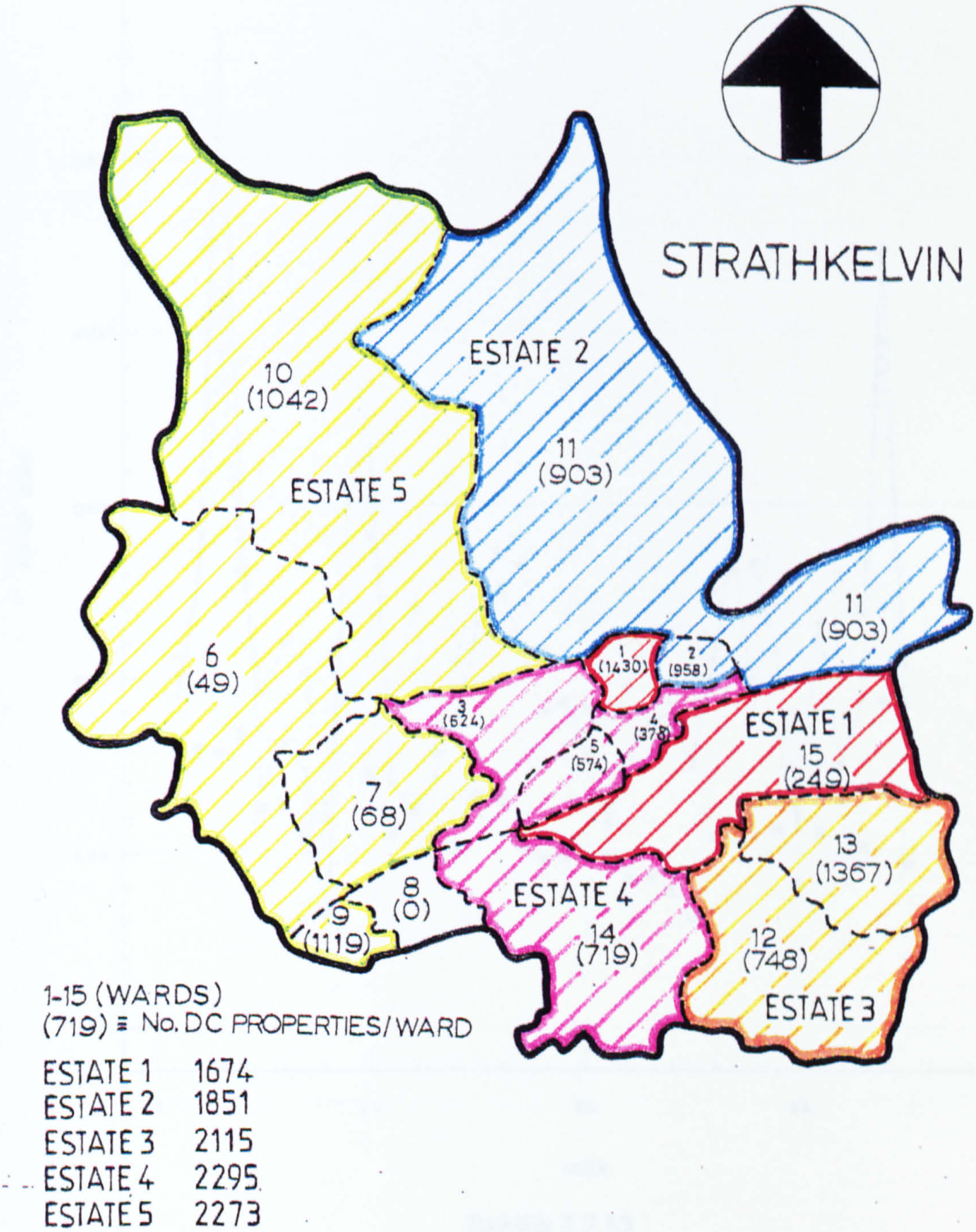


Exhibit 3.7.12

Revised Estate Boundaries

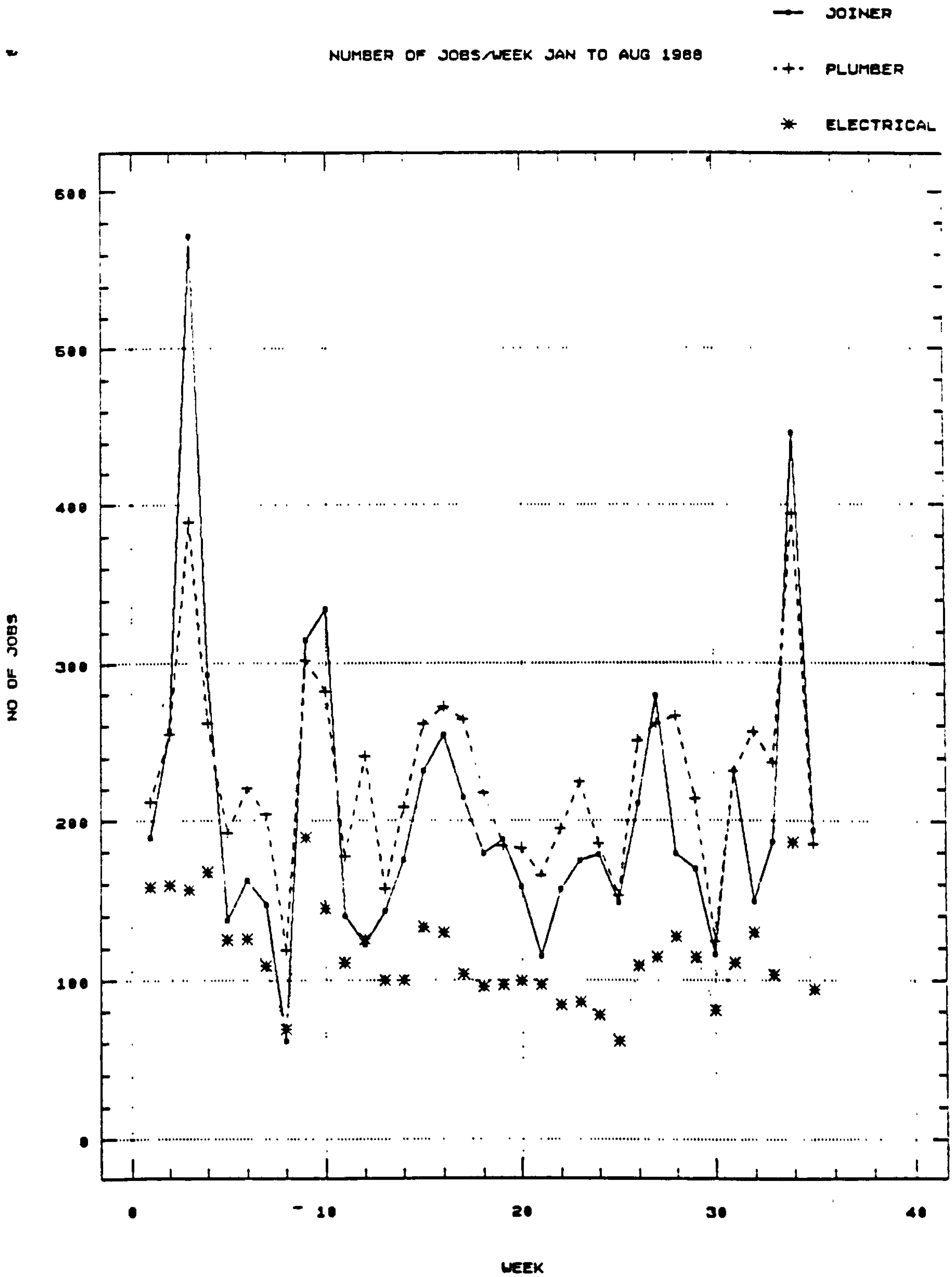


Exhibit 3.7.13

Weekly Fluctuations in Jobs Issued
All Estates

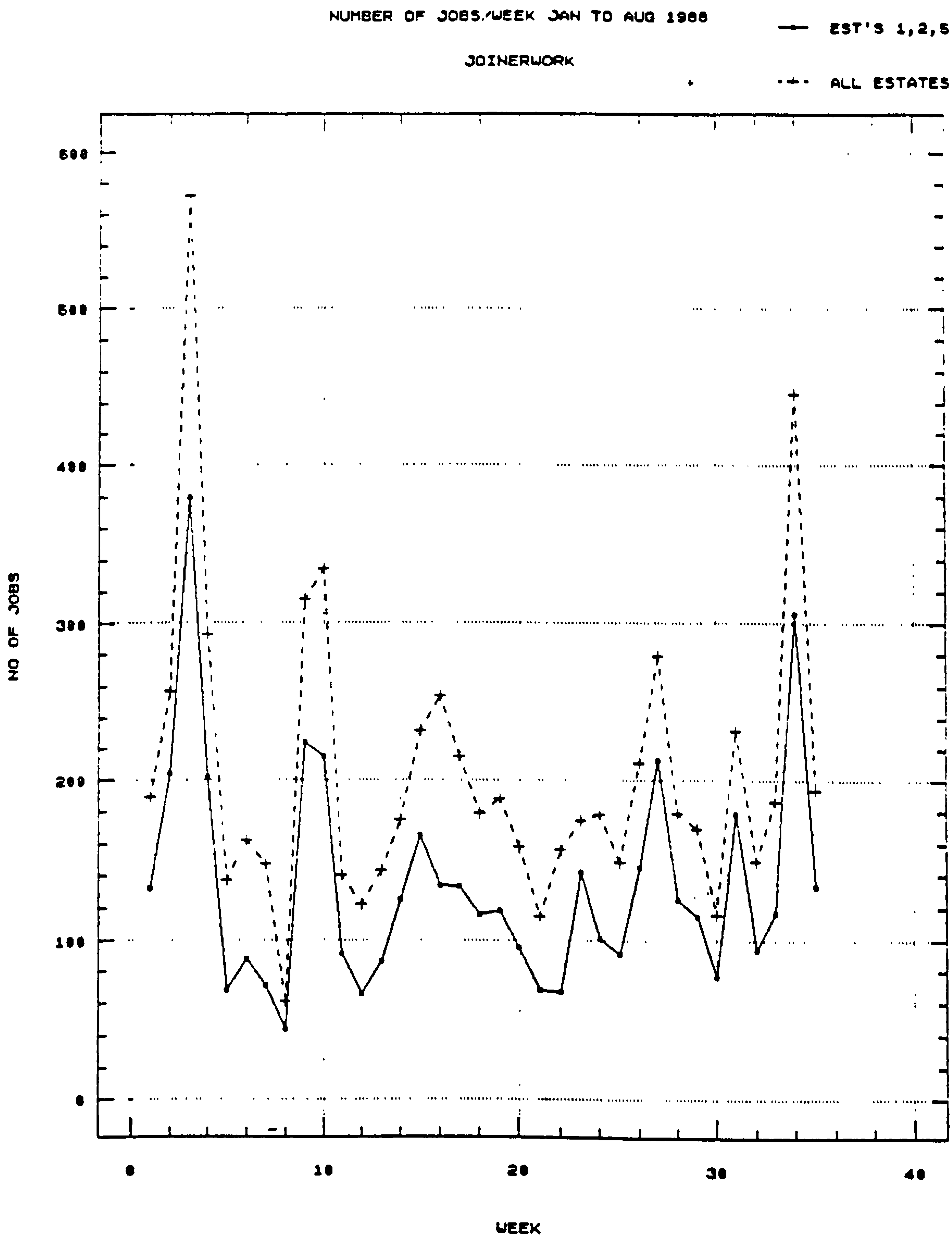


Exhibit 3.7.14

Weekly Fluctuations in Jobs Issued
Joiner Work

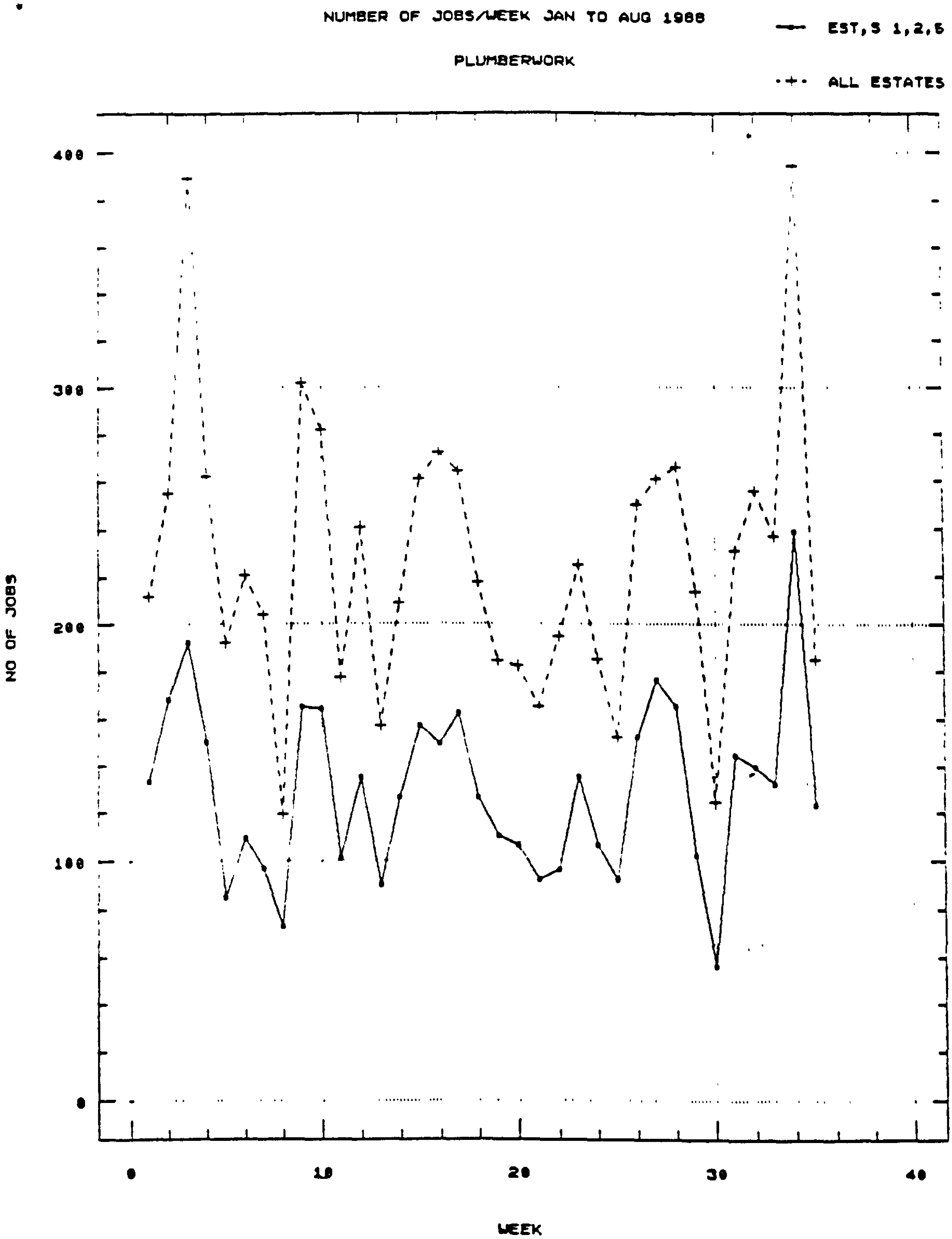


Exhibit 3.7.15

Weekly Fluctuations in Jobs Issued
Plumber Work

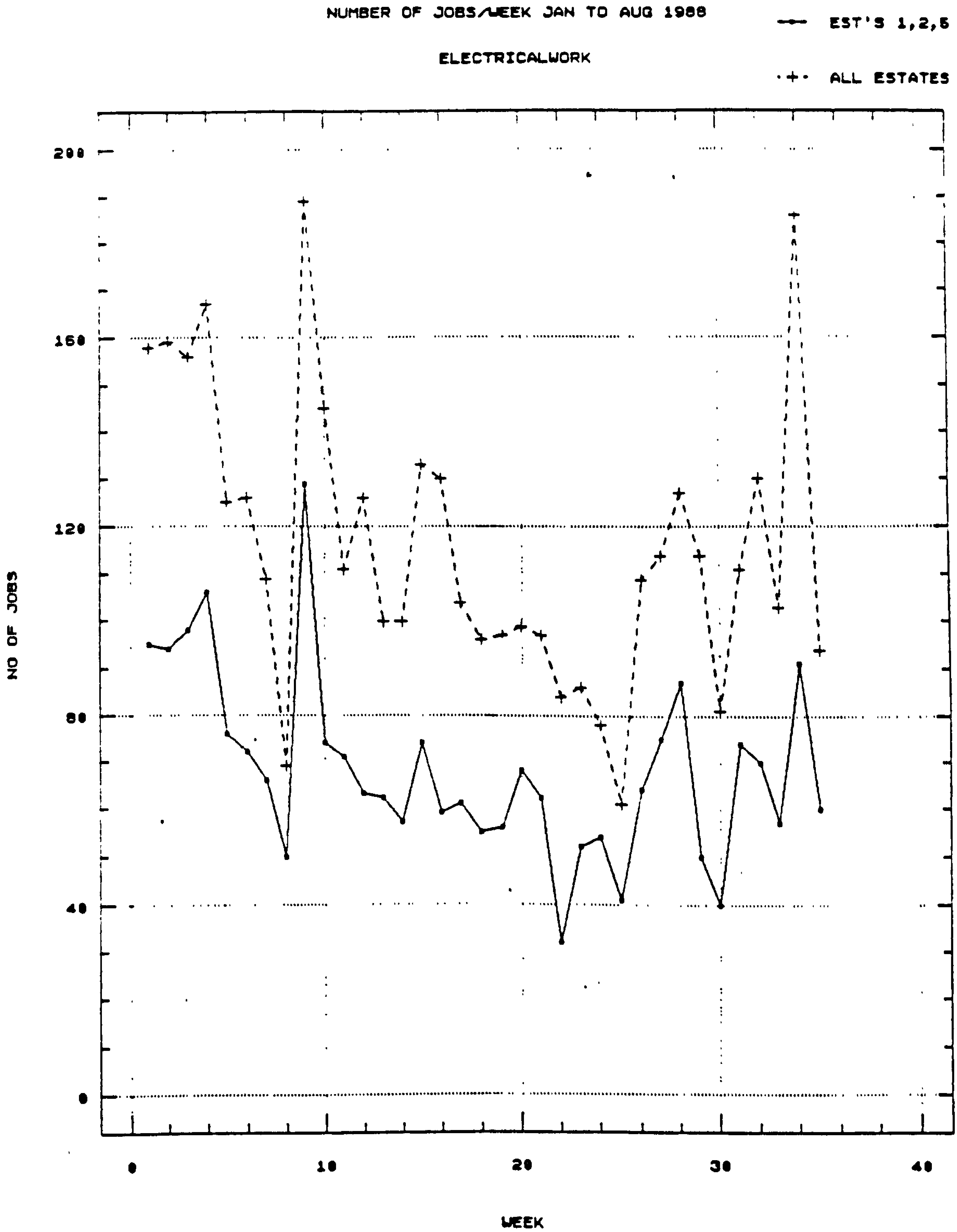


Exhibit 3.7.16

Weekly Fluctuations in Jobs Issued
Electrical Work

Regrettably no data similar to that shown in Exhibits 3.7.13 to 3.7.16 is available either before or after that data collection exercise, this being the only formatted data which could be extracted from the Client Department database for analysis, as outlined in Section 3.6. It is therefore not possible to argue statistically that there are any typical long term trends with time which might, as suggested by Ward[21], prove useful. However discussions with depot managers reveal the "gut" reaction is that these results are broadly representative of current observed arrival variations. Consequently it is not an intention to apply this data to long term statistical forecasting; instead the information is taken to be a sensible predictor of the unevenness of the workload issued to the contractor and will be used to illustrate the modelling processes.

In any competitive situation a contractor requires to aim to sustain a balanced workforce comprising the right amalgam of trades which is capable of responding to enforced variable repair demands. Accepting that the data in Exhibit 3.7.13 represents typical variations in job arrivals a contractor will have little or no chance of achieving such an aim if commercial survival is geared solely to response maintenance contracts. It is therefore likely that a contractor will aim to provide a workload by tendering for combinations of the available building works contracts referred to earlier. The scale and grouping of such targeted contracts constituting the Contractors' Business Plan.

A difficult workforce resourcing problem thus emerges and an employment strategy needs to be established. Two possible policies are:

(i) Establish the labour force for a forthcoming year (say) by winning contracts which ensure sufficient work to sustain the workforce, weathering temporary troughs and adjusting for excessive peak periods by working overtime or subcontracting.

(ii) Adjust the workforce to match workload throughout the year by hiring and firing, usually on a last in first out basis.

Achieving the first of these aims would be an optimal solution, however unenviable the contractor's task of juggling many imponderable variables.

The second policy is not a particularly attractive one for employees, although the itinerant nature of the building industry workforce is, in general, legend. Previously there was a chronic shortage of skilled tradesmen and it should be in a contractor's interest to ensure reasonable job security, pay and related bonus schemes in order to attract and retain a caring, skilled workforce capable of delivering the level of service demanded. This requirement is currently relieved by the recession in the building industry et al.

3.8 THE COMPOUNDING OF TWO DISCRETE DISTRIBUTIONS

To attempt to anticipate the size of a maintenance workforce capable of responding to variable repair demands enforced by fluctuating job arrival and variations in the time necessary to complete individual jobs we require two distinct distributions. One distribution giving the arrival of jobs per day, or jobs per week depending on the level of accuracy aimed for and the other representing the number of hours per job. These distributions require to be combined so as to yield the service level requirement in terms of man job hours arriving on say a day to day basis.

The properties of interest of the distribution of hours of work arriving per day, are the mean, the variance and possibly the shape of the distribution. There will of course be other statistical properties which also merit consideration.

The compounding of two discrete distributions may be achieved by the following techniques.

(a) **A Mathematical Analysis**

This approach requires that each distribution has a known mathematical form, the properties of which may be manipulated to produce theoretical results. Such procedures are not pursued in this investigation, however those interested in a mathematical synthesis should consult for example Beaumont[22] for a full explanation.

(b) **Numerical Convolution of Discrete Empirical Distributions**

Using a computer spreadsheet two discrete distributions may be combined, to find the mean, variance and distribution of say hours per day for very limited variable ranges. Obtaining the distribution of hours per day involves expanding the terms of the binominal $(p + q)^n$. However if only the overall mean and overall variance are required the technique is much less complex.

(c) **Computer Simulation**

By devising a custom tailored program which uses random number sampling from each discrete distribution in turn sample values for hours of work per day, are achievable; from which the mean, variance and distribution of hours per day may be derived.

The problem is made more complex by the requirement to model manpower demands for each Trade not only in terms of hours per day but also to expose the balance of the hours generated in terms of job Categories and Estates of origin.

It was therefore decided that the compounding of any empirical distributions derived from data analysis should be produced by computer simulation. This enables widening of applications to accommodate sampling from several discrete distributions, the process also being applicable in the event that any derived empirical distributions should fit known probability distributions.

3.9 MODELLING WORKFORCE REQUIREMENTS

The trade skill shortage situation is relieved by a contemporary recession in the building industry and although some Client and Contractors Departments could claim that currently the repairs problem is contained and targets met the situation can only worsen as and when the industry moves out of the recession.

A technique for modelling workforce requirements for response maintenance is suggested by Ward[21] and the process for deriving workforce levels is based on the following variables, there described as;

(i) Job arrival rates

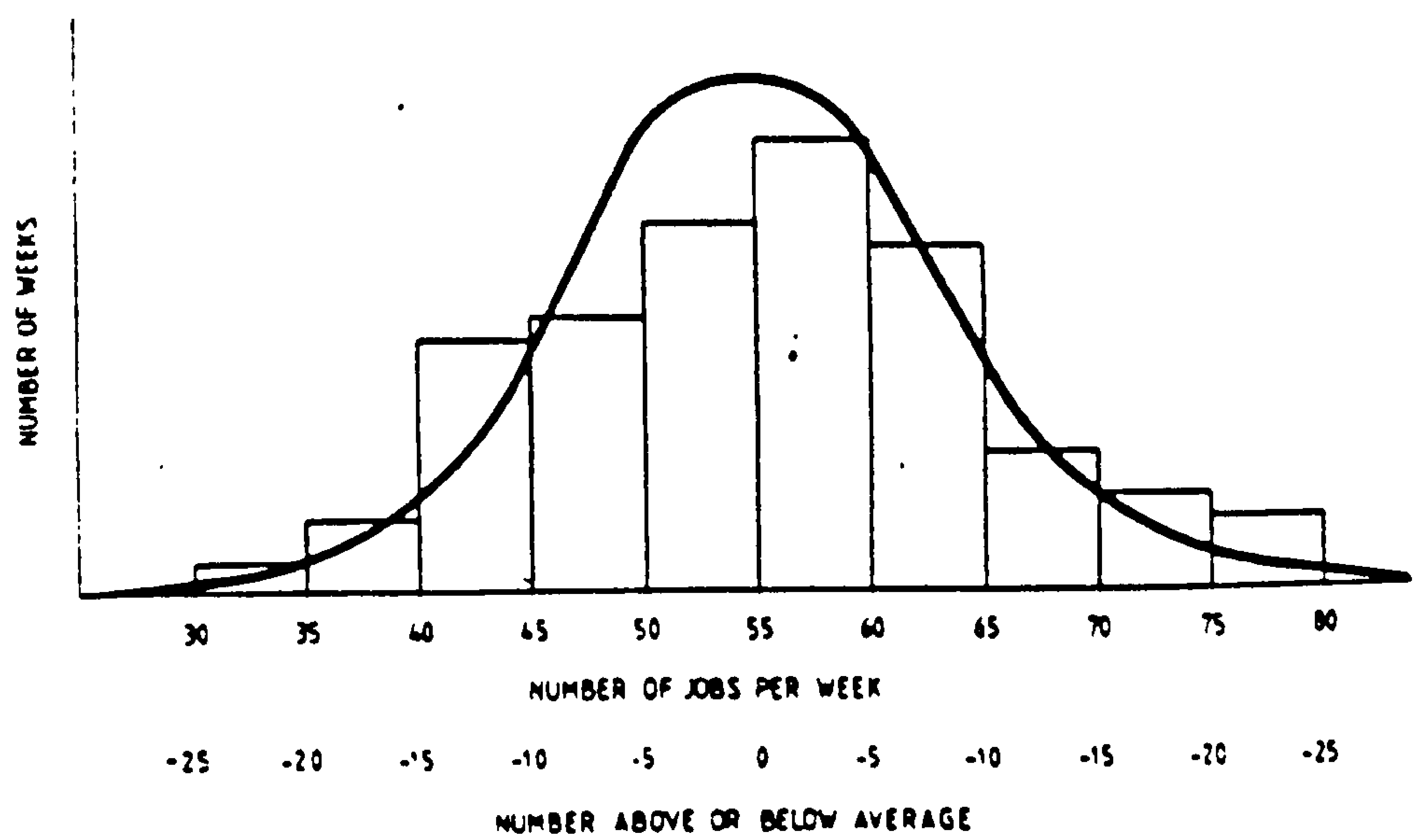
(ii) Job completion times

both of which may be obtained by direct analysis; and;

(iii) Waiting times

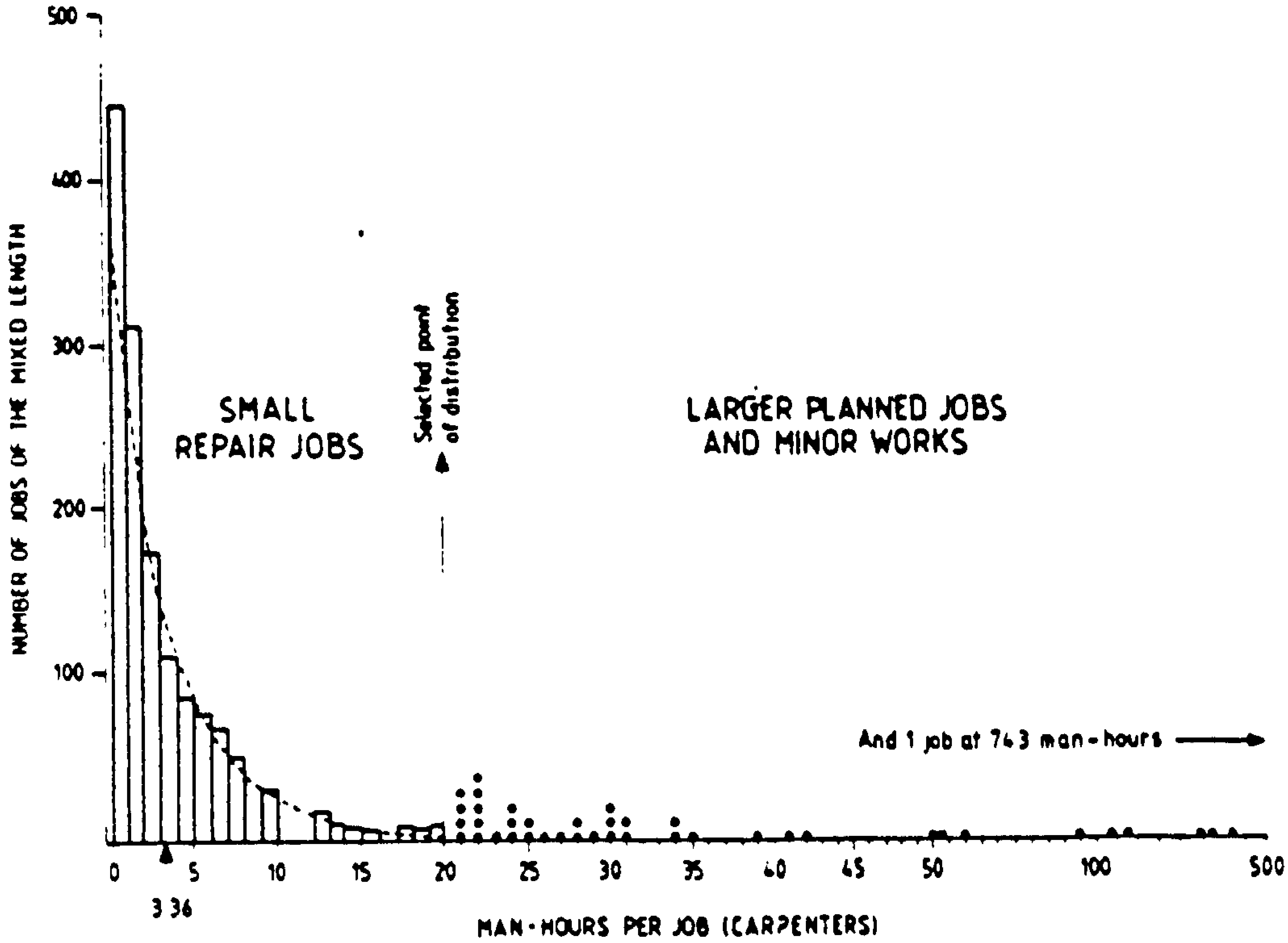
which times are as a consquence of (i) and (ii) and also the available workforce level.

Frequency distributions of the above variables are given and the typical examples cited by Ward are shown in Fig 3.9.1 (a), (b) and (c).



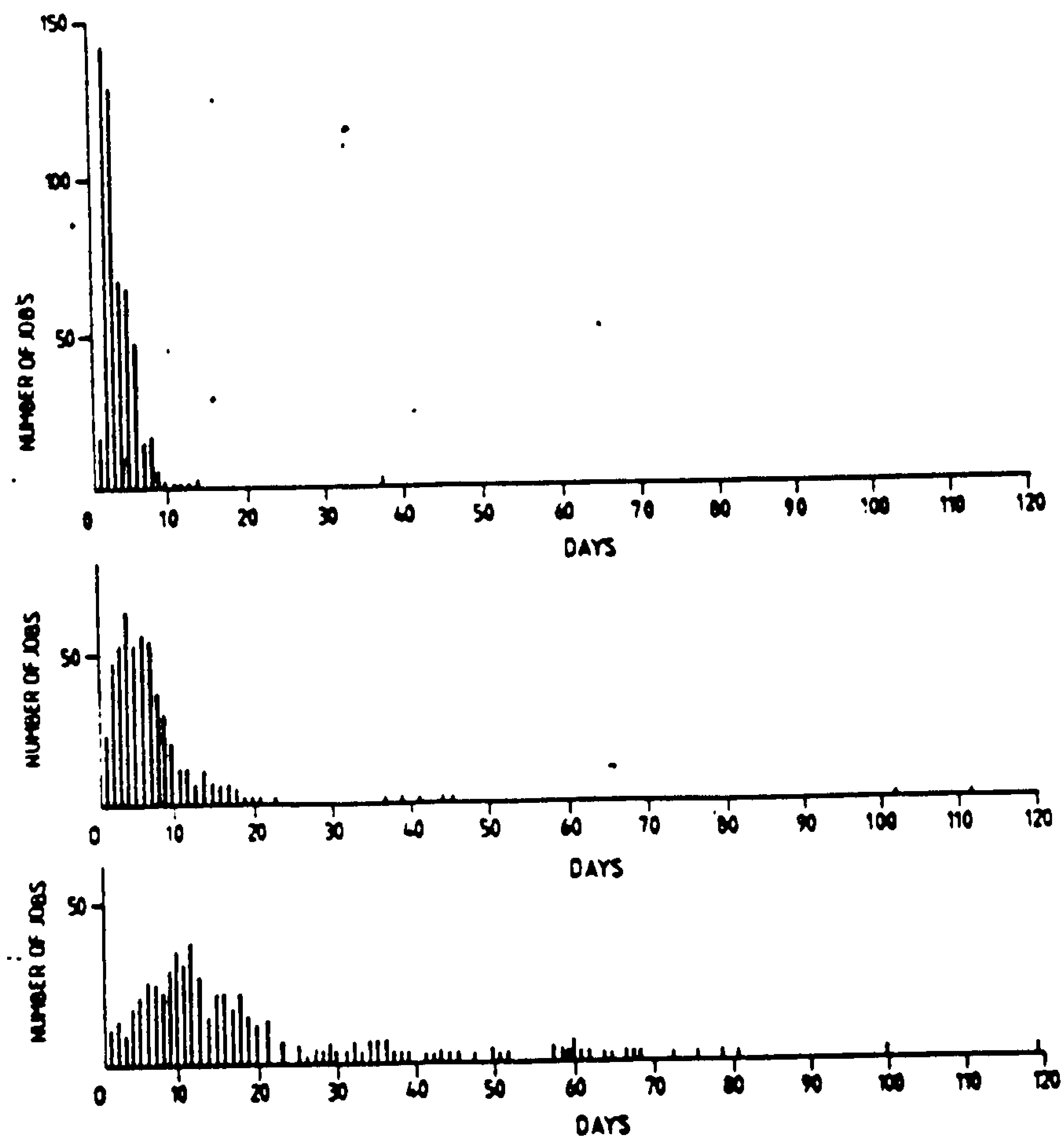
VARIATIONS FROM THE WEEKLY AVERAGE NUMBER OF JOBS

Fig 3.9.1(a)



THE TIME TAKEN TO CARRY OUT CARPENTERS' JOBS

Fig 3.9.1(b)



WAITING TIME IN DAYS

Fig 3.9.1(c)

The means of distributions (a) and (b) are multiplied to give the mean number of man job hours per week. Obviously this average value does not take account of the variance of each distribution. Clearly man job hours in excess of the weekly mean will require to be made available to accommodate repair demands in excess of the mean value which are occasioned by the factors discussed earlier. A further relationship is developed by Ward between % labour reserve and the average delay to repairs in weeks ie the actual response time.

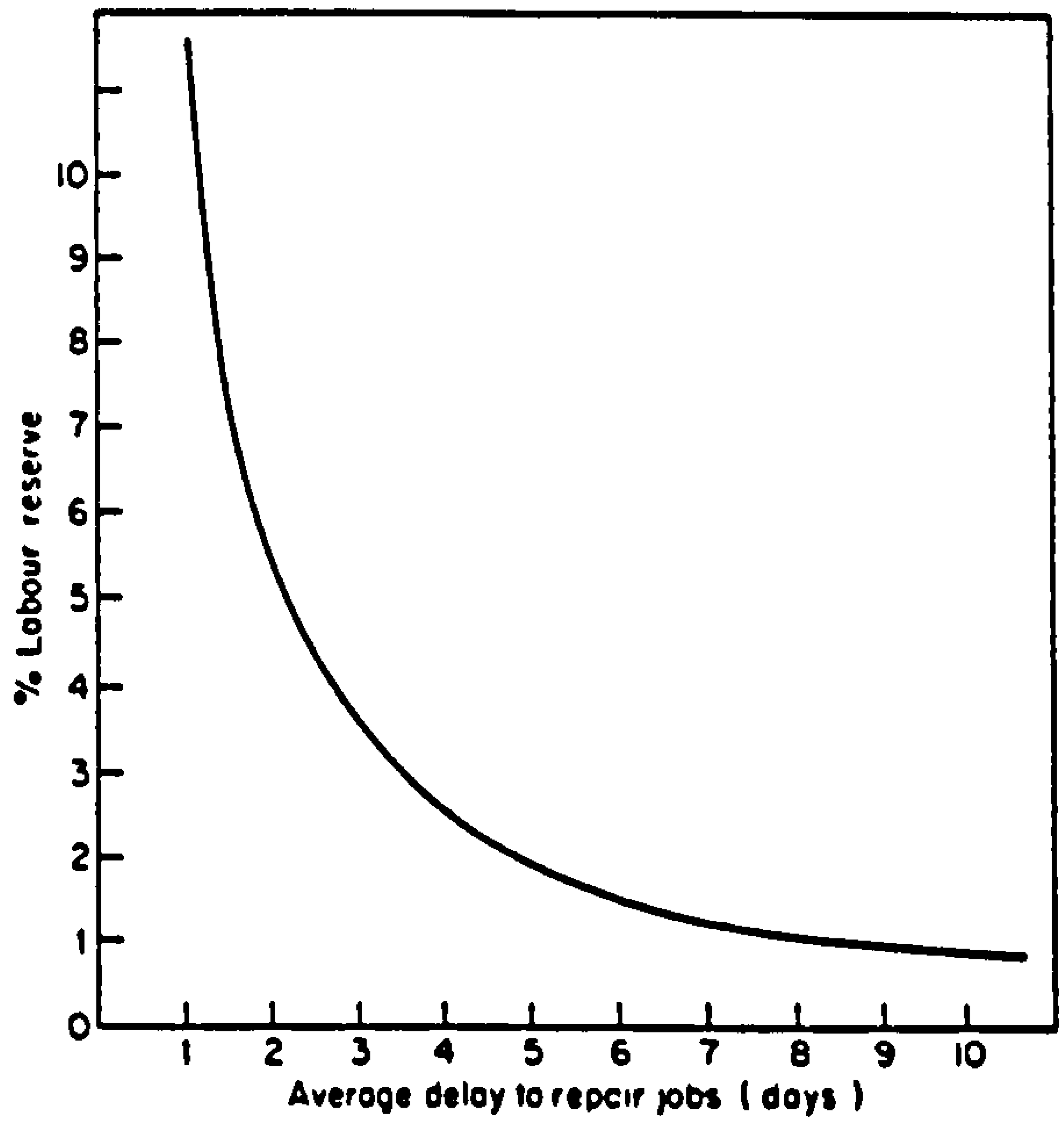


Fig 3.9.11

From this curve reproduced in Figure 3.9.11 the maintenance manager can allocate a labour reserve above the average number of man job hours predicted from the combined means of job arrival rates and completion times. The larger the labour reserve the lower the Contractor Response time and arguably the more effective is the delivery of the service.

No mathematical or statistical rationale is presented by Ward, to justify the development of these above relationships although it is suggested that the frequency distributions derived fit known statistical distributions. To develop such ideas it is necessary to combine discrete distributions and this is achievable by various techniques which were outlined in the previous section.

3.10 AN ADAPTED MODELLING PROCESS

The ideas and techniques, briefly described above, which were developed by Ward in 1974 are as relevant today as when first postulated. However an alternative, modelling process adapted from Ward is advanced in this study in Chapter 4 which we believe is more relevant and for the following reasons.

(a) A mathematical approach requires that the derived frequency distributions of say job arrivals and job completion times, conveniently fit known statistical distributions. A variety of trades require to be investigated with the possibility of an additional requirement to investigate maintenance work on an Estate by Estate or month by month basis. A host of frequency distributions of variable pattern seems a likely outcome. That they should all conveniently fit standard statistical distributions is highly optimistic.

(b) The Ward technique is partially based on a "standard of service" which is defined as the the time which elapses between the reporting of a repair and the completion of the repair; referred to as the "waiting time". Although no distinction is drawn between System Response Time and Contractor Response Time, it is assumed that the "delay time" referred to by Ward is analogous to the System Response Time as previously defined. Three practical situations investigated revealed mean waiting times of 3½, 7½ and 20 days and the derived distributions of these three studies were given in Figure 3.9.1(c).

For Response Maintenance, the level (standard) of service (Target Response Times) prescribed by a client department will approximately embrace all of the data in the three distributions in Figure 3.9.1 (c)with Target Response Times ranging from a few hours to several weeks. The level of service is defined for a range of work categories which may be adjusted with time as development and experience grows. More or fewer categories of work may be introduced or changes in Target Response Times effected, each of which impact on the workforce requirements.

It would therefore seem reasonable to model the problem within the reference frame of Target Response Times and attempt to predict slack or congested periods in workforce demands over intervals of time measured in say a few weeks. The time intervals being determined after an examination of the annual seasonal variations in job arrivals as shown in Exhibit 3.7.13, Section 3.7.

(c) Response maintenance is such that many jobs will fall into the categories, emergency, very urgent and urgent with Target Response Times ranging from a few hours to a maximum of say five days. Maintenance managers are therefore required to distribute and to an extent, plan work on a day to day basis. Hence obtaining accurate data showing the nature of arrival rates and associated job categories would seem a reasonable objective.

(d) Both the Client Department and the Contractor could make more effective use of information relating to the incidence of repair types, costs and locations on an Estate by Estate basis. The Client Department could aim to provide more realistic information enabling more objective preparation and control of budgets and contract tendering procedures which should improve the delivery of the service. Likewise the Contractor could benefit from such improved procedures in terms of enhanced logistical management and manpower resourcing.

It must be noted that with the implementation of the recent changes in legislation, the likelihood is that large scale maintenance contracts will be open to competition from Contractors able to offer the full range of common trade services. This may exclude fairly large specialist single trade contractors, and it is forseeable and not unreasonable that single trade contracts will require to be on offer possibly on the basis of single Estates contingent on the volume of work generated. Such scenarios reinforce the arguments for the proposed modelling of the problem.

(e) The complex matrix of variables which abound in this maintenance problem enforce the need to exploit the power and potential of micro-computer aided analysis and information display. This may provide a flexible capability of offering alternative management scenarios which can be interpreted and assist more effective management of the service. At worst the application of such techniques may serve as an educational instrument for more meaningful and fruitful management training by computer simulation.

3.11 ATTENDANCE TIMES: TARGET TIMES AND BONUS SCHEME

Prior to investigating the possibility of developing a computer modelling technique, let us define four terms relating to quantities of time, available or used within the repairs service. It is necessary to explain how these are connected to a simple bonus scheme; bearing in mind that it is not the intention of this investigation to compare and contrast the relative merits of different incentive schemes. Those wishing to pursue a study of incentive schemes should, in the first instance, refer to Audit Report[13].

GROSS ATTENDANCE HOURS. This is the theoretical total number of man-hours available within the contractors organisation to undertake repairs. For this investigation we will ignore overtime working.

MAXIMUM NETT ATTENDANCE HOURS. This is the Gross Attendance Time factored up or down to compensate for contingencies such as, overtime working, sickness leave, holidays and so on. The Audit Report[13] model for this relationship is reproduced below in Figure 3.12.

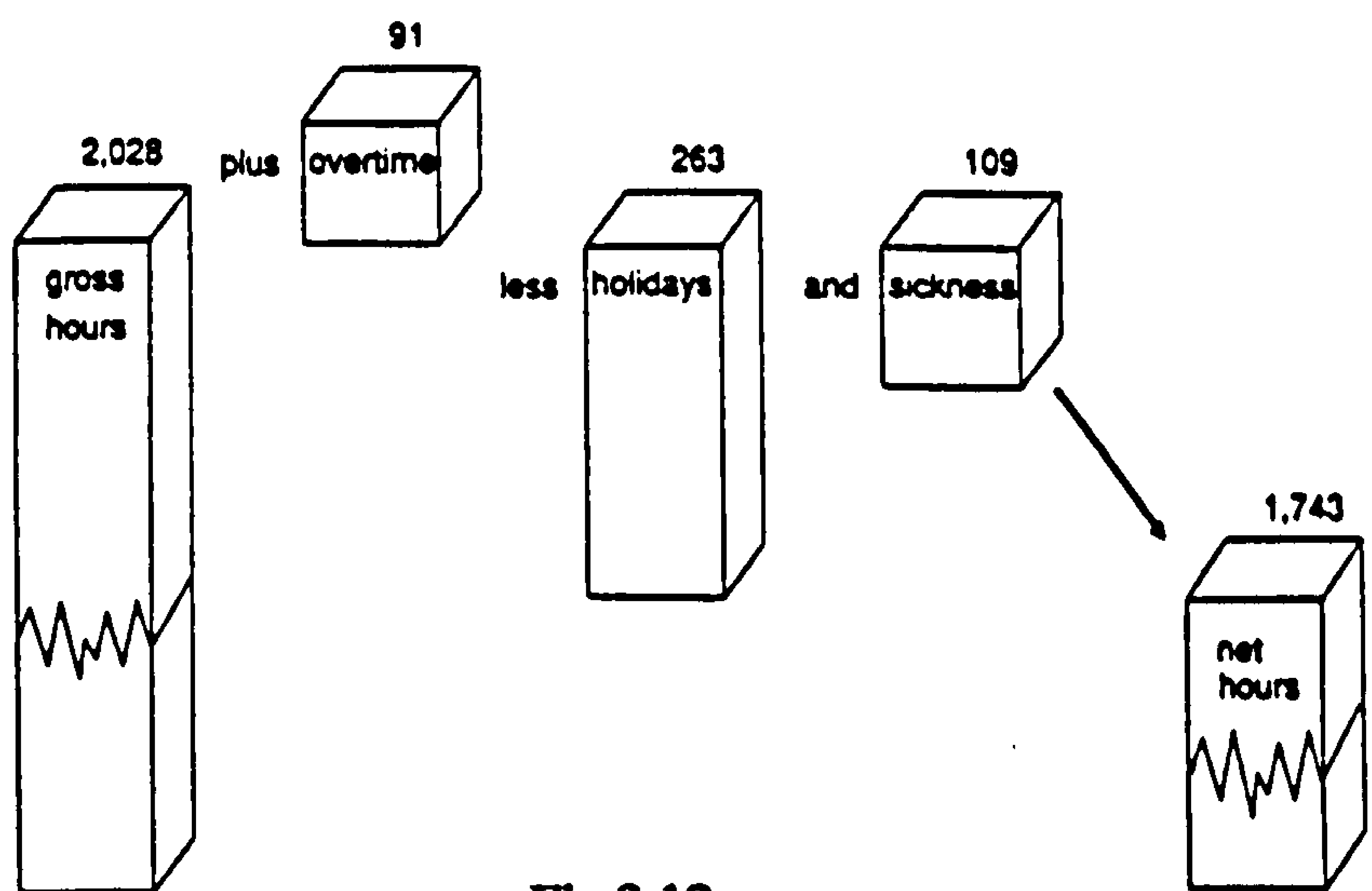


Fig 3.12

Ignoring overtime working meantime, since this can subsequently and arbitrarily be introduced as necessary we have

$$\text{Maximum Nett Attendance Hours} = \text{Gross Attendance Hours} \times \gamma f$$

where γf is a factor in the range (0.816 - 0.95)[13] depending on the incidence of, say holidays, in the interval of time being analysed.

TARGET TIME. Work study techniques may be applied in determining the Target Times to be allowed for the completion of each individual Trades schedule of rates item, be it a single item or a composite. Target Times thus identified are agreed by management and unions as being reasonable and realistic.

Not all of the Target Time allocation per job is gainfully spent on productive work and hence it may be factored down to take account of factors such as travelling time, access problems, materials and specification inaccuracies and so on. The Audit Report[13] suggests a modification factor of between 0.75 and 0.85 and for simplicity here we use a factor of 0.8 hence

$$\text{Productive Time} = \text{Target Time} \times 0.8$$

ATTENDANCE TIME. This is the actual time spent by the tradesman effectively completing repairs and will also include travelling time etc.

A BONUS SCHEME. This may be a simple time saved scheme using Target Times and Attendance Times to calculate any bonus earned thus:

$$\%\ \text{Bonus Earned} = \frac{\text{Target Time minus Attendance Time}}{\text{Target Time}} \times 100$$

Such a bonus scheme is referred to as, consolidated, since no separate allowance is given within the Target Time for travelling time, access problems and so on.

The amount of bonus that can be earned is usually curtailed by the introduction of a cut off point and this typically may be at trade operative efficiency level of around 125%. Obviously incentive schemes require to be revised from time to time to accommodate improved productivity, occasioned by innovations in plant, tools, and components or improved work planning which should increase the differential between Target Times and Attendance Times.

3.13 Summary: What This Chapter Does

This Chapter lays down the foundation for contextually set modelling processes to be developed in Chapter 4.

Initially and importantly the requirements of a Target Response Reference frame are established. The housing repairs service is then contextualoly described in terms of queuing theory with job arrival patterns, the service mechanism and the queue discipline identified. The ramifications that legislative changes may have on the queue discipline are recognised.

Data collection for use in the modelling processes is described. Any cleansing necessary and limitations of available data sources are explained. Difficulties of obtaining data at the time of collection are highlighted.

The size of the District and geographical boundaries between individual Wards therein and Wards grouped to form Estates are illustrated together with the distribution of the housing stock within.

Fluctuating weekly job arrivals received by the Client department for three main trades are quantified and illustrated. The need to examine the effect of fluctuating arrival patterns on manpower resources, at Contractor level, which are necessary to complete repairs within specified target response times is thereby brought into focus.

Techniques which may be utlised to compound discrete statistical distributions are reviewed and a modelling process based on probabilistic simulations is proposed. Previous efforts at tackling this aspect of the repairs service are reconstructed and reviewed in the light of shifting operational maintenance strategies enforced by legislative changes.

CHAPTER FOUR

A TECHNIQUE FOR MODELLING THE RESPONSE MAINTENANCE PROBLEM

4.0 INTRODUCTION

4.1 The Aim of This Chapter

It is widely accepted that the variety of repairs executed within a Response Maintenance System produces variable demands on the system, creates complex administrative and logistics problems and does not yield maximum value for money.

Setting aside the issues of cyclical maintenance, inspections and programmed repairs and any impact these may have on the response maintenance profiles we accept that response maintenance repairs are inevitable and consume a large proportion of the total maintenance budget.

The aim of this chapter is to expose and investigate response maintenance problems likely to be encountered by client and contractor departments and caused by the introduction of the legislative reference frames discussed in Chapter 2. Some of the enforced changes will have an immediate impact on the modus operandi of both departments, while others may produce dynamic changes taking effect in the near future.

Additionally in this chapter we attempt to devise statistical and computer modelling techniques which may assist maintenance managers to meet the anticipated challenges of the future.

4.1.2 The Packaging of Response Maintenance Contracts

Currently and within the framework of the legislation, large scale all trades contracts are being offered to contractors to submit tenders for usually against a priced or unpriced schedule of rates. Which contractor wins the contract and why is not an issue for debate in this investigation. However, large DLO's with a multitrade workforce and some previous experience of operating in a controlled* response maintenance management regime would appear to have advantages over smaller private contractors operating in the field.

* Under previous legislation a stop-go strategy could operate, see Section 3.5

As a consequence of political will the newly introduced legislation is structured such that it enables the Secretary of State to enforce changes in the preparation of the content of functional works contracts which changes reflect the philosophy embedded in the legislation and which seeks to prohibit *anti competitive* behaviour.

It is therefore conceivable, in the not too distant future, that demands may be made on Local Authorities and other organisations involved in housing maintenance, to produce smaller, more flexible response maintenance contracts.

In this event an additional administrative/management burden will be created for Client Departments in their role as enablers and also cause additional logistical problems for the contractor offering a repairs service.

As a consequence of such possible changes in the size and content of contracts and the additional possibility that contractors may change from time to time the following questions which require answering emerge:

(a) How large or small should a contract be? Is it based on Estates, singly or in groups?

(b) Is it based on single trades or groups of trades?

(c) What is the content of the package in terms of repairs type?

(d) What volumes of work may the contractor anticipate receiving?

(e) What is the cash value of the contract?

(f) How many tradesmen within each trade are necessary to execute the work within specified Target Response Times?

There may be other questions to answer, however we proceed with a firm focus on those above.

4.1.3 Client/Contractor Departments Interfacing

Current legislation and possible future changes have a potential to create situation hitherto not experienced by many client and contractor departments under previous legislation. A conflict of interest could develop between client and contractor department. This conflict it must be stressed is independent of the public or private sector base of the contractor and will not necessarily be in the interest of the repairs service in general. For instance the fluctuating nature of the issuing of orders to execute repairs by the client department to a maintenance contractor needs to be analysed. These fluctuating orders for repairs may be distinct from those *true* seasonal variations or otherwise which occur at the interface between the Tenant and the Client Department. Unnecessary problems can therefore be created by a failure to acknowledge the difficulties encountered by contractors attempting to deliver a repairs service. A more quantified approach to exposing the nature of the response repair system and its associated logistical problems is therefore necessary.

A primary reason for attempting to anticipate the fluctuating response maintenance workload is to investigate the potential to undertake additional works contracts and to sensibly predict any workforce reserves in man job hours which are available to do so. The types of contracts which the Contractor may additionally bid for includes a variety of packages in the Planned Maintenance category, minor or major building works or indeed winning subcontracted work from other local authorities bearing in mind that current legislation restricts DLO's to winning work within a more restricted market than the private sector contractor.

Exhibit 3.7.14 page 107 shows the fluctuating job arrivals for joinerwork reproduced on page 130 in the interest of coherence.

It must be reinforced that a Client Department's function is that of ENABLER. This implies that it should do all in its power to assist Contractor Departments providing the repairs service. It is therefore unreasonable that the client is unable to produce a prediction, however approximate, of the likely contents of a response maintenance contract including seasonal workload variations. It is quite conceivable, in the not too distant future, that the demands for *quality assured service delivery standards*, as discussed in Chapter 2, will force Client Departments to address any current inadequacies in this respect. On the other hand some Authorities may already be generating data of this sort, but the question is, to what use if any is the data being put? If the answer is none then this too must be regarded as unreasonable.

The lack of such information can only place a burden on the overall management of the repairs service and complements the intrinsic haphazardness of a response system and underpins the perception that system variables are totally uncontrollable.

The more information that is made available the greater the chance of unearthing potentially viable quality control regimes.

If the Client Department is in the dark, then spare a thought for the Contractor.

Obviously producing information takes time and effort and costs money. Consequently Authorities may well disagree with directing resources towards control regimes. However, this may be regarded as a penalty which has to be paid to achieve quality and there may be not much sympathy offered if quality standards are not realised.

At Contractor level a further condition exists which inhibits the delivery of the repairs service, which is, single trade working practices. We believe that there is much potential for undertaking a proportion of repairs across trade boundaries. It must be possible, particularly in housing repairs, that an individual tradesman could execute a variety of smaller jobs across a range of otherwise separate trades. This would reduce travelling time between specialised trade repairs and permit flexibility in the utilisation of available manpower. An example of such an amalgamation could be Joiner/Glazier/Painter. The advantages of this grouping will be obvious to a maintenance manager, and we will discuss it statistically later in the Chapter.

In the past too little has been done to produce diagnostic aids which may help Client and Contractor Departments to execute their respective duties. Improved efficiency in both of these departments should enhance service delivery and improve customer satisfaction.

With these thoughts to the fore we proceed to develop statistical/computer simulations which may allow response maintenance problems to be more effectively managed in the future.

4.1.4 Introduction to Simulation Problem Solving Techniques

If any advances are to be achieved in the management of response maintenance, more thorough and indepth analysis of its contents itemised over several years is necessary and true response repairs must be ringfenced.

We now propose to develop some techniques, using data derived from Strathkelvin District Council and sifted as described in Chapter 3, which hopefully will be an advance on current state of the art thinking.

The analytical techniques developed in this chapter are embedded in a computer program, written in basic, which generates random numbers and proceeds to systematically sample from four separate and different statistical distributions, summing results in sequence to produce probabilistic forecasts for daily bundles of man job hours for each separate trade in the model and showing the number of individual jobs by category of work, and location by Estate.

The program is further adapted, three separate experiments are performed and the following quantities of interest, which are deemed to be contentious, investigated.

(a) The probable number of man job hours per day likely to be dispatched by the Client Department to a Contractor is generated over a twenty working day, ie one month period for individual trades. From this, experimentation with the following is pursued.

    (i) coalescing individual trades in a variety of groups to produce multi skilled tradespersons and the statistical dispersion of man job hours then measured.

    (ii) predicting maximum and minimum manpower levels required by the contractor to service the fluctuating response repairs demand over the defined twenty day trial period which match Target Response Times demands made by the Client Department.

(b) Forecasting the cost of response maintenance contracts in order to help accommodate demands for a variety of contracts in terms of scale and packaging of work.

(c) Estimating the cash value of materials; required to be held in Contractors stores over a selected period of time. It may be possible in future to predict detail of actual items.

These experiments are subsequently described in detail and in the same sequence as above.

It must be stressed that the main thrust of this chapter is aimed at devising problem solving techniques and in view of the scale of the applications only a limited number of scenarios are illustrated.

4.2 PLANNING RESPONSE REPAIRS

Before the simulation and its applications are considered the pivotal role played by the contractor department's *Maintenance Controller* is highlighted. Even if sensible prediction can be made for job arrival rates and job completion times which lead to forecasts of work arrival rates the *controller* has the capacity to manipulate the work loads allocated to tradesmen to attempt to smooth workloads and match specified Target Response Times.

The situation is that the Contractor Department is required to attempt to provide an even distribution of work across a range of trades and for the purposes of the simulation exercise, we assume that the contractor has opted to attempt to maintain a stable workforce for each trade throughout the year. This being the case the burning question is; how many tradesmen are required to form a basic or *nucleus* workforce which can cope with response repairs at various times throughout the year?

It is patently clear that the maintenance manager's problem could be a difficult and dynamic one. To effectively monitor the situation the manager requires to implement a quality control regime comprising the following three interactive elements:

(i) IMMEDIATE CONTROL
(ii) FORWARD CONTROL ONE
(iii) FORWARD CONTROL TWO

IMMEDIATE CONTROL refers to the hour by hour, day by day manipulation of job arrivals, by a contractor's *maintenance controller*, which ensures that emergency and very urgent repairs are dispatched to tradesmen expeditiously. Additionally such control applies to the distribution of selected work packages to tradesmen on a day by day or more likely week by week basis.

FORWARD CONTROL ONE requires careful prioritisation of jobs into systematic queues for subsequent dispatch to tradesmen. In the interest of the Contractor Department the *maintenance controller* may delay certain jobs and attempt to cluster them into zones with a view to reaping any possible benefits which may accrue as a consequence of doing so.

By cluster calculation Christer[1] demonstrates time saved by the delaying and zoning of repairs. These savings accrue from a reduction in travelling time between individual jobs and any unnecessary excursions to and from the depot. Time savings of the order of 17% and 31% for joiner and plumbing trades respectively are estimated. A case study for the delaying of repairs to a hospital complex is cited where productivity was increased and greater customer satisfaction was expressed as a direct result of implementing a delay system. An additional consequence was that the bonus scheme in operation at the time required to be renegotiated.

At the time of the above investigation no mechanical transportation was used by the tradesmen; a very different situation from that of a contemporary maintenance contractor service, most of which is highly mechanised. However the concept is still valid and coupled with time savings due to learning benefits much potential for savings still exists by introducing delay mechanisms. The influence of repairs clustering on financial savings has also been investigated by Christer[3].

FORWARD CONTROL TWO demands that the *controller* exercises care and vigilance at all times to establish when jobs, previously stacked, are to be liberated from the queues to ensure that Actual Response Times match or better the Target Response Times demanded by the Client Department on behalf of the Tenant.

It must be noted that the proposed simulation uses data for an isolated four week period, start point beginning week sixteen and finish point end of week nineteen. However by identifying the above control procedures we reveal that the completion of jobs by the Contractor Department may be regarded as a continuous if uneven flow, with repairs moving forwards in a time continuum, transcending the artificially introduced lower start point and upper finish point and the enforced condition of working a five day week. Thus the simulation is to an extent static, whereas a dynamic solution is called for.

4.3 FREQUENCY DISTRIBUTION REQUIREMENTS

4.3.1 Introduction

To produce the proposed SIMULATION model by computer the following frequency distributions are required on a Trade by Trade basis.

1. DAILY AGGREGATED JOB ARRIVALS.
2. TARGET JOB COMPLETION TIMES.
3. JOBS IN EACH RESPONSE CATEGORY.
4. JOB ARRIVALS ESTATE BY ESTATE.

The idea now is that by generating random numbers and sampling from the probability distributions listed above, it should be possible to simulate the number of jobs arriving, the repair categories, hours of service required, and locations on a day by day and/or week by week basis.

Accepting that the fluctuating weekly job arrivals shown in Exhibit 3.7.13 page 106 are typical trends with time, it would clearly be of no purpose to produce average predictions over long term periods. Instead a more realistic approach would be to divide the time scale into convenient bands, say quarterly or monthly or other bands which best take account of peaks and troughs, and estimate for each the unplanned and zoned response maintenance demands and concomitant workforce requirements.

After a review of Exhibits 3.7.14 to 3.7.16 pages 107- 109 and for reasons of convenience it was decided to examine the period weeks, 16 to 19 inclusive. Exhibit 3.7.14 is reproduced and shown overleaf. Here fluctuations in job arrivals are evident, but not extremely so, there is little evidence of trend, and since the number of jobs being generated is relatively low, manual data analysis is less time consuming. Daily random variations in jobs per day for joinerwork repairs in all Estates are given in Exhibit 4.3.1 page 131.

For two reasons it was decided to investigate the occurrence of jobs in all five Estates. Firstly, Estate by Estate and day by day the number of jobs arriving is likely to be relatively small, and therefore may not yield viable work packages. Secondly, prior to the recent legislative changes, the maintenance work was allocated to the local DLO and as many as thirty six locally based private contractors (see Appendix 2 for list) on an approximate 40/60 split respectively, with the DLO additionally receiving all emergency repairs. Therefore a clearer picture of the Total Demand for repairs is obviously desirable since in general the likelihood is that neither the DLO or local private contractors or for that matter the Client Department would have had a clear vision of the shape of the total workload. Estimations of such workloads may prove useful in enabling effective work planning and manpower resourcing and may possibly assist with stores and inventory policies, transportation allocations, locations and the packaging of Functional Works contracts by Client Departments.

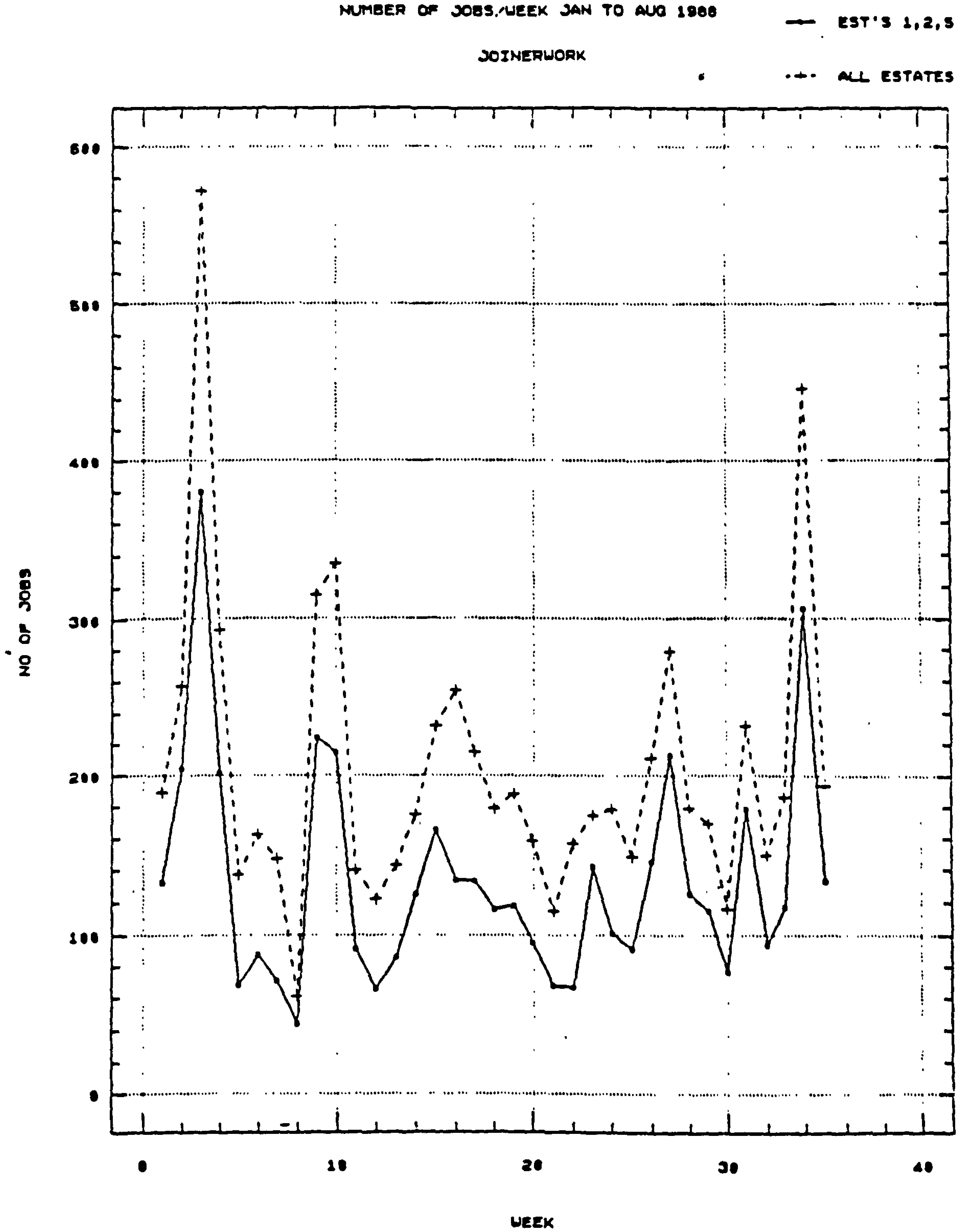


Exhibit 3.7.14

Reproduced from Chapter 3

Weekly Fluctuations in Jobs Issued
Joiner Work

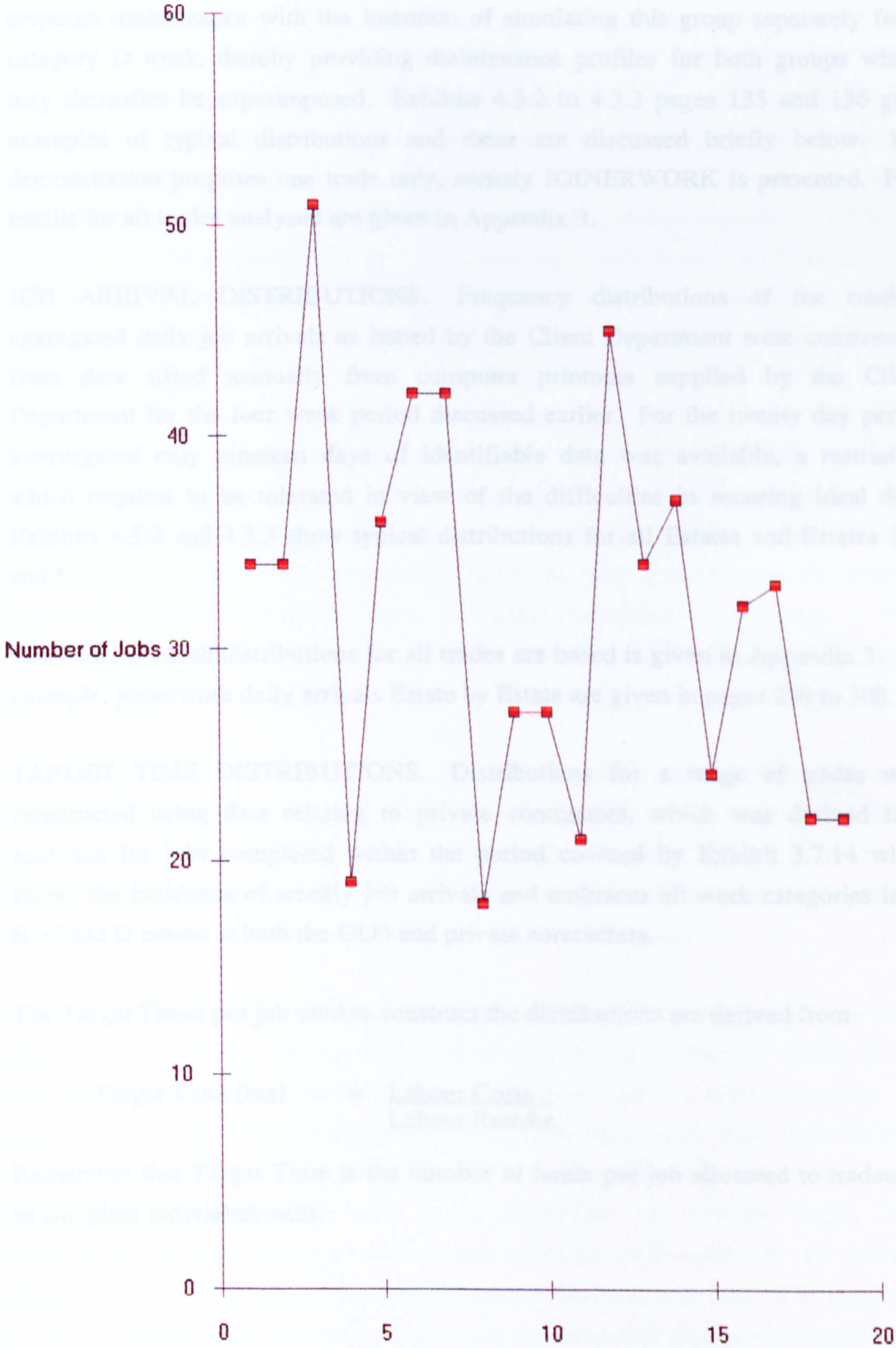


Exhibit 4.3.1

Joinerwork Daily Job Arrivals Weeks 16 to 19 All Estates

4.3.2 Job Arrivals and Target Time Distributions

For each trade, jobs in categories A, B and C are grouped to form unplanned response maintenance with the intention of simulating this group separately from category D work, thereby providing maintenance profiles for both groups which may thereafter be superimposed. Exhibits 4.3.2 to 4.3.3 pages 135 and 136 give examples of typical distributions and these are discussed briefly below. For demonstration purposes one trade only, namely JOINERWORK is presented. Full results for all trades analysed are given in Appendix 3.

JOB ARRIVAL DISTRIBUTIONS. Frequency distributions of the random aggregated daily job arrivals as issued by the Client Department were constructed from data sifted manually from computer printouts supplied by the Client Department for the four week period discussed earlier. For the twenty day period investigated only nineteen days of identifiable data was available, a restriction which requires to be tolerated in view of the difficulties in securing ideal data. Exhibits 4.3.2 and 4.3.3 show typical distributions for all Estates and Estates 1, 2 and 5.

The data on which distributions for all trades are based is given in Appendix 3. For example, joinerwork daily arrivals Estate by Estate are given in pages 299 to 308.

TARGET TIME DISTRIBUTIONS. Distributions for a range of trades were constructed using data relating to private contractors, which was derived from accounts for jobs completed within the period covered by Exhibit 3.7.14 which shows the incidence of weekly job arrivals and embraces all work categories ie A, B, C and D issued to both the DLO and private contractors.

The Target Times per job used to construct the distributions are derived from

$$\text{Target Time (hrs)} = \frac{\text{Labour Costs}}{\text{Labour Rate/hr.}}$$

Remember that Target Time is the number of hours per job allocated to tradesmen to complete individual tasks.

An example of the Target Time distribution for joinerwork is given in Exhibit 4.3.4 page 137. No data was available for Target Times for the DLO workforce, however the distributions developed above and used in analysis are taken meantime as a surrogate for the DLO.

It is not unreasonable to make this assumption, given that skills and learning experiences of both workforces are similar and that jobs are priced against a schedule of rates. However it is acknowledged that variations could arise as a consequence of differences in basic wage rates and incentive schemes negotiated separately by both workforce groups. Nevertheless, it will be shown in Section 4.5 that the proposed compounding of discrete distributions by computer simulation is sufficiently adaptive to accommodate any such variations in *target time distributions*.

Tables 4.3.1 and 4.3.2 page 138 provide frequency tabulations of Exhibits 4.3.2 and 4.3.3. Table 4.3.3 page 139 gives the same properties for Exhibit 4.3.4 and Table 4.3.4 page 139 shows the results of a chi square test which indicates little correspondence between the empirical distribution and a theoretical distribution having a *negative exponential* form. No great importance is attached to this outcome at this stage, although the application of theoretical distributions is pursued later in Section 4.6.

One Target Time distribution only is available for each separate trade and may comprise job target times ranging from 30 minutes up to a maximum of 20 hours, which was taken as the arbitrary cut off point for response maintenance. Some trades, for example electrical work, produced much lower trade dependent upper limits, target time for some trades being in general much shorter.

The use of only one Target Time distribution per trade, which is general to all work categories A to D, may be regarded as limiting. The Audit Report[8] refers to the expensive nature of emergency (category A) work and the need to reduce the proportion of work in this category. Likewise category D work may well exhibit a unique distribution although at this stage there is no available evidence to support this contention. Nevertheless there is the possibility that separate Target Time distributions for each category within each separate trade exist and we proceed taking account of this while restricting analysis to the available data. It is suggested in Audit Report[8] that "the ratio of costs for the same job done on a programmed basis, as a routine jobbing repair and as an emergency could well be of the order of 100 : 150 : 200".

For DLO's operating a bonus scheme the Audit Report[13] recommends that target times (although not referred to as such) for shorter tasks should be banded and cites the following examples.

Lower Limit	Representative Value (Minutes)	Upper Limit
0	13	20
20	28	40
40	57	80

The representative value is different from the midpoint as a consequence of the distribution of the job completion times.

Such sophistication is not embodied in this study in view of the incomplete nature of the available data.

Full results for Target Time Distribution for all trades are produced in Appendix 3 and in the same form as Exhibit 4.3.4 page 137.

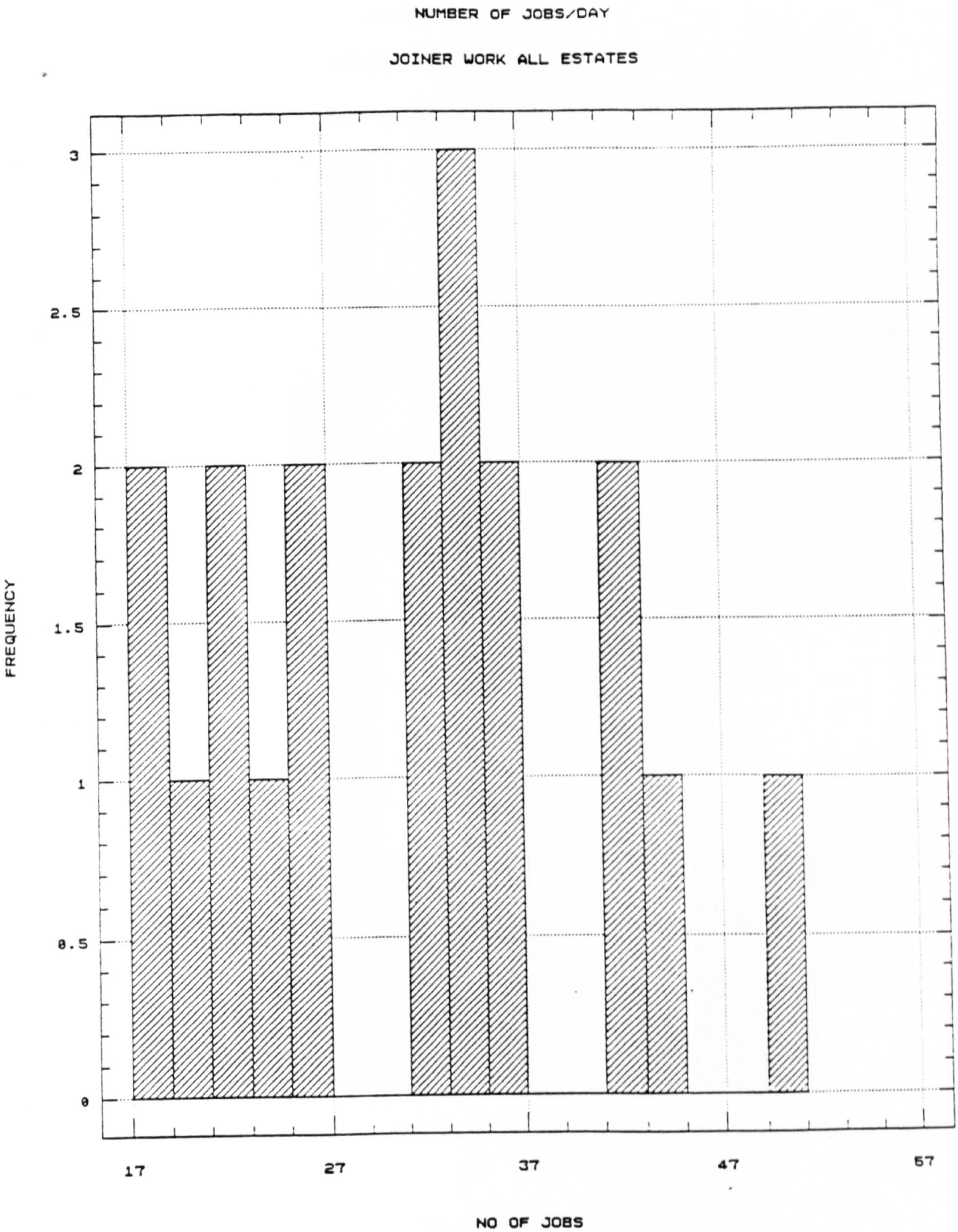


Exhibit 4.3.2

Weeks 16 to 19

Job Arrivals Per Day
Joiner Work All Estates

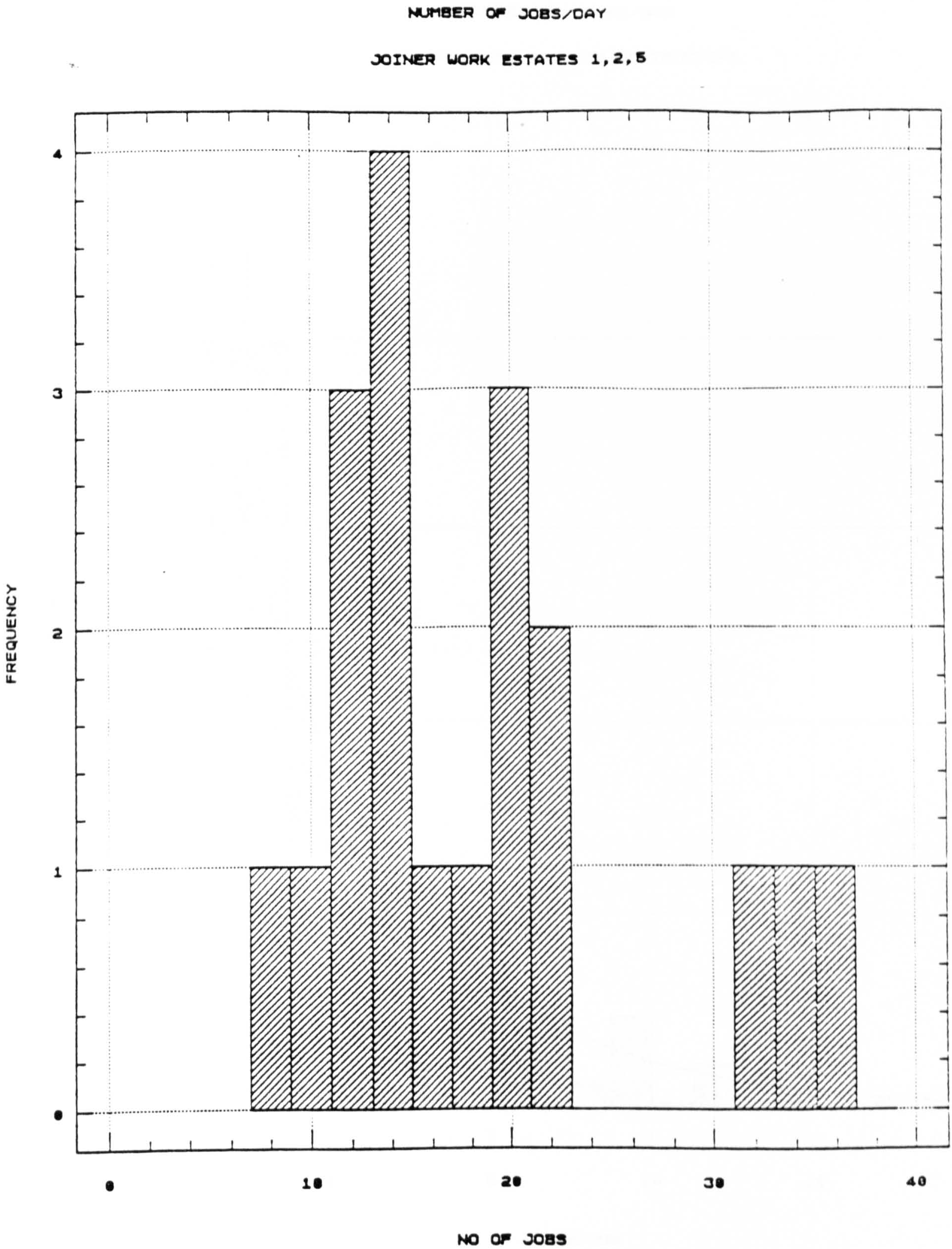


Exhibit 4.3.3

Weeks 16 to 19

Job Arrivals Per Day
Joiner Work Estates 1,2 and 5

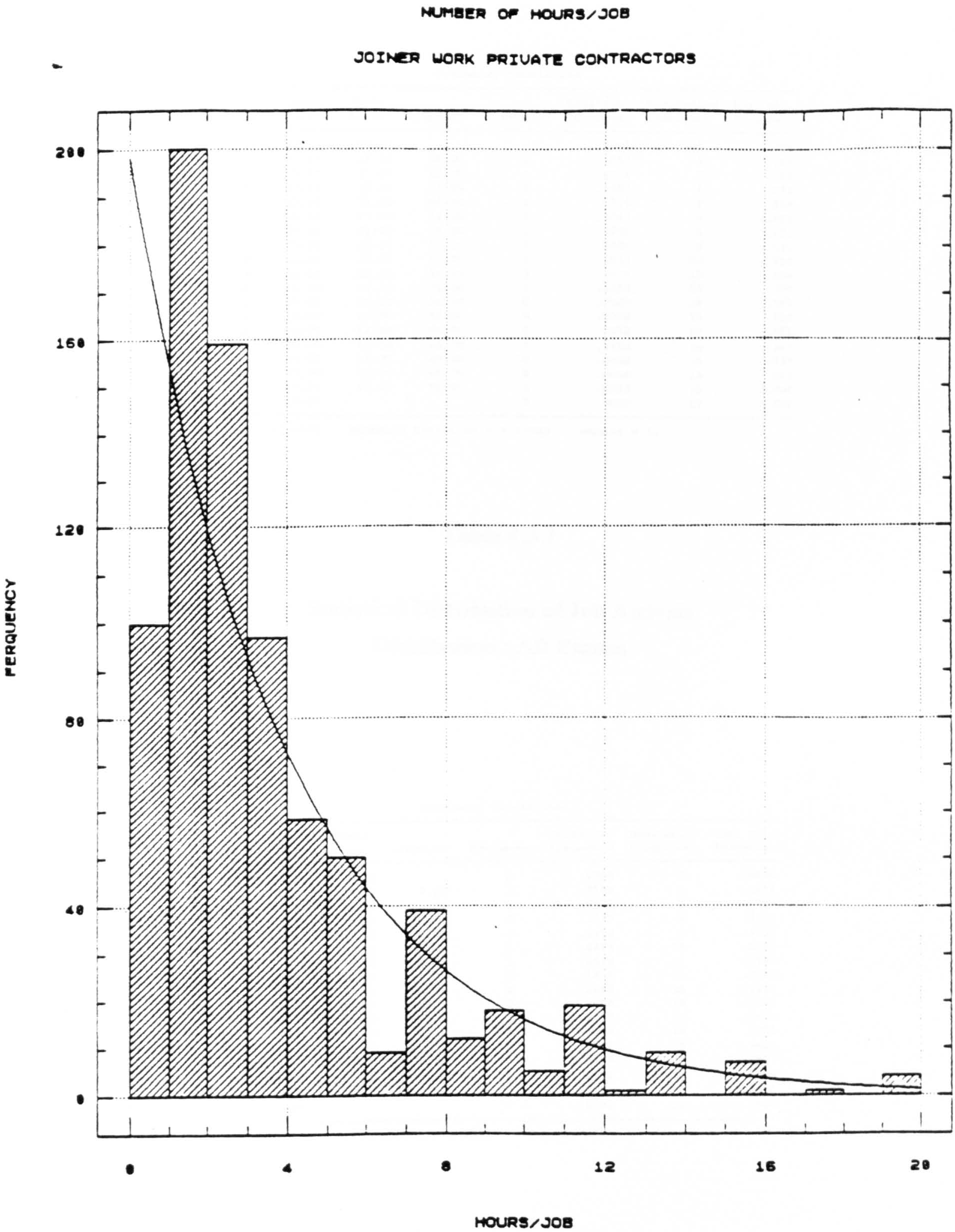


Exhibit 4.3.4

TARGET TIME DISTRIBUTION

Number of Hours Per Job
Joiner Work; Private Contractors

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		17.00		0	.0000	0	.000
1	17.00	19.00	18.00	2	.1053	2	.105
2	19.00	21.00	20.00	1	.0526	3	.158
3	21.00	23.00	22.00	2	.1053	5	.263
4	23.00	25.00	24.00	1	.0526	6	.316
5	25.00	27.00	26.00	2	.1053	8	.421
6	27.00	29.00	28.00	0	.0000	8	.421
7	29.00	31.00	30.00	0	.0000	8	.421
8	31.00	33.00	32.00	2	.1053	10	.526
9	33.00	35.00	34.00	3	.1579	13	.684
10	35.00	37.00	36.00	2	.1053	15	.789
11	37.00	39.00	38.00	0	.0000	15	.789
12	39.00	41.00	40.00	0	.0000	15	.789
13	41.00	43.00	42.00	2	.1053	17	.895
14	43.00	45.00	44.00	1	.0526	18	.947
15	45.00	47.00	46.00	0	.0000	18	.947
16	47.00	49.00	48.00	0	.0000	18	.947
17	49.00	51.00	50.00	1	.0526	19	1.000
above	51.00			0	.0000	19	1.000

Mean = 31.5789   Standard Deviation = 9.37085   Median = 33

Table 4.3.1

Statistical Distribution of Job Arrivals

Distribution : All Estates

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		7.00		0	.0000	0	.0000
1	7.00	9.00	8.00	1	.0526	1	.0526
2	9.00	11.00	10.00	1	.0526	2	.1053
3	11.00	13.00	12.00	3	.1579	5	.2632
4	13.00	15.00	14.00	4	.2105	9	.4737
5	15.00	17.00	16.00	1	.0526	10	.5263
6	17.00	19.00	18.00	1	.0526	11	.5789
7	19.00	21.00	20.00	3	.1579	14	.7368
8	21.00	23.00	22.00	2	.1053	16	.8421
9	23.00	25.00	24.00	0	.0000	16	.8421
10	25.00	27.00	26.00	0	.0000	16	.8421
11	27.00	29.00	28.00	0	.0000	16	.8421
12	29.00	31.00	30.00	0	.0000	16	.8421
13	31.00	33.00	32.00	1	.0526	17	.8947
14	33.00	35.00	34.00	1	.0526	18	.9474
15	35.00	37.00	36.00	1	.0526	19	1.0000
above	37.00			0	.0000	19	1.0000

Mean = 19   Standard Deviation = 8.25135   Median = 16

Table 4.3.2

Statistical Distribution of Job Arrivals Distribution

Estates 1, 2 and 5

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.00000	0	.000
1	.00	1.00	.500	100	.12690	100	.127
2	1.00	2.00	1.500	200	.25381	300	.381
3	2.00	3.00	2.500	159	.20178	459	.582
4	3.00	4.00	3.500	97	.12310	556	.706
5	4.00	5.00	4.500	58	.07360	614	.779
6	5.00	6.00	5.500	50	.06345	664	.843
7	6.00	7.00	6.500	9	.01142	673	.854
8	7.00	8.00	7.500	39	.04949	712	.904
9	8.00	9.00	8.500	12	.01523	724	.919
10	9.00	10.00	9.500	18	.02284	742	.942
11	10.00	11.00	10.500	5	.00635	747	.948
12	11.00	12.00	11.500	19	.02411	766	.972
13	12.00	13.00	12.500	1	.00127	767	.973
14	13.00	14.00	13.500	9	.01142	776	.985
15	14.00	15.00	14.500	0	.00000	776	.985
16	15.00	16.00	15.500	7	.00888	783	.994
17	16.00	17.00	16.500	0	.00000	783	.994
18	17.00	18.00	17.500	1	.00127	784	.995
19	18.00	19.00	18.500	0	.00000	784	.995
20	19.00	20.00	19.500	4	.00508	788	1.000
above	20.00			0	.00000	788	1.000

Mean = 3.9765 Standard Deviation = 3.31352 Median = 3

Table 4.3.3

Statistical Distribution of Hours Per Job Distribution

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
	at or below	1.00	100	175.2	32.285045
	1.00	2.00	200	136.3	29.824501
	2.00	3.00	159	106.0	26.553421
	3.00	4.00	97	82.4	2.587743
	4.00	5.00	58	64.1	.576288
	5.00	6.00	50	49.8	.000585
	6.00	7.00	9	38.7	22.840163
	7.00	8.00	39	30.1	2.608651
	8.00	9.00	12	23.4	5.578634
	9.00	10.00	18	18.2	.002733
	10.00	11.00	5	14.2	5.935403
	11.00	12.00	19	11.0	5.778024
	12.00	13.00	1	8.6	6.686636
	13.00	14.00	9	6.7	.818508
	14.00	15.00	0	5.2	5.182601
	15.00	17.00	7	7.2	.003772
	17.00	20.00	5	5.8	.112022
above	20.00		0	5.2	5.154909

Chisquare = 152.53 with 16 d.f. Sig. level = 0

Table 4.3.4

Chisquare Test on Exhibit 4.3.4
Hours Per Job Distribution

4.3.3 Job Category and Estate Based Job Distributions

In the study outlined in Chapter 3 four categories of work have been identified and with jobs being generated from five estates the possibility exists that, for each trade examined, in this case six, the balance of work in each category is Estate dependent, with the variations conditioned by a combination of factors principally: age and condition of the housing stock, socio-economic conditions, tenant awareness and perception of the repair type by maintenance clerks. Exhibit 4.3.5 page 141, illustrates a typical example of these shifting proportions, for once again, joinerwork. To take account of all such variations was considered unnecessarily complicated for this exploratory study and would place an undue burden on the computer program required for sampling and analysis. It was therefore decided to simplify the job category distribution by taking the *mean value* of the proportions of jobs in all five estates in categories A, B and C for each trade examined to establish the frequency distribution for subsequent sampling. It is evident that as the number of repair categories decreases the more accurate the above simplification becomes.

Accepting that is is now possible to sample and establish the category of each job on arrival, it remains for us to determine its likely location by sampling from the frequency distribution which is developed for the proportions of work Estate by Estate, numerically obtained from the computer printouts provided by the Client Department. Once again for joinerwork, an example of this distribution is shown in exhibit 4.3.6 page 142.

NOTE:

In view of the complex nature of processes required to complete the simulation it will be necessary in order to avoid too much unnecessary duplication; to refer back to this section in order to follow subsequent explanation of the simulation applications.

The cumulative probabilities for the above distributions for all trades are given in Appendix 3 pages 528 to 529.

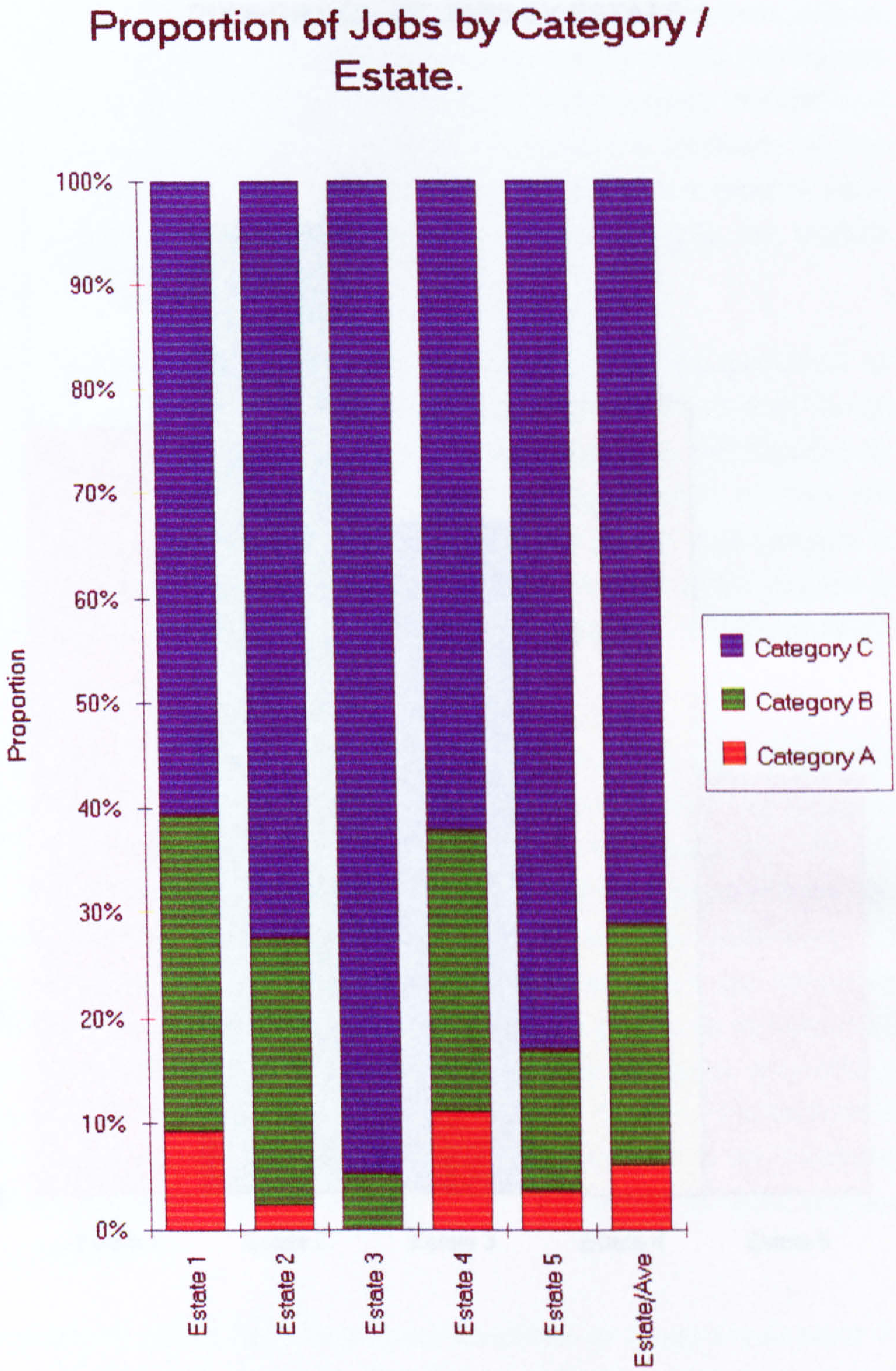


Exhibit 4.3.5

Snapshot of Week 16 to 19
589 Observations.

Proportion of Jobs by Category Joiner Work.

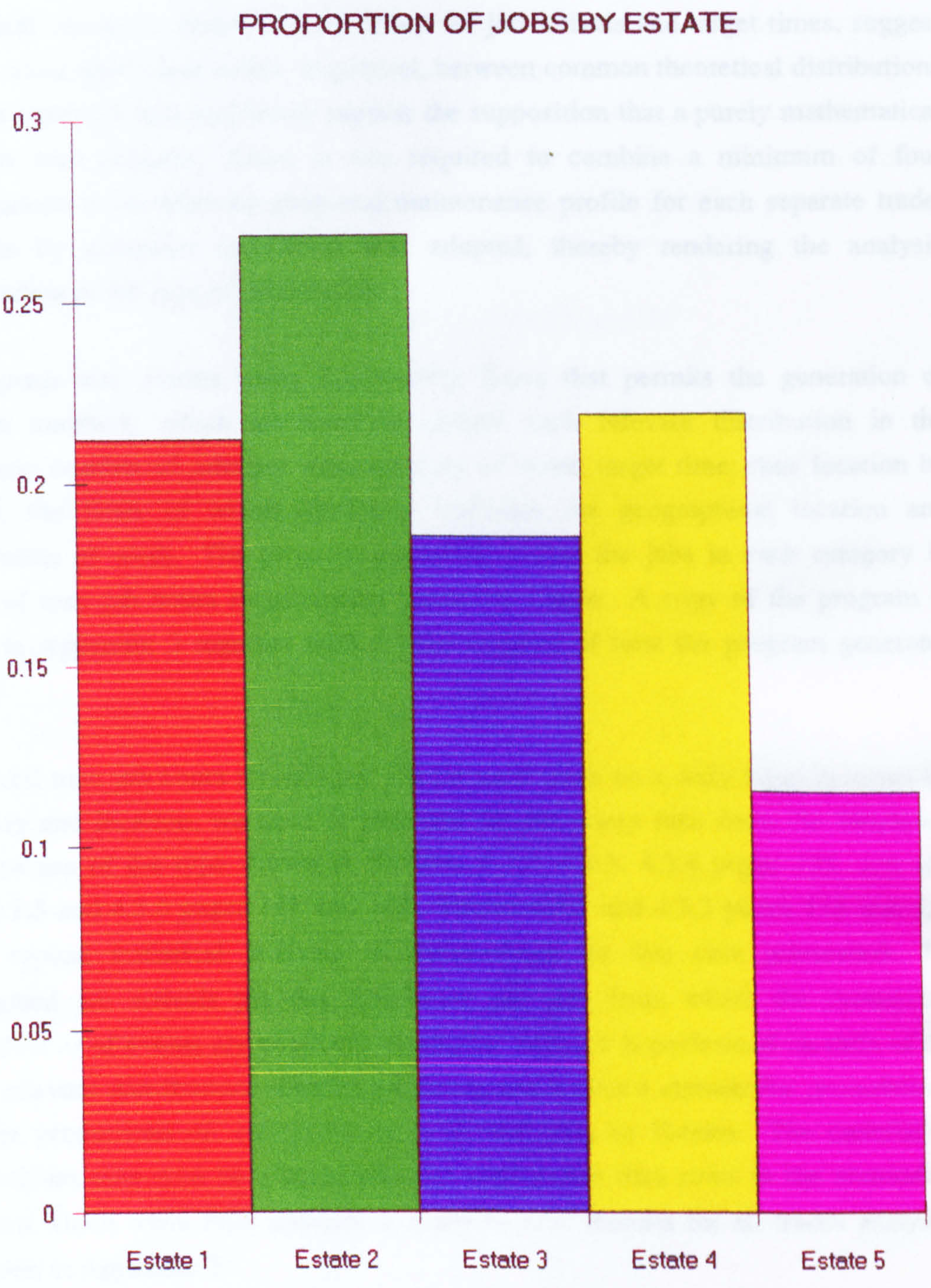


Exhibit 4.3.6

Snapshot of Weeks 16 to 19
589 Observations

Proportion of Jobs by Estate Joiner Work.

4.3.4 Sampling, Analysing and Synthesising Procedures

Statistical checks on derived distributions for job arrivals and target times, suggest that no close agreement exists, in general, between common theoretical distributions and the observed data and hence support the supposition that a purely mathematical solution was unlikely. Since it was required to combine a minimum of four distributions to produce the proposed maintenance profile for each separate trade, analysis by computer simulation was adopted, thereby rendering the analysis independent of the type of distribution.

A program was written using Locomotive Basic that permits the generation of random numbers, which are used to sample each relevant distribution in the sequence: number of jobs per day; category of work; target time; then location by estates, the latter of which obviously indicates the geographical location and distribution of work. The program proceeds to sum the jobs in each category in terms of man job hours requirements Estate by Estate. A copy of the program is given in Appendix 3 together with a brief account of how the program generates results.

To model man job hours arrivals per job for each trade on a daily basis in terms of category and location, we need to generate the necessary data from the frequency distributions of the type shown in Exhibits 4.3.2, 4.3.3, 4.3.4 pages 135, 136 and 137, 4.3.5 and 4.3.6 pages 141 and 142. Tables 4.3.1 and 4.3.3 pages 138 and 139 show typical statistical analysis of distributions, in this case joinerwork, for aggregated job arrivals per day and hours per job; from which the *cumulative probabilities* of events are obtained. A similar analysis is performed on each of the other relevant distributions thereby providing the required *cumulative probabilities* for, the proportions of, categories of work and jobs by Estates. The cumulative probabilities may now be entered into the appropriate data rows in the simulation program which when fully charged is ready to run. Results for all trades analysed are given in Appendix 3.

Examples of typical outputs from the program are shown on the next three pages for All Estates and Estates 1, 2 and 5. The first part of the outputs were used to experiment within the idea of trade amalgamations which follows in the next section. The five by three and three by three matrices were deployed in the experiments on manpower resourcing problems at contractor level.

Thus as shown below it may be possible to construct a realistic picture of unplanned response maintenance showing in probabilistic terms workforce man job hour attendance requirements and the geographical distribution of the workloads. Likewise, using the same computer program, non urgent work in category D can be analysed by inputting a separate job arrival distribution, the results of which can be superimposed on the daily arrivals for unplanned response jobs. Planned response jobs may be added to any existing backlog of such repairs which are possibly being scheduled on a cyclical basis.

SAMPLE COMPUTER SIMULATION OUTPUTS

Plumber All Estates

Random sampling of jobs by duration, category and location.

Total hours for day	1	165.5	No of jobs	31
Total hours to day	1	165.5	No of jobs	31
Total hours for day	2	264.5	No of jobs	43
Total hours to day	2	430	No of jobs	74
Total hours for day	3	119.5	No of jobs	23
Total hours for day	3	549.5	No of jobs	97
Total hours for day	4	129.5	No of jobs	23
Total hours to day	4	679	No of jobs	120
Total hours for day	5	220.5	No of jobs	35
Total hours to day	5	889.	No of jobs	155

	No of Hours			No of Jobs			
	A	B	C	A	B	C	
ESTATE 1	2.5	17	18.5	1	4	3	
ESTATE 2	1.5	18	17.5	1	2	3	
ESTATE 3	4.5	25	16.5	1	4	3	DAY 1
ESTATE 4	7.5	16.5	3.5	1	3	1	
ESTATE 5	0	9	8	1	3	1	
SUM	16	85.5	64	4	15	12	
ESTATE 1	50.5	6.5	39.5	5	1	5	
ESTATE 2	6.5	20.5	43.5	1	3	7	
ESTATE 3	1.5	21.5	3	1	3	2	DAY 2
ESTATE 4	6	10	20.5	2	2	3	
ESTATE 5	8.5	7	17.5	3	2	3	
	73	67.5	124	12	11	20	

	No of Hours			No of Jobs			
ESTATE 1	7.5	7.5	8	1	1	2	
ESTATE 2	0	8.5	7.5	0	3	3	
ESTATE 3	11.5	6	14	1	2	2	DAY 3
ESTATE 4	1.5	5.5	18.5	1	1	3	
ESTATE 5	14.5	5.5	5.5	1	1	1	
	35	33	51.5	4	8	11	

ESTATE 1	0	15.5	0	0	3	0	
ESTATE 2	18	3.5	9.5	4	1	1	
ESTATE 3	1.5	2.5	37.5	1	1	5	DAY 4
ESTATE 4	0	8.5	17.5	0	1	3	
ESTATE 5	0	8	7.5	0	2	1	
	19.5	38	72	5	8	10	

ESTATE 1	0	5	5	0	2	2	
ESTATE 2	9.5	15.5	31.5	1	3	2	
ESTATE 3	2.5	17.5	18	1	3	2	DAY 5
ESTATE 4	25	33	27	2	6	4	
ESTATE 5	10	18.5	2.5	2	3	1	
	47	89.5	84	6	17	12	

SAMPLE COMPUTER SIMULATION OUTPUTS

Plumber Estates 1, 2 and 5

Random sampling of jobs by duration, category and location.

Total hours for day	1	170	No of jobs	28
Total hours to day	1	170	No of jobs	28
Total hours for day	2	224	No of jobs	34
Total hours to day	2	394	No of jobs	62
Total hours for day	3	95	No of jobs	20
Total hours for day	3	489	No of jobs	82
Total hours for day	4	73	No of jobs	12
Total hours to day	4	562	No of jobs	94
Total hours for day	5	156	No of jobs	28
Total hours to day	5	718	No of jobs	122

Program 2 Jobs by Category and Estate

	No of Hours			No of Jobs			
	A	B	C	A	B	C	
ESTATE 1	3.5	32.5	0	1	5	0	
ESTATE 2	31	31	18	4	4	6	DAY 1
ESTATE 5	3.5	29	21.5	1	4	3	
SUM	38	92.5	39.5	6	13	9	
ESTATE 1	7	45.5	49.5	2	7	7	
ESTATE 2	1.5	36	41.5	1	4	5	DAY 2
ESTATE 5	29	14	0	4	4	0	
SUM	37.5	95.5	91	7	15	12	
ESTATE 1	22	9.5	14	2	3	4	
ESTATE 2	30.5	6	13	7	2	2	DAY 3
ESTATE 5	0	0	0	0	0	0	
SUM	52.5	15.5	27	9	5	6	

	No of Hours			No of Jobs			
ESTATE 1	0	2.5	12.5	0	1	3	
ESTATE 2	0	28	0	0	4	0	DAY 4
ESTATE 5	14.5	13	2.5	1	2	1	
SUM	14.5	43.5	15	1	7	4	

	No of Hours			No of Jobs			
ESTATE 1	9.5	9	35	1	2	6	
ESTATE 2	4.5	12	39.5	1	2	7	DAY 5
ESTATE 5	15	14	17.5	2	4	3	
SUM	29	35	92	4	8	16	

4.4 THE STATISTICAL EFFECTS OF GROUPING BY TRADE, ESTATE AND CATEGORY

4.4.1 Statistical Effects of Grouping Trades: By Simulation

To illustrate the first application of the simulation two scenarios are investigated. The use of the number of man job hours arriving per day for each separate trade in the model as derived from the following:

(a) The entire population of the stock; that is all Five Estates.

(b) The combination of Estates, 1, 2 and 5 abitarly chosen earlier in Chapter 3 to demonstrate differences in weekly arrival patterns.

The total number of houses in the experiments are thus 9252 and 5252 respectively. Firstly this permits the influence of the number of houses in the model on the statistical dispersion of the number of man job hours generated, to be tested.

Secondly, the six autonomous trades in the model, which are joiner, plumber, electrician, slater/plasterer, builder and glazier; are combined into what may be described as arbitrary groupings. The influence of coalescing of trades on the dispersion of hours of work generated is then tested.

Results were obtained by running the simulation program sixty times, thereby producing sixty independent random daily sample values for each of the six autonomous trades in the model. Each daily parcel of work thus derived was also sectioned into Estates and the number of man job hours per day displayed by job category, A, B or C, the grouping which constitutes unplanned response maintenance.

Combinations of man job hours per day for the coalition of trades were subsequently determined by summing corresponding daily bundles in arrival sequence. An additional five trade amalgams were arbitrarily produced, these being

(a) Joinery/Glazing
(b) Joinery/Plumbing
(c) Plumbing/Electrical
(d) Joinery/Glazing/Plumbing/Electrical
(e) Slater:plasterer/builder

Some of the trade amalgamations suggested above may well cause initial consternation on the part of the 'trade' workforce and or the Trade Unions; however it is not the intention in this section to discuss any conflict of interest or otherwise which may ensue as a consequence of the coalition of Trades. We simply believe that many 'jobbing' maintenance repairs; especially short duration jobs, could be effected by multiskilled tradespersons, being mindful of innovations in materials/components and jointing techniques and given that adequate apprenticeship training schemes are evolved. The Audit Report[13] cites an example of flexible working practices where the main trade makes good. Three trades, namely, plumber, joiner and plasterer are combined. Savings of the order of thirty eight per cent in attendance time are suggested and the report further suggests that no trade loses work to another in instances where flexible working has been experimented with.

4.4.2 Testing the Models for Dispersions

It is quite conceivable that a client department may wish to devise a variety of baskets of work; varying in both size and content, for which, competitive tenders are invited. Clearly many permutations are possible and it is not the intention here to examine a host of possibilities. Rather we aim to investigate a limited range of scenarios to demonstrate the principle of the analysis highlighting the consequences which may impinge on the delivery of the service at the maintenance contractor level.

The results of the experiments produced by the computer simulation for the aforementioned trades and trade amalgams were statistically tested for dispersion and since a comparison between different distributions was deemed useful the coefficients of variation were determined thus:

$$\text{coefficient of Variation} = \frac{\sigma}{\mu} \times 100\%$$

where σ and μ are the standard deviation and mean of the sample of man job hours per day respectively.

The summary statistics produced are given in tables 4.4.2 (a) to (k) pages 151 to 153.

OBSERVATIONS

The results shown in the above tables (a) to (k) indicate in several instances, notably; Joiner, Joiner/Glazier; Plumber; Plumber/Electrical; Builder; Joiner/Glazier/Plumber/Electrical; that significant reductions in the Coefficient of Variation occur between All Estates and Estates one, two and five in that the larger the number of houses in the model the lower is the dispersion in man job hours. A preliminary conclusion therefore is that management logistic problems may decrease as the size of the maintenance contract increases. Similarly, as trades are progressively coalesced the Coefficient of Variation decreases significantly, again suggesting a reduction in logistical problems as flexibility among trades increases. A general result in statistics illustrated by this simulation is that, given two, independent non-negative quantities, the distribution of the sum of these quantities has a lower coefficient of variation than the larger of the coefficients of variation of the original distribution. The rationale for this result is given in Appendix 3 page 541.

Consider for example, the coefficients of variation of man job hours per day for the independent trades joiner and glazier given in tables (a) and (b). The coefficient of the combined trade joiner/glazier table (c) is less than the smaller of each individual coefficient of variation. The same observation may be made through-out the trade amalgamations selected for testing.

Therefore once such trade amalgams have been established this should lead to more effective use of human resources and a more manageable service at contractor level.

This conclusion may have been reached intuitively however more than intuition may be necessary to convince unions and management of real benefits.

It should be noted that this is purely a statistical outcome of trade coalitions and is independent of the obvious benefits which accrue from reduced travelling time and access problems.

Summary Statistics

Coefficient of Variation Tables 4.4.2 a - k

(a) JOINER

ESTATES	NO OF HOUSES	MIN HRS	MAX HRS	RANGE HRS	μ HRS	σ HRS	σ/μ x 100% coefficient
All	9252	48	192	144	116	36	31.0
1,2,5	5252	22	157	135	78.6	38.1	48.5
						DIFF.	+17.5%

(b) GLAZIER

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	σ/μ x 100%
All	9252	1.5	42.5	41	16.2	10.2	63.8
1,2,5	5252	0.5	27.5	27	11.1	6.6	59.3
						DIFF.	-4.5%

(c) JOINER/GLAZIER

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	σ/μ x 100%
All	9252	62.5	228.5	166	132.3	37.3	28.2
1,2,5	5252	22.5	173.5	151	89.7	39.4	44
						DIFF.	+15.8%

(d) PLUMBER

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	σ/μ x 100%
All	9252	112.5	353.5	241	207.2	51.8	25
1,2,5	5252	50	242	192	122.6	42.1	34
						DIFF.	+9%

(e) ELECTRICAL

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	$\sigma/\mu \times 100\%$
All	9252	7.5	64.5	57	35.8	13.3	37
1,2,5	5252	8.5	42.5	34	19.2	7.5	40
						DIFF.	+3%

(f) PLUMBER/ELECTRICAL

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	$\sigma/\mu \times 100\%$
All	9252	156	408	252	243	53	21.8
1,2,5	5252	60.5	262.5	202	141.7	43.2	30.5
						DIFF.	+8.7%

(g) BUILDER

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	$\sigma/\mu \times 100\%$
All	9252	1.5	123.5	122	55	25.5	46.3
1,2,5	5252	0	70.5	70.5	27.2	17.6	65.0
						DIFF.	18.7%

(h) SLATER:PLASTERER

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	$\sigma/\mu \times 100\%$
All	9252	25	171	146	73	34.2	47
1,2,5	5252	19	157	138	63.2	29.3	46.4
						DIFF.	-0.6%

(i) BUILDER/SLATERER:PLASTERER

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	σ/μ x 100%
All	9252	34.5	236.5	202	128	40.4	31.7
1,2,5	5252	33.5	169.5	136	90.4	29.8	33
						DIFF.	+1.3%

(j) JOINER/GLAZIER/PLUMBER/ELECTRICAL

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	σ/μ x 100%
All	9252	250.5	555.5	305	375.3	61.2	16.3
1,2,5	5252	126	371	245	231.4	59	26
						DIFF.	+9.7%

(k) JOINER/PLUMBER

ESTATES	NO OF HOUSES	MIN	MAX	RANGE	μ	σ	σ/μ x 100%
All	9252	202.5	480.5	278	323.3	58.75	18.2
1,2,5	5252	95	335	240	201.2	59	29.3
						DIFF.	+11.1%

4.5 AN AID TO PREDICTING WORKFORCE LEVELS

4.5.1 Defining The Nucleus Workforce

The second application of the simulation is aimed at manpower resourcing within the Contractor Department.

Perhaps the most difficult problem faced by the Contractor Department is the inability to predict the size of the workforce necessary to execute unplanned response maintenance within previously defined stipulated Target Response Times. Additionally a workforce is necessary which can accommodate unplanned response maintenance plus planned maintenance or other contracts which have been secured, are to be bid for, by the contractor department.

To establish any *slack labour reserves* we model the response maintenance demands within the framework of MAXIMUM NETT ATTENDANCE HOURS available. This is shown diagramatically in Fig 4.5.1 page 156. At the time of the data collection exercise the DLO which assisted in this investigation carried a joinery workforce of fifteen tradesmen. Therefore using the figures derived in Section 3.12 Chapter 3 we have, assuming an eight hour working day

MAXIMUM NETT ATTENDANCE HOURS available /day	=	GROSS ATTENDANCE HOURS x factor ($\lambda f < 1$)
"	"	"
"	=	(15 x 8) 0.816 HRS
"	"	"
"	=	98 hours/day

This value we take as being constant over the period under analysis while accepting that there will be fluctuations. A prediction of the variations in *maximum nett attendance hours* available is of course best derived by the local DLO or contractor gained through knowledge and experience of the available workforce, holidays arrangements and so on.

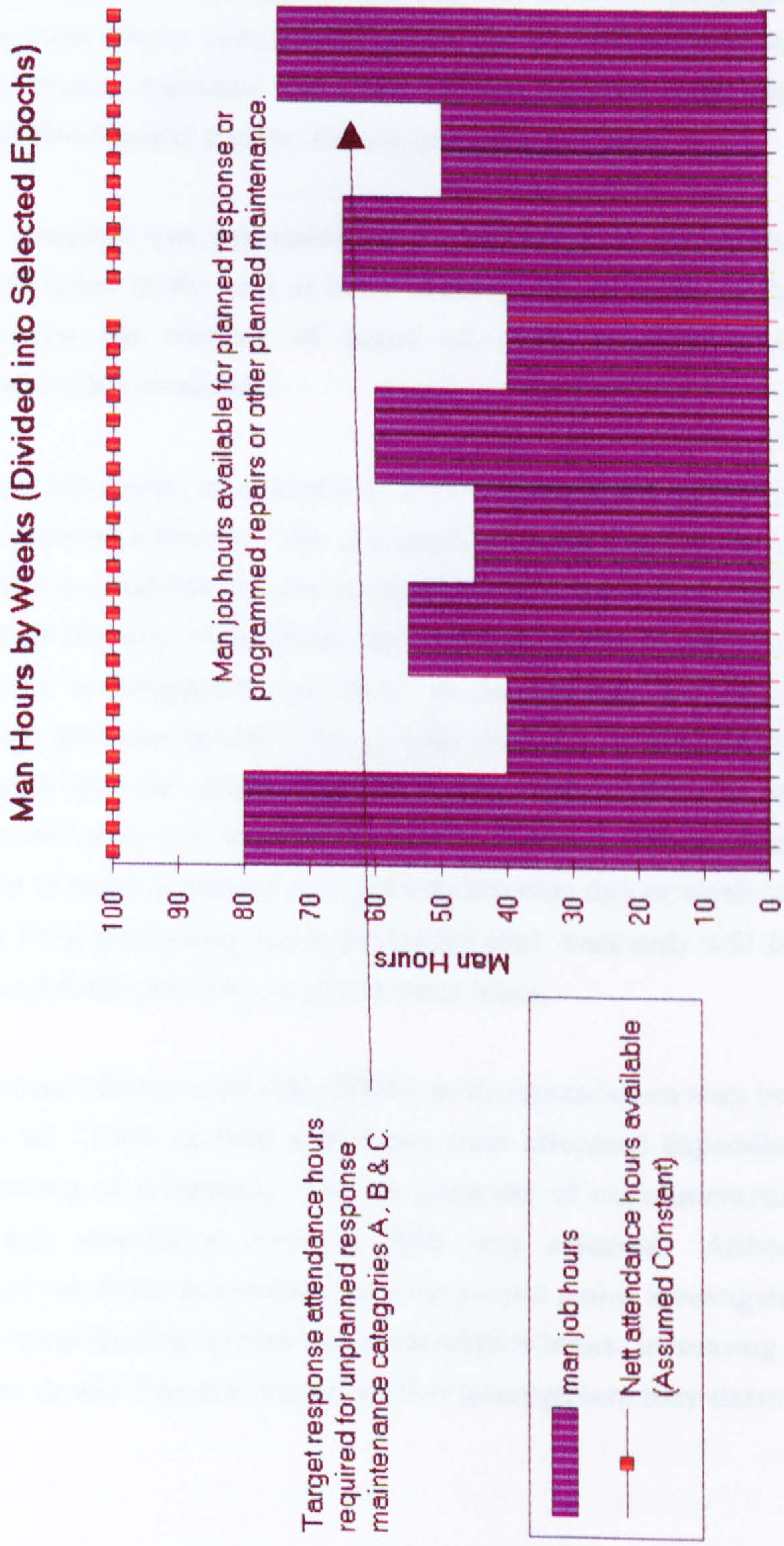
Based on the probabilistic forecasts for the daily bundles of work produced by the simulation we attempt to predict the workforce levels which the contractor needs to make available in order that all jobs in the categories A, B and C are completed within their respective Target Response Times.

This workforce level, hereinafter referred to as the *nucleus workforce* is now defined in terms of service hour requirements as the Target Nett Attendance Hours made available. This we shorten to Nett Attendance Hours. For example suppose it is predicted that ten joiners are necessary to service the repair demands. However all ten joiners may not be available all of the time due to sickness and so on. Therefore for an eight hour day we factored down the total hours available thus.

$$\text{Nett Attendance Hours Available} = (10 \times 8) \times \lambda f \text{ HRS.}$$

where factor $\lambda f < 1$ and based on local knowledge. To provide a satisfactory repairs service emergency and urgent work categories must be adequately serviced with the additional man job hours in reserve being such that all non urgent category 'C' jobs are not detained in the queue for durations exceeding five days. Given that this *nucleus* of the total workforce can be established, category 'D' jobs, which can be deferred for say, up to six weeks, may then be superimposed.

Obviously, in the light of the swinging fluctuations in weekly demands shown earlier in Exhibits 3.7.13 to 3.7.16 it is not possible to model a constant unplanned response repairs workforce, throughout the year. Therefore based on the rationale outlined in Section 4.3.1 we examine, in detail, the manpower levels required on a daily basis over a four week period, that is, weeks 16 to 19 inclusive, acknowledging that work is brought forward as uncompleted repairs prior to week 16 and similarly work will be carried forward into the next epoch beyond week 19. Each successive interval of time would be modelled separately to determine the required nucleus workforce.



Man Hours by Weeks (Divided into Selected Epochs)
Man job hours available for planned response or programmed repairs or other planned maintenance.
Target response attendance hours required for unplanned response maintenance categories A, B & C.
Man Hours
100
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
Weeks
man job hours
Nett attendance hours available (Assumed Constant)

Figure 4.5.1

4.5.2 Modelling the Nucleus Workforce

The first twenty daily demands for service in terms of man job hours which were randomly generated by computer were analysed to *demonstrate* the modelling technique, the hours of work for each day being proportioned into job categories A, B or C. To investigate the influence of the size and nature of possible maintenance contracts, manpower levels were predicted for the six autonomous trades and the additional five trade coalitions discussed earlier together with work packages created from all Five Estates and for Estates one, two and five,

The data thus obtained was processed on a spreadsheet to determine the running totals of manjob hours at the end of each working day in terms of the *cumulative difference* between the number of hours of work outstanding and the Nett Attendance Hours made available.

Table 4.5.1 page 161 shows an example of such a spreadsheet, again for joinerwork. The left hand column represents the uncompleted work carried forward from the previous day and to establish the initial input for this example at the start of sheet the mean value of the sum of the hours for work categories B and C for the twenty day period under investigation was taken as an estimate for the hours carried forward from the previous epoch. This is only one of a number of possible values for hours carried forward which may be input. This embryonic approach was necessary to permit entry into the dynamic cycle of events. Work outstanding at the end of each day or week is carried forward into the next day or week to be analysed. Obviously any truly emergency work occurring over weekends will be attended to by a separate workforce possibly on an overtime basis.

The Nett Attendance Hours available (HRS) on the spreadsheet may be estimated as being between 80 - 95% of total attendance time allocated depending on time of year and experience of workforce. For the purposes of experimentation within the worksheet a nett attendance level of 90% was assumed. Although the nett attendance hours are taken as constant over the period under investigation it must be noted that it is quite feasible to vary daily attendance hours, increasing or decreasing them contingent on any dynamic responses that management may deem necessary.

A variety of outcomes may then be derived experimentally by inputting various prediction of nett attendance hours (HRS) into the spreadsheet and observing the downward or upward trends in *cumulative hours difference* ie the number of outstanding days of work awaiting completion.

For Joinerwork Exhibit 4.5.2 page 162 shows a graphical representation of the results in Table 4.5.1 page 161. Categories A and B are combined for convenience; bearing in mind that the actual classification of work is likely to vary from one authority to another. Clearly with the manpower level made available, in this case 15 joiners urgent work ie everything less than two days response time is adequately serviced and the cumulative difference in hours at the end of each successive day is such that all unplanned response maintenance can be completed within five working days. It should be noted that even though outstanding work may be less than 5 days, jobs could have been in the system for longer. However these simulated outputs represent an unmanaged situation. Therefore we must recall the job monitoring and allocation role of the maintenance controller who should attempt to prevent such eventualities. This was discussed in general terms at the beginning of this Chapter. In the event of a negative amount of work arising at the end of a day, as was the case with say, Electrical repairs, zero hours are carried forward to the succeeding day. Such an eventuality obviously indicates overmanning and in economic terms this would have a significant impact on the effective management of the maintenance system. In this respect the concept of greater flexibility and work packaging among trades comes into focus. An example of the spreadsheet and graphical output for Electrical work are given in Table 4.5.2 page 164 and Exhibit 4.5.3 page 165 respectively. In this example 4 electricians were made available giving nett attendance hours available of 29 hours.

All of the aforementioned individual trades and trade amalgams were processed as discussed above and the **nucleus workforces** for each trade and grouping are summarised in Tables 4.5.3 to 4.5.4 pages 166 to 167 and discussed below. Full results of all simulation experiments are given in Appendix 3.

The information on display cannot be regarded as an exact prediction of the maintenance demands which will occur. Instead the results are a means of illustrating, structured maintenance scenarios on a probabilistic basis and such quantitative illustrations must be regarded as being an advance on having a vague or non-existent perception of possible maintenance profiles.

The accuracy of such results is obviously dependent on the historical consistency of daily patterns and weekly trends in job arrivals and regrettably as stated earlier no previous or subsequent data was available to allow an attempt to *historically match trends with time*. However the results obtained by Ward[21], do show encouraging signs in this respect.

In the next section we run the simulation several times to observe variations in results and attempt to produce more statistically robust predictions.

Using the same procedures, category D, planned zoned response maintenance can be modelled separately. Again, the relevant frequency distribution can be analysed and the necessary cumulative probabilities of aggregated daily job arrivals determined. The results may be superimposed on the job arrivals for unplanned work on a daily basis, thus providing an indication of the total demand for response repairs. However, it is not intended to pursue this possibility in this investigation.

From tables 4.5.3 and 4.5.4 pages 166 and 167 the variation in required manpower levels for the two sizes of maintenance contract under investigation, is evident. The Nett Attendance Hours required to ensure that all unplanned response repairs could be completed within five working days were rounded off for convenience, since the actual factor λf used to obtain nett attendance hours is best estimated by the maintenance manager using local knowledge.

The experimental results are not exact but are approximate predictions which may be regarded as serious indicators of manpower requirements which vary with the size and nature of the maintenance functional works contract.

For most trades both sets of results indicate that for each single autonomous trade minor problems may arise in coping with urgent repairs with some instances of overmanning on a day to day basis; noteably, electrical, slater:plasterer and glazing. In the case of glazing and for estates 1, 2 and 5; two glaziers produce twelve instances of overmanning and to have provided only one glazier, produced delay times of nearly ten working days; a catch 22 situation. Such outcomes strengthen the arguments for the amalgamation of certain trades eg joiner/glazier/painter.

Investigation of the results for the proposed trade coalitions reveals that for all trade combinations urgent work could be completed within the two day requirement and with no incidence of overmanning. Although the total number of tradesmen required within each trade coalition is the sum of the overall requirement for the individual trades in the model, clustering of repairs, learning benefits, and other time savings from say one trade making good in the case of multiple trade repairs, could significantly reduce the overall manpower demand for unplanned response repairs.

Backlog Example : To illustrate the adaptability of this technique an additional example is included which allows for a backlog of repairs to be input as brought forward (BF) at the start of the spread sheet. Again for Joiner work, a backlog of repairs including category B and C work carried forward from the previous week totalling 650 hours is input. The number of tradesmen required to reduce this backlog plus anticipate repair arrivals now numbers approximately eighteen. The manager is now able to consider redeployment manpower strategies. Table 4.5.5 page 168 and Exhibit 4.5.4 page 169 show the respective spreadsheet and graphical outputs for this backlog example.

It is therefore not unreasonable to make bold and state that the application of the proposed simulation experiments may not only be a predictor of manpower levels for a variety of contracts of Variable Size and Work Content but also indicates that greater flexibility between trades will ease the maintenance manager's problems in terms of scheduling of work and general logistics. However it is acknowledged that all of the aforementioned predictions are the results of a one off output by the simulation program. Hence the consequences of multiple outputs is pursued later in Section 4.6.3.

BF	A	B	C	AB	ABC	TOT	HRS	DIF	DAY	BC	DAYS
111	4	36.5	62.5	40.5	103	214	108	106	1	99	0.981481
106	5.5	44.5	87	50	137	243	108	135	2	131.5	1.25
135	1.5	24	96.5	25.5	122	257	108	149	3	120.5	1.379629
149	17.5	44	130.5	61.5	192	341	108	233	4	174.5	2.157407
233	2.5	32.5	100	35	135	368	108	260	5	132.5	2.407407
260	7.5	18	45.5	25.5	71	331	108	223	6	63.5	2.064814
223	0	26	63	26	89	312	108	204	7	89	1.888888
204	0.5	30.5	56	31	87	291	108	183	8	86.5	1.694444
183	12	53	92	65	157	340	108	232	9	145	2.148148
232	0	41	90	41	131	363	108	255	10	131	2.361111
255	16	27.5	98.5	43.5	142	397	108	289	11	126	2.675925
289	24	33	97	57	154	443	108	335	12	130	3.101851
335	0	34	47	34	81	416	108	308	13	81	2.851851
308	3.5	16	40.5	19.5	60	368	108	260	14	56.5	2.407407
260	14	17	109	31	140	400	108	292	15	126	2.703703
292	6.5	20.5	117	27	144	436	108	328	16	137.5	3.037037
328	13	4	129	17	146	474	108	366	17	133	3.388888
366	0	13	115	13	128	494	108	386	18	128	3.574074
386	0	52	34	52	86	472	108	364	19	86	3.370370
364	0.5	9	41.5	9.5	51	415	108	307	20	50.5	2.842592
										111.375	

LEGEND

BF	Work Brought Forward	
A	Emergency Work (Old Definition)	TRT ≤ 24 hrs
B	Very Urgent Work	TRT ≤ 2 Days
C	Urgent	TRT ≤ 5 Days
TOT	Sum of A, B and C	
HRS	Nett Attendance Hours Available	
DIF	TOT - HRS	
DAYS	Numbers of Days Work Outstanding	DIF/HRS

Table 4.5.1 JoinerWork

Nett Attendance Time and Cumulative Hours of Service

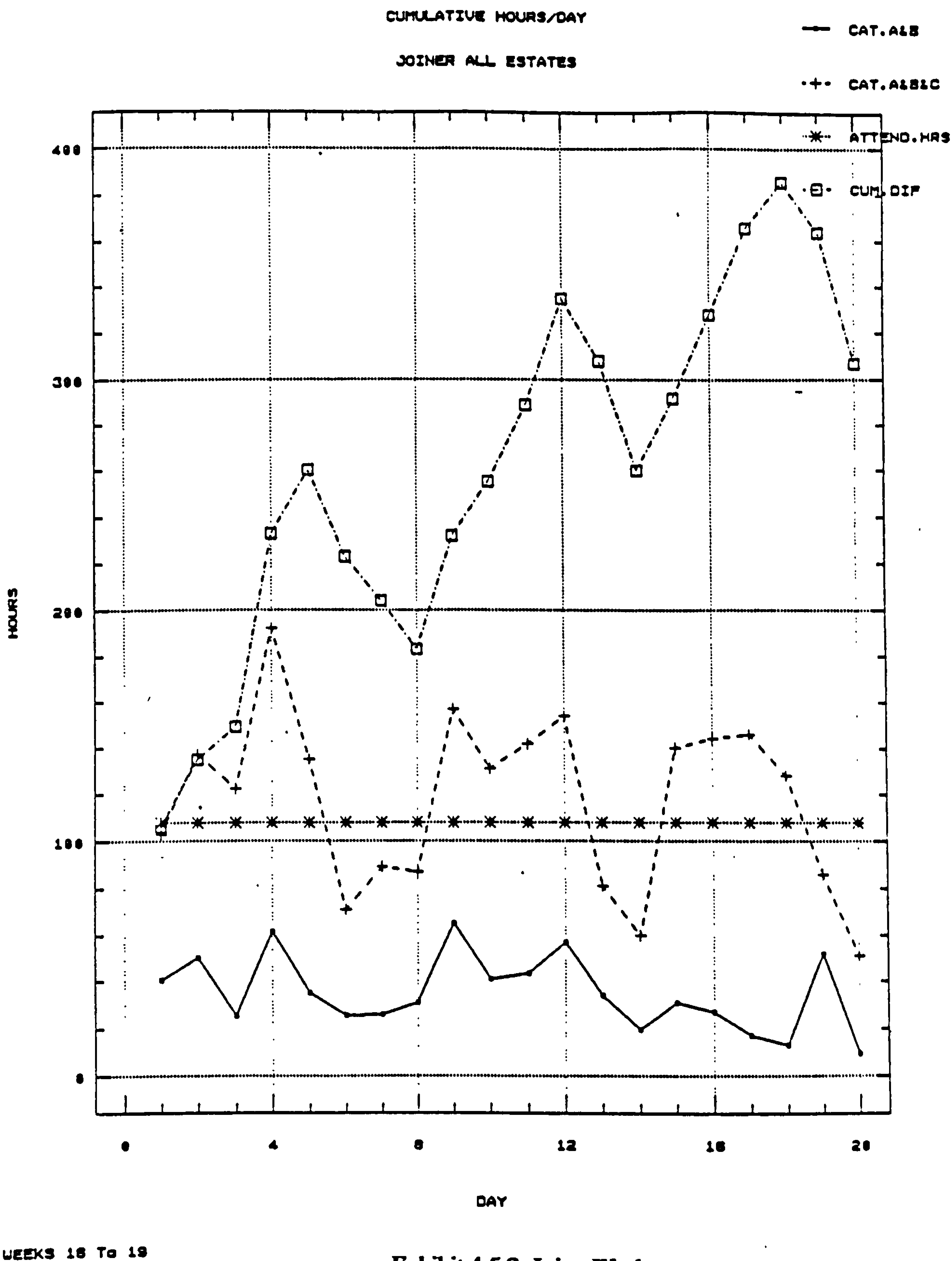


Exhibit 4.5.2 JoinerWork
Nett Attendance Time and Cumulative Hours of Service

Note: Due to a machine malfunction there is no page 163.

MISSING

PAGES

NOT

AVAILABLE

BF	A	B	C	AB	ABC	TOT	HRS	DIF	DAY	BC	DAYS
28	10	13	17.5	23	40.5	68.5	29	39.5	1	30.5	1.362068
39.5	0.5	7	3	7.5	10.5	50	29	21	2	10	0.724137
21	3.5	12.5	3.5	16	19.5	40.5	29	11.5	3	16	0.396551
11.5	7.5	5.5	1.5	13	14.5	26	29	-3	4	7	-0.10344
0	11.5	10.5	35.5	22	57.5	57.5	29	28.5	5	46	0.982758
28.5	0	5	10.5	5	15.5	44	29	15	6	15.5	0.517241
15	1.5	22	18	23.5	41.5	56.5	29	27.5	7	40	0.948275
27.5	11	3	7.5	14	21.5	49	29	20	8	10.5	0.689655
20	2.5	5	9	7.5	16.5	36.5	29	7.5	9	14	0.258620
7.5	8.5	5	20	13.5	33.5	41	29	12	10	25	0.413793
12	1	11	19.5	12	31.5	43.5	29	14.5	11	30.5	0.5
14.5	3	3	14.5	6	20.5	35	29	6	12	17.5	0.206896
6	2	27.5	13	29.5	42.5	48.5	29	19.5	13	40.5	0.672413
19.5	1.5	12.5	37.5	14	51.5	71	29	42	14	50	1.448275
42	6.5	29	10	35.5	45.5	87.5	29	58.5	15	39	2.017241
58.5	0.5	40	18	40.5	58.5	117	29	88	16	58	3.034482
88	0	26.5	8	26.5	34.5	122.5	29	93.5	17	34.5	3.224137
93.5	2	12	12.5	14	26.5	120	29	91	18	24.5	3.137931
91	6.5	26.5	16.5	33	49.5	140.5	29	111.5	19	43	3.844827
111.5	5.5	2.5	7.5	8	15.5	127	29	98	20	10	3.379310
										28.1	

LEGEND

BF	Work Brought Forward	
A	Emergency Work (Old Definition)	TRT ≤ 24 hrs
B	Very Urgent Work	TRT ≤ 2 Days
C	Urgent	TRT ≤ 5 Days
TOT	Sum of A, B and C	
HRS	Nett Attendance Hours Available	
DIF	TOT - HRS	
DAYS	Numbers of Days Work Outstanding	DIF/HRS

Table 4.5.2 Electrical Work

Nett Attendance Time and Cumulative Hours of Service

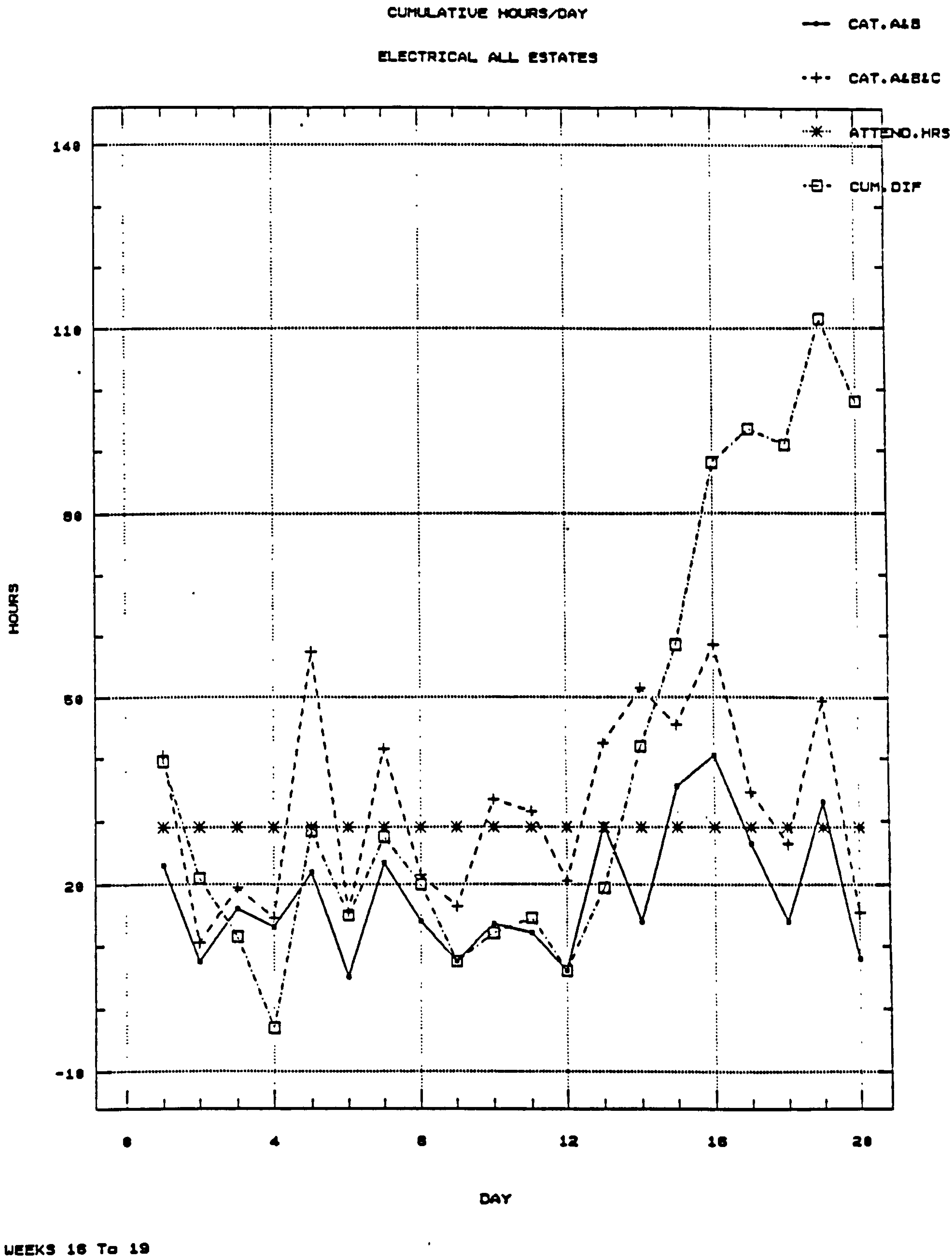


Exhibit 4.5.3 Electrical Work
Nett Attendance Time and Cumulative Hours of Service

WORKFORCE REQUIREMENTS FOR UNPLANNED RESPONSE REPAIRS

TABLE 4.5.3 ALL ESTATES CONTRACT

Trade(s)	No of Tradesmen	Nett Hours	Outstanding Work (days)		Max. hours (A + B)
			Maximum	Minimum	
Joiner	15	108	3.6	1	6.15
Plumber	26	187	3.75	0.43	195
Electrical	4	29	3.8	-0.10	40.5
Builder	7	50	3.86	0.55	54.5
Slater/Plast.	8	58	4.6	-0.5	62.5
Glazier	2	14	4.7	0.93	18.5
Joiner/Glazier	17	122	3.6	1.02	75.3
Joiner/Plumber	41	295	3.50	0.73	260
Plumber/ Electrical	30	216	3.7	0.47	204
Join/Glaz/ Plum/Elect	47	338	3.5	0.73	280
Slater:Plast/ Builder	15	108	3.83	0.05	99.5

This table was produced by extracting the relevant results from the spreadsheets for all trades and trade amalgams investigated. Spreadsheet 4.5.2 is a typical example. The above table gives the Nucleus workforce (No of tradesmen) necessary to cope with the response maintenance demands over weeks 16 to 19 and the corresponding nett attendance hours for this workforce.

The maximum and minimum number of days work outstanding is given and negative quantities indicate overmanning. A comparison of nett hours and max. hours (A + B) identifies instances where problems may arise in coping with emergency and urgent work.

These salient points may also be more readily identified by the graphical representations, for example Exhibit 4.5.2.

WORKFORCE REQUIREMENTS FOR UNPLANNED RESPONSE REPAIRS

TABLE 4.5.4 ESTATES 1,2,5 CONTRACT

Trade(s)	No of Tradesmen	Nett Hours	Outstanding Work (days)		Max. hours (A + B)
			Maximum	Minimum	
Joiner	10	72	3.0	0.65	69.5
Plumber	16	115	3.3	1.1	135
Electrical	3	22	1.5	-0.5	27.0
Builder	4	29	2.5	0.14	28.5
Slater/Plast.	7	50	5.2	-0.36	84
Glazier	2	14	0.96	-0.96	13.5
Joiner/Glazier	12	79	3.5	0.6	68
Joiner/Plumber	26	187	3.0	1.1	169
Plumber/ Electrical	19	137	2.64	1.0	84
Join/Glaz/ Plum/Elect	29	209	3.0	0.65	200.5
Slater:Plast/ Builder	11	79	3.0	0.14	56.5

This table was produced by extracting the relevant results from the spreadsheets for all trades and trade amalgams investigated. Spreadsheet 4.5.2 is a typical example. The above table gives the Nucleus workforce (No of tradesmen) necessary to cope with the response maintenance demands over weeks 16 to 19 and the corresponding nett attendance hours for this workforce.

The maximum and minimum number of days work outstanding is given and negative quantities indicate overmanning. A comparison of nett hours and max. hours (A + B) identifies instances where problems may arise in coping with emergency and urgent work.

These salient points may also be more readily identified by the graphical representations, for example Exhibit 4.5.2.

Note negative quantities indicate overmanning.

BF	A	B	C	AB	ABC	TOT	HRS	DIF	DAY	BC	DAYS
650	4	36.5	62.5	40.5	103	753	130	623	1	99	4.792307
623	5.5	44.5	87	50	137	760	130	630	2	131.5	4.846153
630	1.5	24	96.5	25.5	122	752	130	622	3	120.5	4.784615
622	17.5	44	130.5	61.5	192	814	130	684	4	174.5	5.261538
684	2.5	32.5	100	35	135	819	130	689	5	132.5	5.3
689	7.5	18	45.5	25.5	71	760	130	630	6	63.5	4.846153
630	0	26	63	26	89	719	130	589	7	89	4.530769
589	0.5	30.5	56	31	87	676	130	546	8	86.5	4.2
546	12	53	92	65	157	703	130	573	9	145	4.407692
573	0	41	90	41	131	704	130	574	10	131	4.415384
574	16	27.5	98.5	43.5	142	716	130	586	11	126	4.507692
586	24	33	97	57	154	740	130	610	12	130	4.692307
610	0	34	47	34	81	691	130	561	13	81	4.315384
561	3.5	16	40.5	19.5	60	621	130	491	14	56.5	3.776923
491	14	17	109	31	140	631	130	501	15	126	3.853846
501	6.5	20.5	117	27	144	645	130	515	16	137.5	3.961538
515	13	4	129	17	146	661	130	531	17	133	4.084615
531	0	13	115	13	128	659	130	529	18	128	4.069230
529	0	52	34	52	86	615	130	485	19	86	3.730769
485	0.5	9	41.5	9.5	51	536	130	406	20	50.5	3.123076
										111.375	

LEGEND

BF	Work Brought Forward	
A	Emergency Work (Old Definition)	TRT ≤ 24 hrs
B	Very Urgent Work	TRT ≤ 2 Days
C	Urgent	TRT ≤ 5 Days
TOT	Sum of A, B and C	
HRS	Nett Attendance Hours Available	
DIF	TOT - HRS	
DAYS	Numbers of Days Work Outstanding	DIF/HRS

Table 4.5.5 Joiner Work

BACKLOG EXAMPLE

NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE

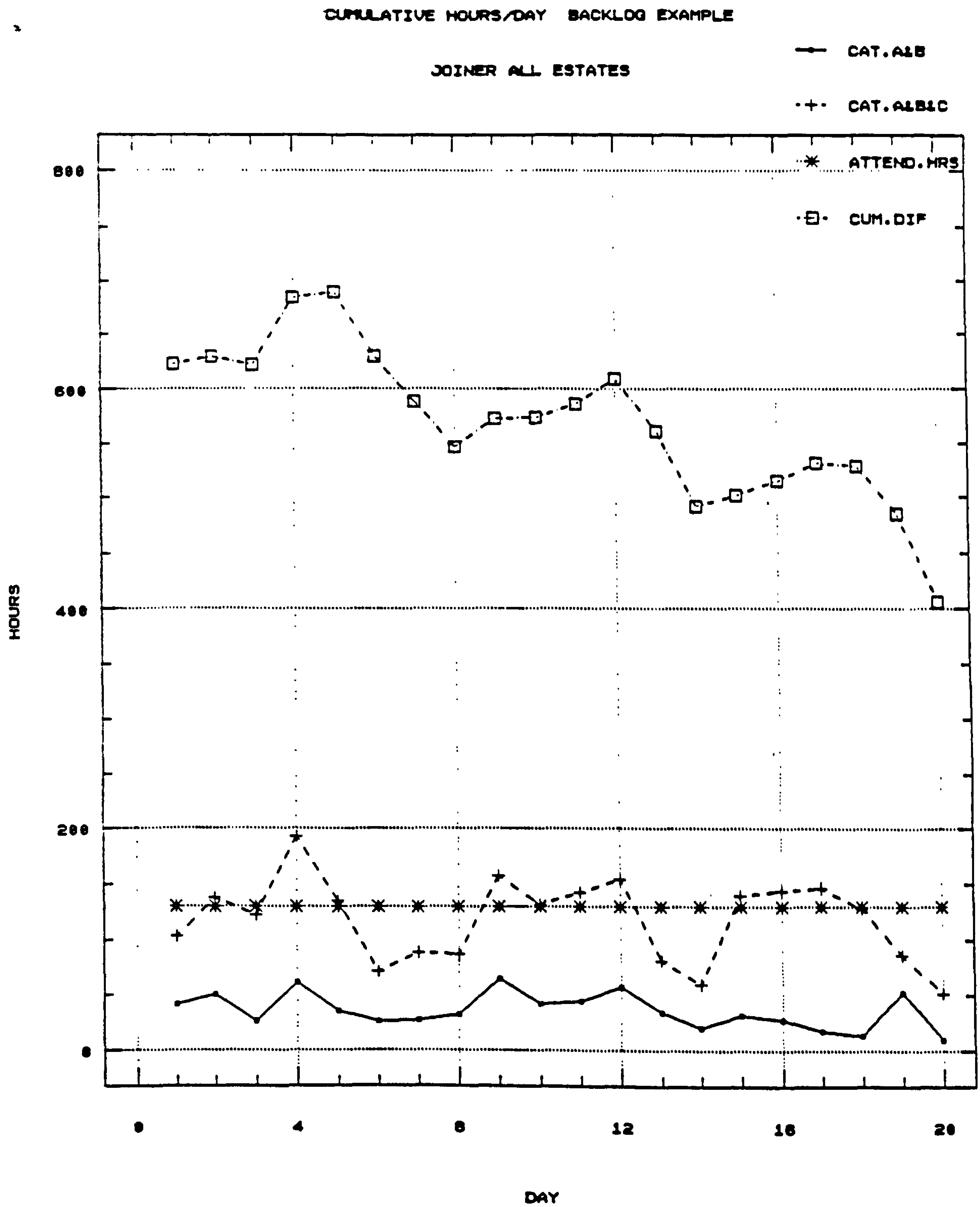


Exhibit 4.5.4 Joiner Work

BACKLOG EXAMPLE
NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE

4.6 A COMMENT ON THE SAMPLING METHOD AND ON REPLICATED EXPERIMENTS

4.6.1 The Compounding of Theoretical or Quasi Theoretical Distributions

In this section we consider the possibility that *theoretical distributions* could be substituted for the *empirical distributions* deployed in the simulations in the previous section. It is not suggested that all of the distributions likely to be encountered in this maintenance application will fit known theoretical distributions, however some may.

For example refer to Exhibit 4.3.2 page 135. This distribution of joiner work arrivals per day could be considered, for the sake of argument, to approproximate to a uniform distribution as shown in Fig 4.6.1 below.

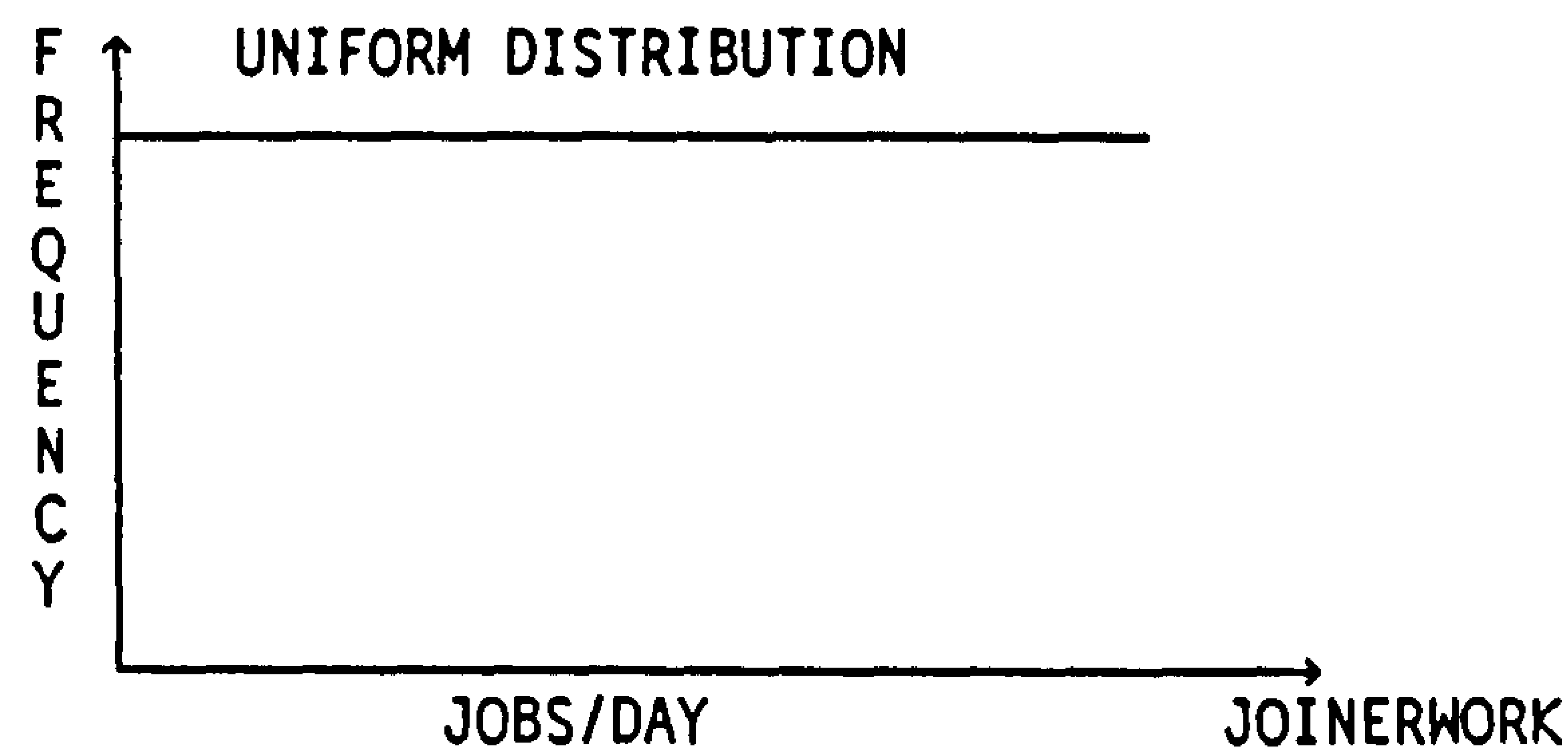


Fig 4.6.1

Likewise consider Exhibit 4.3.4 page 137 which is the distribution of hours/job for joiner work and has the appearance of a negative exponential distribution as shown in 4.6.2.

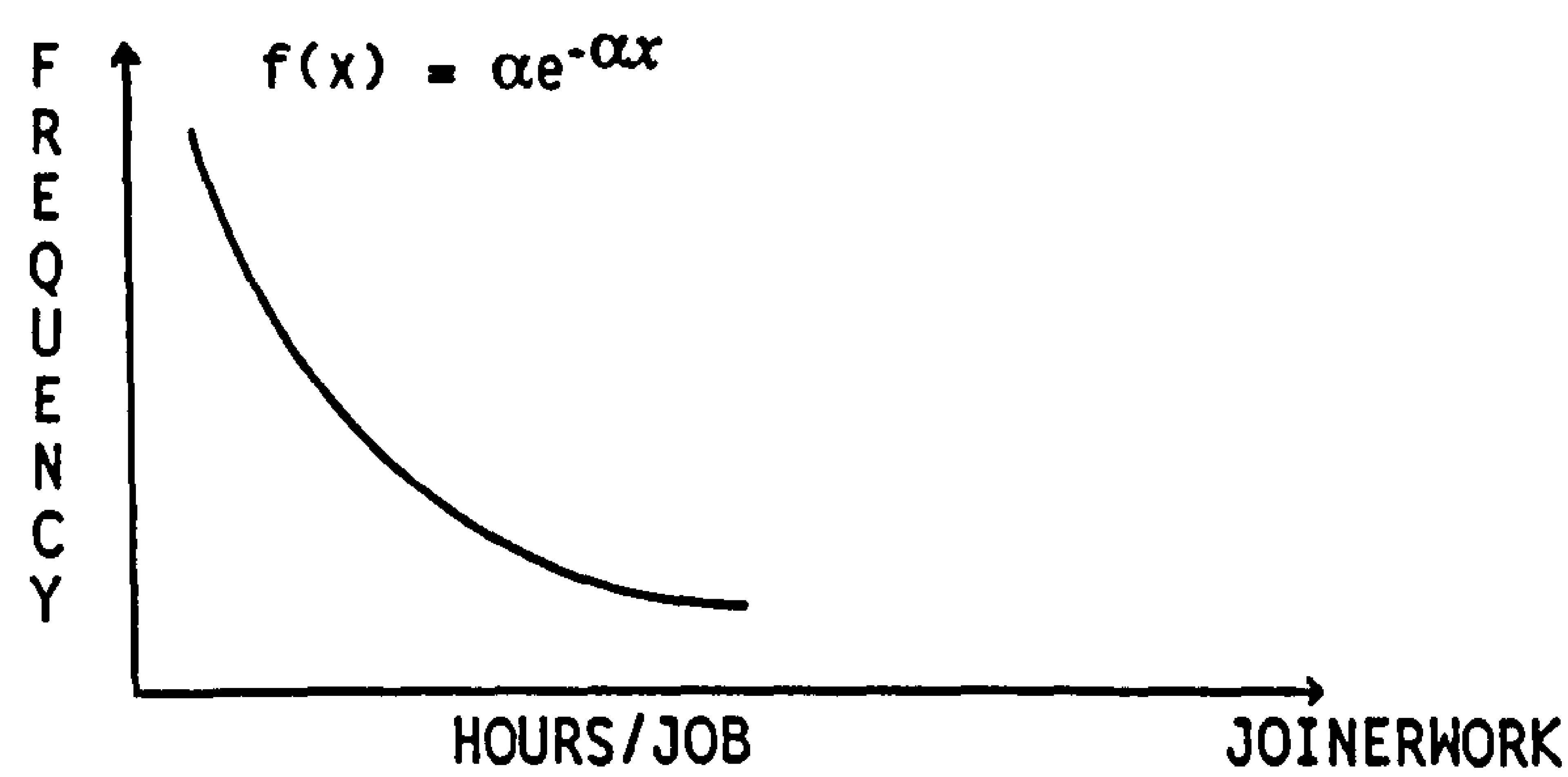


Fig 4.6.2

In anticipation that empirically derived distributions can be represented by known theoretical distributions it is possible that simpler and more flexible solutions will result. It is not an intention to analyse all distributions for all trades; instead the concept of combining discrete distributions is illustrated using two examples to demonstrate the process and to focus attention on any limitations of any derived data and associated problems.

For example the empirical frequency distribution shown in Exhibit 4.3.2 page 135 for the number of joiner work jobs arriving per day was constructed using a class interval of *two jobs*. This gives mid points of eighteen, twenty and so on, jobs per day. Such a small class interval, selected in the interest of accuracy, produced intervals during which there were zero job arrivals. There must of course be a likelihood that say twenty eight jobs will arrive in any one day, albeit that this does not occur in the data. It would be possible to avoid this gap by widening the class interval, however this tactic simply reduces accuracy. It should be noted that no attempt was made to manufacture continuous distributions and all results obtained experimentally by the simulations used the distributions of jobs per day and hours per job as shown and as described earlier in this Chapter.

To utilise theoretical distributions in the simulations as described in the previous section, would require the relevant cumulative probabilities for inputting into the computer program. It is of course quite possible to produce numerical values from theoretical distributions for input into the simulation program. However, here we propose an alternative technique which may be more attractive to maintenance managers in the event of the analytical techniques developed here being taken seriously.

Therefore instead of using mathematically exact distributions we forward here the idea of using QUASI THEORETICAL DISTRIBUTIONS, which is an expression coined to describe a computer generated distribution which is an approximate fit to that of a defined theoretical distribution. Quasi Theoretical Distributions may be produced using a statistical application package, in this case "Statgraphics". To do so, within the package, a theoretical distribution is selected and the associated necessary statistical parameters input.

Random samples are then generated by the package, say one thousand in number, which approximately fit within the theoretical distribution to be emulated. The sample values are then recalled into the statistical functions section of the package and then arranged into a grouped frequency distribution which is an approximate fit to the theoretical distribution selected. Relevant statistical properties are then computed eg. *cumulative relative frequencies*, which may then be input into the computer simulation program as before.

Joiner Work Example : To illustrate applications of the above technique, firstly consider Exhibits 4.3.2 page 135 and 4.3.4 page 137 in Section 4.3 showing the arrival of jobs per day and hours per job for joinerwork. Exhibit 4.3.2 could be, arguably, approximated to a *quasi* uniform distribution as shown in Exhibit 4.6.1 page 175, with the statistical distribution as given in Table 4.6.1 page 177. Exhibit 4.3.4 has the appearance of a negative exponential distribution and has a mean value of 3.97 hrs. This distribution was derived using data gleaned from *Private Contractors job completion times* as explained in Section 4.3, and was based on work charged for on a *day works* basis and *excluded Emergency Work.* Accepting that the mean Target Job Completion Time thus derived is reasonably accurate, then the theoretical distribution of hours per job as shown in Exhibit 4.6.2 page 176 is of the form $f(x) = \alpha e^{-\alpha x}$, with $\alpha^{-1} = 4$ (3.97) hrs.

The above results were achieved using a statistical computer applications package to generate random numbers to fit such a curve of mean equal to α since this is the only statistical parameter necessary to construct this distribution. The sample values produced are then reorganised into class intervals corresponding to that of the empirical distribution to be emulated. A quasi theoretical distribution is thus generated which is not an identical fit to the theoretical curve. There will be minor departures from the true curve in some class intervals, however the results are close and will enable approximate analysis without recourse to mathematical computation. . Thereafter corresponding cumulative probabilities are thereby generated for insertion into the Simulation Program. Table 4.6.2 page 177 shows the statistical output and Exhibit 4.6.2 page 176, the correspondingly derived distrubution. Thus many known theoretical distributions may be represented in this way for application in the Simulation program devised in Section 4.3.3.

The results of the simulation run for joiner work are given on pages 309 to 320 Appendix 3.

Plumber Work Example : Secondly we now consider the empirical distribution for target times for Plumber work shown in Exhibit 4.6.4 page 179. The very low frequency for target times in the first interval with a mid point of a half an hour, renders the distribution an unlikely candidate to fit a negative exponential distribution. However this data must be treated with suspicion, since there will be many plumber work jobs in the interval 0 - 1 hour duration. Audit Report[13] cites a work model for common plumbing jobs where the target times ranged from 10 minutes to 28 minutes and represented activities such renewing tap washers (job frequency = 145), up to renewing or rewashering ball valves to cold water feed tanks (job frequency = 46 and 16 respectively). To support this lack of confidence in the empirical data, the number of plumbers necessary to match demands produced by the simulation model was much higher than the local DLO complement which *appeared* to be coping with the imposed workload. To further support the assumption we recall that the private contractors *did not receive emergency work* during week days.

A negative exponential distribution is therefore likely and a mean value for plumber work repairs of 2 hrs is used (1 hr 47 mins being the estimate given) after consultation with a DLO. The empirical distribution for job arrivals per day shown in Exhibit 4.6.3 page 178 is combined with the Quasi theoretical distribution given in Exhibit 4.6.5 page 182 using the same processes as before to produce new predictions of the manpower requirements for the same four week period used in the initial simulations.

The spreadsheet and graphical display of results for theoretical joiner work distributions are given in page 184 and 185 respectively. Similar data for theoretical plumberwork is given in page 186 and 187.

4.6.2 Comparison of Empirical and Quasi Theoretical Results

For joiner work the compounding of the two Quasi theoretical distributions produced a nucleus workforce of 14 joiners for an all Estates contract compared with a one off prediction of 15 joiners using empirical distributions as given in Table 4.5.3 page 166.

The compounding of the empirical distribution for job arrivals per day and a Quasi theoretical distribution for hours per job produced a nucleus workforce of 10 plumbers compared with 26 plumbers as predicted using empirical distributions; see Table 4.5.3 page 166. This is hardly surprising since the mean completion time for the emprical distribution of hours per job was four hours (3.97 hrs), while the theoretical distribution for hours per job for plumber work was derived taking the mean completion time α^{-1} = 2 hours. No great significance is attached to these outcomes in these early stages of development but they do serve to demonstrate the methodology applied to solving the problems and the suspicion that the empirical data used is not wholly representative of the true global repair completion times for plumber work.

Hence it cannot be concluded with any certainty that these manpower levels are adequate or otherwise since a full comparison with any existing workforce complement is not feasible without testing the effectiveness of the DLO response maintenance service delivery capacity. This scenario was not achievable during this investigation.

Likewise results generated so far are from one, snapshot run of the simulation. Therefore we now attempt in the next section, to analyse one result in detail by replicating the theoretical plumber work simulation example several times.

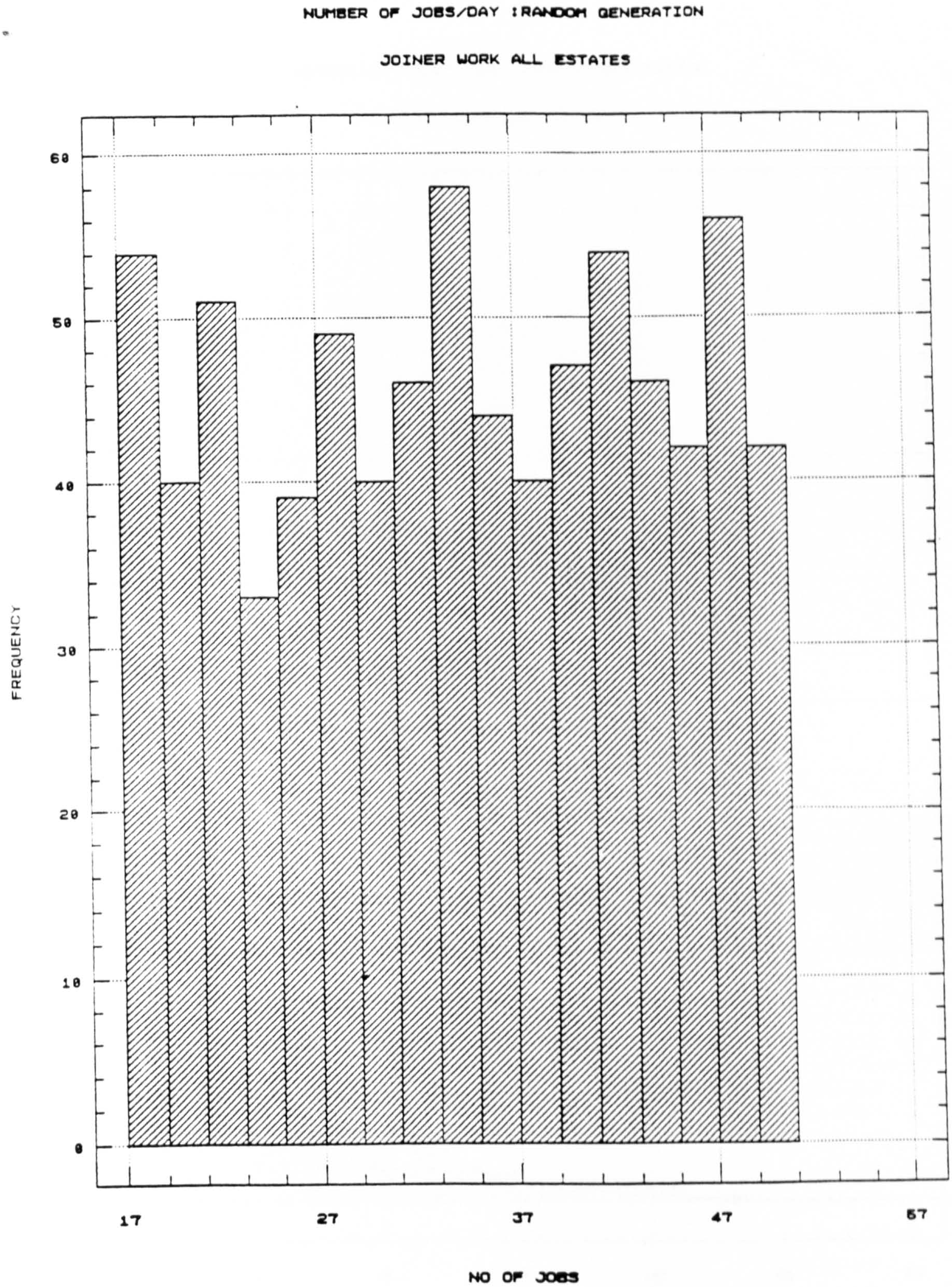


Exhibit 4.6.1
DERIVED (QUASI) THEORETICAL DISTRIBUTION OF
JOB ARRIVALS PER DAY
JOINER WORK

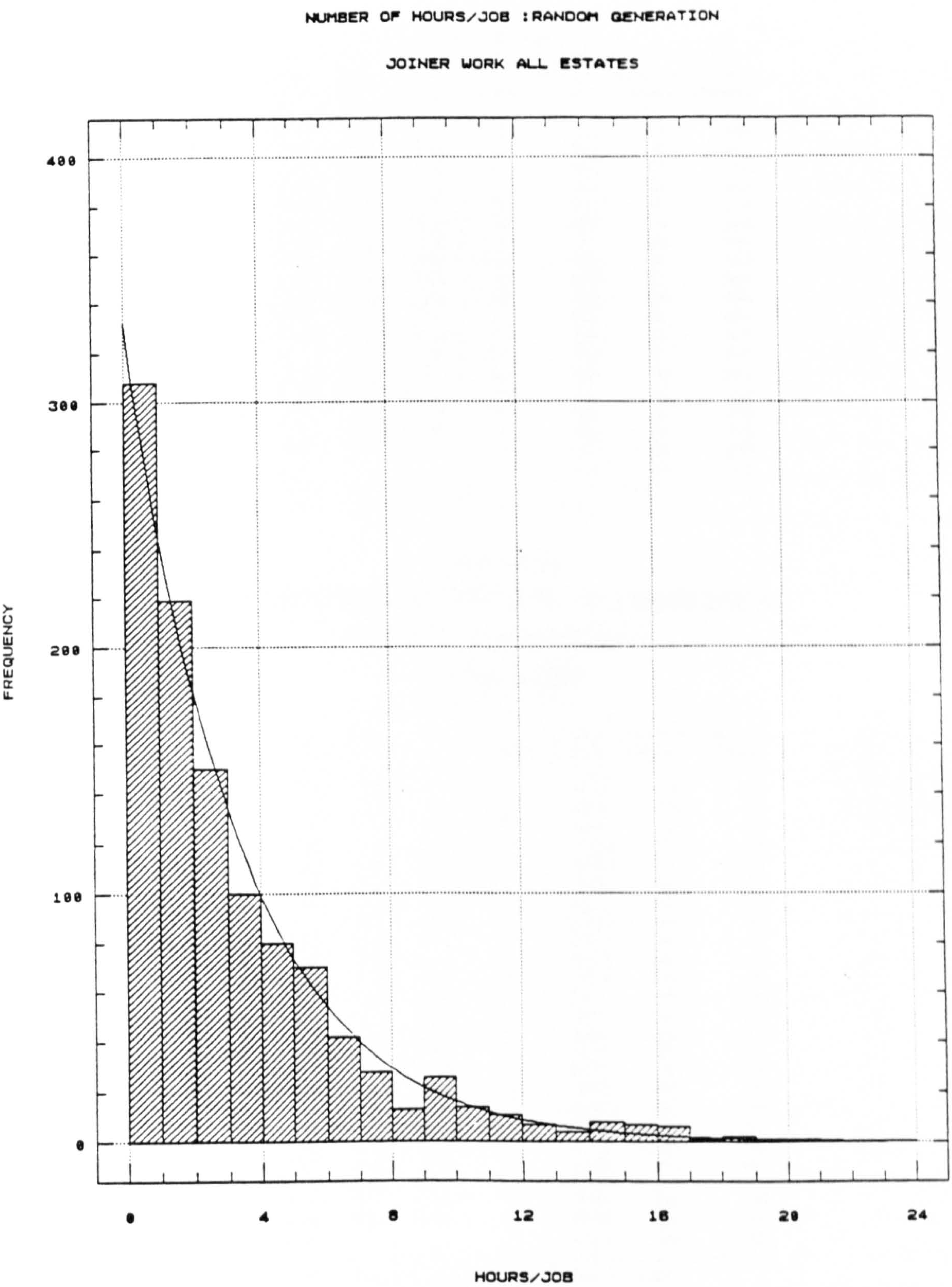


Exhibit 4.6.2

DERIVED (QUASI) THEORETICAL DISTRIBUTION HOURS PER JOB JOINER WORK

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		17.00		19	.0238	19	.0238
1	17.00	19.00	18.00	54	.0675	73	.0913
2	19.00	21.00	20.00	40	.0500	113	.1413
3	21.00	23.00	22.00	51	.0638	164	.2050
4	23.00	25.00	24.00	33	.0413	197	.2463
5	25.00	27.00	26.00	39	.0488	236	.2950
6	27.00	29.00	28.00	49	.0613	285	.3563
7	29.00	31.00	30.00	40	.0500	325	.4063
8	31.00	33.00	32.00	46	.0575	371	.4638
9	33.00	35.00	34.00	58	.0725	429	.5363
10	35.00	37.00	36.00	44	.0550	473	.5913
11	37.00	39.00	38.00	40	.0500	513	.6413
12	39.00	41.00	40.00	47	.0588	560	.7000
13	41.00	43.00	42.00	54	.0675	614	.7675
14	43.00	45.00	44.00	46	.0575	660	.8250
15	45.00	47.00	46.00	42	.0525	702	.8775
16	47.00	49.00	48.00	56	.0700	758	.9475
17	49.00	51.00	50.00	42	.0525	800	1.0000
above	51.00			0	.0000	800	1.0000

Mean = 34.2762   Standard Deviation = 10.1175   Median = 34

Table 4.6.1

STATISTICAL DISTRIBUTION OF THEORETICAL
JOB ARRIVALS PER DAY
JOINER WORK

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.000000	0	.000
1	.00	1.00	.500	308	.280000	308	.280
2	1.00	2.00	1.500	219	.199091	527	.479
3	2.00	3.00	2.500	150	.136364	677	.615
4	3.00	4.00	3.500	100	.090909	777	.706
5	4.00	5.00	4.500	80	.072727	857	.779
6	5.00	6.00	5.500	70	.063636	927	.843
7	6.00	7.00	6.500	42	.038182	969	.881
8	7.00	8.00	7.500	28	.025455	997	.906
9	8.00	9.00	8.500	13	.011818	1010	.918
10	9.00	10.00	9.500	26	.023636	1036	.942
11	10.00	11.00	10.500	14	.012727	1050	.955
12	11.00	12.00	11.500	11	.010000	1061	.965
13	12.00	13.00	12.500	7	.006364	1068	.971
14	13.00	14.00	13.500	4	.003636	1072	.975
15	14.00	15.00	14.500	8	.007273	1080	.982
16	15.00	16.00	15.500	7	.006364	1087	.988
17	16.00	17.00	16.500	6	.005455	1093	.994
18	17.00	18.00	17.500	1	.000909	1094	.995
19	18.00	19.00	18.500	2	.001818	1096	.996
20	19.00	20.00	19.500	1	.000909	1097	.997
21	20.00	21.00	20.500	1	.000909	1098	.998
22	21.00	22.00	21.500	0	.000000	1098	.998
23	22.00	23.00	22.500	0	.000000	1098	.998
above	23.00			2	.001818	1100	1.000

Mean = 3.31398   Standard Deviation = 3.56132   Median = 2.14567

Table 4.6.2

STATISTICAL DISTRIBUTION OF QUASI THEORETICAL
DISTRIBUTION OF HOURS PER JOB
JOINER WORK

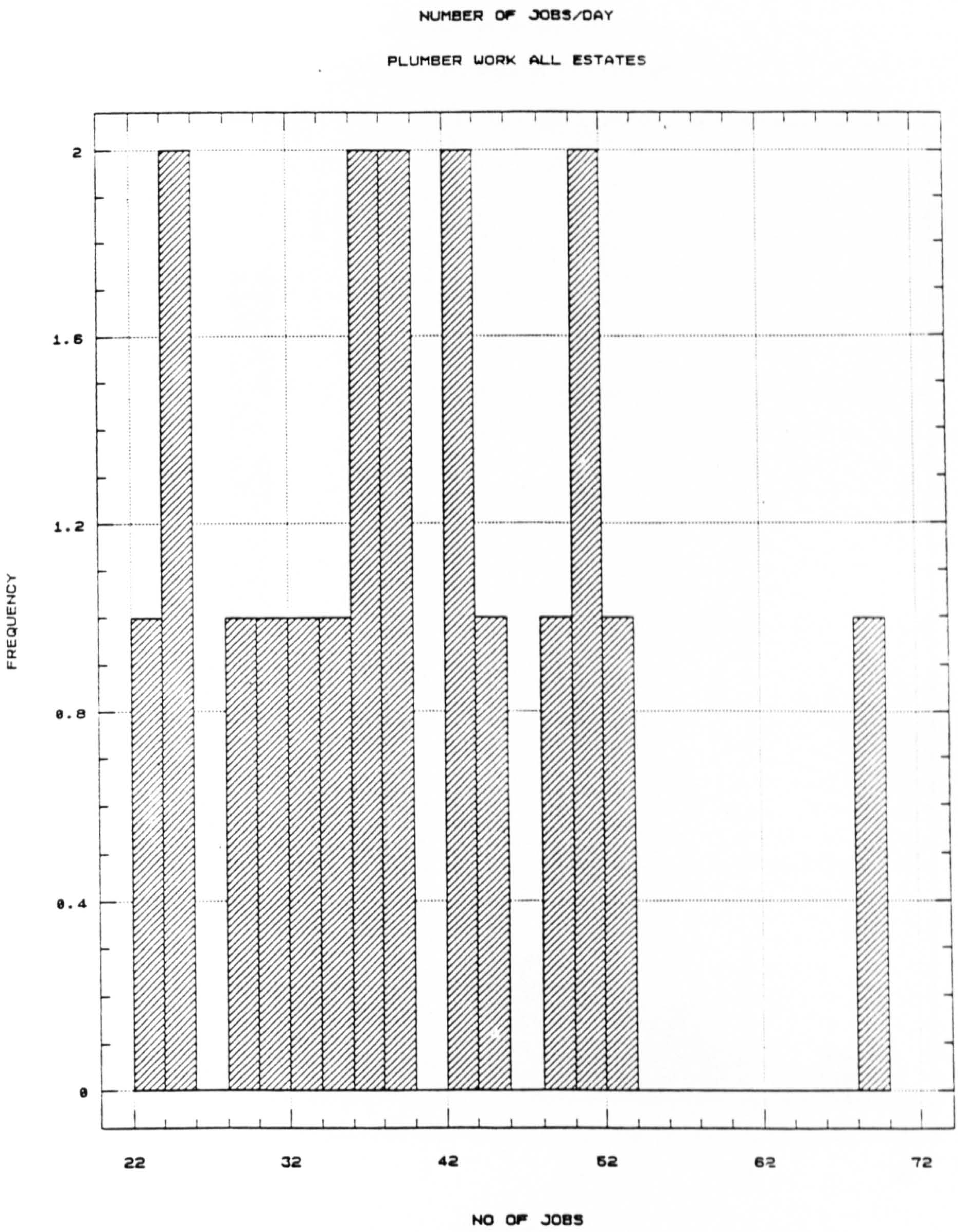


Exhibit 4.6.3

EMPIRICAL DISTRIBUTION OF JOB ARRIVALS PER DAY

PLUMBER WORK

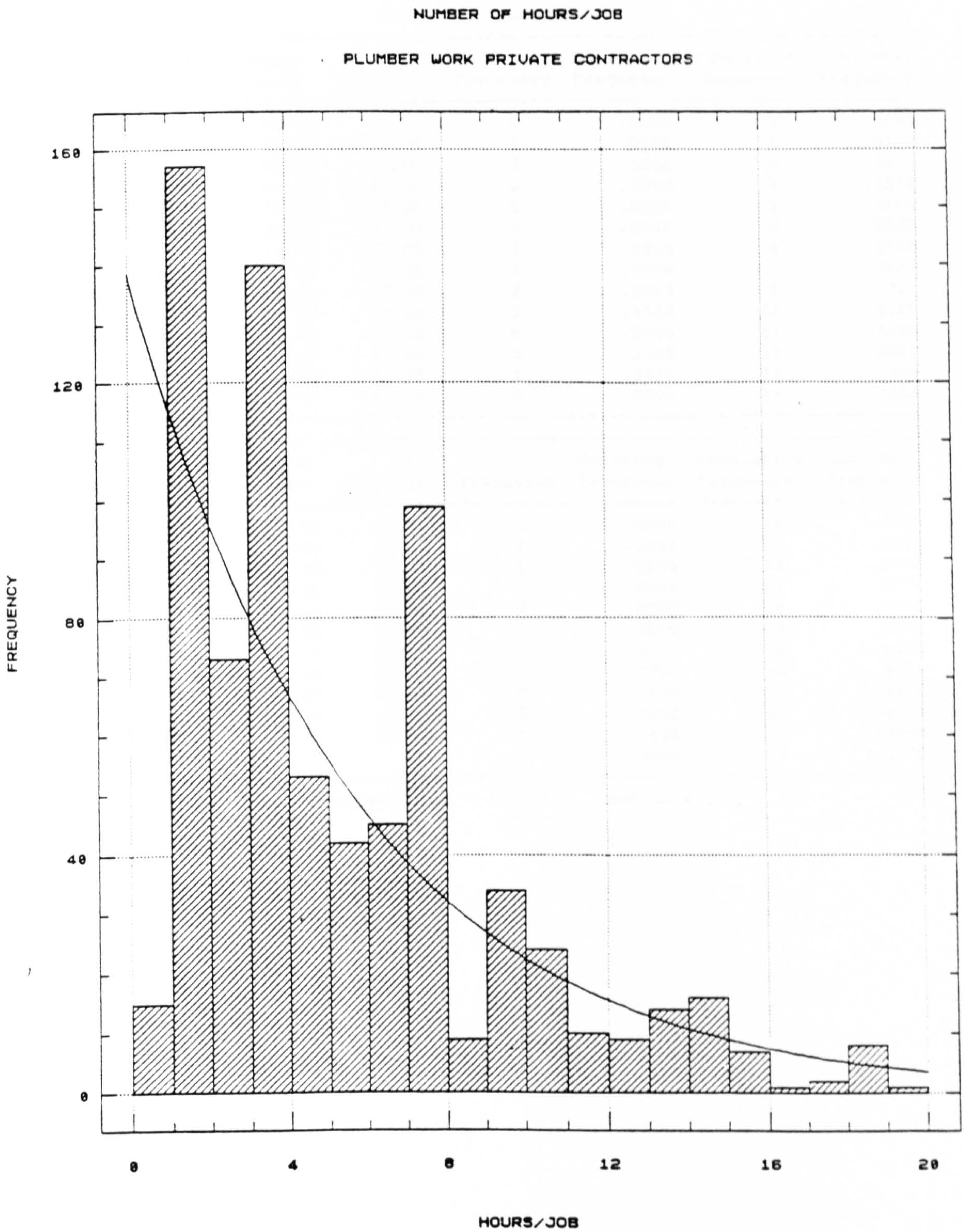


Exhibit 4.6.4

EMPIRICAL TARGET TIME DISTRIBUTION

PLUMBER WORK

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		22.00		0	.0000	0	.0000
1	22.00	24.00	23.00	1	.0526	1	.0526
2	24.00	26.00	25.00	2	.1053	3	.1579
3	26.00	28.00	27.00	0	.0000	3	.1579
4	28.00	30.00	29.00	1	.0526	4	.2105
5	30.00	32.00	31.00	1	.0526	5	.2632
6	32.00	34.00	33.00	1	.0526	6	.3158
7	34.00	36.00	35.00	1	.0526	7	.3684
8	36.00	38.00	37.00	2	.1053	9	.4737
9	38.00	40.00	39.00	2	.1053	11	.5789
10	40.00	42.00	41.00	0	.0000	11	.5789
11	42.00	44.00	43.00	2	.1053	13	.6842
12	44.00	46.00	45.00	1	.0526	14	.7368
13	46.00	48.00	47.00	0	.0000	14	.7368

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
14	48.00	50.00	49.00	1	.0526	15	.7895
15	50.00	52.00	51.00	2	.1053	17	.8947
16	52.00	54.00	53.00	1	.0526	18	.9474
17	54.00	56.00	55.00	0	.0000	18	.9474
18	56.00	58.00	57.00	0	.0000	18	.9474
19	58.00	60.00	59.00	0	.0000	18	.9474
20	60.00	62.00	61.00	0	.0000	18	.9474
21	62.00	64.00	63.00	0	.0000	18	.9474
22	64.00	66.00	65.00	0	.0000	18	.9474
23	66.00	68.00	67.00	0	.0000	18	.9474
24	68.00	70.00	69.00	1	.0526	19	1.0000
above	70.00			0	.0000	19	1.0000

Mean = 40.3684 Standard Deviation = 11.4659 Median = 39

Table 4.6.3

STATISTICAL DISTRIBUTION OF EMPIRICAL JOB ARRIVALS PER DAY

PLUMBER WORK

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.00000	0	.0000
1	.00	1.00	.500	15	.01976	15	.0198
2	1.00	2.00	1.500	157	.20685	172	.2266
3	2.00	3.00	2.500	73	.09618	245	.3228
4	3.00	4.00	3.500	140	.18445	385	.5072
5	4.00	5.00	4.500	53	.06983	438	.5771
6	5.00	6.00	5.500	42	.05534	480	.6324
7	6.00	7.00	6.500	45	.05929	525	.6917
8	7.00	8.00	7.500	99	.13043	624	.8221
9	8.00	9.00	8.500	9	.01186	633	.8340
10	9.00	10.00	9.500	34	.04480	667	.8788
11	10.00	11.00	10.500	24	.03162	691	.9104
12	11.00	12.00	11.500	10	.01318	701	.9236
13	12.00	13.00	12.500	9	.01186	710	.9354
14	13.00	14.00	13.500	14	.01845	724	.9539
15	14.00	15.00	14.500	16	.02108	740	.9750
16	15.00	16.00	15.500	7	.00922	747	.9842
17	16.00	17.00	16.500	1	.00132	748	.9855
18	17.00	18.00	17.500	2	.00264	750	.9881
19	18.00	19.00	18.500	8	.01054	758	.9987
20	19.00	20.00	19.500	1	.00132	759	1.0000
above	20.00			0	.00000	759	1.0000

Mean = 5.48355 Standard Deviation = 3.79363 Median = 4

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
	at or below	1.00	15	126.5	98.30488
	1.00	2.00	157	105.4	25.21958
	2.00	3.00	73	87.9	2.51279
	3.00	4.00	140	73.2	60.92721
	4.00	5.00	53	61.0	1.05104
	5.00	6.00	42	50.8	1.53630
	6.00	7.00	45	42.4	.16417
	7.00	8.00	99	35.3	114.94284
	8.00	9.00	9	29.4	14.16973
	9.00	10.00	34	24.5	3.67218
	10.00	11.00	24	20.4	.62529
	11.00	12.00	10	17.0	2.89615
	12.00	13.00	9	14.2	1.89444
	13.00	14.00	14	11.8	.40239
	14.00	15.00	16	9.8	3.84162
	15.00	16.00	7	8.2	.17754
	16.00	17.00	1	6.8	4.98517
	17.00	18.00	2	5.7	2.40078
	18.00	20.00	9	8.7	.00992
above	20.00		0	19.8	19.78115

Chisquare = 359.515 with 18 d.f. Sig. level = 0

Table 4.6.4

STATISTICAL DISTRIBUTION EMPRICAL TARGET TIME DISTRIBUTION AND CHISQUARE TEST

PLUMBER WORK

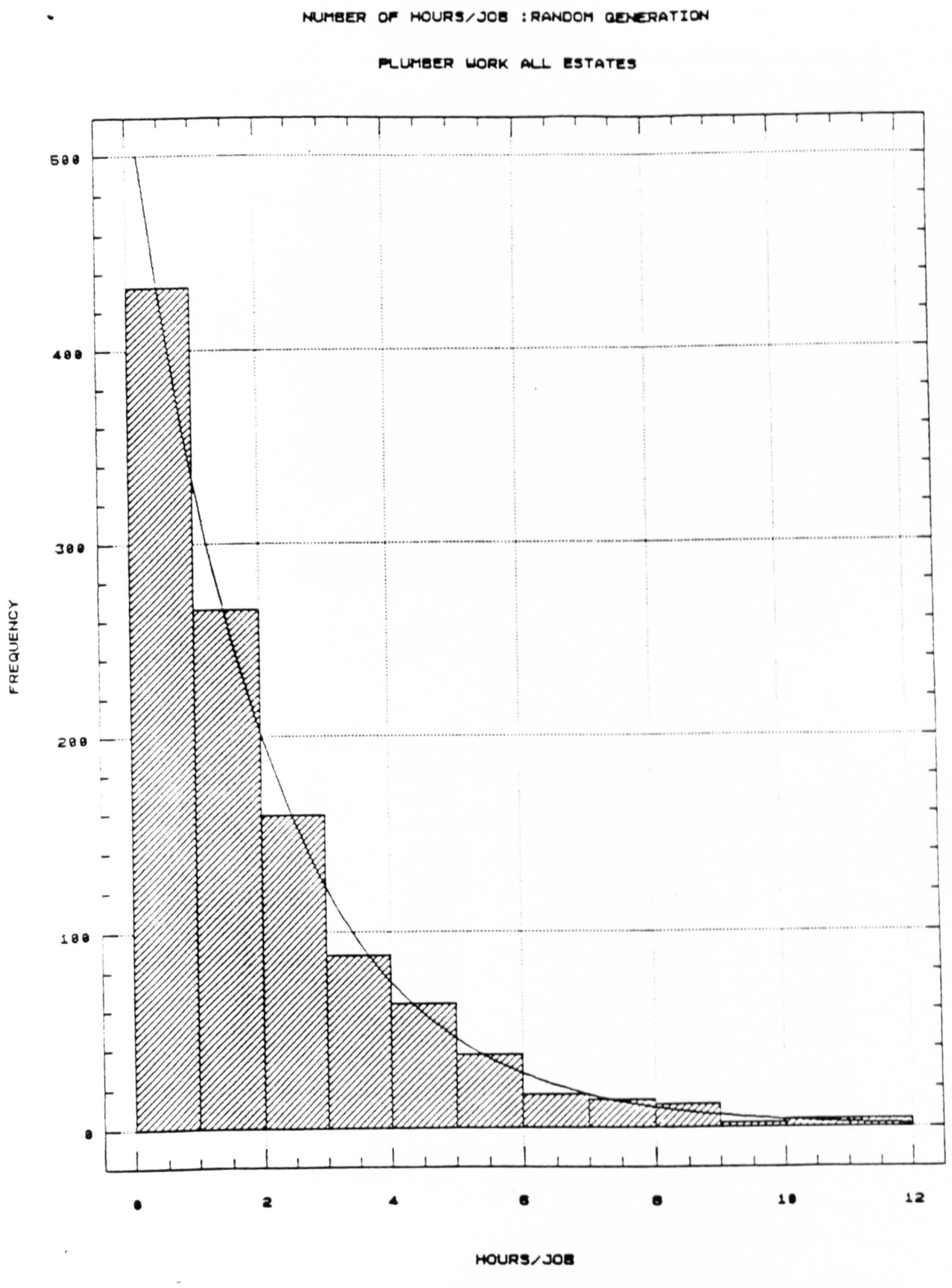


Exhibit 4.6.5

QUASI THEORETICAL DISTRIBUTION OF HOURS PER JOB

PLUMBER WORK

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.000000	0	.000
1	.00	1.00	.500	433	.393636	433	.394
2	1.00	2.00	1.500	266	.241818	699	.635
3	2.00	3.00	2.500	159	.144545	858	.780
4	3.00	4.00	3.500	88	.080000	946	.860
5	4.00	5.00	4.500	63	.057273	1009	.917
6	5.00	6.00	5.500	37	.033636	1046	.951
7	6.00	7.00	6.500	17	.015455	1063	.966
8	7.00	8.00	7.500	14	.012727	1077	.979
9	8.00	9.00	8.500	12	.010909	1089	.990
10	9.00	10.00	9.500	2	.001818	1091	.992
11	10.00	11.00	10.500	4	.003636	1095	.995
12	11.00	12.00	11.500	4	.003636	1099	.999
above	12.00			1	.000909	1100	1.000

Mean = 2.00238 Standard Deviation = 2.05866 Median = 1.36213

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
	at or below	2.000	699	694.9	.02477
	2.000	2.833	139	137.9	.00836
	2.833	3.667	90	91.0	.01037
	3.667	4.500	54	60.0	.60033
	4.500	5.333	41	39.6	.05130
	5.333	6.167	24	26.1	.16935
	6.167	7.000	16	17.2	.08594
	7.000	7.833	14	11.4	.61594
	7.833	8.667	8	7.5	.03478
	8.667	10.333	7	8.2	.17509
above	10.333		8	6.3	.45108

Chisquare = 2.22732 with 9 d.f. Sig. level = 0.987342

Table 4.6.5

STATISTICAL DISTRIBUTION OF QUASI THEORETICAL DISTRIBUTION OF HOURS PER JOB AND CHISQUARE TEST

PLUMBER WORK

BF	A	B	C	AB	ABC	TOT	HRS	DIF	DAY	BC	DAYS
106	10	52.5	68.5	62.5	131	237	101	136	1	121	1.346534
136	12.5	11	90.5	23.5	114	250	101	149	2	101.5	1.475247
149	18.5	52.5	144	71	215	364	101	263	3	196.5	2.603960
263	8.5	23	108.5	31.5	140	403	101	302	4	131.5	2.990099
302	6	10	65	16	81	383	101	282	5	75	2.792079
282	13.5	25	116.5	38.5	155	437	101	336	6	141.5	3.326732
336	3	9.5	36.5	12.5	49	385	101	284	7	46	2.811881
284	22.5	39.5	80	62	142	426	101	325	8	119.5	3.217821
325	15	34	92	49	141	466	101	365	9	126	3.613861
365	34.5	8	125.5	42.5	168	533	101	432	10	133.5	4.277227
432	3.5	16	71.5	19.5	91	523	101	422	11	87.5	4.178217
422	13	5	111	18	129	551	101	450	12	116	4.455445
450	18	2.5	55.5	20.5	76	526	101	425	13	58	4.207920
425	5.5	65	102.5	70.5	173	598	101	497	14	167.5	4.920792
497	10	33.5	113.5	43.5	157	654	101	553	15	147	5.475247
553	7	4	72	11	83	636	101	535	16	76	5.297029
535	1.5	11	29.5	12.5	42	577	101	476	17	40.5	4.712871
476	9	5.5	87.5	14.5	102	578	101	477	18	93	4.722772
477	30	26	45	56	101	578	101	477	19	71	4.722772
477	5	18.5	61.5	23.5	85	562	101	461	20	80	4.564356
										106.425	

LEGEND

BF	Work Brought Forward	
A	Emergency Work (Old Definition)	TRT ≤ 24 hrs
B	Very Urgent Work	TRT ≤ 2 Days
C	Urgent	TRT ≤ 5 Days
TOT	Sum of A, B and C	
HRS	Nett Attendance Hours Available	
DIF	TOT - HRS	
DAYS	Numbers of Days Work Outstanding	$DIF/_{HRS}$

Table 4.6.6

JOINER WORK

QUASI THEORETICAL DISTRIBUTIONS

NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE

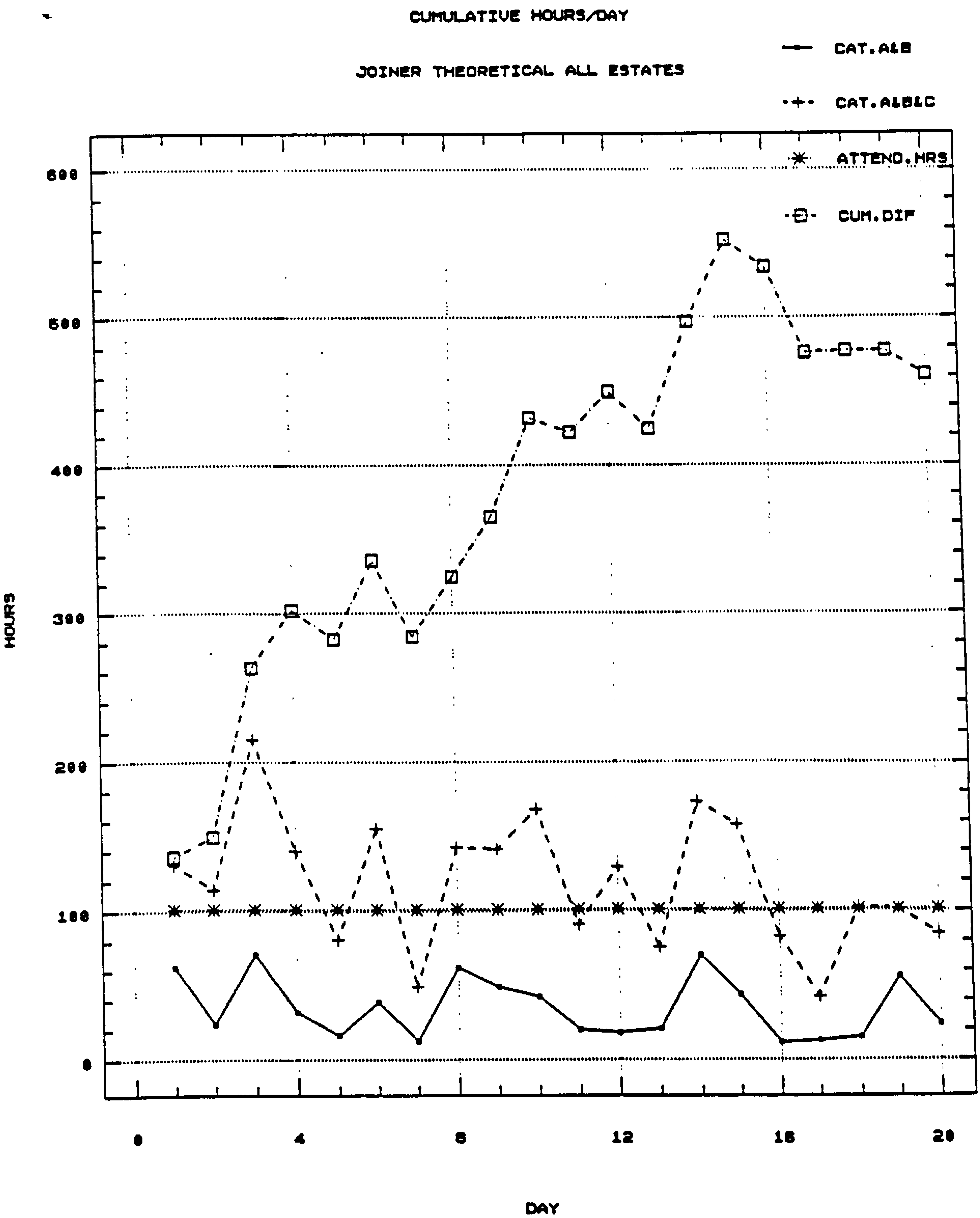


Exhibit 4.6.6 JOINER WORK
QUASI THEORETICAL DISTRIBUTIONS
NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE
JOINER WORK

BF	A	B	C	AB	ABC	TOT	HRS	DIF	DAY	BC	DAYS
58	9.5	4.5	26.5	14	40.5	98.5	72	26.5	1	31	0.368055
26.5	29.5	23.5	21.5	53	74.5	101	72	29	2	45	0.402777
29	45	41.5	32	86.5	118.5	147.5	72	75.5	3	73.5	1.048611
75.5	22.5	25.5	46.5	48	94.5	170	72	98	4	72	1.361111
98	20	43.5	27	63.5	90.5	188.5	72	116.5	5	70.5	1.618055
116.5	17	40.5	21	57.5	78.5	195	72	123	6	61.5	1.708333
123	16.5	26.5	27.5	43	70.5	193.5	72	121.5	7	54	1.6875
121.5	22.5	13	21	35.5	56.5	178	72	106	8	34	1.472222
106	36.5	34.5	31.5	71	102.5	208.5	72	136.5	9	66	1.895833
136.5	13	21.5	34	34.5	68.5	205	72	133	10	55.5	1.847222
133	31.5	53.5	22.5	85	107.5	240.5	72	168.5	11	76	2.340277
168.5	7.5	37.5	29.5	45	74.5	243	72	171	12	67	2.375
171	36.5	38.5	39.5	75	114.5	285.5	72	213.5	13	78	2.965277
213.5	12.5	45.5	37.5	58	95.5	309	72	237	14	83	3.291666
237	11.5	12.5	18.5	24	42.5	279.5	72	207.5	15	31	2.881944
207.5	9	28	29.5	37	66.5	274	72	202	16	57.5	2.805555
202	17.5	22.5	11.5	40	51.5	253.5	72	181.5	17	34	2.520833
181.5	34.5	52	43	86.5	129.5	311	72	239	18	95	3.319444
239	11	17	9.5	28	37.5	276.5	72	204.5	19	26.5	2.840277
204.5	12.5	23	22	35.5	57.5	262	72	190	20	45	2.638888
										57.8	

LEGEND

BF	Work Brought Forward	
A	Emergency Work (Old Definition)	TRT ≤ 24 hrs
B	Very Urgent Work	TRT ≤ 2 Days
C	Urgent	TRT ≤ 5 Days
TOT	Sum of A, B and C	
HRS	Nett Attendance Hours Available	
DIF	TOT - HRS	
DAYS	Numbers of Days Work Outstanding	DIF/HRS

Table 4.6.7 Plumber Work

QUASI THEORETICAL DISTRIBUTIONS

NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE

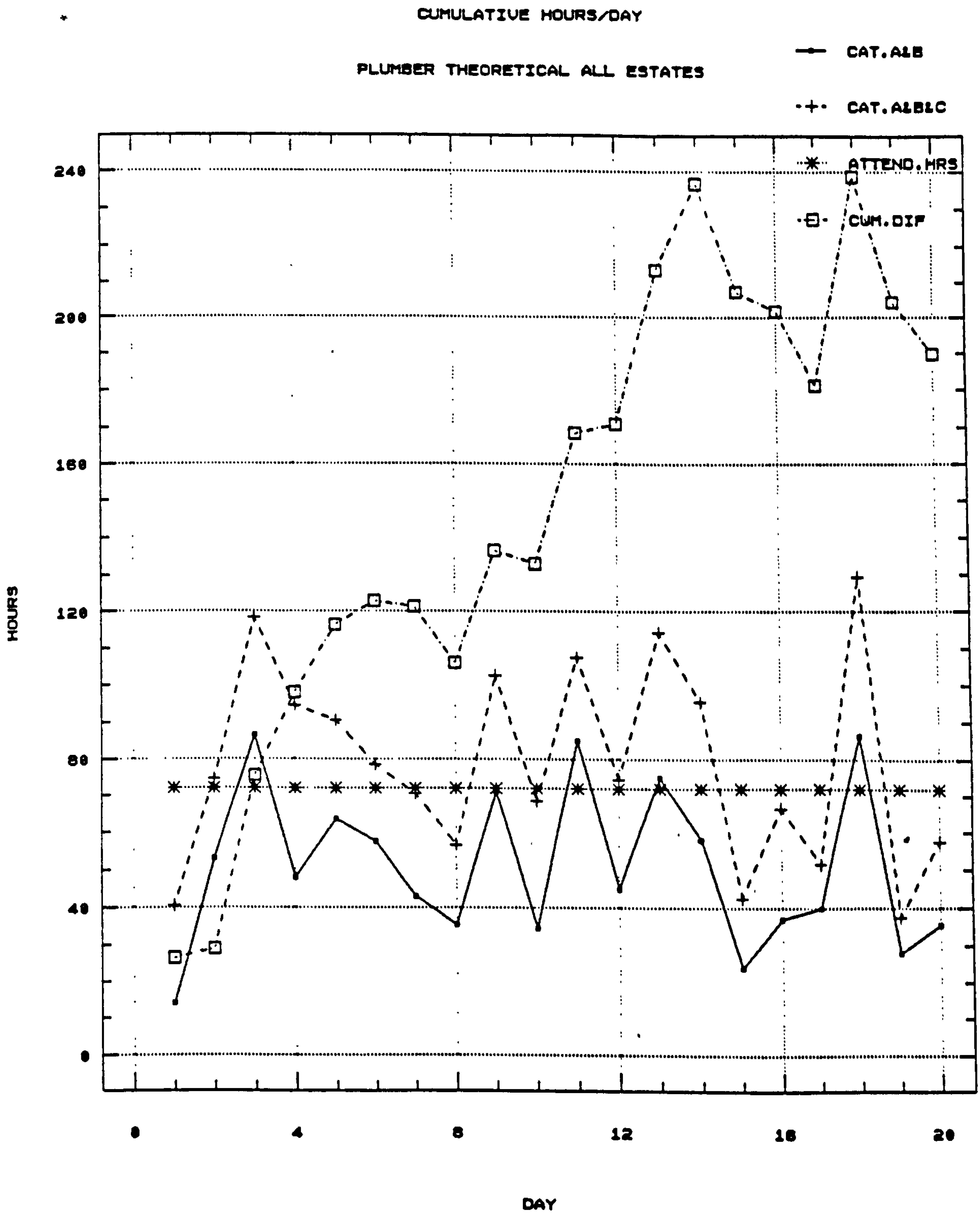


Exhibit 4.6.7 Plumber Work

QUASI THEORETICAL DISTRIBUTIONS

NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE

4.6.3 Predicting Extremes In Service Level Demands

Let us repeat that the aim of this Chapter is to diagnose and analyse response maintenance problems with the intention of devising probabilistic problem solving techniques which may enable response maintenance to be more readily encompassed within the *overall maintenance planning system.* This is distinct from the extensive application and testing of any problem solving techniques identified which will be necessary for future developments. However, it would be judicious in this section to reveal the probable variability in service level demands enforced upon the Contractor Department.

Obviously the single "snapshot", predictions for a nucleus workforce requirement obtained by simulation in the examples in the previous section do not indicate the range of chance results possible in reality. Therefore here we consider a method of representing a variety of predictions for service level demands and the boundary conditions within which they are enveloped.

To do so, the example cited for plumber work, which compounded the empirical distribution for job arrival rates with a Quasi theoretical distribution of the form $f(x) = \alpha e^{-\alpha x}$ and representing target job completion times is utilised. This was modelled in the previous section. With the data rows in the simulation program charged with the cumulative probabilities of the above distributions the program was run, as previously, to produce random sample values for hours of work arriving in the job categories A, B and C as previously defined and for the sequential twenty day period under investigation. The process was repeated *thirty times* and a spreadsheet too large to reproduce here was prepared as shown in Table 4.6.8. Thus thirty different possible results were generated for the twenty day period.

	DAY 1			HOURS	DAY 2			HOURS	
	A_1	B_1	C_1	$\Sigma A_1B_1C_1$	A_2	B_2	C_2	$\Sigma A_2B_2C_2$	
First run				96.5				66.5	
Second run				93.5				95.5	
etc				85.5				96.5	etc
30 Rows Deep				etc					

DAY 20			HOURS
A_{20}	B_{20}	C_{20}	$\Sigma A_{20}B_{20}C_{20}$
			79.5
			80.5
			80.5

Table 4.6.8

To analyse the range of results thus produced the *columns* in the spreadsheet representing probable values for the *sum of the hours* of the job categories A, B and C was selected.

The snapshot of this plumber work example, see pages 186 to 187 used a nucleus workforce equivalent to nett attendance hours of 72 (HRS) ie 10 plumbers to ensure that all values of outstanding work did not exceed five days. The initial input to the spreadsheet, ie work brought forward (BF) from the previous epoch being 58 hours. These values are retained in this experiment.

We now compute the cumulative difference between the total hours of work which require to be done (ΣA,B,C) and nett attendance hours of service available ie 72 hours for each horizontal row over the twenty day period under investigation. This is repeated for the thirty replications of the experiment. An example of this process is given in Table 4.6.9 from which it is possible to identify the following significant values.

(i) The *maximal* value of cumulative work outstanding
(ii) The *minimal* value of cumulative work outstanding
(iii) The *final* value of cumulative work outstanding

ABC Service hrs required	Cumulative Hours outstanding			Total Cumulative Hours Outstanding
Service hours required	Attendance hours available			
96.5	24.5			
66.5	19			
48.5	-4.5			
54.5	-22			
58.5	-35.5	**Minimal Value**	=	22.5
130.5	23			
196.6	147.5			
150.5	226			
106.5	260.5			
49.5	238			
63.5	229.5			
84.5	242			
102.5	272.5			
54.5	255			
42.5	225.5			
82.5	236			
156.5	320.5			
105.5	354	**Maximal Value**	=	412
39.5	321.5			
79.5	329	**Final Value**	=	387

Table 4.6.9

Since the hours of work brought forward (BF) was 58 hours it is easy to see that the minimum amount of work outstanding during the twenty day period is column 2, + 58 hrs (-35.5 + 58) = 22.5 hours and the maximum is (354 + 58) = 412 hours and final value of work outstanding is (329 + 58) = 387 hours.

This process was repeated for each of the thirty runs of the program and the results are summarised in Table 4.6.10. Tables 4.6.13 (a), (b) and (c) page 197 show the statistical properties of the minimal, maximal and final values and Table 4.6.14 page 198 displays the randomly generated results in ranked formation. However no great significance is attached to this representation of the results at this stage in this investigation. Instead we focus on two extreme cases where the *maximum* value of the cumulative hours of true response repairs outstanding is at its *highest* and *lowest* values. As can be seen in Table 4.6.10 the lowest maximal value occurs in Run 4, and the highest maximal value in Run 6. Run 18 is also of interest since this produces the largest difference between maximal and minimal values.

MINIMAL VALUE	MAXIMAL VALUE	FINAL VALUE	SIMULATION RUN
22.5	412	387	1
72.5	331.5	327	2
29	96	39	3
-.5	**84**	**49**	4
41.9	203.5	117.5	5
38	**453**	**453**	6
30	219	166	7
19.5	178.5	139	8
52.5	262.5	218	9
-10	126.5	126.5	10
127	261.5	222	11
21	197	197	12
-8.5	125	75	13
-26	188	146	14
11	169.5	146	15
1	296	268	16
-20	394	394	17
7.5	**450**	**450**	18
7	124.5	106.5	19
16	227	202	20
79.5	369	369	21
43	283.5	283.5	22
19.5	122	74	23
71.5	337	337	24
60.5	207	179	25
62.5	194	110	26
45.5	294	272	27
6	266	266	28
20.5	95.5	62	29
42	225.5	220	30

Table 4.6.10

SUMMARY OF MAXIMAL, MINIMAL AND FINAL VALUES OF CUMULATIVE HOURS OF WORK OUTSTANDING

The results which yield the lowest and highest maximal values of cumulative hours of work outstanding are given in spreadsheets, Tables 4.6.11 and 4.6.12 on page 193 and 195 respectively. Graphical displays of these results are produced in Exhibits 4.6.8 and 4.6.9 on pages 194 and 196 respectively.

It should be noted that no modifications to the inputs for the nucleus work force in terms of nett attendance hours required (HRS) or for work brought forward (BF) is attempted. These are left as in the previous snapshot example for plumber work to enable a comparison of results.

The results however show that for the highest maximal value page 195, with 10 plumbers available some work will remain in the system for more than five days. At the other extreme for the lowest maximal value page 193 having 10 plumbers is bordering on too many with the isolated chance of overmanning in both examples of highest and lowest maximal results.

The statistical and frequency distributions for the lowest and highest values of *days* of work outstanding are given in Tables 4.6.15 and 4.6.16 and Exhibits 4.6.10 and 4.6.11 respectively, pages 198(a) and 198(b). These are based on a nucleus workforce of ten plumbers and negative quantities indicate overmanning. From these results which are derived from actual job arrivals and a quasi theoretical distribution of *target completion times*, it is possible to make the following observations. These two extreme values of the replicated simulation indicate that, approximately, there is a 1 in 20 chance of jobs being in the system for up to six days and also a 1 in 20 chance that about three of the ten plumbers assigned to response repairs in the time period under investigation may need to be redeployed. This of course, takes no account of the facility to physically manage the allocation of repairs.

Nevertheless, a nett attendance service level of 72 hours (10 plumbers) is close to matching the service level demands, which at this stage is encouraging. It cannot be an expectation that exact predictions can be made for manpower levels in these widely fluctuating circumstances. Instead we are aiming for approximate forecasts which will help the contractor to plan the deployment of an available labour force throughout the year and successfully cope with response demands timeously.

It should also be recalled that any results achieved thus far, are independent of any bonus scheme in operation. Therefore any predictions arrived at need to be adjusted downwards to allow for higher productivity, see Section 3.12 for an explanation of Target Times and a Bonus Scheme.

The important role of the Maintenance Controller, described in Section 4.2, must also be recalled. It may be inevitable under or over demands may be made on any probabilistic prediction of nucleus workforce levels. However the Controller should be able to allocate additional work to tradesmen, say planned response ie category D work or any other type of work within the Contractors' Business Plan. It is of course important that a workforce level is able to be made available to cope with day to day repair demands within Target Response Times.

Thus it is; that to effectively manage this problematic and vexatious element of the repair services, a management system which synthesises objective probabilistic forecasting and subjective assessments at Contractor level is required and would appear to be worthy of further investigation.

BF	A	B	C	AB	ABC	TOT	HRS	DIF	DAY	BC	DAYS
58	15.5	19	16	34.5	50.5	108.5	72	36.5	1	35	.5069444
36.5	14.5	8.5	12.5	23	35.5	72	72	0	2	21	0
0	15	29.5	37	44.5	81.5	81.5	72	9.5	3	66.5	.1319444
9.5	22.5	19	23	41.5	64.5	74	72	2	4	42	.0277778
2	38.5	20.5	34.5	59	93.5	95.5	72	23.5	5	55	.3263889
23.5	27	23.5	20	50.5	70.5	94	72	22	6	43.5	.3055556
22	12	22	15.5	34	49.5	71.5	72	-.5	7	37.5	-.006944
0	24	31	34.5	55	89.5	89.5	72	17.5	8	65.5	.2430556
17.5	32.5	43	35	75.5	110.5	128	72	56	9	78	.7777778
56	10	20	28.5	30	58.5	114.5	72	42.5	10	48.5	.5902778
42.5	15	35.5	38	50.5	88.5	131	72	59	11	73.5	.8194444
59	5	43.5	10	48.5	58.5	117.5	72	45.5	12	53.5	.6319444
45.5	16.5	31	46	47.5	93.5	139	72	67	13	77	.9305556
67	16	48.5	25	64.5	89.5	156.5	72	84.5	14	73.5	1.173611
84.5	8	27.5	26	35.5	61.5	146	72	74	15	53.5	1.027778
74	10.5	23	42	33.5	75.5	149.5	72	77.5	16	65	1.076389
77.5	16.5	20.5	26.5	37	63.5	141	72	69	17	47	.9583333
69	10	17.5	31	27.5	58.5	127.5	72	55.5	18	48.5	.7708333
55.5	14	23.5	32	37.5	69.5	125	72	53	19	55.5	.7361111
53	17.5	15	36	32.5	68.5	121.5	72	49.5	20	51	.6875
										54.525	

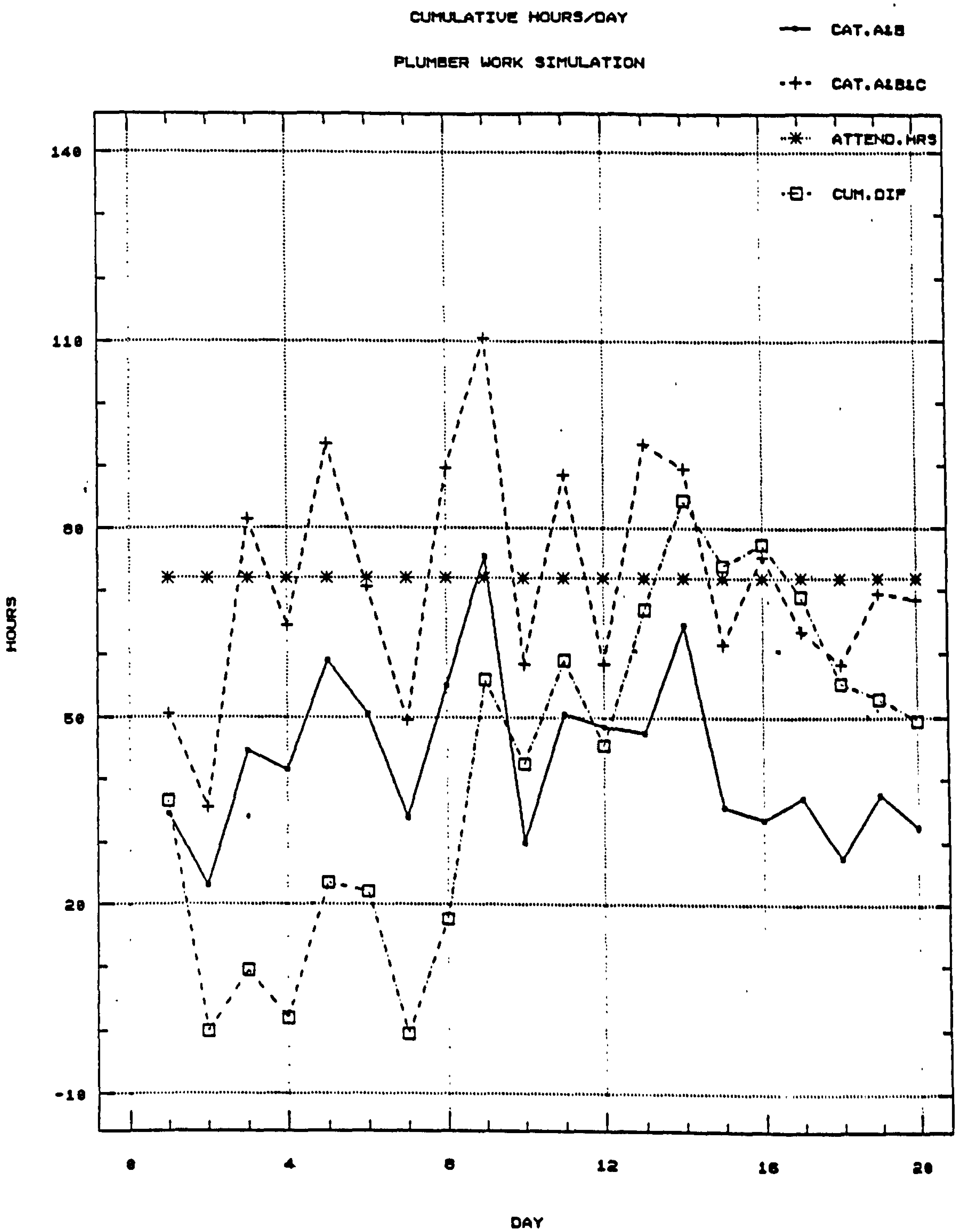
LEGEND

BF	Work Brought Forward	
A	Emergency Work (Old Definition)	TRT ≤ 24 hrs
B	Very Urgent Work	TRT ≤ 2 Days
C	Urgent	TRT ≤ 5 Days
TOT	Sum of A, B and C	
HRS	Nett Attendance Hours Available	
DIF	TOT - HRS	
DAYS	Numbers of Days Work Outstanding	$DIF/_{HRS}$

LOWEST MAXIMAL VALUE RUN 4

Table 4.6.11

QUASI THEORETICAL DISTRIBUTIONS
NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE



LOWEST MAXIMAL VALUE RUN 4

Exhibit 4.6.8

QUASI THEORETICAL DISTRIBUTIONS
NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE

BF	A	B	C	AB	ABC	TOT	HRS	DIF	DAY	BC	DAYS
58	33	54	43.5	87	130.5	188.5	72	116.5	1	97.5	1.618056
116.5	9	13	13.5	22	35.5	152	72	80	2	26.5	1.111111
80	22	38.5	47	60.5	107.5	187.5	72	115.5	3	85.5	1.604167
115.5	20.5	19	55	39.5	94.5	210	72	138	4	74	1.916667
138	12	8	35.5	20	55.5	193.5	72	121.5	5	43.5	1.6875
121.5	22	34.5	30	56.5	86.5	208	72	136	6	64.5	1.888889
136	17	45.5	32	62.5	94.5	230.5	72	158.5	7	77.5	2.201389
158.5	49	35	25.5	84	109.5	268	72	196	8	60.5	2.722222
196	45.5	36	50	81.5	131.5	327.5	72	255.5	9	86	3.548611
255.5	29.5	27	52	56.5	108.5	364	72	292	10	79	4.055556
292	9	31.5	26	40.5	66.5	358.5	72	286.5	11	57.5	3.979167
286.5	22.5	40.5	43.5	63	106.5	393	72	321	12	84	4.458333
321	13	29.5	30	42.5	72.5	393.5	72	321.5	13	59.5	4.465278
321.5	11	60.5	59	71.5	130.5	452	72	380	14	119.5	5.277778
380	21.5	19.5	12.5	41	53.5	433.5	72	361.5	15	32	5.020833
361.5	16.5	17	28	33.5	61.5	423	72	351	16	45	4.875
351	22.5	50.5	27.5	50.5	78	429	72	357	17	78	4.958333
357	45.5	44	55	89.5	144.5	501.5	72	429.5	18	99	5.965278
429.5	13	15.5	24	28.5	52.5	482	72	410	19	39.5	5.694444
410	38.5	46	50	84.5	134.5	544.5	72	472.5	20	96	6.5625
										70.225	

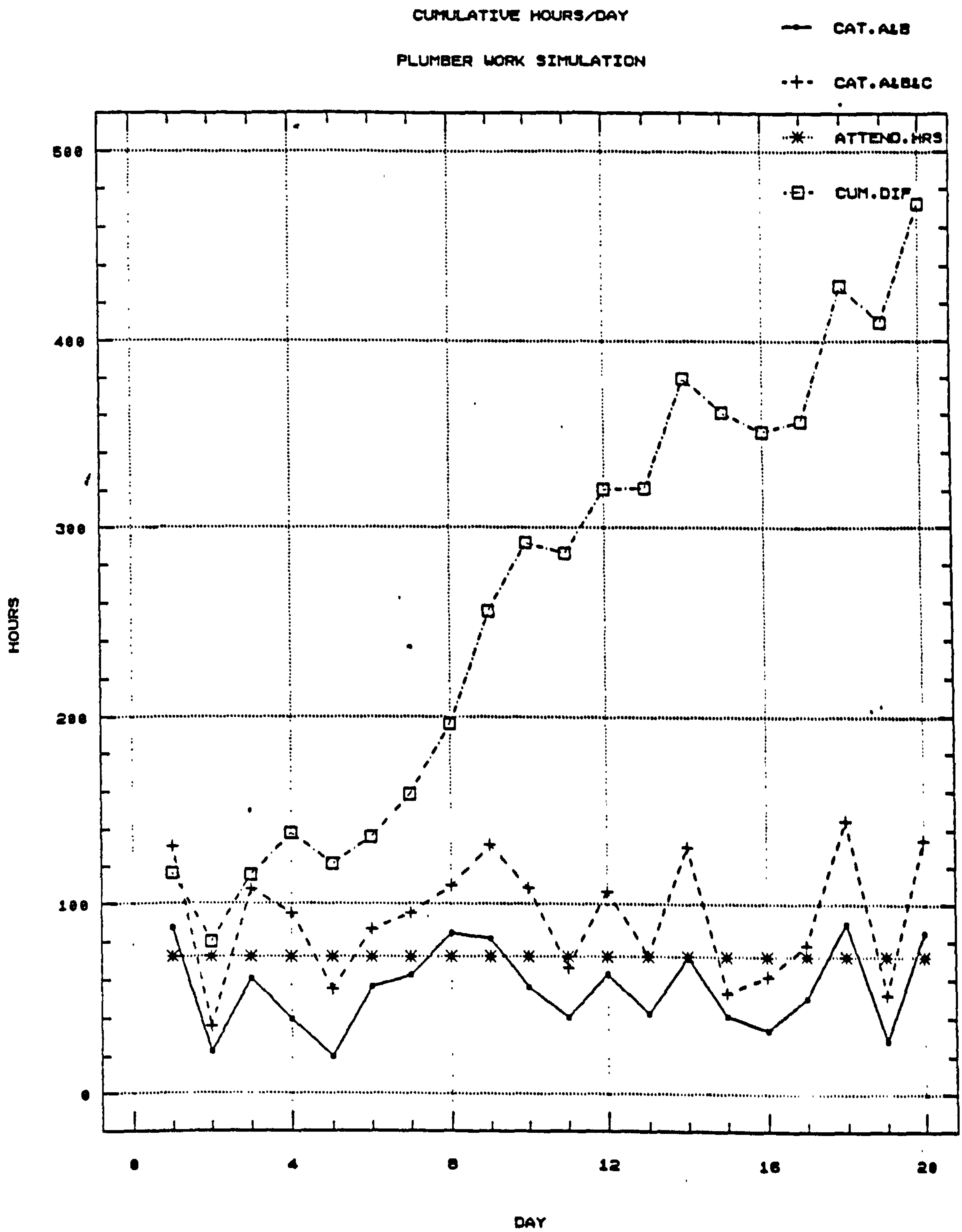
LEGEND

BF	Work Brought Forward	
A	Emergency Work (Old Definition)	TRT ≤ 24 hrs
B	Very Urgent Work	TRT ≤ 2 Days
C	Urgent	TRT ≤ 5 Days
TOT	Sum of A, B and C	
HRS	Nett Attendance Hours Available	
DIF	TOT - HRS	
DAYS	Numbers of Days Work Outstanding	DIF/HRS

HIGHEST MAXIMAL VALUE RUN 6

Table 4.6.12

QUASI THEORETICAL DISTRIBUTIONS
NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE



HIGHEST MAXIMAL VALUE RUN 6

Exhibit 4.6.9

QUASI THEORETICAL DISTRIBUTIONS
NETT ATTENDANCE TIME AND CUMULATIVE HOURS OF SERVICE

Mean	29.41
Standard Error	6.04
Median	22.00
Mode	19.50
Standard Deviation	33.08
Variance	1094.09
Kurtosis	1.21
Skewness	0.81
Range	153.00
Minimum	-26.00
Maximum	127.00
Sum	882.40
Count	30.00

TABLE 4.6.13(a)

STATISTICAL DISTRIBUTION OF MINIMAL VALUES

Mean	239.75
Standard Error	19.32
Median	222.25
Mode	#N/A
Standard Deviation	105.82
Variance	11198.79
Kurtosis	-0.58
Skewness	0.47
Range	369.00
Minimum	84.00
Maximum	453.00
Sum	7192.50
Count	30.00

TABLE 4.6.13(b)

STATISTICAL DISTRIBUTION OF MAXIMAL VALUES

Mean	213.33
Standard Error	21.95
Median	199.50
Mode	146.00
Standard Deviation	120.23
Variance	14455.61
Kurtosis	-0.73
Skewness	0.48
Range	414.00
Minimum	39.00
Maximum	453.00
Sum	6400.00
Count	30.00

TABLE 4.6.13(c)

STATISTICAL DISTRIBUTION OF FINAL VALUES

MIN	MAX	FIN
-26	84	39
-20	95.5	49
-10	96	62
-8.5	122	74
-.5	124.5	75
1	125	106.5
6	126.5	110
7	169.5	117.5
7.5	178.5	125.5
11	188	139
16	194	146
19.5	197	146
19.5	203.5	166
20.5	207	179
21	219	197
23	225.5	202
29	227	218
30	261.5	220
38	262.5	222
41.9	266	266
42	283.5	268
43	294	272
45.5	296	283.5
52.5	331.5	327
60.5	337	337
62.5	369	369
71.5	394	387
72.5	412	394
79.5	450	450
127	453	453

Table 4.6.14

MINIMAL, MAXIMAL AND FINAL VALUES, EACH RANKED SEPARATELY

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		-.500		0	.0000	0	.000
1	-.500	-.100	-.300	4	.1333	4	.133
2	-.100	.300	.100	11	.3667	15	.500
3	.300	.700	.500	8	.2667	23	.767
4	.700	1.100	.900	5	.1667	28	.933
5	1.100	1.500	1.300	1	.0333	29	.967
6	1.500	1.900	1.700	1	.0333	30	1.000
above	1.900			0	.0000	30	1.000

Mean = 0.408519 Standard Deviation = 0.459403 Median = 0.305556

TABLE 4.6.15

STATISTICAL DISTRIBUTION OF DAYS OF WORK OUTSTANDING

RUN 4

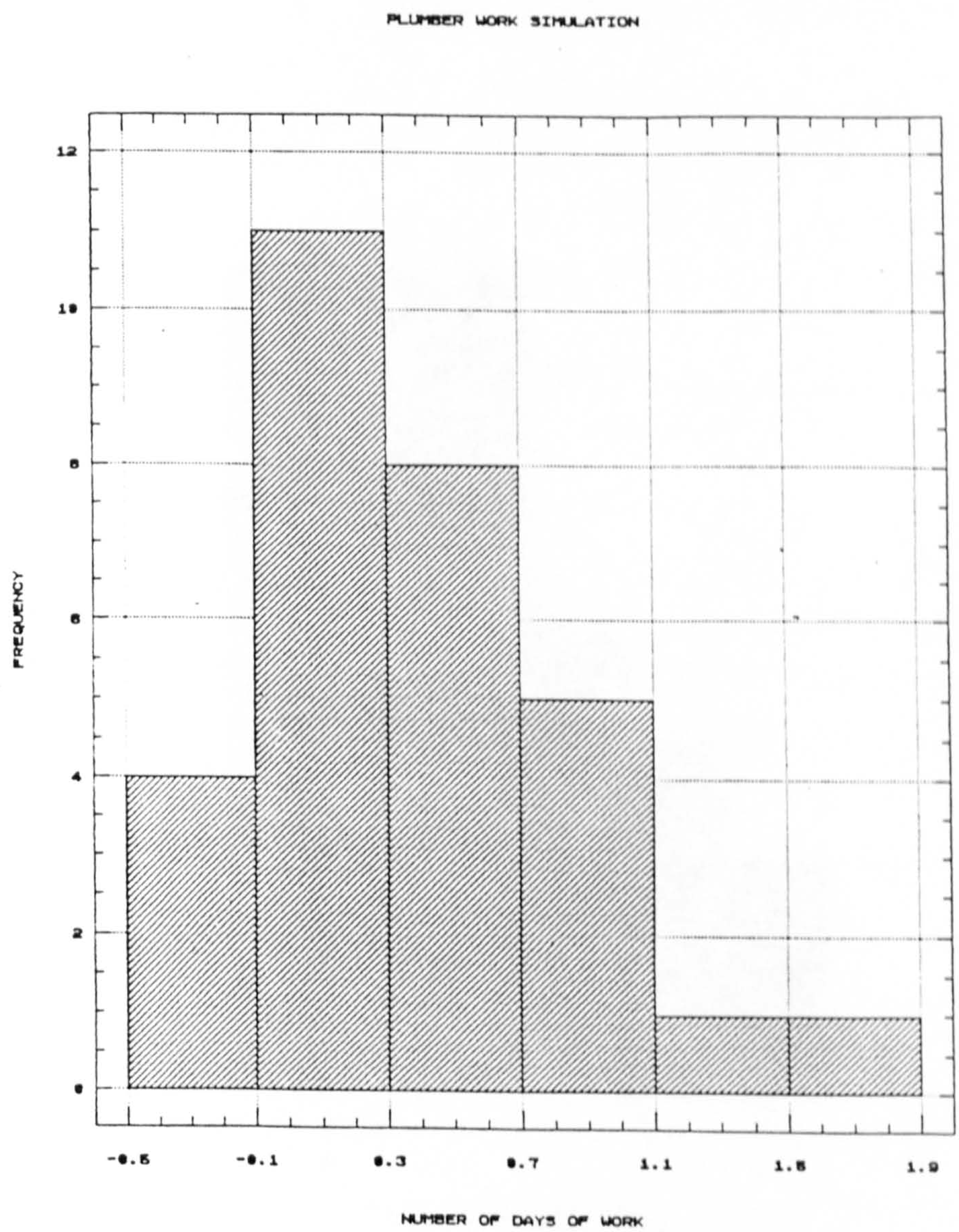


EXHIBIT 4.6.10

LOWEST MAXIMAL VALUE RUN 4

SIMULATED DISTRIBUTION OF DAYS OF WORK OUTSTANDING

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		1.00		0	.0000	0	.000
1	1.00	2.00	1.50	7	.2333	7	.233
2	2.00	3.00	2.50	7	.2333	14	.467
3	3.00	4.00	3.50	7	.2333	21	.700
4	4.00	5.00	4.50	4	.1333	25	.833
5	5.00	6.00	5.50	3	.1000	28	.933
6	6.00	7.00	6.50	2	.0667	30	1.000
above	7.00			0	.0000	30	1.000

Mean = 3.32986 Standard Deviation = 1.46978 Median = 3.08681

TABLE 4.6.16

STATISTICAL DISTRIBUTION OF DAYS OF WORK OUTSTANDING RUN 6

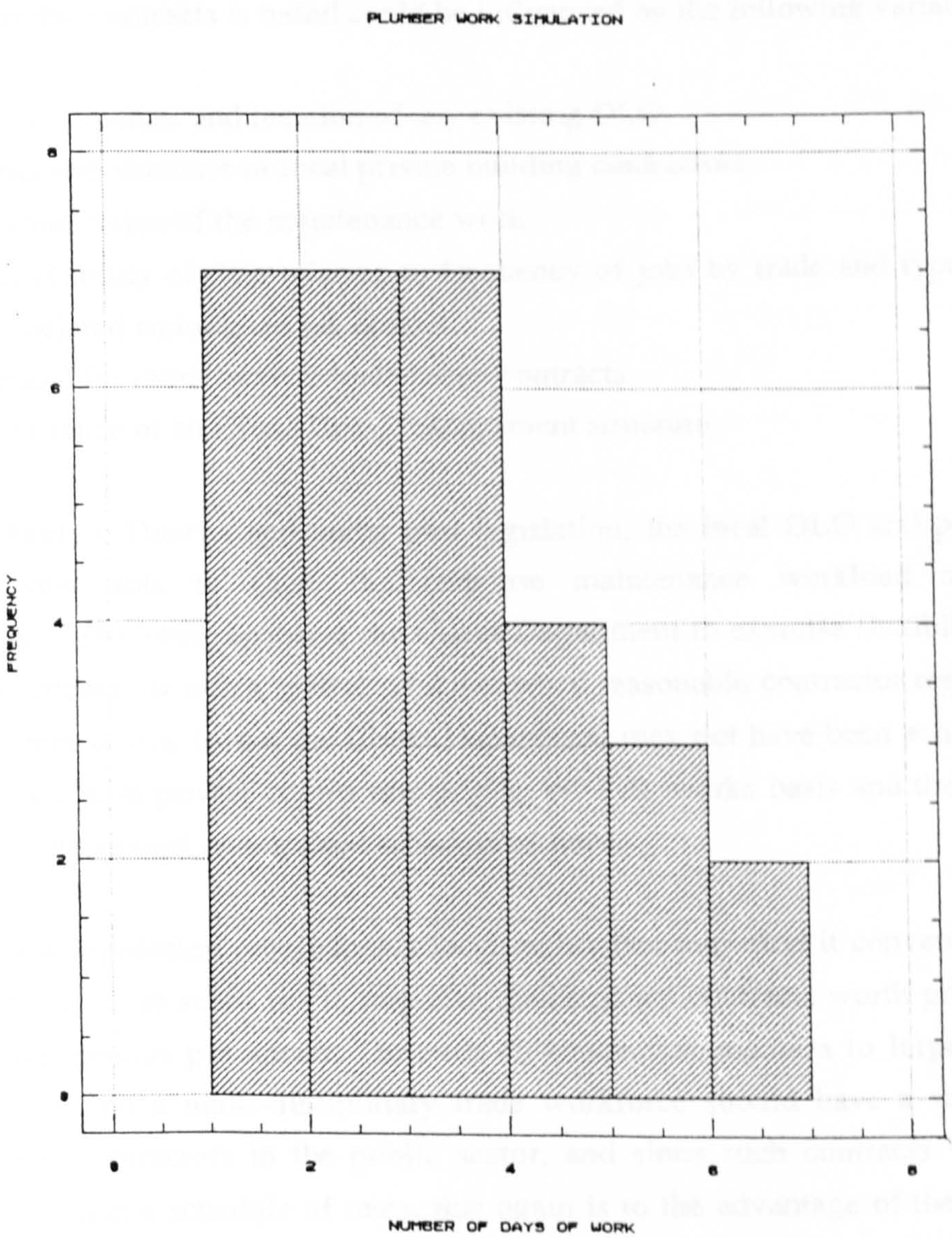


EXHIBIT 4.6.11

HIGHEST MAXIMAL VALUE RUN 6

SIMULATED DISTRIBUTION OF DAYS OF WORK OUTSTANDING

4.7 IMPLICATIONS FOR THE CLIENT DEPARTMENT

4.7.1 Work Packaging and Tendering

The third application of simulation is now aimed at predicting the cash value of response maintenance contracts and budgetary control.

Two primary functions of the Client Department are controlling expenditure and preparing packages of maintenance work to be put out to tender. The nature and size of any such response maintenance contracts may vary and the policy on which the structure of the contracts is based could be influenced by the following variables:

a. The size, structure and location of any existing DLO.
b. The mix and structure of local private building contractors.
c. The capital value of the maintenance work.
d. The availability of data relating to frequency of jobs by trade and type and the associated cumulative job costs.
e. A demand for more flexible trade based contracts.
f. The existence of an Estate based management structure.

Within Strathkelvin District and under past legislation, the local DLO and private contractors were able to share the response maintenance workload on an approximately 50/50 basis, enabling the Client Department to exercise flexibility in issuing repair orders. It was a system which ensured reasonable contractor response times. A counter to this is that the Client Department may not have been achieving value for money with private contractors pricing on a dayworks basis and the DLO possibly charging against an unpriced schedule of rates.

Within the new legislation requirements local authorities may find it convenient to invite tenders for large scale single response maintenance contracts worth probably several million pounds per annum. In such circumstances medium to large sized captive DLO's with a multi-disciplinary trade workforce should have a strategic advantage over contractors in the public sector, and since such contracts will be tendered for against a schedule of rates, this again is to the advantage of the DLOs who have more experience of working to such schedules.

The local private contractors' workforce within Strathkelvin is largely comprised of single trade firms and no single firm is able to offer an autonomous workforce capable of resourcing the spectrum of repairs arising within the response maintenance envelope. It is conceivable that a consortium comprising several individual local contractors could be created under a main contractor to bid for large scale contracts, against the more experienced DLOs. Such senarios are yet to be fully tested in the emerging competitive arena in Scotland and may be fraught with problems including pricing, communications and control.

Likewise the performance of many DLOs working under new contractual arrangements remains, in the main, to be tested, and their task is an unenviable one.

Time could reveal that smaller work packages may be more cost effective and controllable, however much additional work is involved for the Client Department. The creation of smaller baskets of work for tendering purposes would require quantitative knowledge of, say, the capital value of trade based repairs anticipated on an Estate basis. Alternatively larger contracts could be created by the grouping of principal trades involved in maintenance work, e.g. plumbing, joiner work and electrical work, these constituting the bulk of the maintenance demands. Such contracts could be based on Estates singly or in groups. The preparation of such contracts would WIDEN the scope for COMPETITION, encouraging MORE bids from the PRIVATE sector. However that such practices will prove more effective is yet to be determined.

4.7.2 Extended Computer Programme Applications

The simulation program developed earlier can be utilised to generate predictions for work packages of varying capital values based on job occurrence, either for SINGLE Estates or any COMBINATION thereof and on a SINGLE or MULTIPLE trade basis.

The computer programme developed in Section 4.3.3 is in this section modified to accommodate alternative applications of the simulation techniques discussed earlier. Here we consider the potential of the computer programme to produce probable estimates for the cost of a variety of work packages again based on the amount of work created by any combination of trades and or Estates.

To produce such estimates for the cost of a contract(s) requires that the frequency distributions for say the number of jobs/week and the cost/job are compounded as described in the previous sections. The above distributions are shown diagramatically below in Figs 4.7.1 and 4.7.2 respectively for say a single trade and for the sake of discussion all Estates.

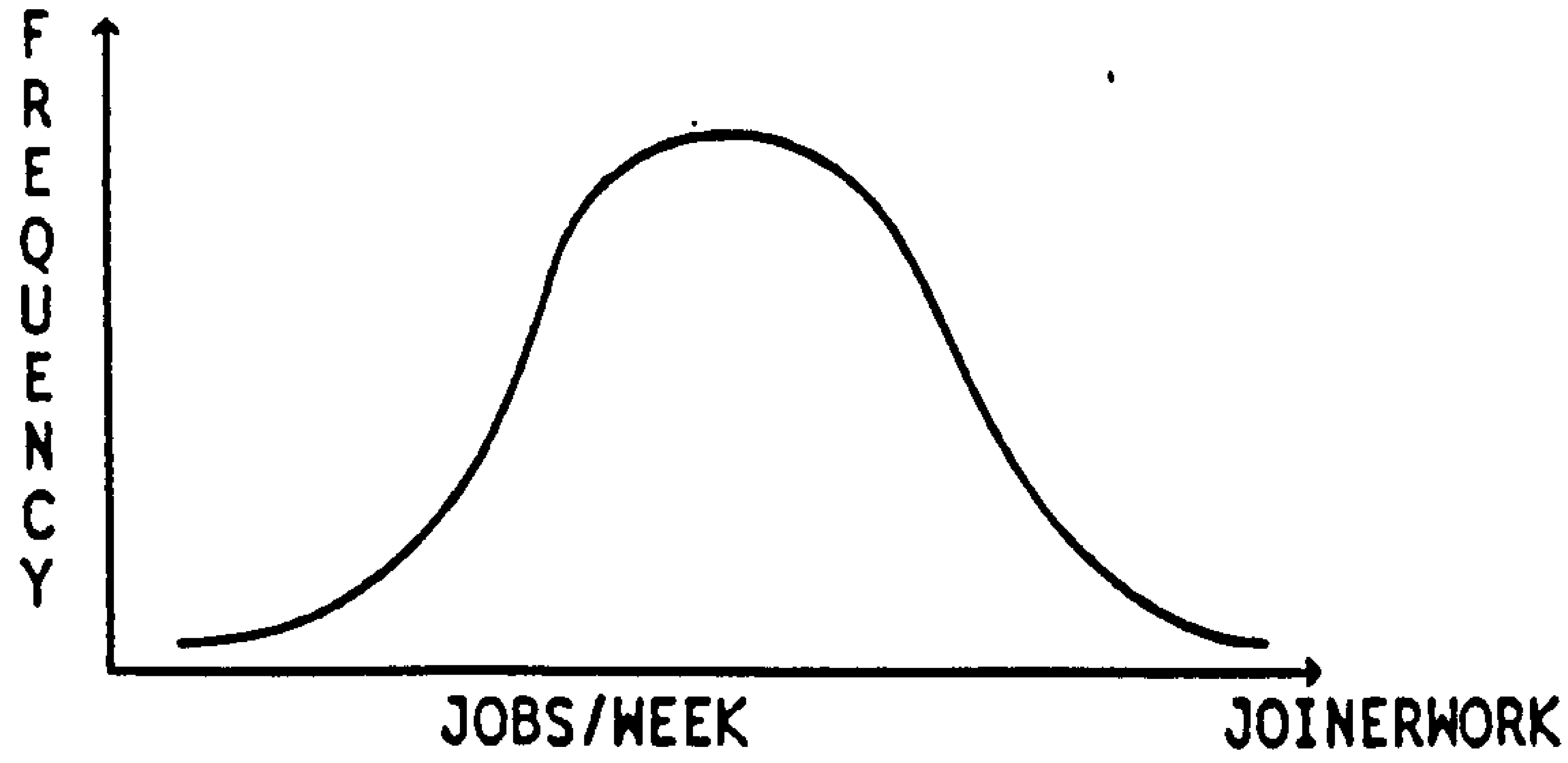


Fig 4.7.1

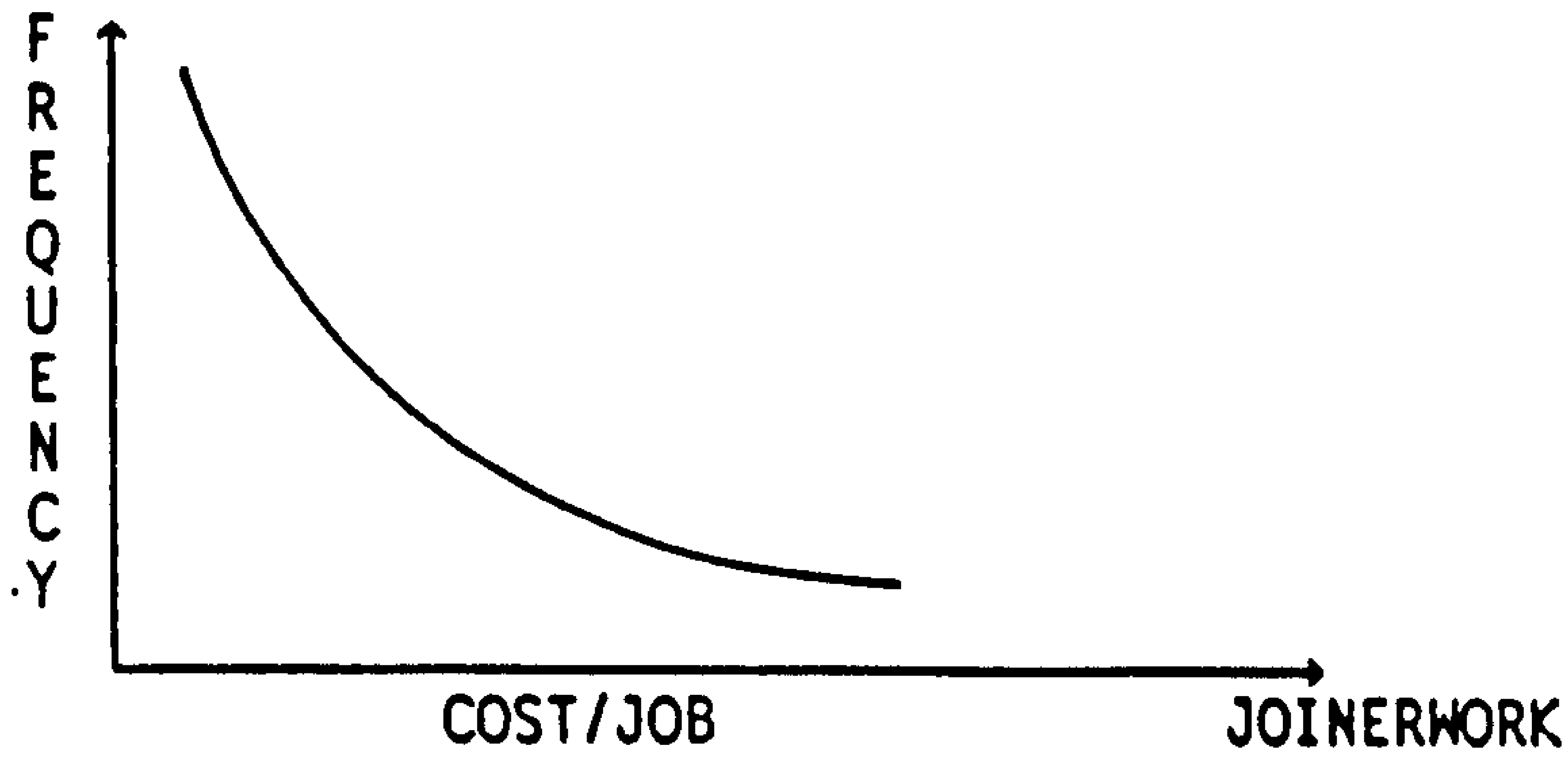


Fig 4.7.2

The process is almost identical to that used previously except that job arrivals/week replaces jobs/day and a unit cost per job distribution replaces the Target completion time distribution. Although not attempted in these concluding sections, the idea of replacing empirical distributions by Quasi theoretical distributions should be recalled. The program which was developed to produce the proposed simulations is given in Appendix 3.

4.7.3 The Empirical Frequency Distributions

The empirical distribution showing the frequency of job arrivals per week is presented in Exhibit 4.7.1. This was derived from the fluctuating job arrivals as displayed in Chapter 3 or by Exhibit 4.7.1 page 204. It must be emphasised that it is suspected that this data includes jobs delayed by the Client Department and is therefore not wholly representative of what has been previously defined as true response repairs. Likewise this display is based on job arrivals from January to September 1988 and is therefore not wholly representative of the entire year.

Exhibit 4.7.2 shows the frequency distribution of total cost per job for joiner work. This was derived from private contractors accounts where work done was charged for on a dayworks basis. This also cannot be regarded as an accurate representation of true costs per job but is nevertheless used as a surrogate to demonstrate the process. It is unlikely that a true cost can ever be obtained due to variations working practices, however the costs allocated to individual repair items on a priced schedule of rates may serve as a barometer to produce a costs per job frequency distribution.

The statistical properties of the empirical frequency distributions for job arrivals per week and costs per job are given in Tables 4.7.1 and 4.7.2.

The program may be run to produce results over a selected time interval. In this single example a contract duration of one year is selected, albeit that the data does not extend over this period. The program may be run for say a fifty week period and the process then replicated to produce say statistical confidence limits. This has not been attempted here in view of the discrepancies in the empirical data. The result of a single run is given in Appendix 3.

It is now possible to model the following outcomes which may be of interest to a Client Department:

1. The total cost of maintenance work, per trade, per year, or other timescale for individual or grouped Estates.

   Such information could be used to predict the capital value of a variety of contracts to be put out to tender against say a priced schedule of rates.

2. The fluctuations in the cost of repairs on the same basis as above between selected epochs throughout the year and founded on true seasonal demands for unplanned and planned response work viewed separately.

This information could be used to enable the Client Department to anticipate fluctuating expenditure requirements and possibly plan a smoother distribution of Revenue budget spending.

It is worth emphasising that it may be possible to produce a variety of predictions for contract costs for either individual trades, selected groups of trades and in packages of various sizes, either Estate by Estate or combinations thereof. This is of course; as with all other simulations; contingent on the accuracy of the empirical data.

4.7.4 A Cautionary Note

It is also cautionary to recall that the Secretary of State can as identified in Chapter 2, intervene in instances where ANTI-COMPETITIVE BEHAVIOUR is identifiable and demand alternative work tendering packages.

Audit Report[25] DLOs in London, November 1990 makes the point that contract conditions, as produced by Client Departments should *define* service delivery standards required in terms of "repair categories and response times together with the number of each category of repair likely to be encountered". The aim being to allow tender prices to more accurately reflect "true costs of the type of service expected by the client department" thereby permitting all contractors tendering for contracts to do so on a fair and equal basis.

Client departments should therefore, in the near future, be geared up to providing more accurate statistical data the nature of which corresponds to the form of the data used throughout this chapter. This strengthens the case for the development of the analytical techniques proposed in this section which may lead to a more systematic and accurate approach to work packaging and preparation of tender documents.

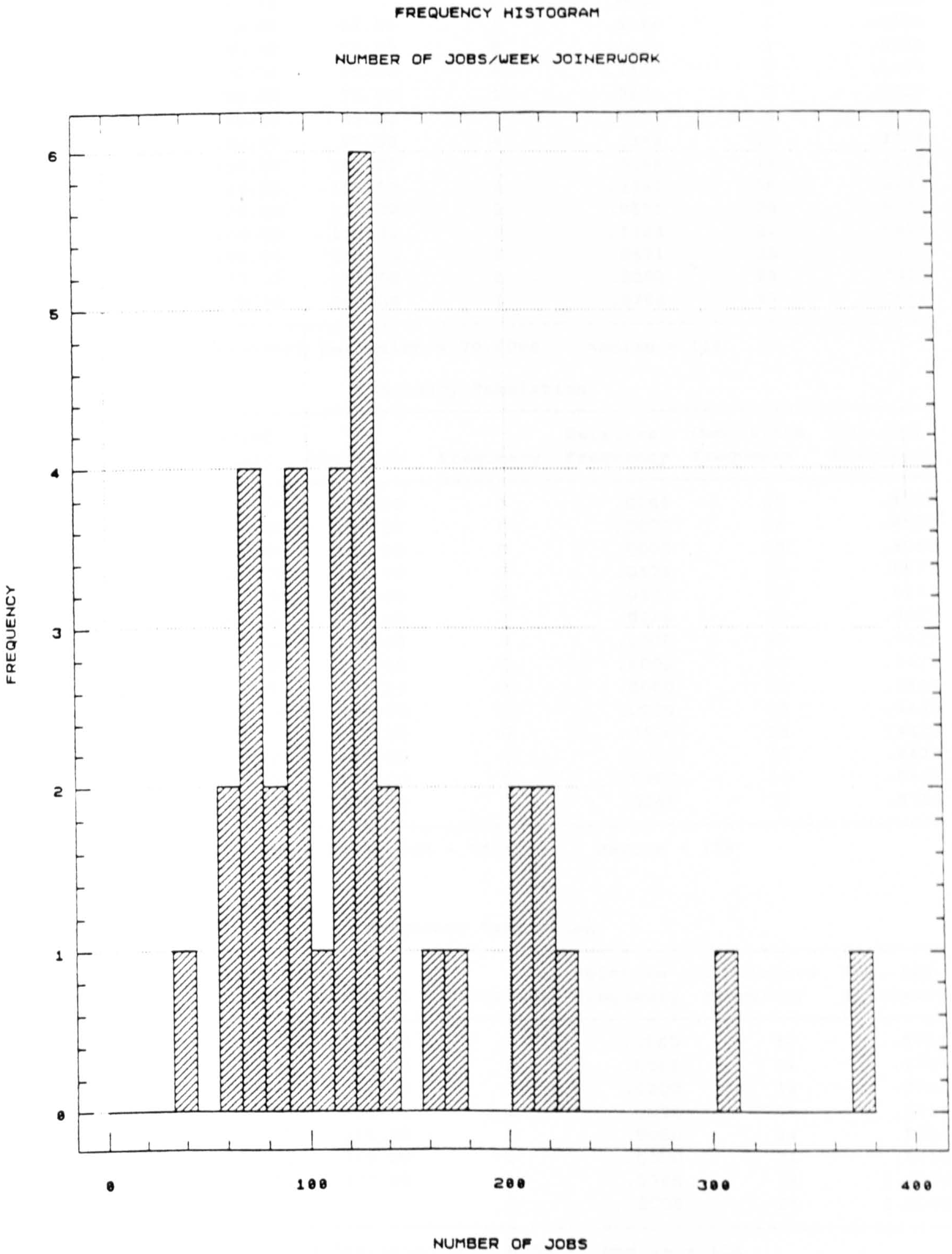


Exhibit 4.7.1

EMPIRICAL DISTRIBUTION OF JOB ARRIVALS PER WEEK

JOINER WORK ALL ESTATES

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		40.00		0	.0000	0	.0000
1	40.00	50.00	45.00	1	.0286	1	.0286
2	50.00	60.00	55.00	0	.0000	1	.0286
3	60.00	70.00	65.00	4	.1143	5	.1429
4	70.00	80.00	75.00	2	.0571	7	.2000
5	80.00	90.00	85.00	2	.0571	9	.2571
6	90.00	100.00	95.00	4	.1143	13	.3714
7	100.00	110.00	105.00	1	.0286	14	.4000
8	110.00	120.00	115.00	4	.1143	18	.5143
9	120.00	130.00	125.00	2	.0571	20	.5714
10	130.00	140.00	135.00	4	.1143	24	.6857
11	140.00	150.00	145.00	2	.0571	26	.7429
12	150.00	160.00	155.00	0	.0000	26	.7429
13	160.00	170.00	165.00	1	.0286	27	.7714

Mea = 135.114   Standard Deviation = 70.8008   Median = 118

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
14	170.00	180.00	175.00	1	.0286	28	.8000
15	180.00	190.00	185.00	0	.0000	28	.8000
16	190.00	200.00	195.00	0	.0000	28	.8000
17	200.00	210.00	205.00	2	.0571	30	.8571
18	210.00	220.00	215.00	2	.0571	32	.9143
19	220.00	230.00	225.00	1	.0286	33	.9429
20	230.00	240.00	235.00	0	.0000	33	.9429
21	240.00	250.00	245.00	0	.0000	33	.9429
22	250.00	260.00	255.00	0	.0000	33	.9429
23	260.00	270.00	265.00	0	.0000	33	.9429
24	270.00	280.00	275.00	0	.0000	33	.9429
25	280.00	290.00	285.00	0	.0000	33	.9429
2F	290.00	300.00	295.00	0	.0000	33	.9429
2	300.00	310.00	305.00	1	.0286	34	.9714

Mean = 135.114   Standard Deviation = 70.8008   Median = 118

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
28	310.00	320.00	315.00	0	.0000	34	.9714
29	320.00	330.00	325.00	0	.0000	34	.9714
30	330.00	340.00	335.00	0	.0000	34	.9714
31	340.00	350.00	345.00	0	.0000	34	.9714
32	350.00	360.00	355.00	0	.0000	34	.9714
33	360.00	370.00	365.00	0	.0000	34	.9714
34	370.00	380.00	375.00	1	.0286	35	1.0000
above	380.00			0	.0000	35	1.0000

Mean = 135.114   Standard Deviation = 70.8008   Median = 118

Table 4.7.1

STATISTICAL DISTRIBUTION OF JOB ARRIVALS PER WEEK

JOINER WORK ALL ESTATES

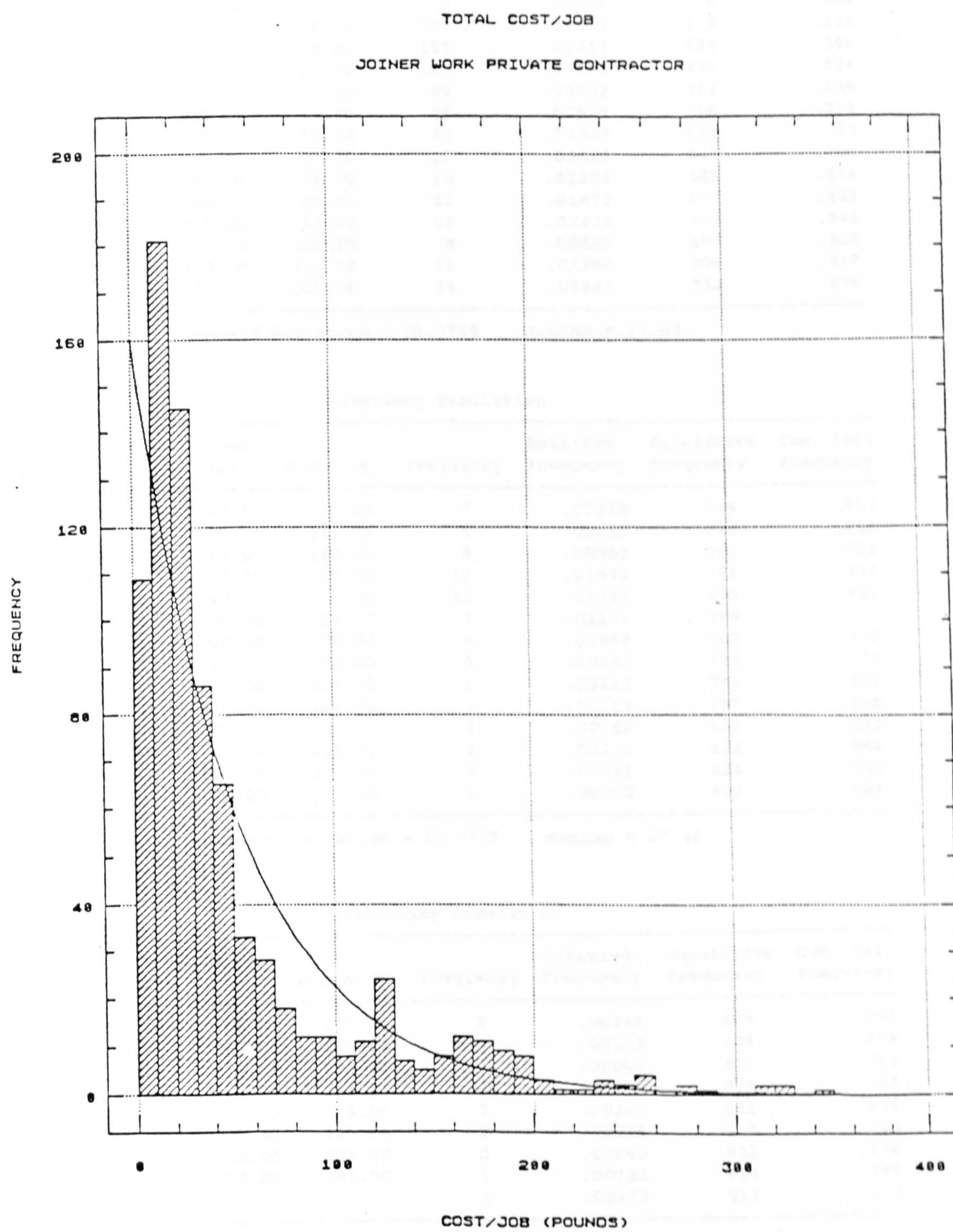


Exhibit 4.7.1

EMPIRICAL DISTRIBUTION OF TOTAL COSTS PER JOB
JOINER WORK : PRIVATE CONTRACTORS

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.00000	0	.000
1	.00	10.00	5.00	109	.13374	109	.134
2	10.00	20.00	15.00	181	.22209	290	.356
3	20.00	30.00	25.00	145	.17791	435	.534
4	30.00	40.00	35.00	86	.10552	521	.639
5	40.00	50.00	45.00	65	.07975	586	.719
6	50.00	60.00	55.00	33	.04049	619	.760
7	60.00	70.00	65.00	28	.03436	647	.794
8	70.00	80.00	75.00	18	.02209	665	.816
9	80.00	90.00	85.00	12	.01472	677	.831
10	90.00	100.00	95.00	12	.01472	689	.845
11	100.00	110.00	105.00	8	.00982	697	.855
12	110.00	120.00	115.00	11	.01350	708	.869
13	120.00	130.00	125.00	24	.02945	732	.898

Mean = 50.846 Standard Deviation = 58.3765 Median = 27.48

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
14	130.00	140.00	135.00	7	.00859	739	.907
15	140.00	150.00	145.00	5	.00613	744	.913
16	150.00	160.00	155.00	8	.00982	752	.923
17	160.00	170.00	165.00	12	.01472	764	.937
18	170.00	180.00	175.00	11	.01350	775	.951
19	180.00	190.00	185.00	9	.01104	784	.962
20	190.00	200.00	195.00	8	.00982	792	.972
21	200.00	210.00	205.00	3	.00368	795	.975
22	210.00	220.00	215.00	1	.00123	796	.977
23	220.00	230.00	225.00	1	.00123	797	.978
24	230.00	240.00	235.00	3	.00368	800	.982
25	240.00	250.00	245.00	2	.00245	802	.984
26	250.00	260.00	255.00	4	.00491	806	.989
27	260.00	270.00	265.00	0	.00000	806	.989

Mean = 50.846 Standard Deviation = 58.3765 Median = 27.48

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
28	270.00	280.00	275.00	2	.00245	808	.991
29	280.00	290.00	285.00	1	.00123	809	.993
30	290.00	300.00	295.00	0	.00000	809	.993
31	300.00	310.00	305.00	0	.00000	809	.993
32	310.00	320.00	315.00	2	.00245	811	.995
33	320.00	330.00	325.00	2	.00245	813	.998
34	330.00	340.00	335.00	0	.00000	813	.998
35	340.00	350.00	345.00	1	.00123	814	.999
above	350.00			1	.00123	815	1.000

Mean = 50.846 Standard Deviation = 58.3765 Median = 27.48

Table 4.7.2

STATISTICAL DISTRIBUTION OF TOTAL COSTS PER JOB

JOINER WORK : PRIVATE CONTRACTORS

4.8 MATERIALS MANAGEMENT

4.8.1 STORES AND INVENTORY IMPLICATIONS

The aim of materials management should be to maintain a stock of materials and components of the right quantitative and qualitative balance to meet the needs of say programmed maintenance demands and also to match the demands of response maintenance.

The cash value of stock held in stores is included in a DLO's working capital. Cash tied up in excessive stores of materials/components is obviously unproductive, and, inadequate or unbalanced stores can cause delays in effecting repairs which may lead to contractual acrimony. Hence the contractor department is required to maintain a minimum stock holding balanced against re-ordering levels and delivery lead times and must attempt to match anticipated withdrawals from stores; for possibly six to eight trades, based possibly only on experience of fluctuating withdrawal demand for historical contract sizes which may be rendered obsolete.

A study conducted by the Audit Commission[13] concluded that many DLO stores departments contained excessive and redundant stock and further suggests, without any rationale, that reducing stock holdings will reduce and even out workloads leading to greater productivity within the stores department.

4.8.2 MODELLING THE VALUE OF THE STOCK HOLDING

The possibility of swingeing fluctuations in the day to day and week to week issuing of orders for repairs to a contractor department has already been well aired. Here we attempt to demonstrate how the computer simulation program developed in section 4.3.3 may be used to produce estimates of the cost value of materials/components stock usage for response maintenance at various times throughout the year. Estimates of stock value may be obtained on a Trade by Trade and Estate by Estate basis. Knowledge of the geographical distribution of stock value may not matter for small to medium sized authorities, however, for very large authorities which could be managing as many as one hundred thousand houses, there could be implications for main stores depot and sub-depot locations.

To run such a simulation, the frequency distributions, used previously for job arrivals, jobs per estate and jobs per category may be combined with a frequency distribution for materials cost for individual jobs. It would again be important to model stock value based on any true seasonal trends as distinct from an enforced demand situation created by say the Client Department as explained in Chapter 3, or at least to acknowledge that a difference could exist.

Daily demands may not be, in this instance, too significant, however, the program generates daily values and sums to provide, say weekly totals. Estimates of stock value required for the combination of all Estates or any combination of individual Estates is achievable. Clearly a knowledge of the cost value of stock by trade does not describe which materials/components should be held in stock or indeed how many, but it does act as a barometer for change and a scaling up or down of known distributions within the stock may possibly yield a simple answer.

The new legislative framework may generate new contracts for packages of work differing from those derived under previous legislation and these could have a significant impact as full competitive tendering confronts commercial survival and the effectiveness of building maintenance contractors is tested in delivering the required level of service within the response maintenance envelope.

By such experimentation a large number of combinations of outcomes is now possible. Yet again it is not the intention here to pursue every option rather the *ideas* and *principles* are illustrated by singular example.

4.8.3 MATERIAL/COMPONENT COST FREQUENCY DISTRIBUTION

Exhibit 4.8.1 page 211 shows the frequency distribution for, as an illustration, joiner work. The data used to construct this distribution is again extracted from the cost of materials per job completed by private contractors on a day works basis and for response repairs. It should however be possible to obtain similar data from a priced schedule of rates, but this would require that material costs are itemized for each schedule of rates item.

The cumulative probabilities of this distribution as used in the simulation program are given in table 4.8.1.

An estimate of the total materials cost for a one year period for a joiner work contract for all Estates is obtained using the above distribution and that for job arrivals per week as shown in Exhibit 4.7.1 which has the statistical distribution as given in Table 4.7.1. The original arrival rates being derived from Exhibit 3.7.13 in Chapter 3.

One output for total materials cost per year obtained by running the simulation is given at the end of the computer program developed for this experiment which is given in Appendix 3.

This approach, although much less sophisticated than required for full control does illustrate the nature of the problem and permits estimates for the usage value to be generated for a variety of schemes. As client departments are progressively forced into producing intricate details of the frequency of repair types and associated costs elaborate techniques as proposed here may, with further development be of value in the future. The comments at the end of section 4.7 should be read in conjuction with this section.

Although the ideas presented here may seem to some elaborate and even unworkable, we must strive to unravel the mysteries that abound in this element of housing maintenance. We must open doors and seek alternative horizons. There will very likely, be other ways and means of representing and attempting to solve the problems identified in this section but these must be teased out of the system and that is what this section begins to do.

4.9 Summary: What This Chapter Does

The frequency distributions which are necessary to permit the simulation of a variety of response maintenance scenarios are identified, quantified and constructed for a trial period representing twenty working days. A computer program is developed which samples from the distributions systematically to produce probabilistic predictions of man job hours of work per day, for any trade showing the distribution of the work by Estate and indicating the category of work in terms of target response times.

Initially experimental results thus produced are used to test the dispersion of man job hours of work for a variety of trade coalitions, to demonstrate a benefit of flexible working among trades. The modelling process is extended to produce predictions of manning levels which can cope with variable repair demands and framed within specific target response times. The idea is further developed to consider the use of theoretical or quasi theoretical distributions for job completion times and the results are replicated to produce maximum and minimum demands thereby testing the robustness of the modelling processes. The concept of variable packaging of work to produce a variety of maintenance contract sizes is emphasised throughout.

Finally the computer program is modified to accommodate the introduction of alternative frequency distributions. This enables the probable cash value of a variety of contract packages to be estimated and the process is sufficiently adaptable to enable other elements of maintenance management to be forecast.

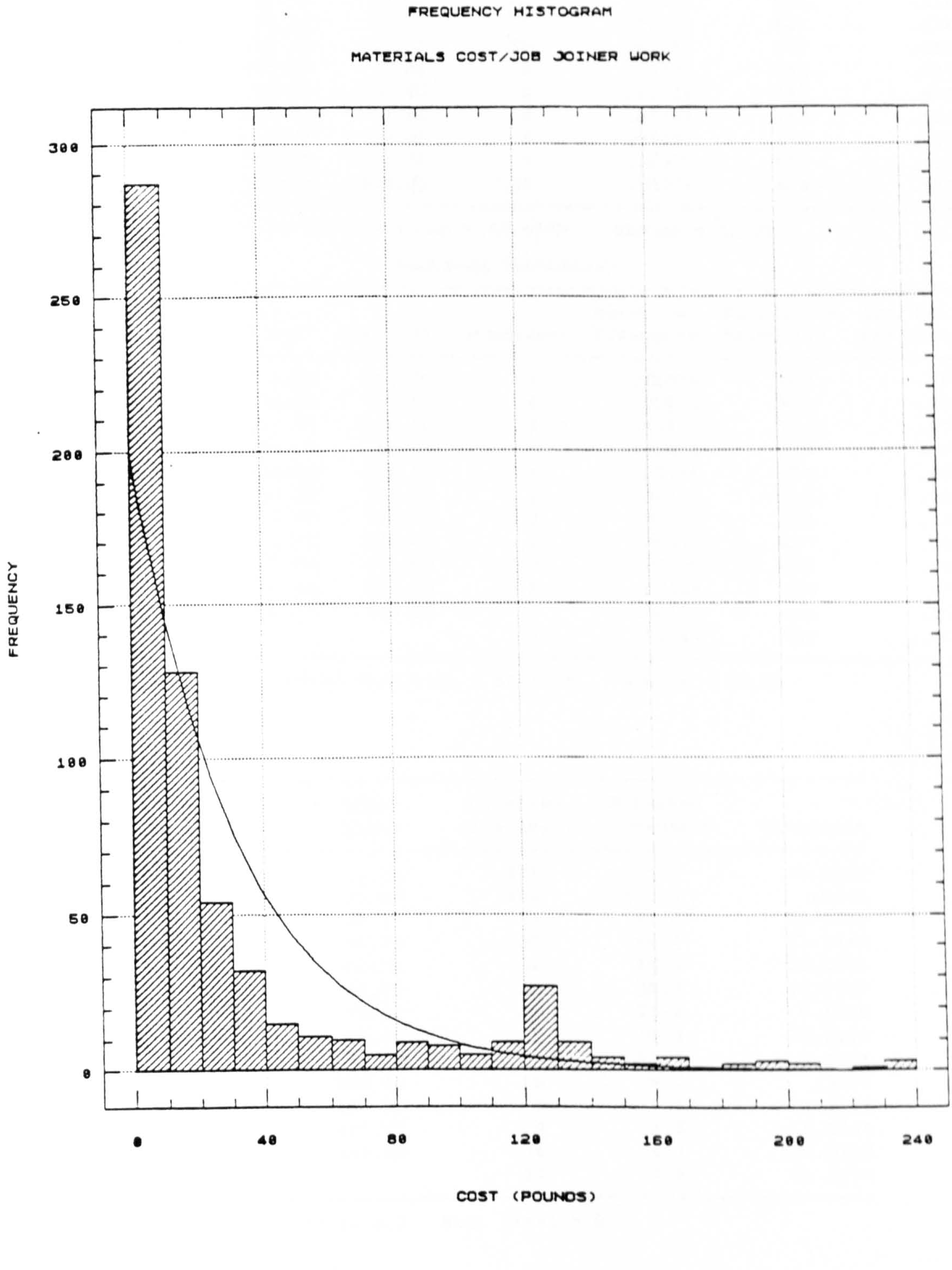


Exhibit 4.8.1

EMPIRICAL DISTRIBUTION OF MATERIALS COSTS PER JOB

JOINER WORK

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.00000	0	.000
1	.00	10.00	5.00	287	.45411	287	.454
2	10.00	20.00	15.00	128	.20253	415	.657
3	20.00	30.00	25.00	54	.08544	469	.742
4	30.00	40.00	35.00	32	.05063	501	.793
5	40.00	50.00	45.00	15	.02373	516	.816
6	50.00	60.00	55.00	11	.01741	527	.834
7	60.00	70.00	65.00	10	.01582	537	.850
8	70.00	80.00	75.00	5	.00791	542	.858
9	80.00	90.00	85.00	9	.01424	551	.872
10	90.00	100.00	95.00	8	.01266	559	.884
11	100.00	110.00	105.00	5	.00791	564	.892
12	110.00	120.00	115.00	9	.01424	573	.907
13	120.00	130.00	125.00	27	.04272	600	.949

Mean = 31.6881 Standard Deviation = 45.9979 Median = 12.09

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
14	130.00	140.00	135.00	9	.01424	609	.964
15	140.00	150.00	145.00	4	.00633	613	.970
16	150.00	160.00	155.00	2	.00316	615	.973
17	160.00	170.00	165.00	4	.00633	619	.979
18	170.00	180.00	175.00	1	.00158	620	.981
19	180.00	190.00	185.00	2	.00316	622	.984
20	190.00	200.00	195.00	3	.00475	625	.989
21	200.00	210.00	205.00	2	.00316	627	.992
22	210.00	220.00	215.00	0	.00000	627	.992
23	220.00	230.00	225.00	1	.00158	628	.994
24	230.00	240.00	235.00	3	.00475	631	.998
above	240.00			1	.00158	632	1.000

Mean = 31.6881 Standard Deviation = 45.9979 Median = 12.09

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below		10.00	287	171.0	78.6193
	10.00	20.00	128	124.8	.0846
	20.00	30.00	54	91.0	15.0369
	30.00	40.00	32	66.4	17.7945
	40.00	50.00	15	48.4	23.0526
	50.00	60.00	11	35.3	16.7319
	60.00	70.00	10	25.8	9.6335
	70.00	80.00	5	18.8	10.1124
	80.00	90.00	9	13.7	1.6115
	90.00	100.00	8	10.0	.3969
	100.00	110.00	5	7.3	.7179
	110.00	120.00	9	5.3	2.5547
	120.00	140.00	36	6.7	128.0153
above	140.00		23	7.6	31.0394

Chisquare = 335.401 with 12 d.f. Sig. level = 0

Table 4.8.1

STATISTICAL DISTRIBUTION OF DISTRIBUTION OF MATERIALS COST PER JOB AND CHISQUARE TEST

JOINER WORK

CHAPTER FIVE

MODELLING AN INSPECTION POLICY

5.1 INTRODUCTION AND BRIEF HISTORICAL BACKGROUND

In this chapter and within the framework of a District Council building maintenance repairs service, we investigate the feasibility of superimposing an inspection system on an existing purely response repairs service.

Types of inspection systems in general use are reviewed and the benefits and disbenefits of a hybrid inspection/response system are identified.

The idea of the life span of defects is defined in terms of 'lapse times' which is the time interval between the origin of a defect and its date of repair.

The aim of this chapter is to develop a cost per unit time model which identifies the optimal time interval between scheduled inspections.

Response repairs likely to occur are expressed as a proportion and an expression for the probability that defects are repaired under a response maintenance system within the inspection interval is given. A cost per unit time model is developed which adjusts for cost savings due to say, cluster benefits derived from repairs being identified under an inspection system. The additional cost of inspections is also incorporated.

The collection of data necessary to construct a distribution of lapse times is discussed. Difficulties in collecting realistic data within a response maintenance system and data limitations are exposed as is the subjective nature of lapse time assessments.

Empirical data thus derived is used to test the model for a limited number of envisaged scenarios.

Hence inspections are considered to take place at regular intervals, T time units apart, at which inspections, existing defects are identified and then rectified at some time before the next inspection. The decision variables which impinge and interact when such an inspection system routine is introduced are discussed and an expression is developed for the cost per unit time of operating a hybrid inspection/response maintenance system. The development of the model requires that a statistical distribution F(h) of the 'lapse time',h , or a p.d.f. f(h) of h is achievable and the modelling process owes its origins to the work of Professor A H Christer; Modelling Inspection Policies for Building Maintenance 1982.

This investigation was implemented in early 1985 at which time the District Council Housing Stock was being maintained by a repairs service which could be described as a purely response system, with the aim of completing virtually all types of defects within Target Response Times of seven days. The only planned maintenance scheduled was that of pre-paint repairs with a proposed Target painting cycle of five years. However, management estimates placed the painting cycle at nearer eight years.

The enforced operating of this emergency/urgent repairs service over a period of many weeks placed great strain on the revenue budget which was in imminent danger of being exhausted well before the end of the financial year. As a consequence of this excessive pressure was induced on all maintenance staff, notably managers, and inspectors caught in the centre of acrimonious debate. In spite of this unsympathetic environment, with the approval of the Council and the co-operation of management and maintenance personnel, an attempt was made to investigate the potential of the proposed inspection/response system.

5.2 INSPECTION SYSTEMS

5.2.1 Types of Inspections, Rationale and Benefits

Prior to focusing attention on the proposed inspection system, we briefly discuss the types of inspection routines commonly employed by Local Authorities or say Housing Associations, bearing in mind that the overall maintenance strategy may be a complex mixture of a response system and some or all of the inspection routines listed below.

1. **Response Maintenance Pre-repair Inspection:** On receipt of repair request, repairs may be selected for inspection individually, in groups or collectively to establish the exact nature of each repair, materials content, approximate cost, access arrangements, or Target Attendance Hours, with a view to forward planning. Such inspections may be undertaken by the Client or Contractor Departments.

2. **Programmed Inspections**: Prior to painting on a programmed cyclical basis certain elements of the building fabric e.g. external doors and windows, rendering, facias, gutter and downpipes, tiffen and so on, are inspected to establish any necessary repairs before painting or spraying. These elements will be inspected by the Client Department in the first instance.

3. **Post Repair Inspections**: Completed work is, say, randomly sampled and a minimum of 10% of jobs are inspected by the Client Department to monitor the quality of materials and workmanship, customer satisfaction, and that value for money has been achieved.

4. **Age Based Inspections**: Certain elements or components of a building will have anticipated maximum life expectancies, e.g., electrical wiring, flat roofs, gutters and downpipes, plastic windows and so on and such elements may be inspected towards the end of their expected life cycles to establish any repair or replacement strategies. Details of life expectancies of components and materials(23) are available.

5. **Ad Hoc Inspections**: As a consequence of a response system it may be observed that a particular defect is occurring frequently and this may be symptomatic of a design or material fault. Such observations could initiate an inspection of all such suspect components.

6. **Periodic Inspections Superimposed on a Response System**: This is the system we propose to model. Defects identified at such inspections will include those which have hitherto been ignored or not observed by the Tenant, but which may be reported by the Tenant within the inspection interval as response repairs. It is important to acknowledge that Inspections Do Not Prevent Defects From Arising, therefore new defects will occur within the inspection interval, a proportion of which will be identified by the Tenant and reported as response repairs.

Much has been said and written on the vexing issue of the role and importance of inspection routines within the context of building maintenance. That repairs, response or otherwise, could or should be inspected remains a contentious subject. With respect to response maintenance, the study commissioned by the Scottish Office "The Delivery of Repairs Service in Public Service Housing in Scotland 1986"[(7)], produced an analysis of the extent of pre-inspections carried out by Local Authorities taking part in the study and concludes "many have a policy of only inspecting serious defects, unclear requests, communal repairs or emergencies while 13, including some very large Authorities attempt to inspect most, if not all, contingency (response) repairs".

Inspections take time, in that they may draw from existing human resources, and cost money, and in the above response maintenance situations arguably increase the System Response Time of the repair. Therefore clear benefits need to be identified to justify the introduction of an inspection system.

In deciding which form an inspection policy should take, it is convenient to accept that repairs are discretely divided into two main groups, namely RESPONSE MAINTENANCE and PLANNED MAINTENANCE. However it should be acknowledged that individual defects are elements of a repair system and are part of the same continum; in that a myriad of defects exists simultaneously, in different states of disrepair and stages of subjective acceptability. Defects leave the system upon repair with new defects entering the system as they arise; although not necessarily at the same rates. It may be worthwhile to remember at this stage that the time scale required for many building defects to reach a terminal condition of acceptability could be measured in months or years.

Hence the distinction between response and planned maintenance may be a little blurred with categorisation being dependant on an arbitrary value placed on cost, the scale of the repair, or its perceived urgency.

Setting aside the issues of pre-inspection of elements for planned maintenance and accepting that the decision as to what proportion of completed work should be post-inspected simply requires a committment to a Quality Assurance Policy, we focus attention on the viability or otherwise of a cyclical pre-emptive inspection system.

Although the implementation of such a system may reduce the number of Tenant generated repair demands, it must be additionally acknowledged that the quantity and nature of response maintenance repairs which are initiated by a Tenant Lead inspection system, will not necessarily be a measure of the number and condition of defects which actually exist within the housing stock; knowledge of which must be regarded as essential if monitoring the condition of the stock is to be treated seriously and a controlled and systematic approach to the servicing of repairs is to be developed.

The importance of the role of pre-emptive inspection systems may, in the near future, become more significant with the termination of new build capital projects and an increase in capital spending on programmable maintenance.

5.3 THE INSPECTION/RESPONSE SYSTEM; BENEFITS AND DISBENEFITS

As a consequence of introducing the proposed inspection system certain benefits may accrue, significant among which are the following:

a) **Improved Resource Management:** The fluctuating maintenance demand which in general dictates the variable work loads issued to the contractor was discussed in chapter 3. Obviously the contractor would prefer a more even distribution of work, bearing in mind the problems created otherwise. Given that sufficient inspection repairs can be identified, more realistic Target Response Times may be ascribed and repairs delayed for periods outwith the structured Target Response Time classifications. The same argument as made in chapter 4 for ZONED, category D repairs applies since realistic Target Response Times may be assigned allowing more effective queuing and clustering of jobs to occur. Jobs are then allocated by trade or specialisms within, and any consequential influences on transport, workshops, stores and so on, given the necessary consideration.

It is worth noting that at the first inspection of the properties a surge in defects requiring repair could be identified and the possibility exists that some repairs maybe scheduled into a current or proposed maintenance programme.

b) **Better Budget Control**: The Client Department may utilise data on repair type which has been identified at an inspection. Repairs may be purposefully delayed, being grouped for subsequent controlled release, thereby producing a more even distribution of the Revenue budget. This approach may once again be at variance with the contractors workforce availability, bearing in mind the likelihood of variable daily or weekly response maintenance demands. Some attempt should therefore be made to harmonise these possible conflicting requirements, be they between the Client Department and its DLO or Private Contractor.

To attempt to balance the fluctuating response repair demand would of course require a knowledge of seasonal variations in workload for repairs in the emergency, urgent and non urgent response maintenance categories. It is important to identify true seasonal variations when collecting data remembering that trends may be masked during the Client Delay Time interval.

c) **Monitoring The Condition of the Housing Stock**: This could be a natural consequence of such an inspection system. Although less exhaustive than a full housing condition survey, it could produce a profile of the general condition of the stock, providing records that may assist short and long term planning of repairs, budget forecasting and replacement or refurbishment strategies.

Given that some or all of the aforegoing benefits can be derived from cyclical inspections, the decision to implement such a scheme may be conditional on the operational cost, which will be the sum of the cost of inspection repairs and response repairs, plus the cost of inspections. Therefore an economic condition which may need to be satisfied, is that the cost of operating the hybrid inspection/response system be no greater than the cost of operating a purely responsive repairs service.

This condition may be achievable contingent on the proportion of inspection repairs and cost savings arising from improved job tendering procedures, economies of scale, learning benefits and so on, thus rendering such repairs cheaper than responsive repairs. Some inspection repairs are taken as being analogous to programmed repairs and the Audit Report[13] suggests a model which contrasts programmed and response repairs and identifies factors which combine to produce cost savings. This is illustrated in Fig 5.3.

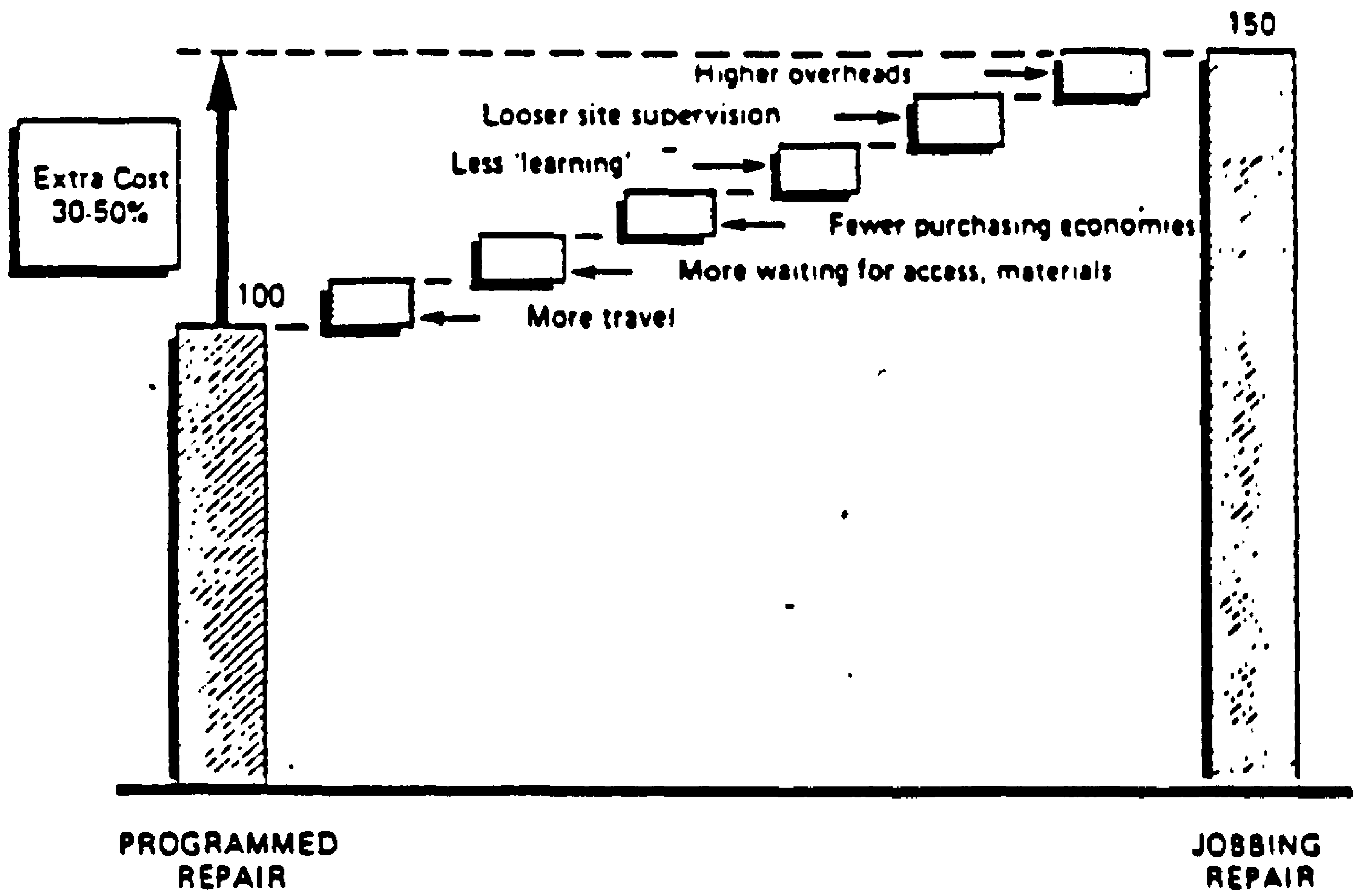


Fig 5.3

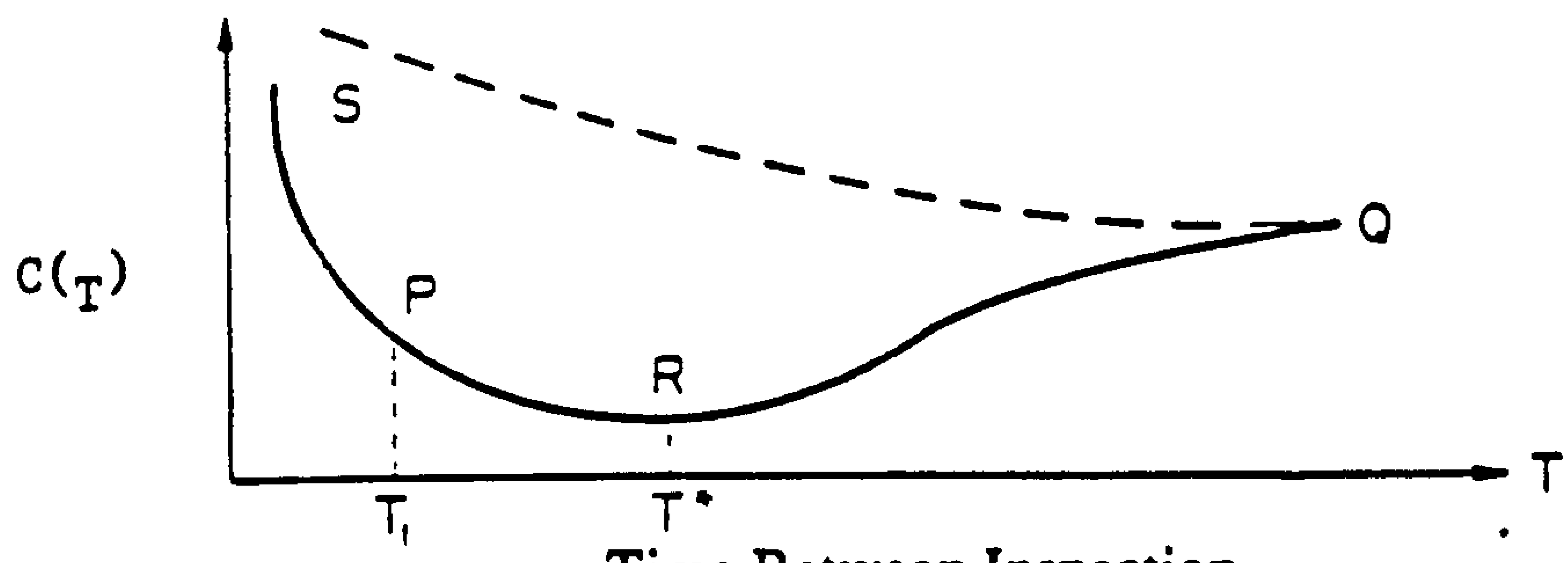
Hence from the aforegoing consideration and in an attempt to model the problem the main objectives are:

a) to express the proportion of repairs which are identified by a response system as a function of T, the time interval, in weeks say, between inspections in series. Here we consider such repairs as being analogous to breakdown repairs.

b) to express the cost per unit time $C_{(T)}$, of operating an inspection/response repairs service as a function of the inspection interval, T.

5.3.1 The Cost per Unit Time Curve and Inspection Implications

Suppose now that the cost per unit time of operating a synthesised inspection/response system is $C_{(T)}$ with inspections at intervals of T time units. Christer[5] suggests that conceptually the relationship between $C_{(T)}$ and T may take one of the forms shown in Fig 5.3.1.



Time Between Inspection

Fig 5.3.1

Accepting this idea, then, if $C_{(T)}$ takes the form SPRQ, the optimal inspection interval is at T*. If no inspections take place the asymptotic point Q given by $T = \infty$ is known. Now if an inspection system is in operation and is totally ineffective in cost terms the curve $C_{(T)}$ takes the form SQ, which implies do not inspect. Knowing only one point on the curve for $C_{(T)}$ will not identify which curve for $C_{(T)}$ applies. The point P could represent a value for $C_{(T)}$ for a current inspection policy with T_1, being the inspection interval. It follows that to model the inspection system it is necessary to model $C_{(T)}$ for a range of stipulated values of T, the inspection interval.

5.4 THE MEASUREMENT OF LAPSE TIME (h)

Some building defects will arise and cause more or less instantaneous failure of a component or fabric while others will arise and progressively worsen, that is, they grow, until a condition is reached where further deterioration is unacceptable for a variety of reasons, which may be subjective or objective. To appreciate the range of rates of growth of building defects consider Fig 5.4.

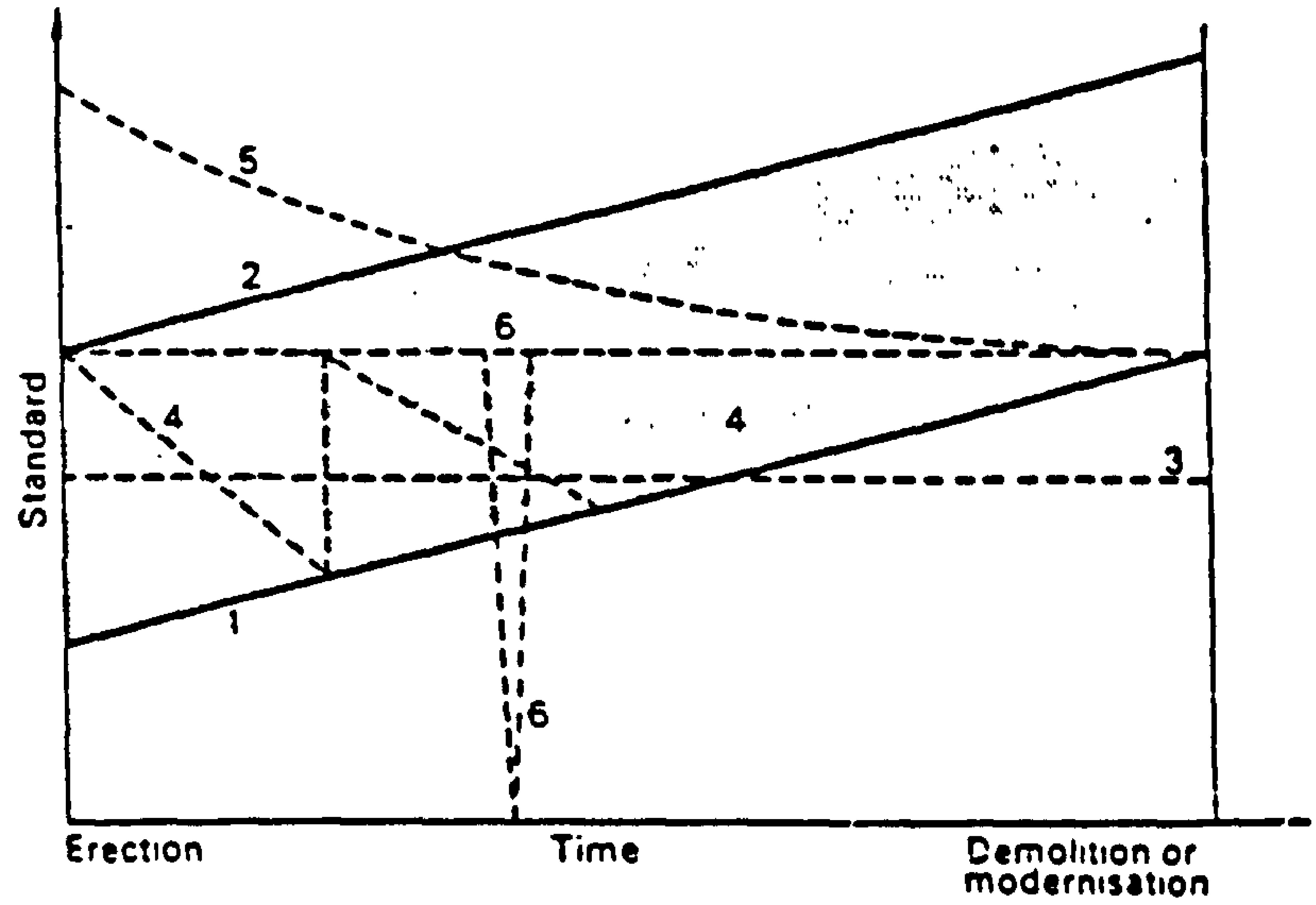


Fig 5.4

Maintenance requirements related to standards over a period of time (Source: ECE. Proceedings of Seminar on Management, Maintenance and Modernisation of Housing, Warsaw. United Nations, 1969 and Building Maintenance Management[24].

1. Lowest acceptable standard during time of use. The upward curve of the line symbolises change in the level of requirements.

2. Optimal standard during time of use; the area between lines 1 and 2 is the accepted standard area.

3. Element with immutable quality, i.e. horizontal line.

4. Rapid wear leading to maintenance during time of use, e.g. wall-paper.

5. Slow, undramatic change during time of use. Can be compensated by providing a higher standard from the beginning.

6. Dramatic failure calling for immediate action, e.g. leakage in water or sanitary installations.

To explain the form of the lapse time, consider the following three points in series in a time continuum which represent significant events in the life span of a defect and these are represented diagrammatically by Fig 5.4.1.

a) θ, the time of origin of the defect.

b) I, the epoch at which the defect is identified.

c) R, the time at which the defect is repaired beyond which time, due to unacceptable consequences the repair cannot be delayed.

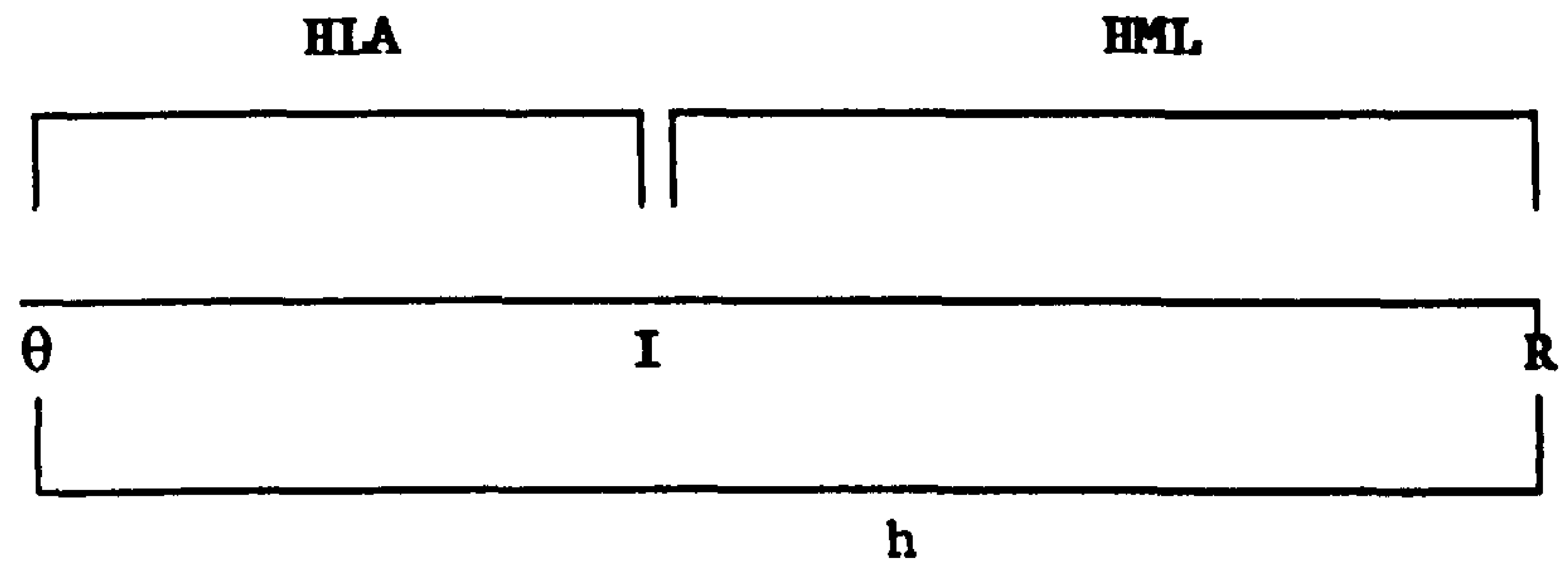


Fig 5.4.1

At the epoch I be it a breakdown situation which is here taken as analogous to a response repair; or be it at some form of inspection the following questions are asked:

a) How Long Ago (HLA) did this defect arise, i.e. when was the approximate date of origin of the defect.

b) How Much Longer (HML) could the repair of this defect be reasonably delayed, without causing, say, hazard, hardship excessive repair costs and so on.

Hence the lapse time h is the interval (R - θ) or h = (HML + HLA). Central to the effectiveness of introducing an inspection system is that defects with measurable life spans quantified by lapse time h, may be identified at an inspection. Equally important is the fact that a defect could be repaired anywhere in interval h, given that knowledge of points θ and R is available. When a response maintenance service only is in operation the epoch I will be the only observable point on the time scale θ to R and unless a preinspection of the response repair is carried out, the maximum estimate for h, or HML, will be based on the repair category assigned by the maintenance clerk, which will, of course, be guided by the Authorities maintenance manual of typical repair types and associated classifications.

5.5 BUILDING A BASIC INSPECTION MODEL

Accepting that sufficient and appropriate data for the lapse time h can be generated, the hybrid inspection/response maintenance system cost per unit time model is developed for the simplest case and may be characterised by the following assumptions:

a) Inspections take place at regular intervals of T time units, cost I units and take t time units to complete, with $t << T$.

b) Inspections are perfect.

c) Defects noticed at an inspection are repaired within the inspection interval T.

d) The time of origin of a defect, θ, is independent of its lapse time h.

e) The times of origin of defects are uniformly distributed over time with defects occurring at a uniform rate of k per unit time.

f) There is no correlation between h and the cost of repairs.

g) A probability density function of the lapse time h is known.

Assumption (a) is easy to accept. Skinner[2] suggests inspection times of the order of 3 hours or approximately 1½ hours per dwelling depending the scale of inspection routines. Additionally the housing stock could be inspected in sub divided groups of dwellings with teams of inspectors being available to complete inspections quickly.

Assumption (b) requires that if a defect exists it will be spotted at an inspection. This may be regarded as a little optimistic bearing in mind that wide range of building types and constructional forms likely to exist. Buildings may be low rise, low rise walk up or high rise which arguably make some aspect of fabric difficult to inspect. Likewise, solum and some roof spaces or coverings could prove awkward. The scale of the inspection system employed needs to be considered and it is unlikely that it would take the form required for a house condition survey. However the idea of non-perfect inspections has been investigated and modelled for industrial plant by Christer and Waller[25] and could possibly be adapted if a more sophisticated approach was required.

It is worth acknowledging that NOT ALL PROPERTIES need be subject to inspection. For example, there may be sections of the stock which are particularly problematic in terms of age, design, socio-economic grouping, member influences and so on, the these factors may combine to identify Target Areas which could benefit most from regular inspections.

Assumption (c) is satisfied if defects identified at one inspection do not recur at subsequent inspections. Obviously this is satisfied if defects are repaired before the next inspection, and would be equally valid for those defects purposefully re-allocated to say, a longer term planned maintenance programme since programmed repairs should generate cluster benefits in terms of cost savings.

Assumptions (d) and (e) are more difficult to justify. No real meaningful data exists to verify the epoch θ, since the component part of the lapse time h, namely HLA, was the most difficult subjective assessment to obtain and was not at any rate obtained for non response repairs. Essentially assumption (e) requires that defects arise uniformly over the year (say) and smoothes out seasonality which may be regarded with scepticism. However with building maintenance a large number of recurring repairs can be identified for both internal and external fabric and components and Audit Report[8] refers to The National Schedule of Rates which contains 222 items for internal plumbing alone. This taken with the many influences which interact to create building defects, then a reasonable scatter of time of origin of defects is quite plausible. Hence an estimate of the anticipated number of defects arising in the interval T is kT, which applies to steady state conditions in property occupied over the period of an ongoing cyclical inspection programme.

Assumption (f) requires that lapse time h is independent of the cost of repairs for both response and inspection repairs.

The situation now in summary is that defects originate at random points in time and have a life span of, duration h. Defects are repaired either as a consequence of a response repair service or as an inspection repair, where the interval between inspections is T time units. It follows that as the inspection interval T increases the probability of a defect being repaired under a response system increases.

To model the situation it is necessary to estimate the proportion of defects identified as Response Repairs, which are here considered analogous to breakdown repairs in that defects may be rectified as a consequence of a DEMAND and matter of policy as distinct from NECESSITY.

5.6 PROPORTION OF RESPONSIVE REPAIRS AS A FUNCTION OF INSPECTION CYCLE T

The proportion of defects occurring as response repairs and the impact on downtime is modelled along the same lines as that for breakdown repairs in mechanical plant by Christer and Waller[56] as follows. When inspections take place at regular intervals T time units apart, any defect with a lapse time $h > T$ will always be noticed at an inspection. Referring to Fig 5.6, now consider those defects with lapse time $h < T$.

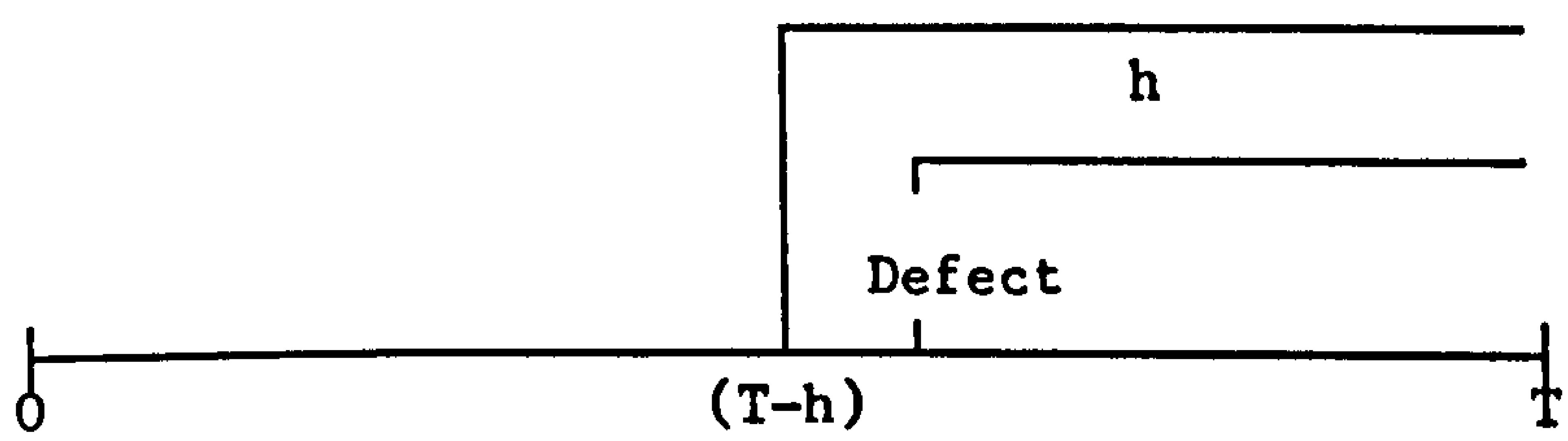


Fig 5.6

For a defect arising in the interval (h, h + dh) somewhere between inspections (O, T), the probability of this event is f(h)dh. Now if the time at which this defect arose, i.e. its point of origin θ, is in the period (O, T - h), it should be identified, reported and rectified as a response repair. The probability of the repair arising before the instant (T-h), accepting that defects will arise in the period (O<T - h), is $T\text{-}h/_T$. Therefore the probability that the defect is rectified as a response repair and has a lapse time in the interval (h, h + dh) is,

$$\frac{T - h}{T} f(h)\, dh$$

summing over all possible values of h, then the probability of a defect arising as a response (breakdown) repair, given by $b_{(T)}$ is,

$$b_{(T)} = \int_{h=0}^{T} \frac{T - h}{T} f(h)\, dh \qquad (1)$$

Correspondingly, the probability that the defect is identified as an inspection repair is given by $(1 - b_{(T)}) = i_{(T)}$ is

$$i_{(T)} = 1 - \int_{h=0}^{T} \frac{T-h}{T} f(h)\,dh \qquad (2)$$

5.6.1 A Cost Per Unit Time Model

By introducing an inspection/response system operating costs must increase with time due to the additional cost of inspections unless benefits accrue which offset such inspection costs. To develop a model the following notation is identified

C_r	=	average cost of a response repair
C_i	=	average cost of an inspection repair
k	=	arrival rate at which defects arise
I	=	cost of inspection
T	=	inspection interval
$b_{(T)}$	=	probability of the defect being repaired under a response (breakdown) system
$C_{(T)}$	=	cost of operating the system per unit time
B	=	a scale factor

Ideally we would expect inspection repairs to be less costly than response repairs. The rationale for this was explained in section 5.3. Therefore inspection repairs are expressed as a function of response repair thus:

$$C_i = BC_r$$

Where B may be a value in the range $0.5 < B \leq 1$.

Hence an expression for the operating cost per unit time is given by:

$$C_{(T)} = \frac{1}{T}\left[kT(C_r b_{(T)} + BC_r(1 - b_{(T)})) + I \right] \qquad (3)$$

$$C_{(T)} = k[(C_r b_{(T)} + BC_r(1 - b_{(T)})] + \frac{I}{T} \qquad (4)$$

5.6.2 Distribution of Lapse Time

The initial shape of the distribution of lapse time may be an indicator of the economic viability of an inspection system and it may also be possible to fit a p.d.f. f(h), to the statistical frequency distribution F(h). Christer and Waller[56] suggest that a negative exponential distribution is possible for lapse times; there referred to as delay times; for mechanical plant. In this eventuality an expression for $C_{(T)}$ may be derived and this is given in Appendix 4. With respect to the shape of this distribution an increasing mean value of lapse time may indicate greater inspection potential. This however remains to be tested.

5.6.3 Switching to an Inspection/Response System

Making the decision to switch over and introduce inspections is a difficult one for management. However if judged cost effective and any of the aforementioned additional benefits accrue from inspections, then such action can only be regarded as an improvement on existing procedures.

A daunting prospect for some Authorities may be a requirement to address the surge of repairs identified at the first inspection and possibly accepting the harsh reality of exposing hitherto poorly maintained stock, a consequence of which will be the financial committment required to re-instate the stock to an acceptably maintained standard. As estimate for the number of repairs, M say, in the initial surge[4] is given by,

$$M = \int_0^\infty kh\, f(h)\, dh = kh \qquad (5)$$

where h is the mean value of the lapse time h. When an inspection system has been in operation for a period of time, and for established properties, steady state conditions maybe assumed and the expected number of response repairs $N_{(T)}$ arising during the course of the inspection interval T, is given by:

$$N_{(T)} = kTb_{(T)} = k \int_{h=0}^{T} (T - h)\, f(h)\, dh \qquad (6)$$

Although no attempt is made to obtain estimates of M and $N_{(T)}$ it is important to acknowledge the likelihood of an initial surge of repairs and a possible reduction in the number of response repairs. Such eventualities will impact on management decision making. It is likely that repairs identified by inspections will be to some extent programmable. Repairs requiring more immediate attention may significantly increase manpower requirements similar to that caused by backlogs of repairs and any additional workforce may be anticipated using the techniques developed in Chapter 4.

5.7 THE EMPIRICAL STUDY OF LAPSE TIMES

5.7.1 Data Collection of Lapse Time h

Due to a resourcing problem caused by cash, time and control constraints it was not possible to make personal subjective estimates of the lapse time for the range of defects necessary to construct a representative statistical distribution. It was therefore necessary that such estimates be determined by District Council housing inspectors, and to this end, visits were made to each of the eleven Areas comprising the District as it was divided at that time for management control purposes. During these and other visits in the company of designated inspectors the housing stock was, in general, reviewed and an appreciation of the nature of the problems encountered by maintenance staff was acquired.

After much counselling, three inspectors agreed to participate in the data collection scheme; support regarded as a bonus bearing in mind the pressure to which the entire maintenance system was being subjected. The repairs to be sampled were therefore drawn from three areas, seven, eight and eleven. The housing stock in these Areas represented fairly typical council dwellings being largely low rise four in a block and built using traditional materials and construction techniques. The properties were well established older dwellings and had not be subject to any major planned maintenance or refurbishment programs. Plates 1 to 3 show typical examples of the form and construction of the dwellings under discussion.

5.7.2 Formatting the Data

It is now required to collect and group sufficient estimates of h to produce a statistical distribution function F(h) from which the proportions of response and inspection repairs may be derived.

To simplify the data collection by tradesman or inspectors, lapse times were selected from a set of discrete, selected time intervals, instead of the supposed continuum. The discrete time scales are approximated to a continuum as necessary. The approach was considered to be less confusing for the data collectors.

The discrete time scales for HLA and HML selected for this study are given in the data collection proforma shown in Exhibit 5.7 and reproduced in Appendix 4 together with guidelines for filling in the proforma.

5.7.3 Sampling Procedures

In the first instance it was agreed to target response repairs and to use a random sampling technique to establish a 10% data base. Here we acknowledge the limitations of such a sample of defects in that they are Tenant generated and take no account of other defects ignored or unnoticed by the Tenant. It must be stressed that it was anticipated that future surveys would be mounted that would reveal the spectrum of defects necessary to yield a representative sample of lapse times which would produce a realistic shape for the statistical distribution, F(h).

On receipt of a repair request, the maintenance clerk listed repairs in order of arrival in a notebook day by day. Maintenance inspectors then sampled from the daily job arrivals using two digits random numbers taken from tables provided until the approximate ten percent sample, or greater, was achieved. As soon as possible thereafter, each repair was pre-repair inspected or where necessary post-repair inspected as could be the case for some emergency repairs; and the aforementioned (Section 5.7.2) maintenance proforma completed. The survey was conducted over the period 28/1/85 until 3/4/85 at which point it was prematurely halted due to a resourcing problem. The timing of the data collection exercise was not significant and was simply enforced by the availability of resources.

PLATE 1
AREA 7

PLATE 2
AREA 8

PLATE 3
AREA 11

CONFIDENTIAL

UNIVERSITY OF STRATHCLYDE

DEPARTMENT OF OPERATIONAL RESEARCH/STRATHKELVIN DISTRICT COUNCIL

HOUSING MAINTENANCE SURVEY

1 Address .... Area .... House Type ....

.... Repair Type | Emergency | Non-Emergency |

2 Date of receipt of Repair .... Date of Completion of Repair ....

3 Brief description of type and nature of defect (seen Note a).

4 Please indicate TRADE CATEGORY(IES) of Repair.

JOINER	PLUMBER	ELECTRICIAN	GLAZIER	SLATER	PLASTERER	BRICKLAYER	SQUAD

OTHERS

Please indicate ....

5 How does your description of the defect correspond to that given by tenant?

EXACTLY	CLOSELY	NOT VERY CLOSELY	NOT AT ALL

6 Into which PRIORITY CATEGORY would you place this repair request? (see Note b)

EMERGENCY	URGENT	NORMAL	LONG TERM

7 In your opinion how much longer could the repair be delayed? (see Note C)

Not at all	1 day	3 - 5 days	1 week	2 - 3 weeks	1 month	3 months	6 months	more (indicate)

8 What, in your opinion, caused this fault to occur?

POOR DESIGN	
POOR WORKMANSHIP	
CHOICE OF MATERIAL	
LACK OF MAINTENANCE	
FAIR WEAR AND TEAR	

VANDALISM	
ACCIDENT	
TENANT MISUSE	
WIND	
OTHERS (PLEASE INDICATE)	

9 Could this repair have been PREVENTED? | YES | NO |

If 'YES' please indicate HOW.

10 Could this defect have been noticed beforehand at an inspection? | YES | NO |

Exhibit 5.7

MAINTENANCE PROFORMA

11 If answer to Q9 is 'YES' how long ago could this defect have been reasonably expected to be noticed at an inspection? (see note d).

1 day	1 day	2 – 5 days	1 week	2 weeks	4 weeks	2 months	4 months	6 months	more

12 What are the relevant costs relating to the repair? (see Note e)

GUESTIMATED ie Defect Unseen	$
ESTIMATED ie Defect Inspected	$
ACTUAL ie Contractor's Cost	$

13 If the repair was left until the delayed time estimated in Q7, please give an estimate of any ADDITIONAL COST which might be incurred.

ADDITIONAL COST [$]

14 If the defect HAD BEEN REPAIRED near the inspection time estimated in Q10, please give an estimate of any COST SAVINGS which might have been made.

COST SAVINGS [$]

15 Into which CATEGORY would you place this repair?

REPLACEMENT	REPAIR	COMBINATION OF BOTH

16 Please indicate ACCESS availability.

[EXTERNAL INSPECTION] [INTERNAL INSPECTION]

17 Who, in your opinion, should be responsible for effecting this repair? (See Note f)

[A] [B]

18 Any general comments?

DATE .... SIGNED ....

Exhibit 5.7 (cont)

5.7.4 Lapse Time Data Analysis

A total of 195 sample values of lapse time h were collected representing a range of defects reported under a response system and the associated corrective trades. Some of the defects recorded will not, due to instantaneous failure, have any inspection potential and the maintenance proforma used during data collection attempts to establish scope for inspections, however subjectively. At this stage no attempt is made to amend the data as collected and all defects are incorporated in the initial demonstration of the model to emphasis the influence of any subsequent censoring of the raw data. The frequency distribution of these lapse times is shown in Exhibit 5.7.1 and tables 5.7.1 and 5.7.11 show the statistical analysis and chi-square test. Clearly no correlation exists between the collected data and a negative exponential distribution. In any case an initial inspection of the shape of the distribution for h rendered it suspect as a candidate which might yield a cost effective inspection system. However, it is worth noting that near the end of the data collecting exercise the local authority ordered a cessation of the normal response service due to a rapidly contracting revenue budget, and introduced an emergency service only which lasted until the start of the new financial year. These circumstances brought to a halt the data collection exercise and were to herald the beginning of an era during which major changes in management structure and general organisational procedures would ensue.

During the interval covered by the emergency repairs service, the maintenance inspectors were ordered to survey the housing stock and inspect non-emergency repairs, to establish, in very general terms, the condition of the building fabric. During this survey, which was outwith the aforegoing data collection exercise, one of the inspectors involved in that study, itemized repairs identified at inspections which would in time have been reported under a response repairs maintenance service. Many of these repairs were judged to be in the "routine" category. The nature of these repairs was such that lapse times of the order of many weeks could be identified and the quantity of repairs large enough to significantly change the shape of the lapse time distribution, by producing more repairs with an inspection potential in the high lapse time region of the distribution.

However, no formal lapse times were assigned to these repairs by the inspectors and are not included as an attempt to amend the existing formal data. This supporting data was convincing and encouraging and as a consequence several subsequent attempts were made to renew the data collecting exercises but without success. The latest attempt, and the one which may have been most fruitful, was made during a housing attribute survey in late 1988.

We are therefore, at this stage only able to demonstrate the model using available data, acknowledging its restricted nature but aware of the potential for development.

5.7.5 The Cost per Unit Time Model

As a consequence of the shape of the distribution of lapse time h and the unconvincing fit to a p.d.f. of the negative exponential form, equation 4 was applied, that is:

$$C_{(T)} = K\,[C_r b_{(T)} + BC_r\,(1 - b_{(T)})] + \frac{I}{T}$$

This equation may be input onto a spreadsheet and modelled for a range of stipulated values of the inspection interval T, and for values of B in the range $0.5 < B \leq 1$.

At the time of the original data collection exercise the average cost of response repairs executed by private contractors and the DLO were £58.97 and £57.67 respectively. The average cost of response repairs was therefore taken as £58.00

During the financial year 84/85 the total number of response repairs completed was 33,505, a considerable increase from the previous years, this being the root cause of the budget capacity being exceeded. This gives an average weekly arrival rate of 644 repairs for all eleven areas. At the time of the data collection exercise area, 7, 8 and 11 contained 1075, 985 and 1252 dwellings respectively, a total of 3312 out of the total housing stock of 10,447 houses.

The data collection period extended over 9½ weeks during which 195 samples were collected representing an approximate 10% sample. From these figures the approximate average rate of defect reporting is determined as 205 per week for all three areas. The average reporting rate over the year was 644 per week for all dwellings and taking a proportion of this based on number of dwellings in the three areas investigated gives a reporting rate of 204 per week. Therefore the estimate for k used in Equation 4 is taken as 200 repairs per week. However, the quantity of real interest and the correct estimate for k should be based on the time of origin of the defects both reported and unreported, since only response repairs are considered and, acknowledging that the time of origin of defect occurrence could not be estimated with sufficient accuracy the estimation for k is basically flawed. The cost of inspections is estimated from the annual salary of an Inspector, taken as £12500, and an inspection time per dwelling of half an hour, this duration being suggested by an experienced Inspector. Therefore the cost of inspecting all 3312 houses in the model is taken as £9950. This cost is likely to be an underestimate since inspection times suggested by Skinner were 3 hours and 1½ hours depending on the scale of the inspections.

Therefore in equation 4 we have

$C_r = £58.00$

$C_i = B(£58.00)$

$K =$ 200 defects per week

$I = £9950$

The results of the modelling process are shown in exhibit 5.7.11 with numerical values given in table 5.7.12 and 5.7.13. The spreadsheet shown as table 5.7.12 was derived from the frequency tabulation for exhibit 5.7.1 given in table 5.7.1 and the expansion of the expression for $b_{(T)}$ as follows

$$b_{(T)} = \int_0^T \frac{T - h}{T} f(h)\,dh$$

$$b_{(T)} = \int_0^T f(h)\,dh - \frac{1}{T} \int_0^T hf(h)\,dh$$

Columns three and four of the spreadsheet show respectively the emprical values for

$$\int_0^T f(h)\,dh \quad \text{and} \quad \frac{1}{T} \int_0^T hf(h)\,dh$$

From the relationships developed between $C_{(T)}$ and T shown in summary in table 5.7.13, observed minimum values for $C_{(T)}$ occur at weeks 26, 18, 12 and 10 for values of B equal to 0.8, 0.7, 0.6 and 0.5 respectively. Achieving a 50% cost saving, ie B = 0.5, by clustering of inspection generated repairs seems optimistic. However 20% to 30% savings may be possible. It is therefore reasonable to suggest that the cost per unit time model has potential. At this stage we must recall the limitations of the data inputs as previously identified and the need to censor data for the reasons discussed below.

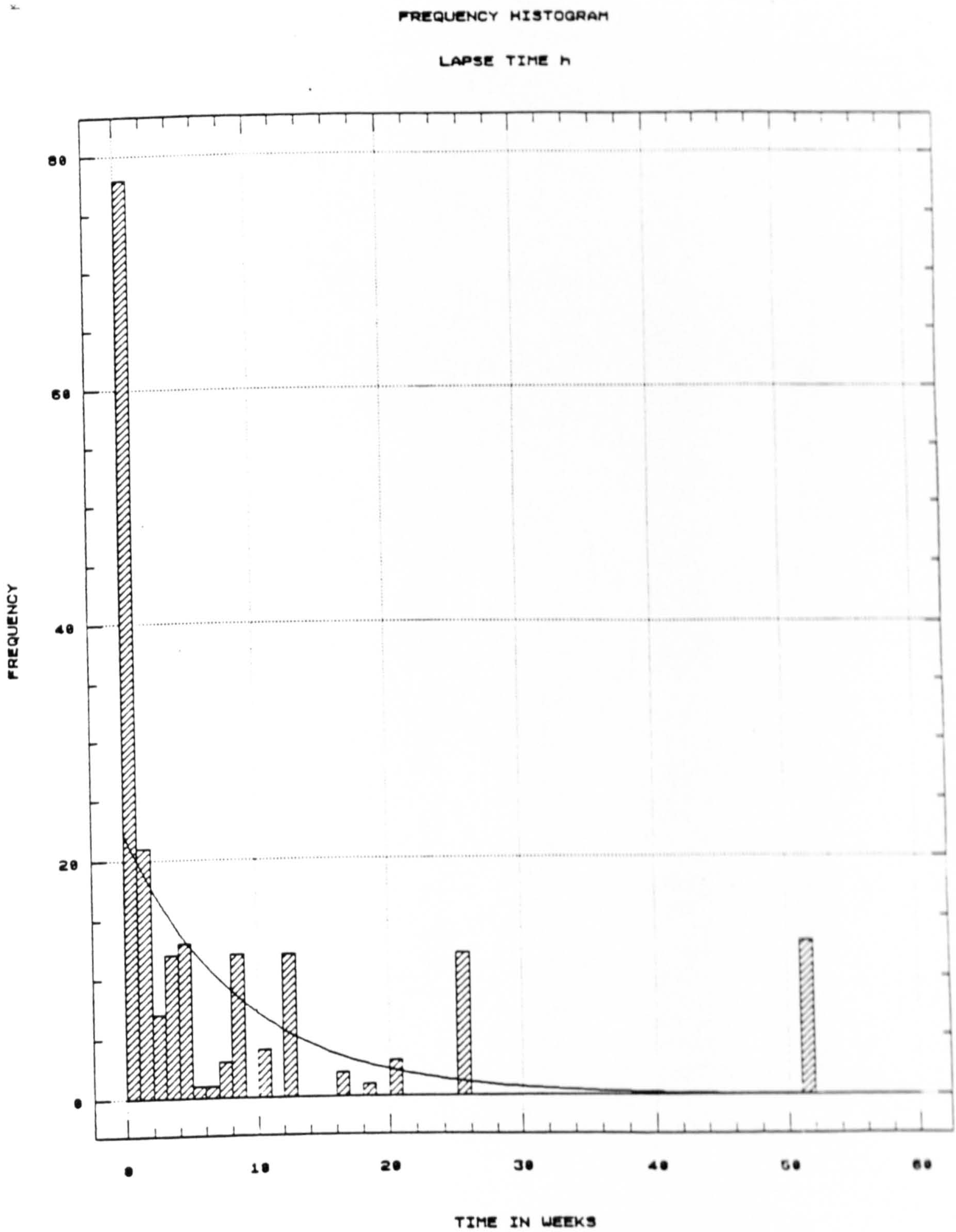


Exhibit 5.7.1
Frequency Distribution of Lapse Times
Areas 7,8 and 11

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.00000	0	.000
1	.00	1.00	.500	78	.40000	78	.400
2	1.00	2.00	1.500	21	.10769	99	.508
3	2.00	3.00	2.500	7	.03590	106	.544
4	3.00	4.00	3.500	12	.06154	118	.605
5	4.00	5.00	4.500	13	.06667	131	.672
6	5.00	6.00	5.500	1	.00513	132	.677
7	6.00	7.00	6.500	1	.00513	133	.682
8	7.00	8.00	7.500	3	.01538	136	.697
9	8.00	9.00	8.500	12	.06154	148	.759
10	9.00	10.00	9.500	0	.00000	148	.759
11	10.00	11.00	10.500	4	.02051	152	.779
12	11.00	12.00	11.500	0	.00000	152	.779
13	12.00	13.00	12.500	12	.06154	164	.841
14	13.00	14.00	13.500	0	.00000	164	.841
15	14.00	15.00	14.500	0	.00000	164	.841
16	15.00	16.00	15.500	0	.00000	164	.841
17	16.00	17.00	16.500	2	.01026	166	.851
18	17.00	18.00	17.500	0	.00000	166	.851
19	18.00	19.00	18.500	1	.00513	167	.856
20	19.00	20.00	19.500	0	.00000	167	.856
21	20.00	21.00	20.500	3	.01538	170	.872
22	21.00	22.00	21.500	0	.00000	170	.872
23	22.00	23.00	22.500	0	.00000	170	.872
24	23.00	24.00	23.500	0	.00000	170	.872
25	24.00	25.00	24.500	0	.00000	170	.872
26	25.00	26.00	25.500	12	.06154	182	.933
27	26.00	27.00	26.500	0	.00000	182	.933
28	27.00	28.00	27.500	0	.00000	182	.933
29	28.00	29.00	28.500	0	.00000	182	.933
30	29.00	30.00	29.500	0	.00000	182	.933
31	30.00	31.00	30.500	0	.00000	182	.933
32	31.00	32.00	31.500	0	.00000	182	.933
33	32.00	33.00	32.500	0	.00000	182	.933
34	33.00	34.00	33.500	0	.00000	182	.933
35	34.00	35.00	34.500	0	.00000	182	.933
36	35.00	36.00	35.500	0	.00000	182	.933
37	36.00	37.00	36.500	0	.00000	182	.933
38	37.00	38.00	37.500	0	.00000	182	.933
39	38.00	39.00	38.500	0	.00000	182	.933
40	39.00	40.00	39.500	0	.00000	182	.933
41	40.00	41.00	40.500	0	.00000	182	.933

Mean = 8.73333 Standard Deviation = 13.4617 Median = 2

Table 5.7.1

Statistical Properties of Lapse Time Distribution

Areas 7,8 and 11

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
42	41.00	42.00	41.500	0	.00000	182	.933
43	42.00	43.00	42.500	0	.00000	182	.933
44	43.00	44.00	43.500	0	.00000	182	.933
45	44.00	45.00	44.500	0	.00000	182	.933
46	45.00	46.00	45.500	0	.00000	182	.933
47	46.00	47.00	46.500	0	.00000	182	.933
48	47.00	48.00	47.500	0	.00000	182	.933
49	48.00	49.00	48.500	0	.00000	182	.933
50	49.00	50.00	49.500	0	.00000	182	.933
51	50.00	51.00	50.500	0	.00000	182	.933
52	51.00	52.00	51.500	13	.06667	195	1.000
above	52.00			0	.00000	195	1.000

Mean = 8.73333   Standard Deviation = 13.4617   Median = 2

Table 5.7.1 Continued

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Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
	at or below	1.00	78	21.1	153.47488
	1.00	2.00	21	18.8	.25380
	2.00	3.00	7	16.8	5.69947
	3.00	4.00	12	15.0	.58703
	4.00	5.00	13	13.3	.00891
	5.00	6.00	1	11.9	9.98509
	6.00	7.00	1	10.6	8.70769
	7.00	8.00	3	9.5	4.41604
	8.00	9.00	12	8.4	1.50046
	9.00	10.00	0	7.5	7.52787
	10.00	11.00	4	6.7	1.09671
	11.00	12.00	0	6.0	5.98709
	12.00	13.00	12	5.3	8.30899
	13.00	15.00	0	9.0	9.00815
	15.00	17.00	2	7.2	3.72270
	17.00	19.00	1	5.7	3.87350
	19.00	22.00	3	6.4	1.83509
	22.00	26.00	12	5.8	6.72460
above	26.00		13	9.9	.94673

Chisquare = 233.665 with 17 d.f. Sig. level = 0

Table 5.7.11

Chisquare Test on Lapse Time Distribution

Areas 7,8 and 11

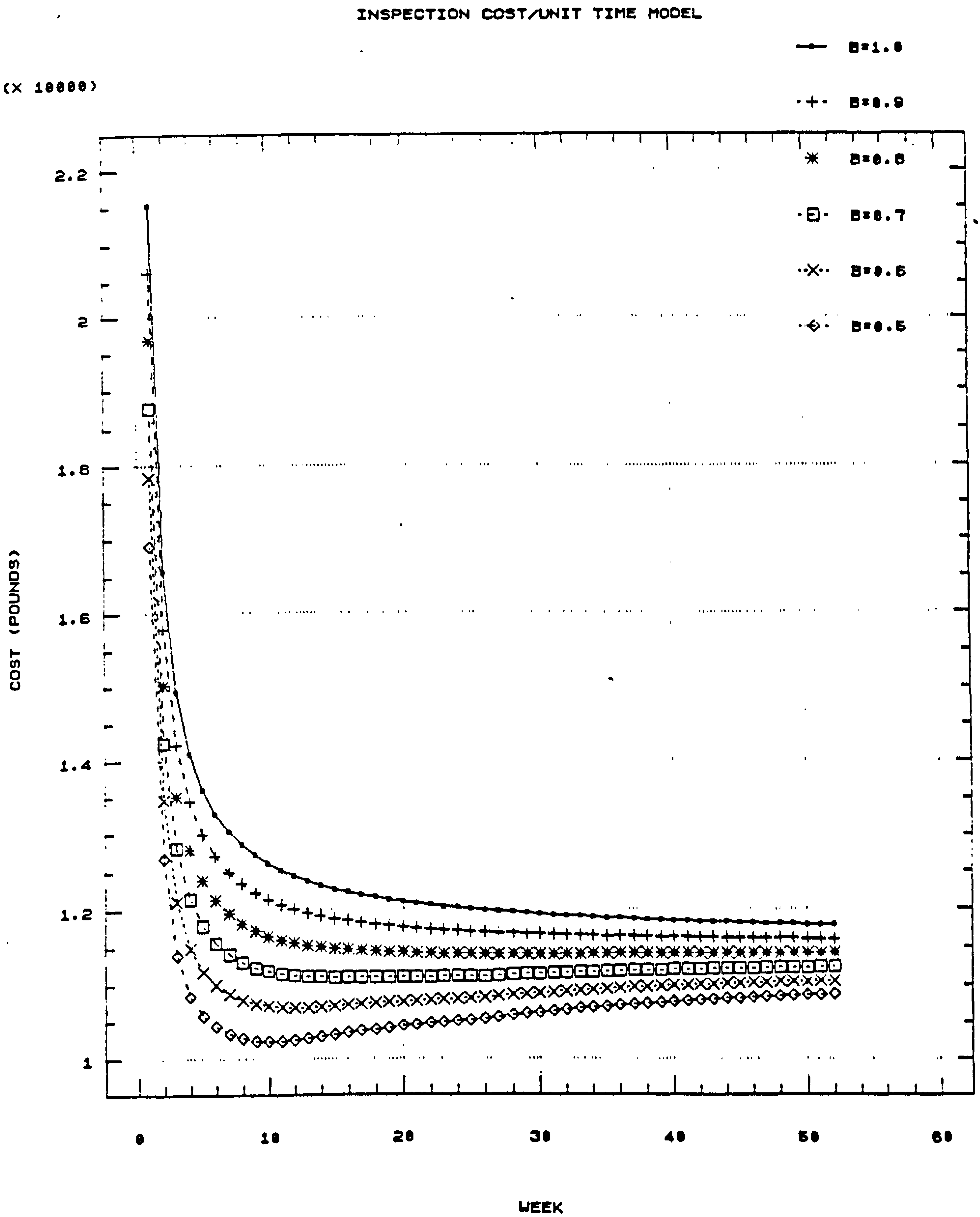

Exhibit 5.7.11
$C_{(T)}$ Cost per Unit Time Model
B = 1 to 0.5
Areas 7,8 and 11

The Economics of Inspection - Analysis of The Model

C(T) = K(Cr*b(T)+B*Cr*(1 -b(T))) + I/T = K*g(T) + I/T

AREAS 7, 8 and 11

K=200 Cr=58 B=1.0 I=9950

200 58 1 9950

Inspect. Period T	f(T	Sigma f(T)	Sigma (T-0.5)*f(T)	b(T)	K*g(T)	I/T	C(T)
1	.4	.4	.2	.200	11600.0	9950.0	21550.0
2	.108	.508	.362	.327	11600.0	4975.0	16575.0
3	.036	.544	.452	.393	11600.0	3316.7	14916.7
4	.062	.606	.669	.439	11600.0	2487.5	14087.5
5	.067	.673	.9705	.479	11600.0	1990.0	13590.0
6	.005	.678	.998	.512	11600.0	1658.3	13258.3
7	.005	.683	1.0305	.536	11600.0	1421.4	13021.4
8	.015	.698	1.143	.555	11600.0	1243.8	12843.8
9	.062	.76	1.67	.574	11600.0	1105.6	12705.6
10	0	.76	1.67	.593	11600.0	995.0	12595.0
11	.021	.781	1.8905	.609	11600.0	904.5	12504.5
12	0	.781	1.8905	.623	11600.0	829.2	12429.2
13	.062	.843	2.6655	.638	11600.0	765.4	12365.4
14	0	.843	2.6655	.653	11600.0	710.7	12310.7
15	0	.843	2.6655	.665	11600.0	663.3	12263.3
16	0	.843	2.6655	.676	11600.0	621.9	12221.9
17	.01	.853	2.8305	.687	11600.0	585.3	12185.3
18	0	.853	2.8305	.696	11600.0	552.8	12152.8
19	.005	.858	2.923	.704	11600.0	523.7	12123.7
20	0	.858	2.923	.712	11600.0	497.5	12097.5
21	.015	.873	3.2305	.719	11600.0	473.8	12073.8
22	0	.873	3.2305	.726	11600.0	452.3	12052.3
23	0	.873	3.2305	.733	11600.0	432.6	12032.6
24	0	.873	3.2305	.738	11600.0	414.6	12014.6
25	0	.873	3.2305	.744	11600.0	398.0	11998.0
26	.062	.935	4.8115	.750	11600.0	382.7	11982.7
27	0	.935	4.8115	.757	11600.0	368.5	11968.5
28	0	.935	4.8115	.763	11600.0	355.4	11955.4
29	0	.935	4.8115	.769	11600.0	343.1	11943.1
30	0	.935	4.8115	.775	11600.0	331.7	11931.7
31	0	.935	4.8115	.780	11600.0	321.0	11921.0
32	0	.935	4.8115	.785	11600.0	310.9	11910.9
33	0	.935	4.8115	.789	11600.0	301.5	11901.5
34	0	.935	4.8115	.793	11600.0	292.6	11892.6
35	0	.935	4.8115	.798	11600.0	284.3	11884.3
36	0	.935	4.8115	.801	11600.0	276.4	11876.4
37	0	.935	4.8115	.805	11600.0	268.9	11868.9
38	0	.935	4.8115	.808	11600.0	261.8	11861.8
39	0	.935	4.8115	.812	11600.0	255.1	11855.1
40	0	.935	4.8115	.815	11600.0	248.8	11848.8
41	0	.935	4.8115	.818	11600.0	242.7	11842.7
42	0	.935	4.8115	.820	11600.0	236.9	11836.9
43	0	.935	4.8115	.823	11600.0	231.4	11831.4
44	0	.935	4.8115	.826	11600.0	226.1	11826.1
45	0	.935	4.8115	.828	11600.0	221.1	11821.1
46	0	.935	4.8115	.830	11600.0	216.3	11816.3
47	0	.935	4.8115	.833	11600.0	211.7	11811.7
48	0	.935	4.8115	.835	11600.0	207.3	11807.3
49	0	.935	4.8115	.837	11600.0	203.1	11803.1
50	0	.935	4.8115	.839	11600.0	199.0	11799.0
51	0	.935	4.8115	.841	11600.0	195.1	11795.1
52	.0667	1.0017	8.24655	.843	11600.0	191.3	11791.3

Table 5.7.12

$C_{(T)}$ Numerical Analysis

B = 1

The Economics of Inspection - Analysis of The Model

C(T) = K(Cr*b(T)+B*Cr*(1 -b(T))) + I/T = K*g(T) + I/T

AREAS 7, 8 and 11

Inspect. Period T	B=1.0	B=0.9	B=0.8	B=0.7	B=0.6	B=0.5
1	21550.0	20622.0	19694.0	18766.0	17838.0	16910.0
2	16575.0	15794.3	15013.6	14233.0	13452.3	12671.6
3	14916.7	14212.9	13509.2	12805.5	12101.7	11398.0
4	14087.5	13436.5	12785.4	12134.4	11483.3	10832.3
5	13590.0	12985.5	12381.0	11776.6	11172.1	10567.6
6	13258.3	12691.9	12125.4	11558.9	10992.5	10426.0
7	13021.4	12482.9	11944.5	11406.0	10867.5	10329.0
8	12843.8	12327.7	11811.6	11295.6	10779.5	10263.5
9	12705.6	12211.9	11718.3	11224.6	10731.0	10237.3
10	12595.0	12122.9	11650.8	11178.6	10706.5	10234.4
11	12504.5	12051.1	11597.7	11144.3	10690.9	10237.5
12	12429.2	11992.4	11555.6	11118.8	10682.0	10245.2
13	12365.4	11945.4	11525.5	11105.5	10685.5	10265.6
14	12310.7	11907.7	11504.8	11101.8	10698.8	10295.8
15	12263.3	11875.1	11486.8	11098.6	10710.3	10322.1
16	12221.9	11846.5	11471.1	11095.8	10720.4	10345.0
17	12185.3	11821.6	11458.0	11094.3	10730.7	10367.0
18	12152.8	11799.8	11446.9	11094.0	10741.1	10388.1
19	12123.7	11780.5	11437.3	11094.2	10751.0	10407.8
20	12097.5	11763.2	11429.0	11094.7	10760.5	10426.2
21	12073.8	11748.0	11422.3	11096.5	10770.7	10445.0
22	12052.3	11734.6	11417.0	11099.3	10781.7	10464.0
23	12032.6	11722.4	11412.1	11101.9	10791.6	10481.4
24	12014.6	11711.1	11407.7	11104.2	10800.7	10497.3
25	11998.0	11700.8	11403.6	11106.4	10809.1	10511.9
26	11982.7	11692.6	11402.6	11112.5	10822.4	10532.4
27	11968.5	11686.4	11404.3	11122.2	10840.1	10557.9
28	11955.4	11680.6	11405.9	11131.2	10856.4	10581.7
29	11943.1	11675.2	11407.4	11139.5	10871.7	10603.8
30	11931.7	11670.2	11408.8	11147.3	10885.9	10624.4
31	11921.0	11665.5	11410.1	11154.6	10899.2	10643.8
32	11910.9	11661.1	11411.3	11161.5	10911.7	10661.9
33	11901.5	11657.0	11412.5	11167.9	10923.4	10678.9
34	11892.6	11653.1	11413.5	11174.0	10934.4	10694.9
35	11884.3	11649.4	11414.6	11179.7	10944.8	10710.0
36	11876.4	11646.0	11415.5	11185.1	10954.6	10724.2
37	11868.9	11642.7	11416.4	11190.2	10963.9	10737.7
38	11861.8	11639.6	11417.3	11195.0	10972.7	10750.5
39	11855.1	11636.6	11418.1	11199.6	10981.1	10762.6
40	11848.8	11633.8	11418.9	11203.9	10989.0	10774.1
41	11842.7	11631.2	11419.6	11208.1	10996.6	10785.0
42	11836.9	11628.6	11420.3	11212.0	11003.7	10795.5
43	11831.4	11626.2	11421.0	11215.8	11010.6	10805.4
44	11826.1	11623.9	11421.6	11219.4	11017.1	10814.9
45	11821.1	11621.7	11422.3	11222.8	11023.4	10824.0
46	11816.3	11619.6	11422.8	11226.1	11029.4	10832.6
47	11811.7	11617.6	11423.4	11229.2	11035.1	10840.9
48	11807.3	11615.6	11423.9	11232.3	11040.6	10848.9
49	11803.1	11613.8	11424.5	11235.1	11045.8	10856.5
50	11799.0	11612.0	11424.9	11237.9	11050.9	10863.9
51	11795.1	11610.3	11425.4	11240.6	11055.7	10870.9
52	11791.3	11609.4	11427.4	11245.4	11063.4	10881.4

Table 5.7.13

$C_{(T)}$ Numerical Analysis

B = 1 to 0.5 Summary

5.7.6 Data Review

From the data used to construct Exhibit 5.7.1 approximately forty per cent of all defects sampled were identified as having lapse times less than one week. This, together with the general form of the distribution could contribute to any lack of success of the modelling process when accurate inspection costs are input. Defects in this interval were therefore examined to check the accuracy of the assigned lapse times and the validity of any corresponding subjective assessment of inspection potential.

Scrutiny of the data, revealed that plumbing and electrical repairs constituted the bulk; approximately seventy five per cent; of repairs in this interval; as might be anticipated. In all instances, the brief repair descriptions and associated lapse times were judged to be in agreement. Typical of such repairs were; burst pipes, sink leak, wc choked, cistern handle broken, cooker switch broken, light fittings, socket switch, communial lights and so on. It was therefore reasonable to conclude that the data was robust and accurately reflective of the reality of the situation.

Similarly the assigned inspection potential for both plumberwork and electrical work were examined on an individual area basis and the results thus obtained are given below in Tables 5.7.14(a) and (b) respectively. From these results it is again reasonable to conclude that these trades have little inspection potential.

Plumberwork Table 5.7.14(a)

	INSPECTION POTENTIAL	
AREA	YES	NO
7	38 (17)%	62 (83)%
8	0%	100
11	29 (14)%	71 (86)%

Electricalwork Table 5.7.14(b)

AREA	INSPECTION POTENTIAL	
	YES	NO
7	24	76
8	0	100
11	25	75

One composite trade grouping referred to as OTHERS likewise yielded little inspection potential. This group included, heating engineer, gas board and grate builder.

Data summary sheets are given in Appendix 4 together with a detailed breakdown of plumberwork for Area 7.

It must be acknowledged that the lapse time data collected is a one off snap shot of a Response maintenance repair system and does not include those defects which existed at the time but remained unidentified or unreported by the Tenants.

5.7.7 Lapse Time Distribution By Area

Exhibits 5.7.12(a), (b) and (c) show the distribution of lapse times for each separate area. Here we attempt to expose any individual potential for the application of the inspection model and acknowledging the previously discussed data limitations.

Areas 7, 8 and 11 yielded the percentage of defects with lapse times less than one week of 39%, 52% and 32% respectively. For Area 11, approximately 50% of defects had lapse times of more than four weeks. For these reasons it was decided to test Area 11 only, separately, accepting that this area contained the largest housing stock yet generated fewest repair requests.

The frequency tabulation for Area 11 is given in Table 5.7.15.

The result of the modelling process again applying Equation 4 is shown in Exhibit 5.7.13 and the numerical values are given in Tables 5.7.16 and 5.7.17.

As with combined areas 7,8 and 11, minimum values for $C_{(T)}$ for Area 11 are observed in table 5.7.17. Weeks 16, 26, 27 and 36 exhibit minimum values for B equal to 0.5, 0.6, 0.7 and 0.8 respectively. A spreadsheet for $C_{(T)}$ for B = 1 is given in table 5.7.16 and was derived as explained earlier. Full results are given in Appendix 4, together with reproduced samples of typical completed maintenance proformas.

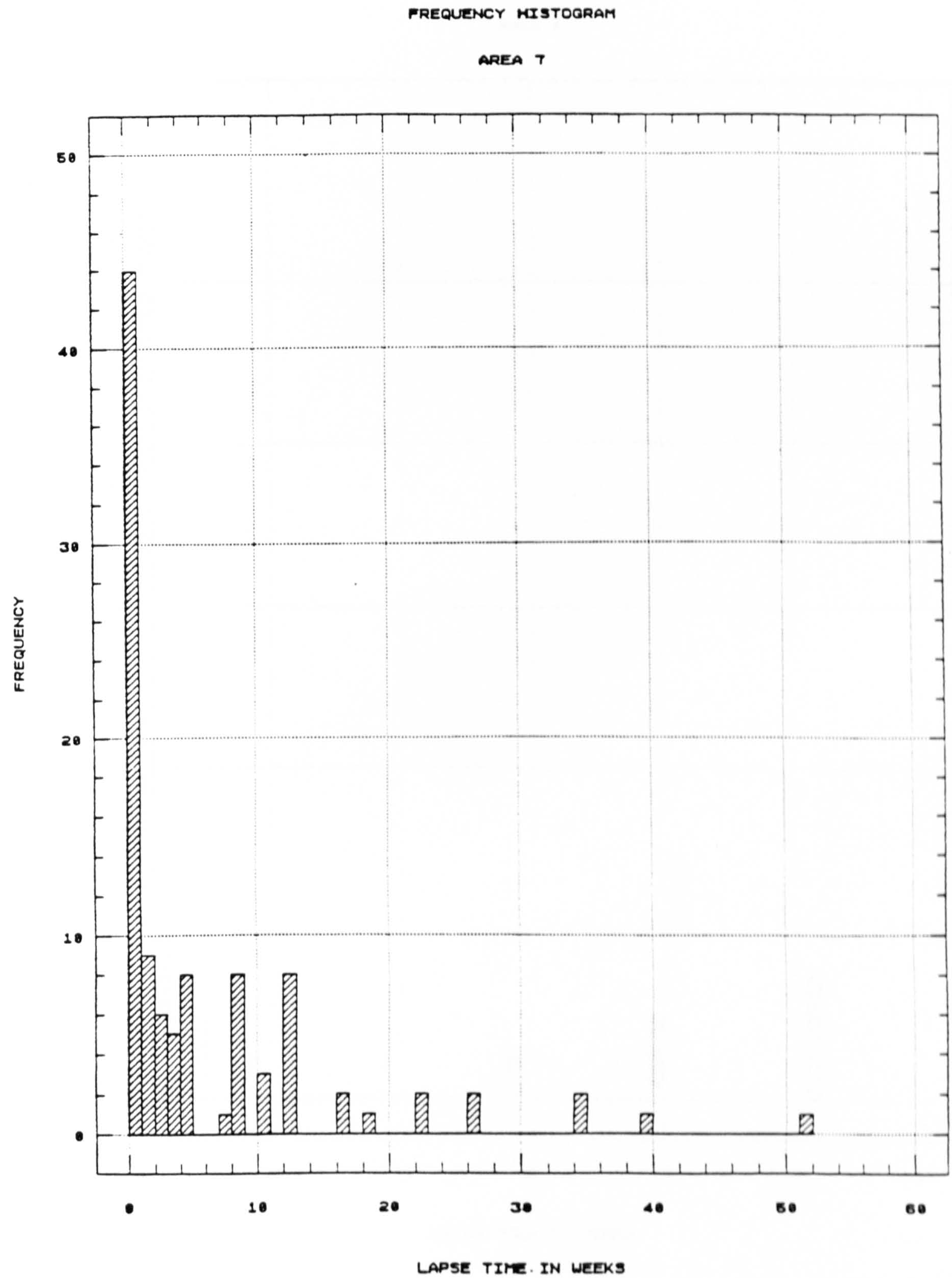

Exhibit 5.7.12(a)
Frequency Distribution of Lapse Times
Area 7

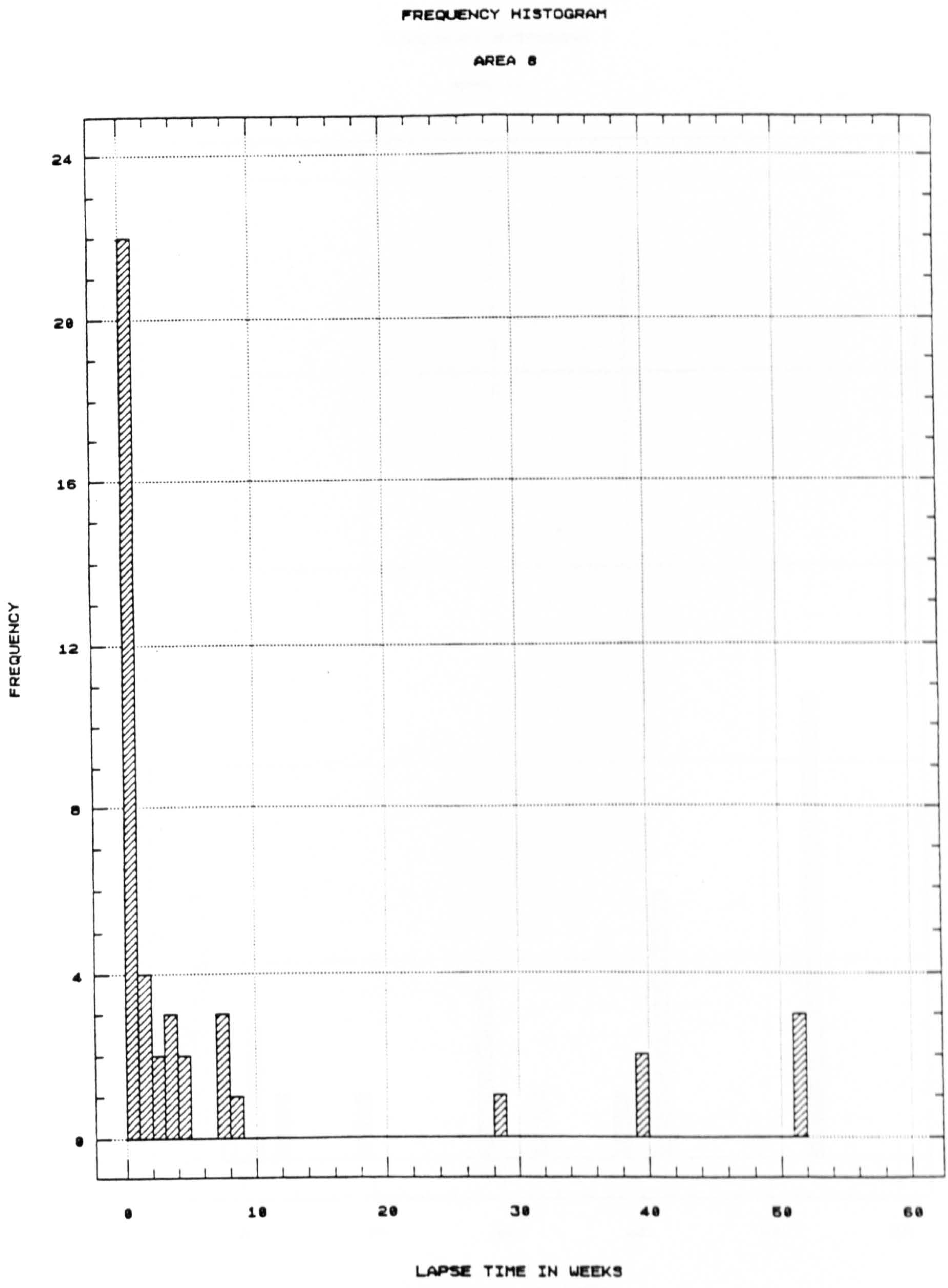

Exhibit 5.7.12(b)
Frequency Distribution of Lapse Times
Area 8

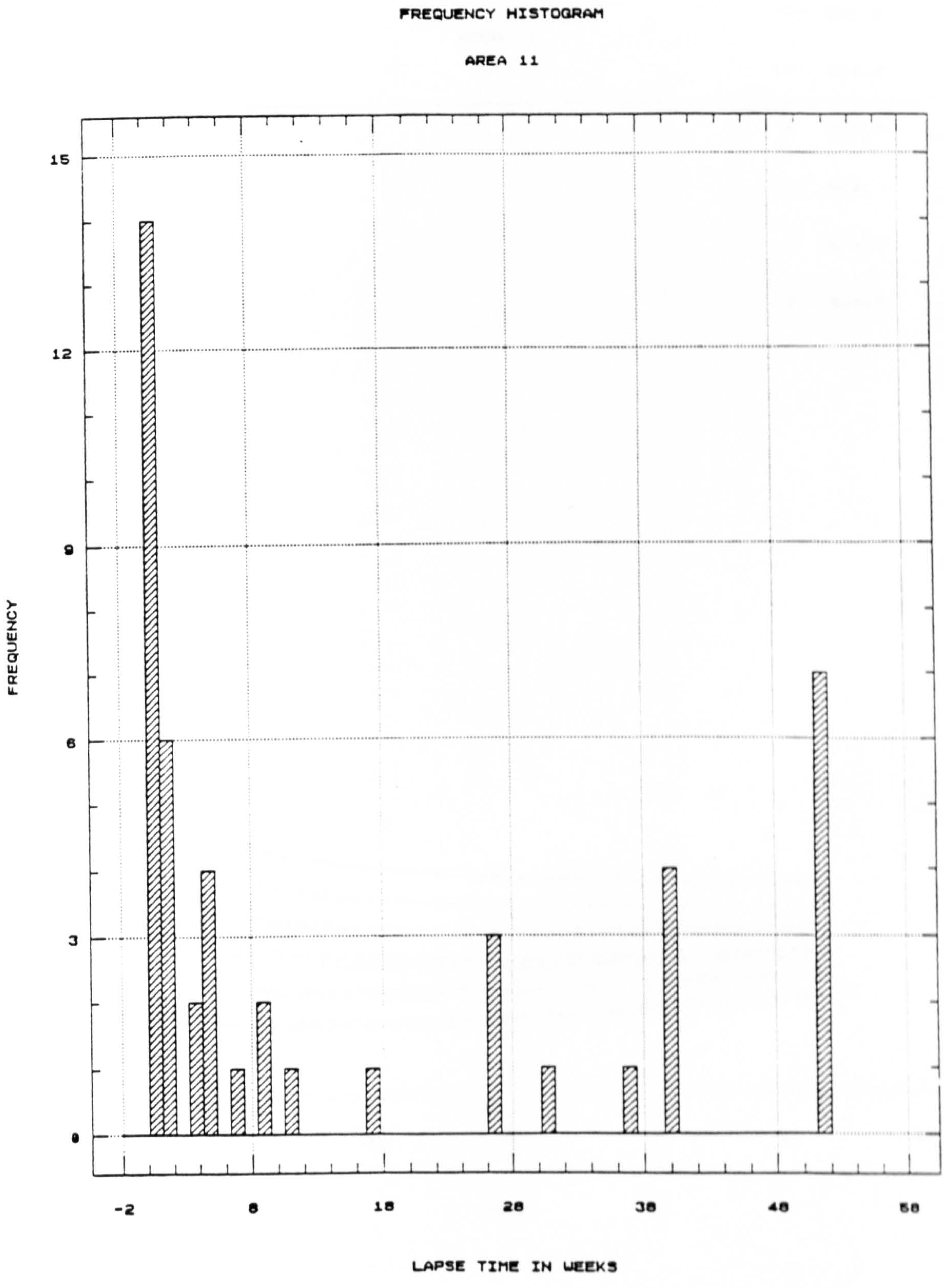

Exhibit 5.7.12(c)

Frequency Distribution of Lapse Times

Area 11

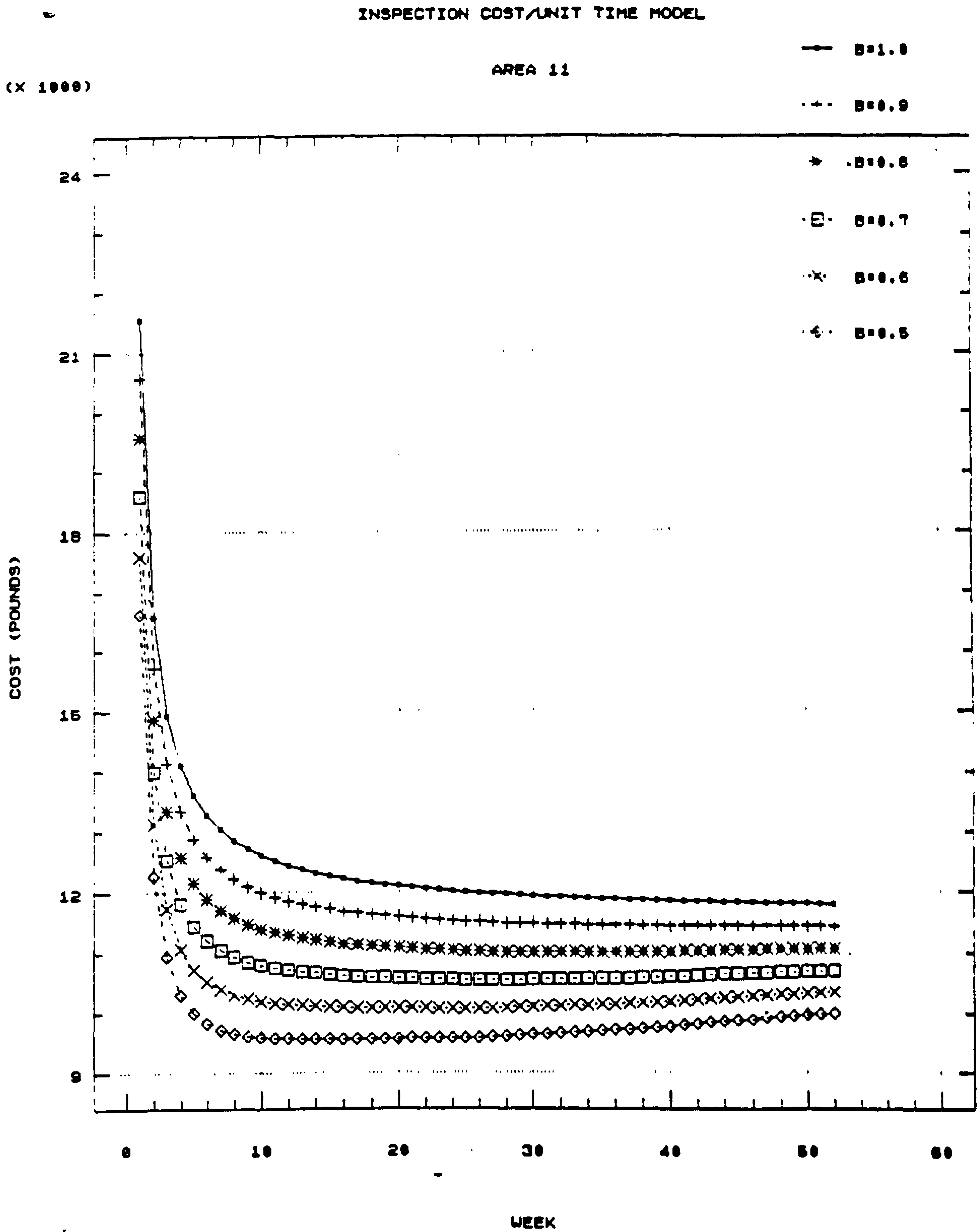

Exhibit 5.7.13

$C_{(T)}$ Cost per Unit Time Model

B = 1 to 0.5

Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.0000	0	.000
1	.00	1.00	.500	14	.2979	14	.298
2	1.00	2.00	1.500	6	.1277	20	.426
3	2.00	3.00	2.500	0	.0000	20	.426
4	3.00	4.00	3.500	2	.0426	22	.468
5	4.00	5.00	4.500	4	.0851	26	.553
6	5.00	6.00	5.500	0	.0000	26	.553
7	6.00	7.00	6.500	1	.0213	27	.574
8	7.00	8.00	7.500	0	.0000	27	.574
9	8.00	9.00	8.500	2	.0426	29	.617
10	9.00	10.00	9.500	0	.0000	29	.617
11	10.00	11.00	10.500	1	.0213	30	.638
12	11.00	12.00	11.500	0	.0000	30	.638
13	12.00	13.00	12.500	0	.0000	30	.638
14	13.00	14.00	13.500	0	.0000	30	.638
15	14.00	15.00	14.500	0	.0000	30	.638
16	15.00	16.00	15.500	0	.0000	30	.638
17	16.00	17.00	16.500	1	.0213	31	.660
18	17.00	18.00	17.500	0	.0000	31	.660
19	18.00	19.00	18.500	0	.0000	31	.660
20	19.00	20.00	19.500	0	.0000	31	.660
21	20.00	21.00	20.500	0	.0000	31	.660
22	21.00	22.00	21.500	0	.0000	31	.660
23	22.00	23.00	22.500	0	.0000	31	.660
24	23.00	24.00	23.500	0	.0000	31	.660
25	24.00	25.00	24.500	0	.0000	31	.660
26	25.00	26.00	25.500	0	.0000	31	.660
27	26.00	27.00	26.500	3	.0638	34	.723
28	27.00	28.00	27.500	0	.0000	34	.723
29	28.00	29.00	28.500	0	.0000	34	.723
30	29.00	30.00	29.500	0	.0000	34	.723
31	30.00	31.00	30.500	1	.0213	35	.745
32	31.00	32.00	31.500	0	.0000	35	.745
33	32.00	33.00	32.500	0	.0000	35	.745
34	33.00	34.00	33.500	0	.0000	35	.745
35	34.00	35.00	34.500	0	.0000	35	.745
36	35.00	36.00	35.500	0	.0000	35	.745
37	36.00	37.00	36.500	1	.0213	36	.766
38	37.00	38.00	37.500	0	.0000	36	.766
39	38.00	39.00	38.500	0	.0000	36	.766
40	39.00	40.00	39.500	4	.0851	40	.851
41	40.00	41.00	40.500	0	.0000	40	.851
42	41.00	42.00	41.500	0	.0000	40	.851
43	42.00	43.00	42.500	0	.0000	40	.851
44	43.00	44.00	43.500	0	.0000	40	.851
45	44.00	45.00	44.500	0	.0000	40	.851
46	45.00	46.00	45.500	0	.0000	40	.851
47	46.00	47.00	46.500	0	.0000	40	.851
48	47.00	48.00	47.500	0	.0000	40	.851
49	48.00	49.00	48.500	0	.0000	40	.851
50	49.00	50.00	49.500	0	.0000	40	.851
51	50.00	51.00	50.500	0	.0000	40	.851
52	51.00	52.00	51.500	7	.1489	47	1.000
above	52.00			0	.0000	47	1.000

Mean = 16.5957 Standard Deviation = 19.6111 Median = 5

Table 5.7.15

Frequency Tabulation

Area 11

The Economics of Inspection - Analysis of The Model AREA 11

C(T) = K(Cr*b(T)+B*Cr*(1 -b(T))) + I/T = K*g(T) + I/T

K=200 Cr=58 B=1.0 I=9950

200 58 1 9950

Inspect. Period T	f(T)	Sigma f(T)	Sigma (T-0.5)*f(T)	b(T)	K*g(T)	I/T	C(T)
1	.298	.298	.149	.149	11600.0	9950.0	21550.0
2	.128	.426	.341	.256	11600.0	4975.0	16575.0
3	0	.426	.341	.312	11600.0	3316.7	14916.7
4	.043	.469	.4915	.346	11600.0	2487.5	14087.5
5	.085	.554	.874	.379	11600.0	1990.0	13590.0
6	0	.554	.874	.408	11600.0	1658.3	13258.3
7	.021	.575	1.0105	.431	11600.0	1421.4	13021.4
8	0	.575	1.0105	.449	11600.0	1243.8	12843.8
9	.043	.618	1.376	.465	11600.0	1105.6	12705.6
10	0	.618	1.376	.480	11600.0	995.0	12595.0
11	.021	.639	1.5965	.494	11600.0	904.5	12504.5
12	0	.639	1.5965	.506	11600.0	829.2	12429.2
13	0	.639	1.5965	.516	11600.0	765.4	12365.4
14	0	.639	1.5965	.525	11600.0	710.7	12310.7
15	0	.639	1.5965	.533	11600.0	663.3	12263.3
16	0	.639	1.5965	.539	11600.0	621.9	12221.9
17	.021	.66	1.943	.546	11600.0	585.3	12185.3
18	0	.66	1.943	.552	11600.0	552.8	12152.8
19	0	.66	1.943	.558	11600.0	523.7	12123.7
20	0	.66	1.943	.563	11600.0	497.5	12097.5
21	0	.66	1.943	.567	11600.0	473.8	12073.8
22	0	.66	1.943	.572	11600.0	452.3	12052.3
23	0	.66	1.943	.576	11600.0	432.6	12032.6
24	0	.66	1.943	.579	11600.0	414.6	12014.6
25	0	.66	1.943	.582	11600.0	398.0	11998.0
26	0	.66	1.943	.585	11600.0	382.7	11982.7
27	.063	.723	3.6125	.589	11600.0	368.5	11968.5
28	0	.723	3.6125	.594	11600.0	355.4	11955.4
29	0	.723	3.6125	.598	11600.0	343.1	11943.1
30	0	.723	3.6125	.603	11600.0	331.7	11931.7
31	.021	.744	4.253	.607	11600.0	321.0	11921.0
32	0	.744	4.253	.611	11600.0	310.9	11910.9
33	0	.744	4.253	.615	11600.0	301.5	11901.5
34	0	.744	4.253	.619	11600.0	292.6	11892.6
35	0	.744	4.253	.622	11600.0	284.3	11884.3
36	0	.744	4.253	.626	11600.0	276.4	11876.4
37	.021	.765	5.0195	.629	11600.0	268.9	11868.9
38	0	.765	5.0195	.633	11600.0	261.8	11861.8
39	0	.765	5.0195	.636	11600.0	255.1	11855.1
40	.085	.85	8.377	.641	11600.0	248.8	11848.8
41	0	.85	8.377	.646	11600.0	242.7	11842.7
42	0	.85	8.377	.651	11600.0	236.9	11836.9
43	0	.85	8.377	.655	11600.0	231.4	11831.4
44	0	.85	8.377	.660	11600.0	226.1	11826.1
45	0	.85	8.377	.664	11600.0	221.1	11821.1
46	0	.85	8.377	.668	11600.0	216.3	11816.3
47	0	.85	8.377	.672	11600.0	211.7	11811.7
48	0	.85	8.377	.675	11600.0	207.3	11807.3
49	0	.85	8.377	.679	11600.0	203.1	11803.1
50	0	.85	8.377	.682	11600.0	199.0	11799.0
51	0	.85	8.377	.686	11600.0	195.1	11795.1
52	.1489	.9989	16.04535	.690	11600.0	191.3	11791.3

Table 5.7.16

C_T Numerical Analysis

B = 1

The Economics of Inspection - Analysis of The Model

C(T) = K(Cr*b(T)+B*Cr*(1 -b(T))) + I/T = K*g(T) + I/T

AREA 11

Inspect. Period T	B=1.0	B=0.9	B=0.8	B=0.7	B=0.6	B=0.5
1.0	21550.0	20562.8	19575.7	18588.5	17601.4	16614.2
2.0	16575.0	15711.4	14847.8	13984.1	13120.5	12256.9
3.0	14916.7	14119.0	13321.3	12523.6	11725.9	10928.2
4.0	14087.5	13329.0	12570.5	11812.0	11053.5	10295.0
5.0	13590.0	12869.9	12149.7	11429.6	10709.5	9989.4
6.0	13258.3	12572.0	11885.7	11199.3	10513.0	9826.7
7.0	13021.4	12361.0	11700.5	11040.1	10379.6	9719.2
8.0	12843.8	12204.2	11564.7	10925.2	10285.7	9646.1
9.0	12705.6	12085.1	11464.6	10844.1	10223.7	9603.2
10.0	12595.0	11992.3	11389.5	10786.8	10184.1	9581.3
11.0	12504.5	11917.4	11330.3	10743.2	10156.1	9569.0
12.0	12429.2	11856.1	11283.0	10709.9	10136.8	9563.7
13.0	12365.4	11804.2	11243.0	10681.7	10120.5	9559.3
14.0	12310.7	11759.7	11208.6	10657.6	10106.5	9555.5
15.0	12263.3	11721.1	11178.9	10636.7	10094.4	9552.2
16.0	12221.9	11687.4	11152.9	10618.4	10083.9	9549.3
17.0	12185.3	11658.3	11131.3	10604.4	10077.4	9550.4
18.0	12152.8	11633.2	11113.5	10593.9	10074.3	9554.7
19.0	12123.7	11610.7	11097.6	10584.6	10071.6	9558.6
20.0	12097.5	11590.4	11083.3	10576.2	10069.1	9562.0
21.0	12073.8	11572.1	11070.4	10568.6	10066.9	9565.2
22.0	12052.3	11555.4	11058.6	10561.7	10064.9	9568.0
23.0	12032.6	11540.2	11047.8	10555.4	10063.0	9570.6
24.0	12014.6	11526.3	11038.0	10549.6	10061.3	9573.0
25.0	11998.0	11513.4	11028.9	10544.3	10059.8	9575.2
26.0	11982.7	11501.6	11020.5	10539.4	10058.3	9577.3
27.0	11968.5	11492.0	11015.5	10538.9	10062.4	9585.9
28.0	11955.4	11484.4	11013.4	10542.4	10071.4	9600.5
29.0	11943.1	11477.3	11011.5	10545.6	10079.8	9614.0
30.0	11931.7	11470.7	11009.7	10548.7	10087.7	9626.7
31.0	11921.0	11464.9	11008.8	10552.7	10096.5	9640.4
32.0	11910.9	11459.8	11008.7	10557.5	10106.4	9655.3
33.0	11901.5	11455.1	11008.6	10562.1	10115.7	9669.2
34.0	11892.6	11450.6	11008.5	10566.5	10124.4	9682.3
35.0	11884.3	11446.4	11008.5	10570.5	10132.6	9694.7
36.0	11876.4	11442.4	11008.4	10574.4	10140.4	9706.4
37.0	11868.9	11439.0	11009.0	10579.0	10149.0	9719.1
38.0	11861.8	11436.0	11010.2	10584.4	10158.5	9732.7
39.0	11855.1	11433.2	11011.3	10589.4	10167.5	9745.6
40.0	11848.8	11431.8	11014.9	10598.0	10181.0	9764.1
41.0	11842.7	11431.7	11020.7	10609.7	10198.7	9787.6
42.0	11836.9	11431.5	11026.2	10620.8	10215.4	9810.1
43.0	11831.4	11431.4	11031.4	10631.4	10231.5	9831.5
44.0	11826.1	11431.3	11036.4	10641.6	10246.7	9851.9
45.0	11821.1	11431.2	11041.2	10651.3	10261.3	9871.4
46.0	11816.3	11431.1	11045.8	10660.6	10275.3	9890.1
47.0	11811.7	11431.0	11050.2	10669.4	10288.7	9907.9
48.0	11807.3	11430.8	11054.4	10678.0	10301.5	9925.1
49.0	11803.1	11430.7	11058.4	10686.1	10313.8	9941.8
50.0	11799.0	11430.7	11062.3	10694.0	10325.6	9957.3
51.0	11795.1	11430.6	11066.0	10701.5	10337.0	9972.4
52.0	11791.3	11432.1	11072.9	10713.7	10354.5	9995.3

Table 5.7.17

C_T Numerical Analysis Area 11

B = 1 to 0.5 Summary

5.7.8 Discussion of Results

The results derived from the above modelling process, were hindered by the lack of accurate data, however experience indicates that data which could yield more fruitful results could be dislodged from the system however intractable. The circumstances under which Local Authorities and DLO's are required to operate in a highly charged competitive environment makes the resourcing of such data collection exercises very difficult indeed.

We must be mindful of the broader consequences of inspection systems. Large capital budget allocations are currently; and will be for the foreseeable future; being directed to a variety of planned maintenance programs which may run in parallel or series with the continuum of response maintenance repairs. A major objective should be a more controlled approach to random reactive management solutions to the delivery of the repairs service within both Client and Contractor departments. The most effective way of monitoring such a possibility is by controlled inspection of *selected* elements of the housing stock.

Many repairs effected under a response maintenance system could well be delayed and parcelled into work packages with programming advantages for both the Client and Contractor departments.

It would be folly to dismiss the idea of planned inspections even if such an inspection system cannot be shown to be wholly cost effective. The additional benefits; as discussed earlier, which could accrue, must outweigh any financial shortfall, bearing in mind, as reported earlier[7] some Authorities find it acceptable to pre-inspect nearly all response repairs. Such a policy must be viewed with some scepticism, and a policy which may well benefit from a pre-inspection cost model.

5.8 Summary: What This Chapter Does

Inspection systems in general are briefly defined and their applications and benefits discussed. The idea of superimposing a cyclical inspection system upon an otherwise purely response repairs system is introduced and the benefits and any disbenefits of doing so are examined. The concepts of a cost per unit time curve and the life spans of building defects are introduced. A basic inspection model is discussed and a cost per unit time expression which synthesises the cost of response repairs and the cost of inspection repairs is presented. The model is then tested within a purely response repairs system.

The collection of the data necessary to construct the model and any limitations imposed on the scale and accuracy of such data is fully discussed. Likewise the subjective nature of the assessment of the lifespan of the defects, these referred to as "lapse time", and problems associated with its interpretation are explained. The cost of inspections is loosely estimated and optimal inspection frequency intervals are calculated based on the probable number of response repairs which could be identified at an inspection, the costs of which are expressed as a proportion of the cost of the same repairs, rectified under a purely response system. The idea is extended to a targeting of specific (problematic) Estates which may be deemed most likely to benefit from periodic inspections.

CHAPTER SIX

DISCUSSION AND RECOMMENDATIONS

6 DISCUSSION AND CONCLUSIONS

6.1 A Review of the Problem and its Analysis

The Management of Local Authority housing repairs services is complex, diverse and fraught with Political sensitivities. Therefore we must make it clear from the outset that this investigation is apolitical in both origin and content.

Because of the limited resources available this investigation was focussed on only *one* Local Authority and sought to examine how the seemingly ever changing legislative demands may influence maintenance management and working practices in both Client and Contractor departments.

Individual Authorities may well adopt different tactics which enable them to respond to both changing customer and legislative requirements. Therefore a wide range of alternative ploys which temporarily secure commercial survival are likely to be devised. Consequently the contents of this investigation cannot reflect the state of the art management thinking across the spectrum of all possible management strategies. Nevertheless, there will be certain common denominators.

We must recall that the main thrust of the legislation is targeted at forcing Contractor Departments into a fully competitive tendering environment and more importantly, doing so in a way that prohibits anti competitive behaviour. This is the nub of the matter. Consequently practices which are deemed to be biassed toward say a DLO, or equivalent, which enable it to win contracts by having an unfair advantage over competitors, say private sector competitors, will be more rigorously challenged and quashed in the future.

All of the main Political parties have expressed a commitment to Quality Assured local government services. Initially there was the Citizens Charter and next The Improved Citizens Charter. An extension of this is proposed legislation which is channeled towards forcing Client Departments to compete for the right to act as Enablers. Following on from this, as in other public sectors, is likely to be the establishment of some kind of league tables against which a Public Sector Landlord's performance, as Enabler, will be judged. The reference criteria for comparison of performance will possibly be a defined set of Performance Indicators. This will of course intensify the polarisation of Client Department linkages with say a DLO.

Many Authorities will have anticipated the need to adapt to the changes demanded and will have done so progressively while others may have deferred action until the last moment. Either way these are still early days in a new era in the evolution of housing maintenance management.

Likewise we believe that it is becoming increasingly more important if indeed not essential that more scientific methodology is channeled into the management of the repairs service. Only when clear statistical patterns or otherwise are available can the scale and nature of this rogue problem be identified and more effectively controlled. It is highly probable that the key to the implementation of strong management control regimes is contained within the detailed and systematic analysis of Frequencies of job arrivals and Frequencies of individual repair categories. There is of course little point in knowing such detail unless it is analysed and attempts made to fashion the contents into system control devices.

The enforcement of the legislation discussed in Chapter 2 and any immediate reactions by maintenance organisations to meet the demands set, are only the beginning of the challenges to be faced which may possibly extend over the next decade. Such challenges will confront not only local authorities but also other development bodies involved in the large scale maintenance of housing stock. Although similar legislation has been in effect for almost two years in England and Wales we believe that many of the problems generated are yet to be fully exposed and understood. To avoid redundancies or even closure, contractor departments will need to be able to adjust to variable packaging of work as Client departments are pressured to alter the scale and content of maintenance contracts offered for tenders.

In the short term the survival of DLOs may be achieved by producing large scale contracts across the complete range of common trades thereby limiting scope for competition. Alternatively, work packages may be produced which fall below the de minimis value. Neither of these strategies is likely to go unchallenged. The ability of contractor departments to deliver a repairs service is assisted by the current recession in that a workforce is available and that hiring and firing as workloads fluctuate is the managers' prerogative. This hopefully will not be the situation for long and in any case is hardly the way to achieve a quality assured repairs service.

We have no position on whether the public or the private sector can provide the better service. The fact is that whichever wins maintenance contracts, the problems remain the same and fresh attempts at solving these problems must be rigorously pursued.

With respect to Local Authority housing the current National situation could be described as dire, with no immediate relief on the horizon. The general condition of the housing stock is not improving, large backlogs of repairs exist and the country is in the grip of a recession. Old working practices and relationships are being systematically dismantled by legislation. Competitive tendering and associated newer work packaging methods must be effected with slicker and more effective management and delivery of the housing repairs service being the order of the day. Quality assured services, customer satisfaction and value for money are the clarion calls which will sound through the next decade and beyond. All this and not enough sustenance afforded to the people who have to make things work.

6.2 Reprise and Action

Over the past thirty years a great welter of research into building maintenance has been undertaken and much achieved. However too little quantitative effort has been directed towards solving response maintenance problems. The work of Christer, Princes Risborough Laboratory and of course Ward as outlined in Section 1.8 being the most significant since these represent the main efforts to assist managers in understanding and coping with this important component of the maintenance process. It is vital that response maintenance is more thoroughly researched and mapped in order that the response system is brought more under control and so that any planned maintenance system can be matched against work which has or needs to be done. Likewise the profile of the response demands needs to be framed more accurately within an organisation's Business Plan, otherwise resources will not be effectively utilised and controlled.

We believe that this study makes a significant contribution to alleviating the uncertainties and difficulties associated with the management of Response maintenance.

Local Authorities now need to consider what action should be taken so that they may effectively combat current and future challenges enforced by Central Government Policies.

In the short term maintenance coding systems should be reviewed and information systems developed which enable the extraction of alternative forms of information from databases that permit statistical analysis and modelling processes such as developed in this study. New computer packages should consider the incorporation of these ideas so that the mistakes of the Eighties are not repeated[62] and old systems are not simply adapted to cope with the Legislation of the Nineties. Some kind of Quantum Leap is now required in areas of computer programming applications. The type of computer programming for simulations as developed by this study could be utilised to assist this. The data analysis in the first instance should be aimed at the frequency of job arrivals per day/week and repair type frequency within each trade and trends with time analysis over an extended period of time investigated. From this the analysis of the overall response maintenance profile and how it impinges on the performance of the repair service as identified in this study, may be developed.

The modelling techniques, emanating from this study are intended to help combat any resultant difficulties which may ensue for autonomous Client and Contractor departments intending to survive in the competitive Legislative labyrinth of the Nineties.

However we believe that much more work remains to be done especially on the issues raised by the Legislation in Chapter 2 and the associated modelling processes developed in Chapters 3 and 4.

6.2.1 How this study may help

In Chapter 4 a computer program was devised which generates probabilistic forecasts that show the likely incidence of repairs occurring for individual trades and the location of such repairs Estate by Estate. The response time categories of individual repairs and job completion times are also forecasted. From these experimental results a variety of permutations and combinations of the above variables is made possible. In other words it is possible to simulate a host of maintenance scenarios which the manager can juggle and manipulate to create say viable work packages.

The main thrust of the analysis and techniques developed in Chapter 4 was largely aimed at enabling client departments to produce a variety of combinations of baskets of work, either trade by trade or combination of trades. From these the scale and possible content of individual contracts may be more accurately predicted. The techniques discussed were also developed to allow contractor departments a facility for predicting manpower requirements to match variable contract packages for response maintenance only. We believe this study can, in the future, make a valuable contribution in this respect. Estimating the capital value of a response maintenance contract is usually guesswork based on previous estimates or a cost allocated per dwelling times the number of dwellings covered by the contract. As the demand for a variety of baskets of work of variable content increases, the greater is the need for more accurate predictions of contract costs. These could be probabilistic and based on a sounder appreciation of job type frequencies. The models developed in Chapter 4 could be expanded to achieve this in future. Such techniques allow the amorphous nature of response repairs to be more readily compartmentalised producing a clearer vision of the demands on the repairs service and a range of trade based maintenance profiles to be identified.

It must be emphasised that any outputs achieved are probabilistic and predictions cannot be wholly accurate. Also there may be shifts in the global maintenance profile year by year therefore the ideas advanced need to be *developed further to accommodate trends with time.*

The statistical evidence for the trade coalitions produced in Section 4.4 indicates that, biggest is best, in that as the size of the contract increases the variation in or spread of job completion times decreases and this coupled with flexible working among trades or certain groups of trades should reduce the contractors' logistics problems which in a competitive environment must lead to reductions in costs. However, bearing in mind that it is unlikely, with the exception of large DLOs, that single contractors will have the capacity to deliver maintenance contracts over the entire range of commonly required trades, the alternative and conflicting demand for smaller scale specialised contracts may be enforced. Although considered a fairer way of encouraging competition it would be more cumbersome and expensive for a Client department to manipulate. Additionally the sixty four thousand dollar question is, do client departments of large scale maintenance organisations have the capacity to predict, with reasonable accuracy the scale of the contract in terms of quantity of work and cost and also to advise the contractors of likely job frequencies? It must be the case that experienced managers of say DLOs, will be able to give a gut prediction based on historical averages or even astute DLO managers may have this facility on computer. However with the variety of scenarios now ultimately enforceable by the legislation it would be a forlorn hope to expect sensible predictions for contracts newly packaged. This clearly places any Contractor bidding for such work even with local knowledge at a distinct disadvantage.

We believe that the analytical techniques exposed by this investigation make a significant contribution by attempting to address this problem. The techniques developed although in embryonic form afford the opportunity to build clearer pictures of the nature of a range of response maintenance profiles less amorphous than those currently existing and this should be of benefit to both Client and Contractor departments.

6.2.2 Data Generation Initiatives

During this investigation the extraction, sifting and sorting of the raw data necessary to permit realistic experimental analysis was both time consuming and tedious and due to the subjective interpretation necessary from time to time minor inconsistencies and errors may have occurred. However we believe that many local authority client departments and development bodies are now capable, with modest investment and efforts, of generating more accurate and realistic data. This data when statistically processed could produce clearer blueprints of individual authorities maintenance profiles providing a sharper focus on system requirements and the development of appropriate maintenance strategies.

Since the date of the data collected and analysed in Chapter 4, the state of art of the computer application packages within Client and Contractor Departments has progressed. The Scottish Special Housing Association are reported[62] to being employing what is described as a "second generation" system which is being installed in various authorities. Much useful data has existed for some time[49] which is coded by trade, job type and category of work. The burning questions are to what use is this valuable information being directed and is it accessible in a useable form. Obviously not in the areas of development identified by this research for there is no such modern application for discussion in Section 1.8 earlier. A study could be made of type of data and its accessibility currently stored in Local Authorities' computer systems, together with a review of coding systems possibly by using a structured questionnaire.

Likewise DLOs could make good use of such data. For example, given that it can be more convincingly proved that job completion time distributions are of the negative exponential form as explained in Chapter 4 (and the distributions produced by Kavilondo[55] are encouraging in this respect), then only the mean target completion time is required to simulate manpower requirements rendering the process not only speedy but relatively simple. This must be regarded as a significant advance on current ad hoc practices which are riddled with uncertainty. Many DLOs are likely to be using microprocessors for other purposes. It would be in the interest of the astute DLO manager to accumulate data on say; frequency of certain job types. This may allow a more competitive price to be quoted against items in an unpriced schedule of rates. However as cited in Audit Report[25] this is really the responsibility of the Client Department. Either way frequencies of job types, job arrivals and other information necessary to construct computer models which may help solve or alleviate the managers problems is likely to be available.

6.2.3 Optimal Inspection Frequency Model

The model for optimal inspection frequency, developed in Chapter 5, requires further testing especially for defects with longer lapse times. This is likely to be the case for fabric elements with inspection potential, for example, roofs, external walls, gutters/downpipes, doors, windows and general environmental aspects all of which could be targeted for inclusion in the modelling process.

The collection of data for the above model was and will continue to be a problem and experience is needed to assess the lapse time of defects. All defects existing at the time of data gathering need to be embraced within either the sample or the population collected. The local authority which assisted in this investigation undertook an attribute survey of all district council stock in late 1988. The type of information collected for such surveys is clearly at variance with that required for modelling inspection cycles. However we believe that a modified version of the proforma given in Chapter 5 could be filled in at the same time as the attribute survey data without a great deal of additional effort. Such a scaled down proforma was produced, but management were unable to find the necessary additional support personnel due to the limited time available for completion of the survey.

6.3 Required Developments and Research

The ideas developed in this investigation are not advanced as a panacea for all of the ills afflicting the delivery of every repairs service but modified and tuned to specific organisations, however limited the state of the art, they must be considered an advance on the current understanding of response maintenance problems. This work now needs further development and in summary the following aspects of this research are worthy of further investigation.

(a) An analysis of true response seasonal trends to identify the frequency of jobs in target response time categories, say A, B and C as previously defined or other groupings contingent on maintenance philosophy is required. Likewise further development on non-urgent work, say category D is required to model this separately. This would enable the work loads issued to contractors to be identified and possibly smooth out some extremes. This requires further research by an extensive study over several years in order that any trends with time can be analysed. This could be collated on a weekly basis in the first instance.

(b) The identification of the proportion of work for each separate trade in terms of category of work, nature of the repair and corresponding frequencies. This should be by Estate or other such subdivision of the housing stock. This is an extension of the area of work as analysed in Chapter 4 and should be aimed at improving accuracy.

(c) It is possible that each category of work, say A, B, C and D has its own unique statistical frequency distribution for job completion times. This still requires to be established by further research. To accommodate this the computer program developed in Chapter 4 can easily be extended by the addition of extra WHILE Loops, thus enabling more detailed and accurate analysis.

(d) The idea of producing more statistically accurate contract sizes, associated costs and contents could be further developed. This would enable more accurate yet flexible work packaging. This may be a useful approach when the contract is based on a priced schedule of rates and a contractor is quoting a percentage price above, but more likely below a guesstimated lump sum capital value. Alternatively the schedule of rates may be unpriced in which case at least some attempt at forecasting the frequencies of job types should be made so that budgets are more readily anticipated and controlled. It should be said that the practice of offering large scale contracts over extended time scales is unlikely to escape the rigour of the legislation.

(e) The data generated by (a), (b), (c) and (d) above should be utilised and extended to develop the ideas for modelling manpower requirements at contractor level for variable contract sizes, promulgated by the breaking down of large single contracts into alternative and possibly variable baskets of work. This requires an extension of the research work produced in this study by determining more realistic job completion time distributions.

(f) Flexible working among trades requires more investigation. The statistical treatment could be extended however we believe this requires little further attention. More importantly, the implications for appropriate apprenticeship or training schemes needs to be reviewed together with a study and comparison of any experimental pilot attempts at flexible working which may have been undertaken by maintenance organisations.

The quality and type of repairs effected under any such schemes and customer satisfaction need to be analysed, in the light of any training programs undertaken or otherwise.

(g) The computer modelling of the integration of planned, category D, and unplanned response maintenance ie categories A, B and C, framed within the nett attendance hours available could be developed. This has not been attempted in this investigation but is clearly part of the next stage of development.

(h) More adaptable procedures which permit details of stores holding could be investigated which may indicate the likely proportions of components required, eg, for plumberwork, giving possible turnover and costs for newly created baskets of work.

(i) The potential to introduce sampling techniques in data collecting could be investigated and tested. However given that data inputs to computer data bases are clearly coded it should be possible to access entire populations of selected data for analysis. The computer simulations in this study could have been extended further to statistically test the outcomes of all proposed modelling techniques. However and primarily the basic data used requires refining and until sufficiently accurate data is made available by further research, extensive statistical analysis is fruitless.

6.4 More New Horizons

It must be made absolutely clear that this investigation has focussed on *exposing* the nature of local authority housing response maintenance problems within a *dynamic* legislative framework and *devising* associated problem solving techniques using realistic data gleaned contextually. Although the results achieved thus far are specifically targeted at attempts to alleviate real life problems we must be mindful of any contribution which this work could make to Training and Education programmes in the field of housing maintenance management. Likewise the ideas contained within may possibly be extended to other applications within similar public and private sector commercial enterprises. It could be argued that an aim of the legislation is to produce a fairer, more efficient and cost effective maintenance service. Commercial survival will therefore be contingent on the maintenance organisation's ability to be adaptable and responsive to such demands. Therefore sound organisations' management systems and practices must be identified and effected where lacking. There can be little doubt that the power of the micro computer has yet to be fully exploited in attempts to speedily match the swinging organisational changes enforced by legislation. Further research and development is listed in (a) to (i) above is therefore recommended if we are to dispel many of the uncertainties that characterise housing response maintenance.

In the current climate of competitive uncertainty building maintenance managers may be reluctant to liberate the resources which are necessary to underpin research and development. Nevertheless such resources must be deployed to enable more systematic statistical approaches which attempt to harness the maverick nature of response maintenance. The response maintenance problems tackled by this investigation have been largely avoided over the years possibly because of the mystery and complexity which bedevil this aspect of maintenance. This study was unfunded and it was not possible to pursue the full scale analysis which this vast and complex topic requires. Response Maintenance Repairs constitute annually a billion pound industry, and when total maintenance budgets are confined response maintenance is likely to take precedence over say cyclical or other such programmed maintenance. Surely then some financial resourcing is justified for more research and development.

There can be no doubt that the coupling of hard statistical evidence and the power of the microcomputer are yet to be fully exploited as an aid to identifying and solving certain building maintenance problems. Local Authorities in Scotland and other organisations, working within the same or similar legislative constraints, have only just embarked on what could be a troublesome journey, however with good stewardship who knows what serendipity lies ahead.

We hope that this study of response maintenance makes a contribution to housing maintenance management by attempting to level the playing fields for a whole new ball game during which the goalposts will be ever moving.

We believe that Management Science has a significant role to play in helping maintenance managers to respond to these problems both current and in the future.

BIBLIOGRAPHY

BIBLIOGRAPHY

1 The Purposeful Delay of Maintenance Work Economic and Behavioural Aspects
A H Christer, 1981
Applied Systems and Cybernetice, Vol 11 (GE LASKER ed)
Pergammon Press, Oxford

2 The Matching of Planning Systems To the Maintenance Work That is Actually Done
By N P Skinner, DOE Building Research Establishment, Princes Risborough Laboratory, March 1983

3 "The Gasman Cometh", duet by Flanders and Swann, 1975.
Chappell, London

4 Modelling Inspection Policies for Building Maintenance.
A H Christer, 1982
J. Opl Res. Soc. Vol 33 pp 723 to 732

5 Operational Research Applied to Industrial Maintenance and Replacement.
A H Christer
Developments in OR, edited by R W Eglese and G K Rand, Pergammon Press, 1984

6 Operational Research in Maintenance
Edited by AKS Jardine
Manchester University Press

7 The Delivery of Repairs Service in Public Sector Housing in Scotland
March 1986
Scottish Office Central Research Unit Papers

8 Improving Council House Maintenance
Audit Commission Report, 1986, HMSO
Local Authority Property, A Management Handbook

9 Computerised Data Base as a Fabric and Engineering System Control Aid for a Hospital Complex
A H Christer
Hospital Engineering Vol 30, March 1976

10 Local Government Act, 1988, Part I and Schedule I
Competition in the Provisions of Local Authority Services, DOE
Aug 1988

11 Standards for Housing Management
National Federation of Housing Associations 1987

12 Memo from Housing Department
Strathkelvin District Council, 1991

13 Building Maintenance Direct Labour Organisations
A Management Handbook, Audit Commission, April 1989

14 The Competitive Council, Audit Commission Management Papers
March 1988, England and Wales

15 Business Plans - A Future for DSOs? Fred Jackson
Building and Maintenance, Journal of the Institute of Maintenance and Building Management, October 1990

16 The MOB Rationale, Paper by Mike Dockray based on a seminar at the London Press Centre, May 1989

17 Strathkelvin District Council; Internal papers on Housing Department and DLO restructuring proposals, 1984

18 Strathkelvin District Council; Internal report on restructuring and centralisation of Technical Services, Housing Services Departments, 1985

19 Strathkelvin District Council; Internal report on proposed restructuring of the DLO, 1985

20 Government White Paper Cm. 1599. The CITIZEN's CHARTER A Guide
July 1991, HMSO

21 Operational Research in Local Government
Ward R A, 1984
Geo Allen and Unwin Ltd, London

22 Introduction to Applied Probability, G P Beaumont
Published by Ellis Worward

23 Maintenance Cycles and Life Expectances of Building Components and Materials
NBA Construction Consultants, 1985

24 Building Maintenance Management
Reginald Lee
Granada

25 DLOs in London
Audit Report
November 1990

26 The Local Government Planning and Land Act 1980 and Amendments up to April 1st, 1991

27 Repairs: Tenant Rights, Jan Luba
Legal Action Group, 1991
Second Edition

28 Scottish Local Authorities Special Housing Group
Maintenance Practice Manuals Sections 1 to 10
1977-1984

29 Defect Action Sheets
BRE Housing Defects
Building Research Establishment
DOE 1982-1992

30 The Birmingham Tem Project Non-Traditional Housing
Defects and Repair
Structural Survey, 1989

31 The Development of the English House Condition Survey
Alan O'Dell
Building Research Establishment
'Building Maintenance and Modernisation Worldwide
1990

32 English House Condition Survey 1986
HMSO 1988

33 An Enquiry Into Housing in Glasgow
By Glasgow District Council (Housing)
1986

34 Scottish Special Housing Association Maintenance: Developments and Directions
F Colston and E Ross
Planning Exchange Occasional Paper, 1984

35 Maintenance Planning The long-term care of housing stock
Scottish Special Housing Association, 1984

36 Housing Maintenance Kit for Housing Associations
Scottish Office: Scottish Homes
HMSO 1989

37 Benefits of Planned Maintenance
A E Colston
Housing Review, Vol 39, No 3, 1990

38 Whole Life Maintenance
A E Colston
Voluntary Housing, July 1987

39 Is Programmed Maintenance a Good Idea
R Henderson
Housing Review, Nov/Dec 1989

40 Value for Money In Housing Maintenance
Peter Fogg
Planning Exchange Occasional Paper, 1984

41 Capital Programme Control in Glasgow District Council
Martin Nichol
Planning Exchange Occasional Paper, 1984

42 Making the Most of Your Money
Understanding and Controlling The Financing of Maintenance
Ann M Gibson
National Federation of Housing Associations, 1991

43 Long-term Maintenance The Size and Nature of the Problem Facing Housing Associations
National Federation of Housing Associations
September 1991

44 Managing the Crisis in Council Housing
HMSO March 1986

45 Direct Labour Organisations: Maintenance
NBA Construction Consultants
Published by the Former Audit Commission 1982

46 Local Government Planning and Land Act, 1982

47 Repairing for the Future
Association of Metropolitan Authorities
1988

48 Organisation On Effective Repairs and Maintenance Service
Housing Services Advisory Group
Department of the Environment, 1980

49 Computer Aids to Housing Maintenance Management
R Pettit
Maintenance Information Service
The Institute of Building, 1979

50 Computer Aided Job Planning for Building Maintenance
K R Dickens and N George
Maintenance Information Service
Institute of Building, 1980

51 Maintenance Coding and Monitoring: two case studies
Roy Holmes and Penelope Mellor
Technical Information Service
The Chartered Institute of Building, 1985

52 Computerised Maintenance Management in A Housing Authority
A Savile
Technical Information Service
Institute of Building, 1990

53 An Introduction to the Information Needs of Housing Management
Tong, Wilson and Ellis
Housing Review, Vol 5 No 2
April 1986

54 SDD Housing Research Bulletin
Central Research Unit and the Building Directorate
SDD HRB No 2, March 1990

55 Modelling Resource Allocation for Building Maintenance
J H Kavilondo
Research Thesis Department of Operational Research
University of Strathclyde, 1981

56 Delay Time Models of Industrial Inspection Maintenance Problems
A H Christer and W M Waller, 1984
J.op. Res. Soc. Vol 35, No.5, pp 401-406

57 Reducing Production Downtime Using Delay Time Analysis
A H Christer and W M Waller, 1984
J.opl Res. Soc. Vol 35, No 6, pp 499-512

58 Economic Cycle Periods for Maintenance Painting
A H Christer
Department of Oprational Research, University of Strathclyde
Opl Res. Pergamon Press, 1976, Vol 27

59 Interpreting Feedback Information - Some Examples From Housing Maintenance
N P Skinner
Princes Risborough Laboratory
Building Research Establishment, DOE, April 1983

60 Renovation of Public Housing: Suggestion From a Simple Model
Michael E Gleeson
School of Public and Environmental Affairs, Indiana University
Management Science
Vol 38, No 5, May 1992

61 Building Maintenance and Modernisation Worldwide
Q Lee Kiang
Singapore 1990

62 The Changing Nature of Maintenance Management - Factors Affecting Efficiency and Cost Effectiveness
Roy Holmes
Bristol Polytechnic, England
see Ref 61

63 Renewal Theory and Its Practical Application Spreadsheet Application for the Determination of Optimal Replacement Strategies
Trevor Briggs
Leeds Polytechnic, UK
See Ref 61

64 A Decision Model for The Building Renewal Problem
O Coskunoglu and A Moore
Department of General Engineering, University of Illinois
See Ref 61

65 The Cost And Benefits of Rehabilitation and Refurbishment
C Pugh
Sheffield City Polytechnic, UK
See Ref 61

66 Optimal Repair and Replacement Strategies for Built-Up Roofs, Using the Roofer System
D M Bailey and D E Brotherson
US Army - Construction Engineering Laboratory and University of Illinois

67 The Use of Decision Models in Maintenance Work
D B James and M F Green
Department of Health and Social Security, London, UK
See Ref 68

68 Developments in Building Maintenance
Edited by E J Gibson
Applied Science Publishers, 1979

69 Operational Research Can Do More for Managers Than They Think
Fortuin, Van Beek and Van Wassenhove
OR Insight Vol 5, Issue I, Jan-March, 1992

70 Housing in the Dearne Valley : Doing Community OR with the
Thurscoe Tenants Housing Cooperative - Part 1
Thunhurst, Ritchie, Friend and Booker
J. Opl Res. Soc. Vol 43 No 2, 1992

71 Quality and Reliability : Some Recent Developments and a Historical
Perspective
D R Cox
J. Opl Res. Soc. Vol 41 No 2, 1990

72 Optimal Replacement Policy for a General Model with Imperfect
Repair
Makis and Jardine
J. Opl Res. Soc. Vol 43 No 2, 1992

73 Costing a Finite Minimal Repair Replacement Policy
Nat Jack
J. Opl Res. Soc. Vol 42 No 1, 1991

74 Survey of Literature on Continuously Deteriorating Inventory Models
Fred Raafat
J. Opl Res. Soc. Vol 42 No 1, 1991

75 Control Variate Models for Estimating Transient Performance Measures in Repairable Item Systems
Ahmad, Gross and Miller
Management Science Vol 38 No 3, 1992

76 An Optimal Vehicle-Fleet Inspection Schedule
A K S Jardine and M I Hassounah
J. Opl Res. Soc. Vol 41 No 9, 1990

77 Testing the Efficiency of Preventive Maintenance
R D Baker
J. Opl Res. Soc. Vol 42 No 6, 1991

78 A System Dynamics Model for Submarine Operations and Management Schedules
R G Coyle and P A Gardiner
J. Opl Res. Soc. Vol 42 No 6, 1991

79 Managing Building Maintenance
Chartered Institute of Building, 1984

80 Management Reasearch Needs - Maintenance
S Britton
International Journal of Construction Management & Technology, 1990

81 Joint determination of production cycle and inspection intervals in a deteriorating production system
Lee & Park
J. Opl Res. Soc. Vol 42 No 9, 1991