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A study into the concept and practice of terotechnology and life-cycle costing as applied to manufacturing industry

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A STUDY INTO THE CONCEPT AND PRACTICE
OF TEROTECHNOLOGY AND LIFE - CYCLE
COSTING AS APPLIED TO MANUFACTURING INDUSTRY

by

Graham Harvey, B.Tech(Hons), FIPC., AA.Cost.E., MBBGS.

A Doctoral Dissertation
Submitted in partial fulfilment of the
requirements for the award of

Doctor of Philosophy of the Loughborough
University of Technology

August 1978

Supervisor: Professor T.M.Husband, Ph.D.
Department of Engineering Production

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The work contained within this dissertation is entirely the responsibility of the author and any opinions expressed are entirely personal and do not represent the views of any official bodies.

SYNOPSIS

The Atkinson Committee for Terotechnology found that it was hampered in its task of making recommendations to the Secretary of State for Industry due to the lack of research and information regarding the application, by manufacturing industry, of terotechnological practices. It was this lack of research and information which provided a major justification for pursuing this research work.

This research has attempted to provide a contribution to our knowledge in the fields of terotechnology and life-cycle costing. This has been achieved by investigating the historical development of terotechnology, examining the way in which the concept should be interpreted, developing a 'levels-of-care' model and, by industrial field research, examining the extent to which terotechnological practices, as defined within this dissertation, have been applied by manufacturing industry. The field work was based on a sample of six manufacturing organisations in which detailed research was undertaken. A further sixteen organisations were visited to obtain a more general and wider view of application. The comparative organisational analysis was based on the differences observed due to differing levels of production

system mechanisation. The results of the field research are presented and comparisons made, to the limited extent possible, with the findings of other work.

A major part of the terotechnological approach to physical asset life-cycle management is based on the comparative economic evaluation of assets over their life-cycles. Life-cycle costing is a quantitative economic evaluation technique which can be used for such comparisons. The historical development of life-cycle costing has been determined. A postal questionnaire survey, of experienced practitioners in the United States and Sweden, was undertaken to determine the general body of knowledge and experience required to utilise the technique. The results of the survey are presented. One of the major constraints on the application of life-cycle costing has been the lack of any procedural model to facilitate such application within manufacturing industry. This research has conceived and developed such a procedural model. An example of the application of the model, based on real data, is presented.

Future developments in the concept and practice of terotechnology and life-cycle costing are postulated. Suggestions for further research work are outlined.

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CHAPTER 1

INTRODUCTION

This chapter sets out the general purpose of this dissertation. It states the objectives of the work, the justification for pursuing such research work, the limitations and setting of the research and the chapter then previews the organisation of the dissertation.

1.1 The General Purpose of this Dissertation.

The general purpose of this research work was to investigate the concept and practice of terotechnology and life-cycle costing within manufacturing industry.

Specifically, the research work had the following objectives:-

- (a) To investigate the historical development of terotechnology and to examine the way in which the concept should be interpreted.
- (b) To investigate the extent to which terotechnological practices, as identified within this dissertation, have been applied by manufacturing industry.
- (c) To investigate the historical development of life-cycle costing.
- (d) To investigate some of the fundamental precepts surrounding life-cycle costing. In particular the qualifications and experience, the use of quantitative and accounting techniques, the management and organisational considerations and the limitations associated with the application of the technique.

- (e) To develop a generalised procedural model to facilitate the use of life-cycle costing as an economic evaluation technique for manufacturing systems.

1.2 The Justification for this Dissertation.

The Atkinson Report on Terotechnology(1), presented to the Secretary of State for Trade and Industry in June 1973, states, under the heading of 'Research Projects', that:-

In planning a programme of action the committee have been hampered by lack of data on the extent to which terotechnology is being applied in the various sectors of industry, and the adverse effects of not doing so. Information on the practices adopted by industry is also required to indicate those areas where special emphasis should be placed. (Atkinson Report, 1973, p.10)

In summarising the findings of the Committee on Terotechnology the report states:-

Lack of information on the extent to which terotechnological principles are being practised in industry, ... has led the committee to recommend that a number of investigations be carried out. It is expected that the information resulting from these researches will assist in the identification of the main problem areas and will enable a further programme of action to be planned. (ibid. p.2)

Hence, the need for exploratory research of the type mentioned in the Atkinson report represented a major justification for pursuing this work at this time. In addition, the dearth of knowledge and understanding in this field of physical asset management presented another justification for such an exploratory and generalised research project.

Another justification was found in the desire to assist with the solving of some of industry's many problems. Not least of these problem areas is that of the management of plant and equipment. However, before techniques can be developed or existing ones applied, it is necessary to understand the current level of awareness of these techniques and to understand what the problems of industry are. The Atkinson Report (ibid, p.3), states that:-

... despite a growing awareness of the need to protect and look after capital invested in plant, machinery and equipment, there is serious lack of knowledge in industry regarding techniques which are already available to assist decision making in this area. (Atkinson Report, 1973, p.3)

Hence, another justification for this work is seen in the contribution that it can make to furthering our understanding of the problems of industry and the extent to which scientific management techniques are applied to the management of physical assets. In recent years there has been a growing awareness of the considerable impact that on-going maintenance expenditure has on the total operating costs of plant and equipment. This has led to a desire to examine investment in capital equipment in greater depth than has hitherto been the case. One technique which could be utilised is life-cycle costing. However, little work has been done on the application of life-cycle costing to the comparative evaluation of manufacturing systems. Consequently, the dearth of knowledge in this field was

a further justification for this research work. One of the major constraints on the application of life-cycle costing is the lack of any generalised procedural model to enable industry to adopt the technique. Therefore, the objective of developing such a model was regarded as another justification for pursuing the research.

Hence, the problems associated with physical asset management, the desire to understand and pursue solutions to these problems, the need for an appropriate economic evaluation technique and the general dearth of research focusing on terotechnology and life-cycle costing have been the primary justifications for pursuing this research work.

1.3 The Setting and Limitations of this Dissertation.

Exploratory research effort, such as that presented in this dissertation, has many inherent limitations. The recognition of these limitations by a researcher is of paramount importance if objectivity and the search for truth is to be maintained. The industrial field research was carried out during a period of high inflation and industrial depression. As a result, the degree of industrial co-operation was limited and comparative analysis on the basis of financial performance was very difficult to pursue with confidence. Indeed, some of the companies visited were engaged in the development of redundancy plans or were experiencing a decline in business activity. The research work began in January 1975. At this time the Department of Industry had not published any of

the explanatory brochures and manuals that are available in 1978. Hence, the interpretation that this research has placed on the concept of terotechnology was that formed before the Department of Industry's publicity campaign was undertaken and descriptive material became available. Hence, it should be understood that the interpretation placed on the concept of terotechnology within this dissertation, was that of the author's and it may not coincide with the official view expressed by the Department of Industry or the National Terotechnology Centre.

The field research was based on companies within the manufacturing industry classification. The research was not intended to include service, distribution or building sectors of industry.

It is recognised that the process of management is a dynamic one. Nevertheless, the 'photograph' of this process, which results from industrial field research of the type undertaken, is considered to be of considerable value as a contribution to our knowledge. The primary source of data collection was the interview supported by questionnaires. The weaknesses of the interview, as a means of data collection, were recognised and steps taken to minimise their impact. However, the accuracy of the results were governed by the inherent limitations associated with the collection of descriptive data.

Further limitations were recognised due to the limited number of organisations that agreed to participate with the research. The inclusion of six organisations cannot be said to represent the whole of manufacturing industry. As a consequence, the results and conclusions presented in this dissertation are formulated on the basis of the data collected in the six organisations. However, a section of this work has concerned itself with making some speculative statements about the application of terotechnology and life-cycle costing. Wherever these speculations have been made, they were formulated by consideration of the approach to terotechnology which had been observed in a further sixteen organisations which had been visited during the course of this research work.

1.4 Dissertation Structure.

This dissertation has been arranged on the basis of a three part structure. This was considered necessary in order to present this work in a logical and readable manner. Part I is concerned with terotechnology. Part 2 with life-cycle costing and Part 3 presents some general statements regarding future developments and suggestions for further work.

✓ Part 1. Terotechnology. Part 1 of this dissertation deals with the concept and practice of terotechnology. It covers the definition, the historical development, the interpretation placed on the concept and develops a 'level-of-care' model of terotechnological practice over the life-cycle of an asset. It then covers the industrial research design, states the objectives of the field research, details the response rate, the data collection techniques and the selection of an appropriate research methodology. The results of the research are presented in a life-cycle manner. That is, each phase in the life-cycle of an asset is surveyed for all the companies included in the research. The findings are given and conclusions drawn from these findings. Comparisons with other work are made to the limited extent possible.

Part 2. Life-Cycle Costing. This part of the dissertation covers the concept and practice of life-cycle costing. It presents an overview of the technique, it establishes the historical development and presents some of the definitions. The justifications for adopting the technique are established. A postal questionnaire was designed and a survey of experienced practitioners was undertaken. The survey design, questionnaire design, response rate, approach to participants and the findings of the survey are presented.

A generalised procedural model for the implementation of life-cycle costing is developed and the model characteristics described. An example of the application of the model is presented. The findings of the research are presented and conclusions drawn from these findings. No comparisons with other work were possible in this part of the research.

Part 3. Future Developments and Further Work. This part of the research work was concerned with presenting some speculative ideas for the future development of terotechnology as a discipline within the general field of industrial management. In addition, some speculative ideas are postulated regarding the possible future development of life-cycle costing as a technique within the general field of economic evaluation and analysis for engineered systems. Some suggestions for further research work are also made.

1.5 Summary.

This chapter has introduced the research work presented in this dissertation. The objectives of the research have been stated, the justification for pursuing the work outlined, the setting and limitations explained and the general organisation of the work has been described. Part 1 of this dissertation follows this introductory chapter.

PART 1

TEROTECHNOLOGY

CHAPTER 2

THE HISTORICAL DEVELOPMENT

This chapter provides insight into the historical development of terotechnology. It states some of the milestones in the growth of interest in maintenance engineering over the twenty year period from 1946 to 1966. From 1967 onwards the analysis is deepened to examine, in detail, the emergence of terotechnology. This chapter establishes why and how the word terotechnology was coined. Finally, the definition is stated.

2.1 The Initial Growth of Interest.

This section outlines some of the milestones in the development of plant engineering as a profession..

In 1946 the first Institution of Plant Engineers was set up in the United Kingdom. In 1949 the first national maintenance conference was held in the United States and in 1952 an Institution of Plant Engineers was set up in the United States. In 1957 the first maintenance engineering journal appeared in the United Kingdom and in 1959 the Japanese formed an Institution of Plant Engineers. In 1961 the first U.K. national maintenance conference was held and in 1963 the first international maintenance conference was held again in the United Kingdom. Also in 1963 the first maintenance association was established and in 1964 the first glossary of

terms for maintenance engineering was published. In 1965 the Eastern European Countries held a conference in Budapest. In 1967 the British Council of Maintenance Associations was set up. Considerable interest in maintenance engineering was now being shown and it was in 1967 that the editor of the journal, 'Maintenance Engineering' approached the Minister of Technology regarding a proposal that the Minister should commission a survey into the cost of engineering maintenance in the United Kingdom. More specifically Mr. Parkes, the editor of 'Maintenance Engineering', suggested that a committee or other body be set up to consider the following:-

- (a) How small firms can be encouraged to undertake planned maintenance.
- (b) The setting of standards for maintenance and the dissemination of maintenance information.
- (c) Support for research into the cost of maintenance work and the consequential effect of downtime, whether planned or caused by breakdown.

As a result of this approach by Mr. Parkes, a working party on Maintenance Engineering (2) was set up.

2.2 The Findings of the Working Party on Maintenance Engineering.

The working party was established under the Chairmanship of Mr. I. Maddock, Controller Industrial Technology, in the Ministry of Technology. The working party met seven times and their report was published in 1970. A summary of the findings

✓ of this working party is presented below:-

1. A Steering Committee should be set up to guide future activities.
2. Maintenance education and training as a whole must be examined and action taken to ensure adequate education and training. A Joint Committee of Industrial Training Boards, augmented by other organisations having major interests, should be set up to pursue this on an urgent basis.
3. A National Maintenance Centre should be set up.
4. The possibilities of using grouped maintenance resources should be explored.
- ✓ 5. Research into all aspects of maintenance engineering is required and should be started soon, now that the results of the survey into the national cost of maintenance are known.

This last recommendation, based on the knowledge of the national cost of maintenance, was the most important as far as this research work was concerned. The national cost of maintenance was determined by a firm of management consultants who were commissioned by the Ministry of Technology Working Party. The survey that they carried out will be described briefly in the next section.

2.3 The Study of Engineering Maintenance in Manufacturing Industry.

In September 1968, P.A. Management Consultants Limited were commissioned by the Ministry of Technology to carry out a study of engineering maintenance in British manufacturing industry. The study was published in April 1969 (3).

The study surveyed 515 companies, each of which was requested to complete a questionnaire. From this sample 283 questionnaires were returned. In addition, the consultants then visited 80 companies in order to carry out an in-depth study of maintenance practice. Because the findings of the survey were central to the development of terotechnology, they are quoted below, almost verbatim et literatim, from the consultants' report (ibid. p.3):-

1. The total direct costs of engineering maintenance in British Manufacturing Industry are approximately

£1,100 million p.a.

2.(a)

There is available an increase in productivity of maintenance staff of about 60% which would facilitate the release of up to 200,000 maintenance personnel. This could lead to a reduction in Direct Maintenance Expenditure of around:

£200 - £250 million p.a.

(b)

Inadequate maintenance appeared to have an adverse effect on production in at least 20% of the firms visited, mainly as a result of loss of output from plant which could otherwise have been productive. We estimate that the savings available from this source are in the region of

£200 - £300 million p.a.

[Authors' note: All costs quoted were at 1968 values.]

A summary of the P.A. Consultants' Report is included in the Maddock Report on Maintenance Engineering (op.cit. p.13).

2.4 Terotechnology-The Evolution of the Word.

Of the many conclusions drawn by the Maddock Report, the most significant in the development of terotechnology, was concerned with three important plant characteristics and management functions. That is, reliability, maintainability and the feedback of information to designers.

Again, because this finding was central to the development of terotechnology, it is quoted below:-

We considered that there was a need for the results of maintenance investigations to be fed back to engineering designers. The engineering designer has to take into account many aspects of his product: the problems posed by production techniques and the skills of labour, the user's needs, the cost, the need for reliability and the need for easy maintenance [maintainability]. ... Reliability and ease of maintenance have so far not been given the importance they deserve. (Maddock, ibid. p.4)

This statement was one of the first to break away from considering maintenance as an isolated discipline. It started the move towards an awareness of the broader implications of maintenance engineering. That is, the consideration of reliability, maintainability and information feedback as important elements in the management of physical assets.

The awareness of these wider implications led to the setting up of a Steering Committee to examine the broader findings of the Maddock Report. However, Parkes(4) suggests that even as the Steering Committee was being established, suggestions were made that 'maintenance' was no longer the right word to use. He suggests that even 'Plant Engineering' was not regarded favourably. Parkes went on to state :-

There was too, the undeniable fact that few practising maintenance engineers or plant engineers had been really successful in finding the link between economic design, efficient operation and effective maintenance. (Parkes, ibid.)

This point was extended by Jost(5), who commenting on the

Maddock Report, stated that:-

It became quite obvious that the designing - out of maintenance and minimisation of maintenance was as important as the management of maintenance. ... to the maintenance functions were added non-manufacturing functions such as installation, removal etc. (Jost, ibid.)

Jost went on to say:-

Hence, after many letters with the Editor of the Oxford English Dictionary, the late Sir Richard Clarke and myself [Dr. H. P. Jost], one Sunday after dinner, in my sitting room, decided on the word Terotechnology. (Jost, ibid.)

Therefore, when the Steering Committee was established in April 1970 it became the Committee on Terotechnology.

This is confirmed in the Atkinson Report (op.cit. p.5) which covers the activities of the Committee for Terotechnology between April 1970 and September 1972. The report states:-

Consideration of the Working Party's [Maddock] findings indicated that the whole nature of maintenance activity was determined by the manner in which plant and equipment was designed, selected, installed, commissioned, operated, removed and replaced. It was concluded that major benefits could accrue to British Industry from the adoption of a broadly based technology which embraces all these areas, and because no suitable word existed to describe such a multi-disciplinary concept the name 'Terotechnology' based on the Greek word 'terein', was adopted. (Atkinson Report, op.cit., p.5)

In September 1972, the Committee on Terotechnology was reconstituted to form part of a new committee structure dealing with the four industrial technologies that were to receive Government support. The four industrial technologies were; Terotechnology, Materials Handling, Tribology and Corrosion and Protection.

2.5 Terotechnology-The Definition.

The definition of terotechnology evolved between 1972 and 1974. At the time of the Atkinson Report of the Committee on Terotechnology (ibid., p.5) the definition of terotechnology was stated as:-

The technology of installation, commissioning, replacement and removal of plant, machinery and equipment, of feedback to design and operation thereof, and of related subjects and practices. (Atkinson Report, ibid.)

One of the working party sub-committees, responsible for the definition of terotechnology, took account of opinions that had been expressed at conferences and in the press.

As a result of this, a wider definition evolved. This definition appeared in a Department of Industry booklet (6) published in July 1974. The definition was then stated as:-

Terotechnology is a combination of management, financial, engineering and other practices applied to physical assets in pursuit of economic life-cycle costs; it is concerned with the specification, and design for reliability and maintainability of plant, machinery, equipment, buildings and structures, with their installation, commissioning, maintenance, modification and replacement, and with feedback of information on design performance and costs. (Terotechnology: Concept and Practice, H.M.S.O., ibid., p.3)

Further refinement to this definition took place and in November 1975 a new booklet (7), published by the Committee on Terotechnology, defined terotechnology as follows:-

A COMBINATION OF MANAGEMENT, FINANCIAL, ENGINEERING AND OTHER PRACTICES APPLIED TO PHYSICAL ASSETS IN PURSUIT OF ECONOMIC LIFE - CYCLE COSTS.

The remainder of the definition was then added, as a note,

as follows:-

Note:

Its practice is concerned with the specification and design for reliability and maintainability of plant, machinery, equipment, buildings and structures, with their installation, commissioning, maintenance, modification and replacement, and with feedback of information on design, performance and costs.
(Terotechnology: An Introduction to the Management of Physical Resources, H.M.S.O., ibid., p.2)

This format received wider approval and is still the accepted way of presenting the definition of terotechnology.

2.6 Summary.

This chapter has examined the historical development of terotechnology. It has been seen that terotechnology emerged out of the considerable growth of interest in maintenance engineering. From the findings of the Maddock Working Party on Maintenance Engineering, there was a demand for a new approach to the care of physical assets. This new approach was found in the word terotechnology, the technology of 'caring for'. The concept has evolved into a new approach to the way in which industry manages physical assets in pursuit of economic life-cycle costs. The definition has been stated and its evolution described. The next chapter will examine the literature in an attempt to understand the way in which this new word has been interpreted.

CHAPTER 3

A REVIEW OF THE LITERATURE

This chapter reviews some of the literature on terotechnology. The review is confined to two aspects of the concept and practice of terotechnology. That is, attempting to understand what is meant by the definition and how that understanding has been interpreted within the literature. This was considered essential in order to establish answers to two questions, hitherto not examined by a literature survey.

Firstly, was terotechnology viewed as a multi-disciplinary or inter-disciplinary technology or has no clear understanding yet been arrived at? Secondly, what interpretation, if any, has been placed on the concept and practice of terotechnology? It was considered that with these two fundamental questions answered, a clearer understanding of the role of terotechnology within manufacturing industry could follow.

3.1 Terotechnology: Multi-Disciplinary or Inter-Disciplinary?

This section examines the literature in an attempt to answer the confusion which surrounds the problem of defining terotechnology as multi-disciplinary or inter-disciplinary. The Atkinson Report on Terotechnology (op.cit.), published in June 1973, does not assist in this matter. For example, on page 1, it stated "The inter-disciplinary nature of terotechnology"

yet on page 5 it stated that "... because no suitable word existed to describe such a multi-disciplinary concept the name 'Terotechnology' was adopted". The Department of Industry booklet(8) stated that one of the main requirements for the implementation of terotechnology is " an acceptance of the multi-disciplinary approach to the running of an enterprise". Another Government Report, TT139, (9) of the Committee for Terotechnology stated that:-

It was realised that improvements in life-cycle performance could only be achieved by the co-ordinated application of several disciplines which had not before been brought together in such a way and because no existing word adequately described the new multi-disciplinary approach ... Terotechnology was chosen.
(Committee on Terotechnology, TT139, p.3)

Other Department of Industry booklets such as TT103 (10) and a later publication 'Terotechnology: An Introduction to the Management of Physical Resources' (op.cit.p.2) described terotechnology as "multi-disciplinary". However, another Department of Industry publication, 'Terotechnology-Education and Training' (11), used both the terms inter-disciplinary (p.1) and multi-disciplinary (p.4).

Partington(12) suggested that "taking care of plant items throughout their life-cycle, is the business of terotechnology ... this illustrates the multi-disciplinary aspect of what is involved". Westlake(13) described terotechnology as a "multi-disciplined science". Venton(14) also took the view that terotechnology is a "multi-disciplinary concept". Husband(15) described terotechnology as a "multi-disciplinary approach to maintenance engineering".

However, McCallum(16) stated that "Terotechnology is an inter-disciplinary subject" and Atkinson(17) described terotechnology as an "inter-disciplinary subject, involving interplay between electrical and electronic engineering, mechanical engineering, civil engineering etc."

The initial confusion expressed in the Department of Industry booklets seems to have led to some confusion in the literature. However, this review has indicated that the majority of authors take the view that terotechnology is a multi-disciplinary technology. Therefore, this is the view which will be expressed throughout this research work. The next section will examine how terotechnology has been interpreted in the literature.

3.2 Terotechnology: How has it been Interpreted.?

This section examines the way in which the concept of terotechnology has been interpreted within the literature. That is, is it considered to be merely an attitude of mind, a concept, a science, or just another word to describe something which it is felt has been practised for many years?

The literature takes many viewpoints on terotechnology. It is the purpose of this section to arrive at a consensus, if this is possible, in order to develop the interpretation further to facilitate the research design. The first interpretation is that given in the Department of Industry booklet, Terotechnology: Concept and Practice (op.cit.), which describes terotechnology as being "concerned with improving industrial efficiency through optimisation of the whole

life-cycle of physical assets". Another Department of Industry booklet(18) used the following alternative descriptions of terotechnology:-

- (a) Resource Management
- (b) Whole-Life Costing
- (c) Costs in Use
- (d) Total Cost of Ownership
- (e) Cradle to Grave Management
- (f) Physical Assets' Management
- (g) Life-Long Care

A later booklet (19) published by the Department of Industry replaced (b), (c) and (d) above with the term "Cost of Ownership".

In 1975, the Duke of Kent, when opening a conference, said of terotechnology "it is more of a management technique than strictly a technology". Finniston(20) stated, "Terotechnology views plant as requiring integrated treatment from first concept to final shutdown at the end of its life". Darnell(21) has interpreted terotechnology "as a system of an organisation which interacts with the General Management System ... with the Design and Manufacturing System ... and with the Operational Management System ". White (22) stated, "what the definition of terotechnology really means is that we must look at physical assets in terms of whole-life economics". Perry (23) stated that "Terotechnology can be thought of as an attempt to optimise the life-cycle cost of a ... physical asset".

*when the
life ends
ECONOMICAL*

De la Mare (24) stated that "Terotechnology means a total systems approach to maintenance problems". McCallum (25) said of the definition of terotechnology "it is an absurdly naive description", but he did not suggest an alternative.

Answering criticism in the literature that terotechnology was just another word for maintenance engineering, Atkinson (26) suggested that "maintenance engineering is to Terotechnology as lubrication is to Tribology". The Chartered Mechanical Engineer (27) in an editorial, considered terotechnology "to be a systems' approach to the non-operational management of plant". Jost (28) stated that "Terotechnology is not only a product, but a requirement of modern technological development. It has been forecast to become one of the great technological movements of our age". Wiegel (29), when describing the model of his 'functional maintenance system', said of his model:-

The model must be developed into an expanded external system. Planning, design, assembly, manufacture and maintenance must be integrated to form the basis of a new technical thinking which is covered by the concept of terotechnology (Wiegel, Functional Maintenance-A Systems Approach, Metals Technology, January 1974 pp.6-12)

Darnell and Smith (30) stated that:-

Terotechnology ... concerns the application of the business objectives of an enterprise to the management of its permanent physical resources ... As such Terotechnology can be considered to be one of a number of sub-systems ... which taken together comprise the business.

(Darnell, H. and Smith, M. Management Aspects of Terotechnology. University of Durham, September 1975)

A later booklet published by the Department of Industry (op.cit.) suggested the following alternative interpretations can be placed on the word terotechnology:-

- (a) Resource Management
- (b) Cost of Ownership
- (c) Life-Cycle Management
- (d) Physical Assets' Management
- (e) Life-Long Care

It is interesting to note that the descriptions given in (b) and (c) above replaced the earlier four descriptions, given on page 20. This is an illustration of the maturing in the interpretation that has taken place over a fairly short period of time.

3.3 Summary

This chapter has reviewed the literature on terotechnology in two specific areas of concern. That is, whether the concept is multi-disciplinary or inter-disciplinary and in what way had the concept been interpreted within the literature.

The review has shown that despite early confusion over terotechnology the literature has tended to interpret the concept and practice of terotechnology as multi-disciplinary. Furthermore, the interpretations that have been placed on the definition of terotechnology have been very varied and it has not been possible to arrive at a consensus of views merely on the basis of a literature review. Hence, these interpretations will be examined in greater depth in the next chapter which will be concerned with developing a

generalised interpretative model¹ for the definition of terotechnology.

¹The definition used by the author, throughout this dissertation, for the noun "model" is as follows:-

"a framework or structure to describe a system"

CHAPTER 4

A DEVELOPMENTAL INTERPRETATION OF TEROTECHNOLOGY.

4.1 Examination of the Definition.

This chapter examines the definition of terotechnology in order to develop a generalised interpretative model of the definition. This model will then be used as a foundation for the development of a more detailed understanding of the nature of terotechnological practice within industry.

The analysis takes the form of an examination of the meaning of certain words which the author has perceived to be important to the development of a generalised and wider understanding of the definition of terotechnology. To facilitate such an analysis account is taken of the use of synonyms to replace the words actually used in the definition. Such synonyms have been selected because they are commonly used terms in organisational and economic analysis. As a result, the use of these terms facilitates the logical development of a generalised interpretation of the definition.

The definition of terotechnology states that it is:-

A combination of management, engineering, financial and other practices applied to physical assets in pursuit of economic life-cycle costs.

Note:

Its practice is concerned with the specification and design for reliability and maintainability of plant ... , with their installation, commissioning, maintenance, modification and replacement and with feedback of information on design performance and costs. (Terotechnology: An Introduction to the Management of Physical Resources, H.M.S.O., ibid. p.2)

The first word to consider in the definition is the noun 'combination' meaning 'a union of individual things'. The things which are required to be combined in terotechnology are management, financial, engineering and other practices. The verb 'combine' means 'to unit and form a new compound' and the word 'compound' means 'a whole composed of a number of parts'. Turning to organisational language, a commonly used expression is that of an 'organisational system', where a system is defined as 'a whole composed of a number of parts or subsystems'. The necessary combination of practices suggested by the definition of terotechnology is here likened to an organisational system of management, engineering, financial and other practices applied to physical assets in pursuit of economic life-cycle costs. Turning to convention in organisational language, the word 'system' is generally used only to describe the total organisation. Subordinate combinations of practice are described generally as 'subsystems'. Therefore, the author contends that terotechnology can be seen as a subsystem of management, engineering, financial and other practices operating within a total organisational system.

The second word of interest in the definition is 'pursuit' meaning 'to endeavour to attain'. The context of this word is important within the definition which states that terotechnology is in pursuit of economic life-cycle costs. That is, the definition recognises the difficulty, if not impossibility, of actually achieving economic life-cycle costs given the problems of estimation, forecasting, inflation and so on.

In other words, it is suggested here that the definition of terotechnology is allocating a responsibility to the terotechnology subsystem to pursue the goal of economic life-cycle costs in the same way as, for example, the operations' subsystem would be required to pursue a given level of output and the marketing subsystem a certain level of sales.

Another word considered in this analysis is the adjective 'economic' meaning 'the efficient use of something'. The word 'efficient' is an adjective of the noun 'effective' meaning 'successful in producing a result or effect'. The word 'effective' is a commonly used term within management, financial and engineering literature. For example the terms 'management - effectiveness', 'cost-effectiveness' and 'systems-effectiveness' are typical. This leads to the concept of 'effective life-cycle cost' as a more meaningful term than 'economic life-cycle cost'. The use of quantitative techniques in the field of life-cycle costing and the requirement to pursue the 'efficient use of physical assets' leads to the development of a measure of the degree to which terotechnology is 'cost-effective' in a life-cycle cost sense. That is, the author suggests, there is a requirement for the use of 'life-cycle cost-effectiveness analysis', as a quantitative economic evaluation technique to measure the performance of the terotechnology subsystem.

In addition, the technique could be used for investment appraisal and as a management decision making tool.

Further analysis of the definition shows that the functions over which terotechnology is said to be concerned in the life

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of a physical asset are:- specifying, designing, installing, commissioning, maintenance, modification, replacement and feedback of information on design, performance and costs.

The function, not included within the direct life - cycle of a physical asset, is that of 'operation'. Consequently, it is suggested that terotechnology is intended to embrace the non-operational management, engineering, financial and other practices over the life-cycle of a physical asset.

4.2 A Generalised Interpretative Model

The analysis in the previous section has enabled the following general statements to be postulated:-

- a) That terotechnology can be considered as a subsystem of the total organisational system.
- b) That the subsystem is charged with the responsibility for pursuing cost-effective life-cycle costs for an organisation's physical assets.
- c) That the subsystem is responsible for the non-operational management, engineering, financial and other practices over the life-cycles of an organisation's physical assets.

Superimposing these three postulates into the definition of terotechnology the following interpretative model of the definition is proposed:-

Terotechnology can be considered to operate as a subsystem of an organisation responsible for the non-operational life-cycle management, engineering, financial and other practices applied to that organisation's physical assets in order to pursue cost-effective life-cycle costs for those assets.

It exists as one of a number of subsystems in a total organisational system, which when combined, are responsible for pursuing the business objectives of that organisation.

It is suggested that this generalised interpretation could be applicable to any organisational system which manages physical assets. That is, it could apply to government organisations, transport and distribution organisations, rental and leasing organisations and so on. However, within the context of this work, it is intended to apply to manufacturing organisations only.

4.3 Summary.

This chapter has developed a generalised interpretation to be placed on the definition of terotechnology in terms of its perceived role as part of a total organisational system. The fact that terotechnology has been interpreted as a subsystem of an organisation with responsibility for the non-operational life-cycle management of an organisation's physical assets could have far reaching implications. For example, what is meant by a terotechnological practice or principle? What consequences could such an interpretation have on organisation design? What consequences could it have for the communication requirements between professional disciplines and functional groups? What consequences could it have for the existing use of the 'low-bid' as a means of plant selection? What consequences could it have for the approach to the education

and training of engineers, managers, accountants and others?

Whilst it would be desirable to seek answers to all of these questions most of them are outside the scope of this work. The question which must be answered in order to pursue this research further is the first one. That is, what is meant by a terotechnological practice? It is this problem which is the subject of the next chapter.

CHAPTER 5

TEROTECHNOLOGICAL PRACTICE: A 'LEVEL-OF-CARE' MODEL

5.1 Introduction.

In Chapter 4 the concept of terotechnology was analysed and a generalised interpretation of the concept was developed. However, the problem of describing what is meant by so called 'terotechnological practices' still remains. It is the purpose of this chapter to attempt to identify these practices over the life-cycle of a physical asset.

5.2 The Concept of 'Caring-For' Physical Assets.

Terotechnology is the technology of 'caring-for' plant and equipment in order to pursue economic life-cycle costs. The term 'caring-for' is synonymous with the nursing profession. Hence, the author examined the literature to determine what attempts had been made at defining or, at least, describing what is meant by 'caring-for' sick patients. Wahlin, et al. (31) states that there are three 'levels' of patient care. These are identified as 'light-care', 'intermediary-care' and 'intensive-care' with specific practices being associated with each level. For example, light-care could include treatment of minor cuts and bruises and the administration of medicines at regular intervals.

Intermediary-care could include the care associated with pre- or post-operative situations of a less serious nature. Whilst intensive-care involves the continuous and detailed monitoring and treatment of a patient's condition, when suffering from critical injuries or a very serious illness.

These 'levels-of-care' are most useful to the nursing profession in the identification of the necessary resources that must be available to deal with different numbers of patients requiring treatment at the various levels. Stephenson¹, for example, mentioned their application in manpower planning and in the determination of the degree of patient dependency on staff and equipment.

This type of application is just the sort that such a scale of care could be used for in an industrial situation. If such a scale could be developed for the care of physical assets, based on the identification of terotechnological practices, then it could be used in the identification of resources required to operate at a given 'level-of-care'. Furthermore, it could be applied as a tool for the comparative analysis of terotechnological practices within the industrial field research.

5.3 Macro or Micro Levels ?.

In order to develop some form of conceptual framework for terotechnological practices in terms of 'levels-of-care' two alternatives were considered. Firstly, the concept of there

being overall or macro level practices applicable throughout all phases of a plant's life-cycle. However, this would require identification of practices that were equally applicable to say, the design phase as they were to the installation or maintenance phases. Several attempts were made to develop such a model but the resulting scales were too generalised and ambiguous to withstand application.

The second alternative was to consider separately each phase in an asset's life-cycle and to attempt to develop a specific or micro level model of terotechnological practice for each phase. This would facilitate closer examination of possible practices and would be a more meaningful methodology in the light of the overall research objectives stated in Chapter 1. As a consequence, it was the second alternative that was chosen and developed.

5.4 Defining the Terotechnological Life-Cycle.

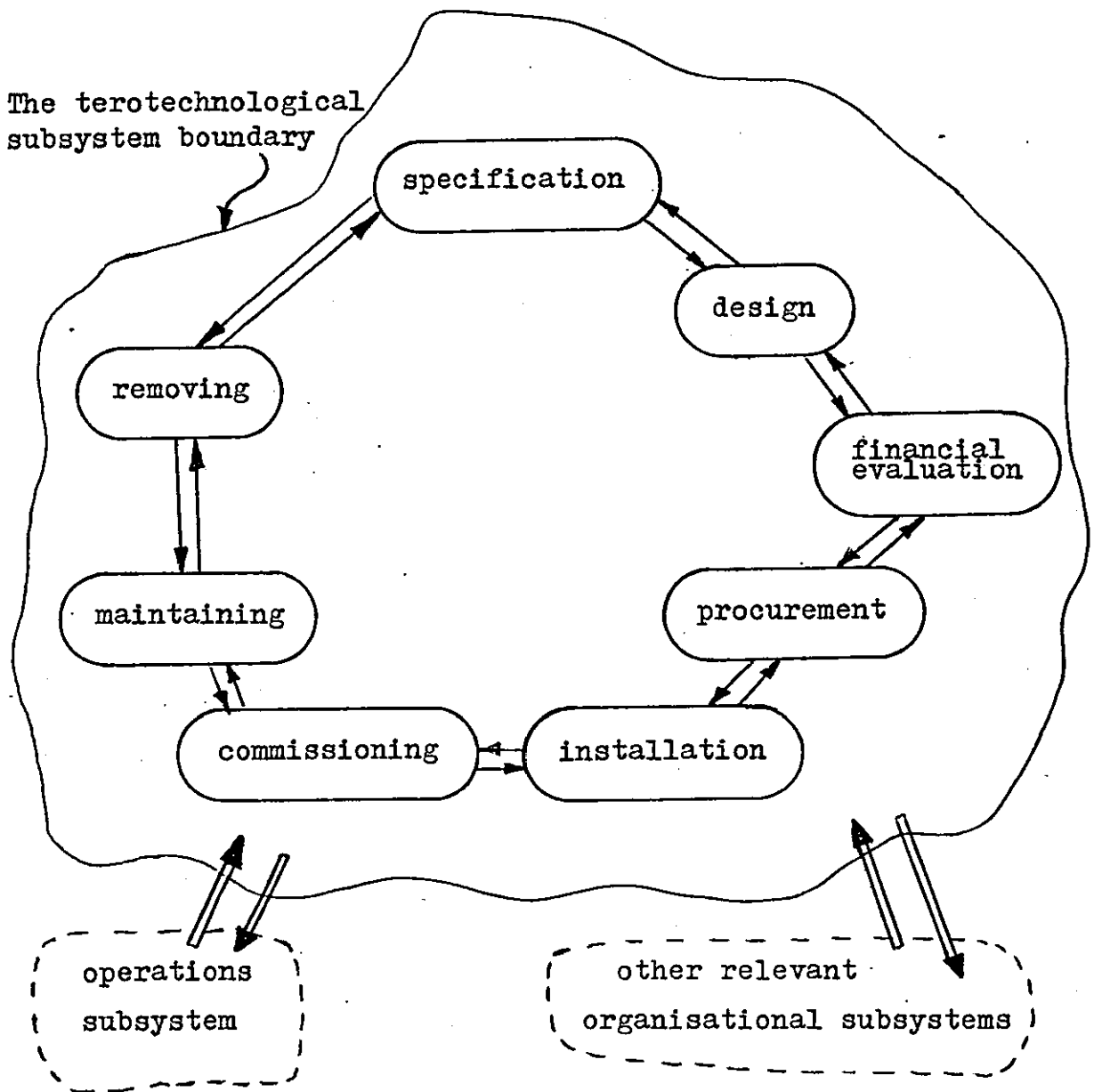
In order to develop levels-of-care within each phase of a plant's life-cycle it is firstly necessary to define the terotechnological life-cycle through which a plant will progress. The definition of terotechnology states some of these phases. These are specification, design, installation, commissioning, maintenance, modification and replacement, together with feedback of information on design, performance and cost. However, this definition would be inadequate when applied in conjunction with the generalised interpretation of what

is meant by the definition of terotechnology as developed in Chapter 4. That analysis concluded that the interpretation to be placed on terotechnology, within this dissertation, would be as follows :-

Terotechnology can be considered to operate as a subsystem of an organisation responsible for the non-operational life-cycle management, engineering, financial and other practices applied to that organisation's physical assets in order to pursue cost-effective life-cycle costs for those assets. It exists as one of a number of subsystems in the total organisational system, which when combined, are responsible for pursuing the business objectives of that organisation.

As this interpretation differed in emphasis from the definition, it was necessary to consider how this affected the definition of the terotechnological life-cycle.

In almost all engineering projects the first phase is concerned with defining what is actually required. That is, writing the specifications. The next stage would be to design the plant according to that specification. Having laid down one or more design schemes, it is then necessary to carry out the costing and general financial evaluation of the design(s). From this phase follows the procurement of bought-out items together with their installation and commissioning. After commissioning the plant comes into full scale operational use during which time it must be maintained. At the end of its life the plant must be removed and replaced. Throughout the life there should be feedback of information on design, performance and cost characteristics. From this



The Terotechnological Life-Cycle

Figure 1



= life-cycle phases



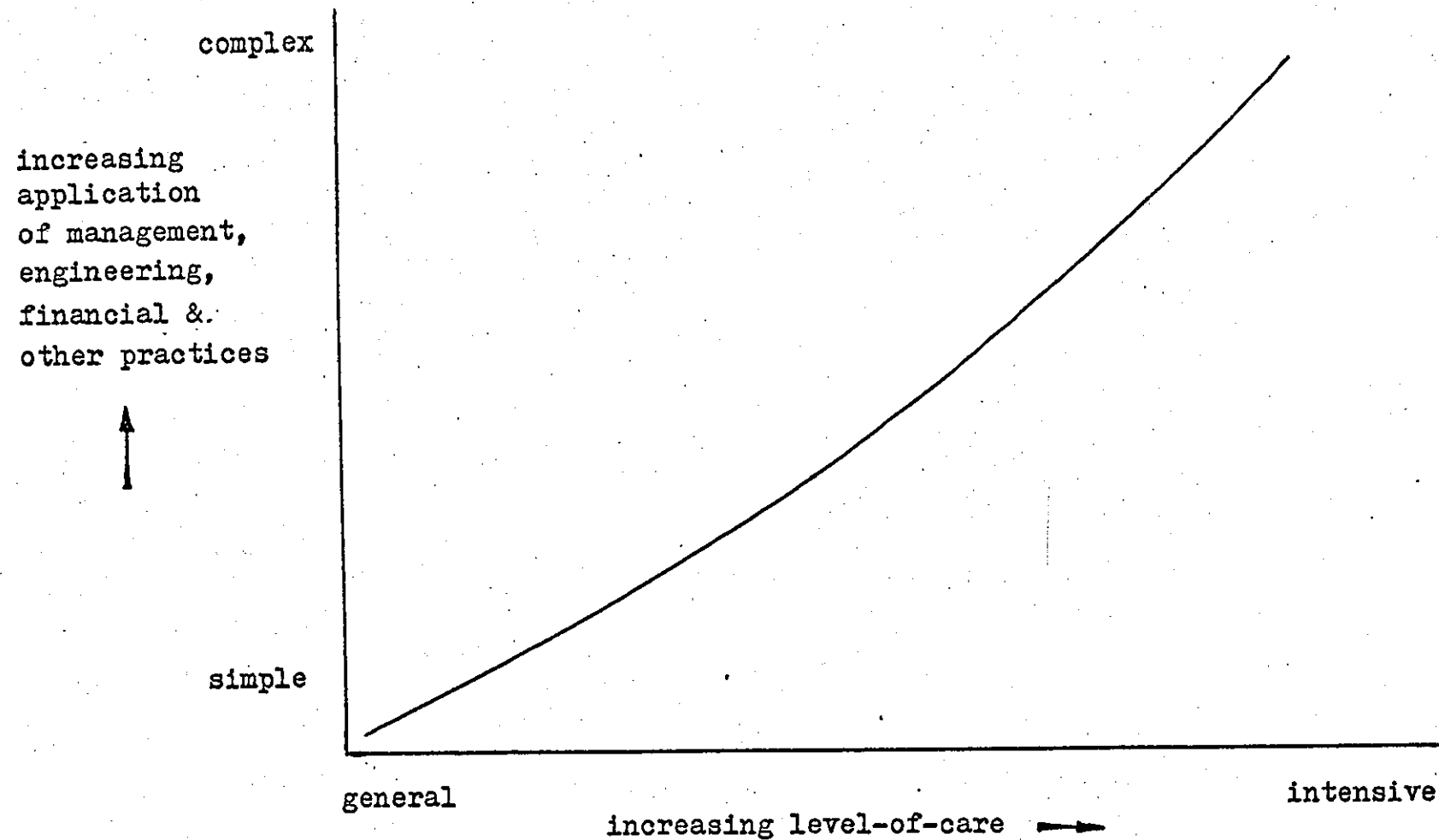
= flows of information on design, performance and costs.

rationale a definition of the terotechnological life-cycle was derived. It is seen to be a cyclic process during which a plant is prepared for operational use, put into use and maintained such that it remains in an operational condition and is finally removed from use at the end of its life. This life-cycle is depicted schematically by Figure 1.

5.5 A 'Level-of-Care' Continuum.

Within the literature several examples exist of attempts to develop levels, scales and degrees of practice. For example, Wahlin's levels-of-care in nursing, Amber and Amber's degrees of automaticity, Bright's levels of mechanisation and the scales of yarn quality within the textile industry. These attempts, although subjective, do provide a framework for analysis, understanding and development within the particular subject area.

If a combination of management, engineering, financial and other practices are to be applied to physical assets then it is conceivable that such practices could vary along some form of continuum from the very simple level to one which is very complex or intensive. This concept is depicted schematically by Figure 2. This figure is an attempt to illustrate the proposition that increasing the degree of application of terotechnological practices will, by definition, increase the 'level-of-care' applied to an asset. This idealised



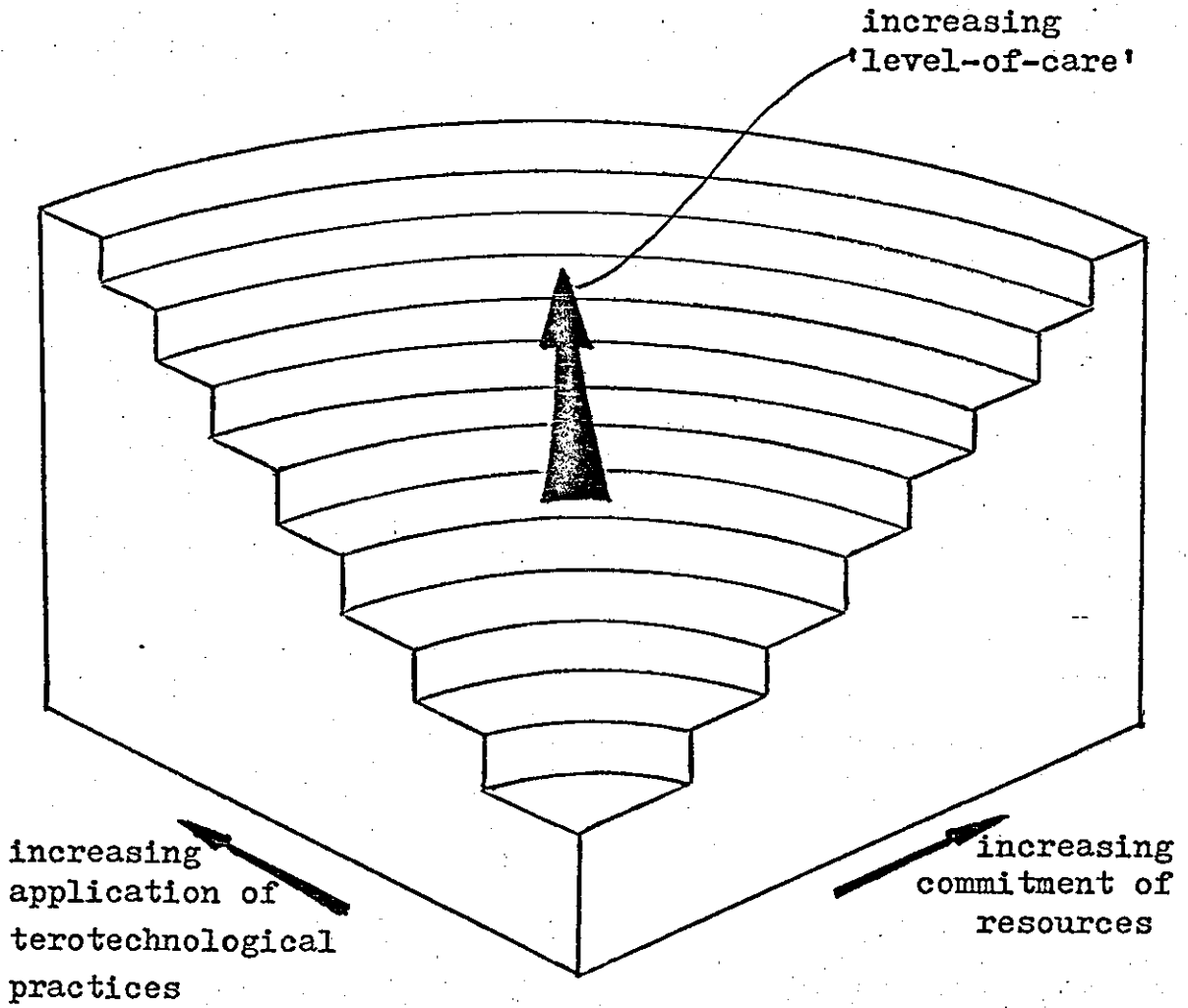
An Idealised Level-Of-Care Continuum

Figure 2

representation is however an incomplete picture.

Figure 2 is inadequate because it has not taken account of that aspect of management policy which facilitates such an increase in terotechnological practice, that is the commitment of resources to a particular endeavour. Figure 3 is intended to provide for this factor. In this figure the 'level-of-care' is shown as depending on both the degree of application of terotechnological practices and the commitment of resources within an organisation. Further consideration of the way in which resources are committed leads to a more realistic model of the continuum. That is to say, capital is usually allocated in discrete sums. Furthermore, the application of particular practices does not usually take the form of a smooth transition from one level of practice to another. It is more appropriate to consider changes of practice again as discrete events often occurring at a specific time as a result of new personnel or equipment entering the organisational system. Therefore, Figure 3 illustrates these concepts by showing the increases as steps in which each step represents a discrete change in practice, commitment of resources and a consequential change in the 'level-of-care'.

From this concept of step-wise increases in terotechnological practice, commitment of resources and hence, levels-of-care, it was thought feasible to consider the application of terotechnology in terms of different levels



A Realistic Level-Of-Care Continuum

Figure 3

of sophistication. These levels could vary from the most generally applicable practices to those which are very advanced and require considerable resources..

The next section considers the problem of describing such levels-of-care when applied to physical assets.

5.6 Describing the 'Levels-Of-Care'.

The literature shows that attempts have been made by the nursing profession to describe levels of patient care. For example, Wahlin et al (op.cit.) described three levels of patient care as 'light-care', 'intermediary-care' and 'intensive-care'. In addition, Norton et al (32) have described the levels as 'basic-care', 'technical-care' and 'total-care'. Other work has also been carried out by the profession to describe levels of patient dependency and capability.

Such subjective scales are also found in Woodward's (33) scales of technical complexity and other work on automation mentioned earlier. Considerable thought was given to the possibility of developing detailed and rigorous definitions for levels of physical asset care. However, as this task had not even been attempted within the discipline of the nursing profession, it was considered an unworkable method to adopt, at this point in time, for research within manufacturing industry. As a consequence, it was thought to be more appropriate to attempt to formulate generalised descriptions of the forms of care that could be envisaged. Such levels could then

be more closely described by the identification of specific practices that could be associated with each 'level-of-care'.

The first level proposed is a level of 'general-care'. The second level is that of 'moderate-care'. with the third level being described as 'advanced-care'. The fourth and highest level will be described as 'intensive-care'. Each of these levels are described below:-

5.61 General-Care: The adjective, general, is defined as :-
not restricted or specialised, relating to the whole or most, nearly universal, prevalent, widespread.

Hence, the word has been chosen to describe a level-of-care which encompasses a group of simple practices that could be applied in almost all manufacturing organisations at each phase of an asset's terotechnological life-cycle.

5.62 Moderate-Care: The adjective, moderate, is defined as :-
not excessive or extreme, characterised by temperance, not rigorous, of middle rate.
Hence, the word has been chosen to describe a level-of-care which is intended to encompass those practices which would require a reasonable commitment of resources in order to apply terotechnological practices during an asset's life-cycle.

5.63 Advanced-Care : The adjective, advanced, is defined as :-
a far-on stage in any course of ideas
or actions.

Hence, this word was chosen to describe a
level-of-care in which the practices
adopted could be associated with a
considerable degree of development in the
application of terotechnology.

Such practices could be expected to provide
a comprehensive life-cycle management
system for an organisation's physical assets.
To operate at this level-of-care would
require a further commitment of resources
over and above those employed at the
'moderate' level-of-care.

5.64 Intensive-Care: The adjective, intensive, is defined as :-
concentrated, unremitting, of a very high
degree of depth or fullness.

Consequently, the word has been chosen to
describe a level-of-care in which
terotechnological practices are applied
to an organisation's physical assets in
order to provide a system of detailed
monitoring and observation of plant
performance with subsequent intensive
analysis and treatment. This could be

considered as the level at which an organisation has developed a complete terotechnologically based physical asset life-cycle management system. This level would require a further commitment of resources to supplement those employed at the advanced level-of-care.

The generalised levels-of-care, described above, provide a framework around which specific terotechnological practices can be proposed as being representative of each level-of-care. The next section considers the problem of determining what these terotechnological practices should be.

5.7 What are Terotechnological Practices?

The problem of determining what constitutes a terotechnological practice had not been considered in the literature. As a result the identification of practices, within the terotechnological life-cycle, are entirely those considered appropriate by the author.

The method adopted was to consider each phase in the life-cycle and to identify representative practices that could be adopted within each phase. These practices were then considered in greater detail and subsequently allocated to a particular level-of-care. Several alternative schemes were drawn-up and analysed. The resulting scheme is presented in matrix form in Table 1. This table shows the four levels-of-care described earlier, with the representative practices to be associated with each level for each phase in the life-cycle.

The rationale behind the allocation of a particular practice to a given level-of-care, whilst subjective, is praxeological² in nature. In order to illustrate this it was thought appropriate to describe here the way in which terotechnological practices were identified and associated with a given level-of-care for one of the phases of the terotechnological life-cycle. As maintenance is the major phase in the life-cycle of most physical assets, the rationale adopted for this phase is described in the next section.

5.8 Terotechnological Practice in Maintenance.

In developing a scale of terotechnological practice from the 'simplest' to the most 'complex', the posture taken was to consider what practices should be adopted, in the authors view, by an organisation if it is to progressively apply terotechnologically (caring) orientated practices to the life-cycle management of its physical assets.

Within the maintenance phase the first practice thought necessary was that of providing a breakdown maintenance service. This was thought to be the minimum level at which a maintenance system should operate. Hence, breakdown maintenance was considered a practice applicable to the level of 'general-care'. Further consideration of practices appropriate to 'general-care' indicated that the next provision of resources should be directed towards

a system of regular lubrication for plant and equipment. From this stage, the provision of a supply of spare parts, for those items known to need regular replacement, was considered as the next most appropriate practice. Having provided the resources for breakdowns, lubrication and spare parts the next stage of development was thought to be in terms of the provision of a system of priority allocation for work. This was considered as the minimum level of control that could be envisaged at the level of 'general-care'. Hence, within the framework of the level of 'general-care' the practices of breakdown maintenance, lubrication, spare parts and priority allocation were identified as representative of those which could be expected to be almost universally applied.

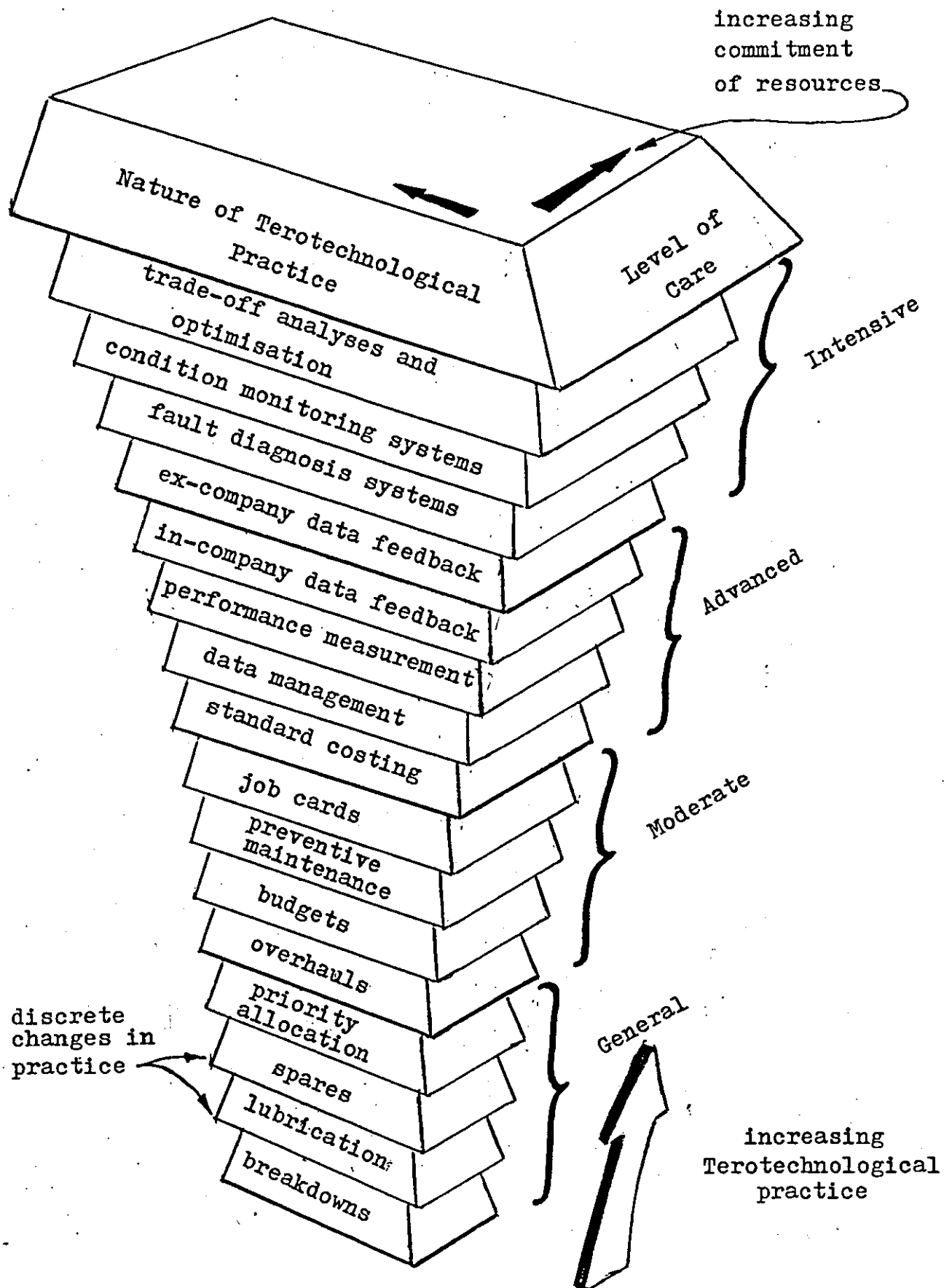
The next stage in the rationale was to identify those practices thought to be within the level of 'moderate-care'. The first practice considered appropriate to this level was that of overhauls. A system of regular plant overhauls was considered to be a moderately sophisticated practice which would not necessarily be universally applied. From this, the need to adopt a form of maintenance budgetary control was thought to be the next stage of development. The maintenance system has now reached a stage of development in which breakdowns, lubrication, spare parts, priority allocation, overhauls and budgets are all catered for.

The next stage of 'moderate-care' was considered to be the use of preventive maintenance inspections carried out at regular intervals. From this stage it would then be possible to introduce a formalised system of job recording with the use of job cards designed to produce a range of control information. The consideration of moderate practices (ie. the practices considered to be non-rigorous, but more sophisticated than the 'general-care' ones) ended at the 'job cards' stage of development.

The next level-of-care to consider was the 'advanced' level. The first practice considered to be applicable at this level was that of standard costing. The use of standard costing, as a planning and budgeting tool, was considered to be an advanced practice within a maintenance system. This would enable more detailed management information to be produced and create the need for some form of data management. Hence, it was data management that was considered as the next most desirable practice to employ. This would facilitate the collection, manipulation, reporting, analysis, feedback and storage of management information. Having established a system of data management then the next practice was considered to be the use of some form of maintenance performance measurement. The use of this 'advanced' practice would enable management to identify those aspects of the maintenance system that were not functioning effectively and to take action

accordingly. As a system of data management would exist, then the next development was thought to be the use of an in-company data feedback system. This practice would ensure that relevant information on plant design, performance and cost characteristics was fed back to the functional groups with responsibility for those characteristics.

With a system of information feedback in operation within the organisation then the next development in terotechnological practice was thought to be the adoption of a system of information feedback to suppliers, contractors, equipment designers and other external organisations. Hence, a system of ex-company data feedback is seen as the first practice that could be associated with an 'intensive' level-of-care. Further consideration of intensive-care for plant and equipment led to the use of fault diagnosis as the next most appropriate practice to adopt. Fault diagnosis systems would provide a very rapid and systematic approach to the location and subsequent treatment of a plant failure or malfunction. The next development over and above the use of fault diagnosis aids was seen to be the use of condition monitoring systems. This would enable intensive observation of a plant's health in order that early signs of deterioration could be detected and corrective action taken before any disruption to production is experienced. The use of data gathered from the condition monitoring systems would then enable further intensive management of the plant. This could take the form of simulating the operating, reliability,



Maintenance: The Levels of Terotechnological Practice

Figure 4.

maintainability and cost characteristics, performing 'trade-off' studies and optimisation techniques in order to develop an optimum terotechnologically based maintenance policy. This level of practice was considered to be the most intensive level that could be envisaged in relation to the current level of knowledge within physical asset life-cycle management. As a consequence this was the final level of practice considered.

The foregoing section has described the way in which the various terotechnological practices were identified and associated with a particular 'level-of-care'. The rationale for the maintenance phase has been described. In the model shown in Figure 4 this analysis is depicted schematically. The figure is an attempt to illustrate the step-wise nature of advancement in practice from one stage to the next. Each stage requiring an increase in the resources employed. The figure shows each practice that was identified within the maintenance phase together with the levels-of-care. The figure illustrates the increasing depth and breadth of resources needed to operate a terotechnological system of maintenance management as the level-of-care increases.

A similar procedure was adopted to analyse all of the terotechnological life-cycle phases in order to identify practices and associate them with a particular level-of-care. The resulting matrix is shown in Table 1.

TABLE 1

A LEVEL-OF-CARE/LIFE-CYCLE MANAGEMENT MATRIX

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES EMPLOYED TO 'CARE - FOR' A PHYSICAL ASSET DURING ITS LIFE-CYCLE							
	SPECIFYING	DESIGNING	FINANCIAL EVALUATION	PROCUREMENT	INSTALLATION	COMMISSIONING	MAINTENANCE	REMOVAL
INTENSIVE	life-cycle costing life-cycle estimation M.T.B.F. anticipated component life M.T.T.R.	trade-off studies cost-effec. analysis life-cycle costing reliability and maintain-ability analysis	trade-off studies & optimisation Life-cycle costing Post completion auditing	incentive contracting approved supplier listings	review and information feedback recording of problems with services	reliability testing maintain-ability testing maintenance fitter training	optimisation studies condition monitoring fault diagnosis ex-company data feedback	assess reliability of new plant recording and feedback of experience
ADVANCED	fault diagnosis systems use of historical data training schemes modular construction	design data bank historical information on M.T.B.F. historical information on M.T.T.R. condition monitoring information feedback to design	performance analysis use of quantitative techniques	late delivery penalties formal supplier vetting	recording problems with plant use of network analysis manpower planning	maintenance management training formal reviews & information feedback recording of auxiliary equipment faults	in-company data feedback performance measurement data management standard costing	assess life of new plant assess maintain-ability of new plant review reliability of old plant
MODERATE	preventive maintenance schedules overhaul schedules ease of access ease of control	analysis of breakdown data & job cards analysis of maintenance costs discussions with maintenance	investment appraisal	receipt inspection	task planning budgeting equipment planning	recording plant faults training of production management training of operators formal acceptance procedure	job cards preventive maintenance inspections budgets overhauls	review maintain-ability of old plant formal plans for removal budget for removal
GENERAL	maintenance manual list of spare parts	scheduling of work reviews of reports, journals etc plant modification system	budgets	progressing	work scheduling 'services' layouts site layouts	evaluation of operation against spec. production of comps. tests of performance commissioning schedule	priority allocation spare parts lubrication breakdowns	assess residual value of plant assess operating requirements for plant assess market for product

5.9 Summary.

This chapter has explored the concept of 'caring-for' plant and equipment. It has attempted to develop a model based on 'levels-of-care' in which each level is associated with the employment of particular practices and commitment of resources. The literature showed that similar models had been attempted by the nursing profession.

Four 'levels-of-care' were derived. These were, general-care, moderate-care, advanced-care and intensive-care. The terotechnological practices associated with each level were identified and are shown in matrix form, for all the phases in the life-cycle, in Table 1. This identification has provided a description of what is meant by the use of terotechnological practices within the context of this dissertation. Furthermore, it has provided a framework for the comparison of organisations within the industrial field research.

The next chapter describes the formulation of the research objectives, the field research design and the method of presentation adopted to show the results of the field research.

¹ Miss C. Stephenson, Principal Lecturer in Nursing, Leeds Polytechnic, March 1978. Discussions held with the author regarding research into levels of patient care and their value to the nursing profession.

² The word "praxeological" used in this chapter requires some explanation because a wider meaning is placed on it than the dictionary suggests. The dictionary defines praxeology as "the study of human action and conduct". However, the word is used here in its wider context as described by Nottage, H.B. in Praxeology and Subjective Values in Project Management, School of Engineering and Applied Science, University of California, October 1974. Quoting Nottage:

...Praxeology is an individual's intelligent, aprioristic and subjective values encompassing a think-search-predict and decide prelude to his purposive human action ... The personal decision choice procedure requires the person's comparative evaluation between alternatives in terms of their predicted future personal-meaning consequences, with subjective values entirely dominant. ... Praxeology is a personalised and inherently non-quantitative procedure --- only an individual can think praxeologically ...

CHAPTER 6
INDUSTRIAL RESEARCH
OBJECTIVES AND DESIGN

6.1 Introduction.

This chapter describes the objectives of the industrial field research and the way in which those objectives were determined. The field research design methodologies available are then examined and the most appropriate is selected. The research design and presentation of results is then explained in detail.

6.2 Industrial Research Objectives.

The Atkinson Report (op.cit. page 10) stated, under the sub-heading of Research Projects that:-

In planning a programme of action the committee have been hampered by lack of data on the extent to which terotechnology is being applied in the various sectors of industry, and the adverse effects of not doing so. Information on the practices adopted by industry is also required to indicate those areas where special emphasis should be placed. (Atkinson Report, 1973, page 10)

A further statement from the Atkinson Report of the Committee on Terotechnology states that:-

Lack of information on the extent to which terotechnological principles are being practised in industry ... has led the committee to recommend that a number of investigations be carried out. It is expected that information resulting from these researches will assist in the identification of the main problem areas and will enable a further programme of action to be planned. (ibid. p.2)

These two statements provided the initial focus for

determining the objectives of an industrial research project into the practice of terotechnology. In order to limit the research focus it was found useful to concentrate on two statements contained within the Atkinson Report, (ibid.p.10)these were:-

"Lack of data on the extent to which terotechnology is being applied in the various sectors of industry".
and

"Information on the practices adopted by industry is also required to indicate those areas where special emphasis should be placed."

However,these extracts use global terms such as "various sectors of industry" which was too wide an objective for the basis of a research project to be carried out by a single researcher. Hence,taking this factor into account,the following objectives were defined:-

1. To investigate the extent to which terotechnological practices,as identified within this dissertation, were applied in a small sample of companies within the manufacturing industry classification.
2. To suggest,as a result of the above investigation, those areas of management practice where special emphasis should be placed in order to improve the 'level-of-care' applied to industrial plant and equipment.

3. To employ frameworks for the comparative analysis of industrial practice that were considered to be independent of the economic factors that were affecting company performance at the time of the research programme.

In order to further limit the focus of these objectives the following specific practices were considered for investigation :-

- a. What terotechnological practices were included when specifying plant ?
- b. What terotechnological practices were included when designing plant ?
- c. What terotechnological practices were included when carrying out the financial evaluation of plant ?
- c. What terotechnological practices were included when procuring plant ?
- d. What terotechnological practices were included when installing plant ?
- e. What terotechnological practices were included when commissioning plant ?
- f. What terotechnological practices were included when maintaining plant ?
- g. What terotechnological practices were included when removing plant ?

Operational practice was excluded from the research focus because of the conclusions drawn as a result of

the analysis carried out in Chapter 4 . Having stated the specific objectives of the industrial field research it was necessary to examine the alternative research methodologies available and to determine which would be the most appropriate to use for this work. Once the correct methodology had been determined the field research could then follow. A review of some alternative research methodologies follows in 6.3 below.

6.3 A Review of Alternative Research Methodologies.

This section reviews four basic forms of research methodology in relation to their applicability to the research objectives defined earlier. The four methodologies described by Leedy (34) are :-

- (a) The historical method.
- (b) The analytical method.
- (c) The experimental method.

and

- (d) The descriptive survey method.

(a) The historical method. This methodology relies on data that are derived primarily from documentary sources. These sources are generally documentary remains, written records and artifacts that man has left behind him. The intention of this type of research would be to study the events of past time and to try to comprehend the meaning of these events. Such a study might be conducted into the history of technology or management science. However, the purpose of this research work is to investigate industrial activity as it is happening. Therefore,

it is suggested that the historical methodology is inappropriate to this work.

(b)The analytical method. The purpose of the analytical methodology is to collect and analyse data that are essentially quantitative in nature (numerical) and then to analyse this data using analytical techniques. In the analytical methodology the researcher would be concerned primarily with the testing of a statistically based hypothesis. Such a research effort may be to examine a relationship between the number of production operators against the number of units of output per unit time. In this case all the data would be numerical, hypotheses could be set-up and tested for significance by the use of analytical techniques applied to the numerical data.

This methodology is inappropriate also for the research envisaged because it is to be concerned with establishing 'practices' which are essentially activities in which numerical data is not expected to be available. Furthermore, the objective of the work is not to test a specific hypothesis about the practice of terotechnology, but to determine what that practice actually is. Hence, the analytical methodology was considered to be inappropriate.

(c)The experimental method. This methodology is often referred to as the laboratory method. The essential characteristic is one of control. The experimental method attempts to control the research situation, except for those input variables under study. Such a methodology would be appropriate to a laboratory experiment say to determine the breaking point of a steel bar

or to test the reliability characteristics of electronic components. Clearly, this methodology would have been inappropriate to this research work.

(d) The descriptive survey method. This methodology is designed to facilitate the observation of human activity and other complex processes. The word 'survey' is composed of two elements from the Latin 'super' meaning 'above' 'over' or 'beyond' and the word 'videre' meaning 'to look' or 'to see'. Thus the word survey means 'to look over or beyond'. The word 'descriptive' is derived also from the Latin word elements 'de' meaning 'from' and 'scribere' meaning 'to write'. Hence, the essential characteristic of this methodology is to look or observe and to record what is seen. In research terms the interpretation of this activity is to utilise questionnaire, interview, discussion, observation and data recording techniques. The data then being presented, generally speaking, in the form of tables, charts, figures and descriptive text. Oppenheim (35) says of the descriptive survey:-

Descriptive surveys are well known and important ... The job of such surveys is essentially fact-finding ... they are not designed to "explain" anything or to show relationships between one variable and another. (Oppenheim, 1966, page 8)

Leedy (op.cit.p.114) says of the descriptive survey:-

Descriptive studies deal with questionnaire data, interview data and simple observational information.... Case-studies, Community Surveys and opinion polls are all typical studies in the descriptive survey category. (Leedy, 1974, page 114)

It has already been stated that the objective of the industrial field research was to investigate the extent

to which 'terotechnological practices' were applied to the non-operational management, engineering, financial and other practices over the life-cycles of physical assets. These practices were seen as essentially activities which would be descriptive in nature. The most appropriate method of collecting data was thought to be the questionnaire and interview technique. Hence, the descriptive survey methodology was considered to be the most appropriate technique for conducting the industrial field research defined in section 6.2.

The determination of the most appropriate research methodology led on to examining and recognising the limitations that it would impose. These are examined in detail later in this chapter. However, the author was particularly conscious of the problem of 'researcher role' when carrying out research within an industrial organisation. Barnes(36) recognises this problem when he states that:-

Organisational research also differs from laboratory experiments with regard to researcher status. The experimenter is typically master within the laboratory ... The organisational researcher, however, is typically a guest in someone else's establishment. The various organisational parts and persons may all choose to ignore him, or they may all demand attention simultaneously. When they demand attention it may not be for purposes of cooperating. They may only be suspicious or curious about "whats going on?". At times the organisational researcher will feel that he has absolutely no control over his "subjects". He can only cross his fingers and hope that natural events and some skill will permit him to carry out his work. (Barnes, 1971, pages 77-78)

Perhaps Barnes was quoting from bitter experience or exaggerating to make a point, it is not clear from his book. However, it is certainly true that this author did experience some of the problems that Barnes highlights in that quotation.

The next section deals with the detailed design of the field research project.

6.4 Research Design.

This section covers the design of the research effort. It explains the methods used to select companies, to approach these companies for their co-operation, the response rate, data collection methods, the problems of error and bias and the method of data presentation that was adopted in order to present the results of the field research.

6.41 The Selection of Companies. A list of possible companies, which would be prepared to co-operate with the research project, was drawn up from the Kelly Trade Directory of Company Information (37). The Central Office of Information Business Monitor, PA 1003, (38) was used to identify the manufacturing industry classifications. The counties of Leicestershire, Derbyshire and Nottinghamshire were surveyed. One company was chosen from Yorkshire. Thirty companies were selected on the basis of the expected type of production system and size. It was understood that the University of Aston, Small Business Centre, were engaged on a survey of companies employing less than 200 employees.

Consequently, the size range chosen was that of 200 employees and over, but up to a maximum of 10,000 employees. It was considered that a company larger than 10,000 employees would be too large a unit to be researched adequately by a single researcher. In total, 31 companies were approached.

6.42 Approach to Companies. The formal approach to each company was in the form of an introductory letter and a detailed brochure. The letter explained the objectives of the research and requested the co-operation of the company to carry out the work within the company's premises. The brochure included a brief introduction to terotechnology, a brief account of the objectives of the research, a description of the data that would need to be collected, how the data were to be collected, how confidential the study would be, what assistance would be required from the host company, a brief description of the benefits the host company may expect from the study and those which the university may expect. In addition, a brief curriculum vitae of the researcher was included together with a summary of the P.A. Management Consultants' Report. The covering letter and brochure are to be found in Appendix 1 .

6.43 Response Rate. As mentioned earlier 31 companies were approached to co-operate with the research. The response was as shown in Table 2 over . From the table it can be seen that 16 companies did not reply, 7 companies replied but were unable to co-operate, 2 companies replied that they

TABLE 2
RESPONSE PATTERN OF COMPANIES
ASKED TO PARTICIPATE WITH
THE RESEARCH

Response	Number of Companies
No reply	16
Replied but not wishing to participate	7
Replied but required further discussions	2
Replied and willing to participate	6
Total number of companies approached	31
Response rate	19%

wished to have further discussions. The remaining 6 companies agreed to participate. Of the 2 companies that wished to have further discussions, one company was visited but showed no further interest. The other company was visited, but on mutual agreement it was decided not to use the company as part of the sample.

6.44 Research Period. The research within the six companies was carried out between September 1975 and December 1976. The details of the companies are given in Table 3.

6.45 The Companies. The 6 companies that agreed to co-operate with the research ranged in size from 200 employees to 6,000 employees. All of the companies operated 'flow' type production systems as defined by Lockyer(39). Table 3 shows the details of each company in terms of size, type of product, production system and the alphabetical letter which was allocated to it.

6.46 Data Collection. The methods of data collection adopted were questionnaires, interviews and documentary evidence.

Questionnaires. Questionnaires were designed to cover each of the life-cycle functions that were defined in section 6.2 page 54. Hence, eight questionnaires were drawn up and are shown in Appendix 2. Each questionnaire contained a mixture of open-ended and closed questions. Because of the inherent difficulties in interpreting open-ended question responses, the majority of questions were of the closed type.

TABLE 3
BASIC DETAILS OF THE COMPANIES
THAT AGREED TO PARTICIPATE

Company	Size(1)	Product(2)	Production(3) System
A	350	Textile/ Resin based	Flow
B	200	Chemicals	Flow
C	800	Fine Chemicals	Flow
D	500	Plastics/ Electronics	Flow
E	2,200	Foodstuffs	Flow
F	6,000	Metal Processing	Flow

- (1) Size relates to the number of employees at the location visited.
- (2) Product is that description felt to most accurately describe the companys' products without disclosing the identity of the company.
- (3) Type of production system was determined using the description given by Lockyer(39).

That is, required 'yes' or 'no' answers only. The questionnaires remained under the control of the researcher. A space was left at the end of each question in order to allow for any expansion of the respondents' answer. If a respondent was not sure of the accurate answer to a question he was asked to say so and to refer the researcher to the most appropriate employee. In general, the questionnaires were used to form the basis of an interviewing schedule. The questionnaires are to be found in Appendix 2.

Interviews. The interviews were held with each person who had been allocated the responsibility for each of the life-cycle functions defined earlier. In every case interviews were arranged by appointment and were always held on the company's premises. During the research a total of 90 interviews were conducted with directors, managers and engineers responsible for the life-cycle management of physical assets. The length of interview varied from approximately 40 minutes to 2 hours.

Documentary Evidence. In all cases documentary evidence was asked for in order to provide further evidence of a company's practices. However, in many cases individuals were reluctant to provide documentation, or it was not available at all. Nevertheless, whenever it was available it was collected and the evidence that it provided was examined. As a consequence of the limited documentation available to the researcher it must be recognised that some of the results presented in this dissertation are based only on interview

responses. Some of the documentary evidence collected during the field research has been included in this dissertation and can be found in Appendix 4 .

Errors and Biases. The descriptive survey methodology, by its very nature, is particularly susceptible to distortion from error and bias. It is an important function of the researcher to remain severely critical in the control and elimination of error and to avoid statements of 'exactness' when presenting results. Leedy (op.cit., page 107) states, "Bias is, of course, indigenous to all research projects." Oppenheim (op.cit., page 21) states, "it behoves the research worker to remain severely critical, to search out biases in others and himself and to avoid giving the appearance of spurious exactitude".

Therefore, it is recognised that statements prescribing absolutely certain practices cannot reasonably be made with the certainty ascribed to many physical laws and relationships. Hence, the statements and conclusions made in this dissertation have been bound as formulations in terms of 'tendencies' when dealing with a general population of companies and in terms of an 'indication towards' when dealing with an individual company. The various techniques for control of error and bias, which are outlined by Leedy and Oppenheim, have been incorporated, whenever applicable, into this research work.

6.47 A basis for comparative analysis. The research, as has already been explained, was performed during a period when industrial performance was affected severely by high inflation and a decline in world trade. As a result, it was considered important that from the inception of the research, a basis for comparative analysis should be found that could reasonably be expected to be independent of these influences. Several alternatives suggested themselves. For example, comparison on the basis of number of employees, or size of turnover, or type of product, or by type of industry. However, one other basis for comparison on which little work had been performed was that of the level of mechanisation of the production system. This comparative analysis method could allow the researcher to assess the level of mechanisation of the company's production system and to compare the way in which the life-cycle of the plant is managed in relation to its mechanisation level. A reasonable premise being that the higher the level of mechanisation, the higher would be the need to employ terotechnological practices in order to 'care for' the plant adequately. Three alternatives presented themselves with respect to defining mechanisation. Firstly, the definition offered by Bright (40). Secondly, the definition offered by Amber and Amber (41). Thirdly, to devise a framework for the definition of mechanisation as part of this research work. The third alternative was considered inappropriate as this task could probably form the basis

of a single research project. Therefore, the use of Bright or Amber and Amber was considered more appropriate. On analysis of the two types of mechanisation frameworks, it was found that the Amber and Amber framework was more suited to classifying individual types of machinery such as lathes or milling machines etc. In addition, it was found to be fairly insensitive because of the low number of scales that were included. Bright's 'levels of mechanisation' were, on the other hand, more appropriate for defining mechanisation in process plants. Indeed all of his applications of the technique were in process plants. Furthermore, it was considered to be much more sensitive to changes in mechanisation from one plant to another. Hence, it was considered to be a more accurate measure of mechanisation. A further justification for the use of the Bright method came from the fact that it was well explained and an appendix on its use was included in Bright's book. The advice given in this appendix was considered to be extremely valuable in the application of the technique and in avoiding errors and biases. Hence, the Bright 'mechanisation profile' technique was adopted as a basis for comparative organisational analysis. The 'mechanisation profile' is described, together with the six profiles obtained from the research, in Appendix 3.

6.48 Presentation of results. The results of the industrial field research provided the researcher with a considerable volume of descriptive data, documentary evidence and interview responses. The method of presentation of this

data required considerable thought and planning. Two methods were considered. Firstly, the use of individual case-studies of the companies visited. This would take the form of describing the life-cycle management, engineering, financial and other practices adopted by each company. However, because of the volume of information involved and the fact that there were 6 companies to analyse, it was considered that this method would not be appropriate. Firstly, because it would be difficult to present as many as 6 companies on a case-study basis that would enable the reader to absorb all of the data collected. It would then become difficult to read and to examine the findings. Secondly, it was considered more meaningful if the data were presented and analysed at each stage of the life-cycle management process because one of the objectives of the research was to indentify areas of management practice where more emphasis needs to be placed for the application of terotechnology. The case-study method would make this objective more difficult to achieve.

The second method of presentation of the results could be the 'survey!'. This would entail describing the practices of all the companies visited for each function in the life-cycle. That is, describing specification practices or maintenance practices and comparing these against the mechanisation of the production system for all of the companies visited. Using this method would also be more meaningful and immediate to the reader and would facilitate

the identification of those practices that were lacking from a terotechnology viewpoint. This method would also enable as many as 6 companies to be analysed more constructively and economically. Consequently, the survey method was chosen and it is on this basis that the results are presented. That is to say that each function in the life-cycle is presented and analysed in relation to the application of terotechnological practices. These practices are compared against the level of mechanisation of the production system. The practices that were examined are given in Chapter 5 Table 1.

6.5. Summary.

This chapter has stated the objectives of the industrial field research. It has stated the practices that were to be investigated in the companies that agreed to participate with the work. The chapter has reviewed some of the alternative research methodologies which could have been utilised. The most appropriate was selected. The research design has been described in detail. This included analysis of the method adopted to select and approach the companies, the response to these approaches, the research period, the details of the participating companies, the method of data collection and the problem of error and bias. In addition, this chapter has

covered the basis of the method of comparative analysis which was considered to be most appropriate for this work. The chapter has described also the way in which the findings of the research have been presented.

The findings of the industrial field research are given in Chapters 7 to 14 .

CHAPTER 7

TEROTECHNOLOGICAL PRACTICE IN SPECIFYING PHYSICAL ASSETS

7.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices when specifying plant. In order to maintain confidentiality the companies are referred to by their alphabetical code only. The results are presented by grouping the terotechnological practices according to their associated level-of-care. The findings are summarised in tabular form using the average level of production system mechanisation as the basis for comparative analysis.

7.2 Employees Interviewed.

Within each company a person responsible for specifying plant and equipment was interviewed. Table 4 shows the title of the position held by each employee within each company.

7.3 Terotechnological Practices.

7.31 General Care. All of the companies surveyed were found to carry out the practices associated with the level of 'general-care' as given in Table 1 Chapter 5.

TABLE 4
EMPLOYEES INTERVIEWED WITH RESPECT
TO SPECIFICATION PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	ENGINEERING MANAGER
B	WORKS' MANAGER
C	CHEMICAL PROCESS ENGINEER
D	CHIEF PRODUCTION ENGINEER
E	SENIOR PROJECT ENGINEER
F	DEPARTMENTAL ENGINEER

7.32 Moderate Care. In Chapter 5 four practices were proposed at the level of 'moderate-care' in the specifying of physical assets. These were; ease of control for operators, ease of access for maintenance, the supply of overhaul schedules and the supply of preventive maintenance schedules.

Only company D did not consider the need for ease of operator control. In the case of company A the engineering manager commented that "often it would not be a formal requirement but would be expected to have been considered". In company E the project engineers and control engineers planned the positions of controls using 3D models of the plant. In company F a method of 'functional systems documentation' had been adopted. This required additional instrumentation and control systems which also had to be considered. In this case the operator was located in an ergonomically designed control cabin fitted with television monitors, computer printout terminals, instrumentation, telephones and visual observation of the process. Company F also built 3D models for use in operator familiarisation. Company C made use of mock-up panel layouts for planning the positions of controls.

Ease of access for maintenance was not considered by company C or company D. In company E ease of access for maintenance was considered by project engineers using 3D models. Company F regarded ease of access for maintenance

as a very important consideration. The interviewee stated, " This is a very strict requirement on which great emphasis is placed and finance allocated to facilitate any necessary modifications ".

The specifying of overhaul schedules was not considered by company C or company D. All other companies included this practice.

Preventive maintenance schedules were considered by all companies except C and D.

7.33 Advanced Care. Four practices were proposed at this level of-care. They were; modular construction, training schemes, use of historical data to evaluate specifications and the use of fault diagnosis systems.

Companies B, C and D did not consider modular construction. In company B the interviewee commented, " This is not considered at the moment but may be in the future ". In company C the interviewee commented, " we do not specify it but if the plant supplier has it designed-in then we accept it ".

In company A the concern was more for modular construction to facilitate plant modifications rather than for ease of maintenance. In company E use was made of plug-in control circuit boards. In company F modular construction was widely used to facilitate maintenance. It was incorporated into the maintenance system by the use of "module change-overs" in which a new module of the plant would be fitted rather than trying to repair a fault on the line. The faulty module would then be repaired at the central workshops.

Training schemes were not specified by companies A, B, C and D. However, in company A the plant manager, concerned with the asset being specified, would be involved from the start of the project. In company B the interviewee stated, "the plant is not sophisticated enough for this". In company E training for operators was carried out during commissioning and management training began when the project team was first selected to investigate the feasibility of a particular project. In company F training for operators and maintenance fitters was organised on a formal basis. Specialist courses were run at the company's training school. In total, sixty one days of training were conducted for each fitter and electrician. Management training was started during the feasibility study stage of design. Training of operators was considered very important. Operators were selected and then attached to an experienced operator for a period of three months prior to the commissioning of the new plant. In company F both production and maintenance personnel were trained in the use of 'functional-systems-documentation'.

The third practice associated with advanced-care was the use of historical information on plant reliability and maintainability in order to provide a basis for decision making regarding the plant being specified. This practice was not adopted in companies A, B, C and D. In company E historical records existed and would be examined on an informal basis by project engineers. In addition, visits to other companies

and members of the parent group would be made in order to gain information to assist in the development of a plant specification. In company F historical records were also available. Managers, engineers and designers also made visits to Japan, Europe and the U.S.A. in order to gain information about the performance of similar plant.

The fourth practice associated with advanced-care was the use of fault diagnosis systems 'specified-in' to the design of the plant. This practice was not adopted by companies A, B, C, D and E. In company F it was adopted. This took the form of specifying the need for functional systems documentation to be an integral part of the plant design concept. Indeed, two suppliers to company F had to establish new departments in order to meet this requirement.

7.34 Intensive Care. Five practices were identified as being intensive in nature when specifying new plant.

The first of these was the specifying of a mean time to repair (MTTR) for a breakdown maintenance activity. This was not adopted by companies A, B, C, D and E. In company F an "average job length of 1.75 hours" was specified.

The second practice was the need to be supplied with information on anticipated component lives. This was not carried out by companies A, B, C, D and E. In company F use was made of data from H.Q. laboratories regarding material specifications and tests. From this and using engineering experience, expected lives were given to components in order

to facilitate the forward planning and budgeting of replacement parts.

The third practice was the specifying of a mean time between failure (MTBF) for the plant or specific components. None of the companies surveyed adopted this practice. However, in company F a standard for "engineering delays" was specified as 5.4% of total operating time.

The fourth practice was the specifying of an anticipated life-cycle for the plant. This was not adopted by any of the companies surveyed. A comment made by the Works' Manager of company B was, "we are quite prepared to use it until it collapses". All companies used an accounting life for depreciation purposes.

The fifth practice of specifying a life-cycle cost for the plant was not adopted by any of the companies surveyed.

7.4 Summary.

This chapter has presented the findings of the industrial research into the application of terotechnological practices when specifying plant. Company D had the lowest level of mechanisation and the lowest level of application of terotechnological practices as proposed by this dissertation. All the companies surveyed specified plant to the 'general-care' level. However, company D did not exceed this level and company C included only one additional

practice at the level of moderate-care. Companies A,B,E and F all adopted the four practices included within the level of moderate-care, but company B did not exceed this level.

At the advanced-care level company A adopted the first practice, company E included three of the practices and company F utilised all of the practices associated with this level.

At the intensive-care level only two practices were adopted by company F. No other company operated at this level-of-care.

Table 5 summarises the findings of the research described in this chapter. The findings have shown that the company with the lowest level of production system mechanisation also has the lowest level of application of the terotechnological practices postulated in Chapter 5 Table 1. With the exception of company B, as the level of mechanisation increases so does the level of application of terotechnological practices. In the case of company B, the divergence from this trend was thought to be due to the fact that the Works' Manager himself set plant specifications. In this situation it is likely that he is more conscious of the need to set high quality specifications as he is also ultimately responsible for the performance of the plant when in use.

TABLE 5

THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN SPECIFYING PLANT RELATED TO THE AVERAGE
LEVEL OF PRODUCTION SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	SPECIFYING	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	life-cycle costing						
	life-cycle estimation						
	M.T.B.F.						
	anticipated component life						
	M.T.T.R.						
ADVANCED	fault diagnosis systems						
	use of historical data						
	training schemes						
	modular construction						
MODERATE	preventive maintenance schedules						
	overhaul schedules						
	ease of access						
	ease of control						
GENERAL	maintenance manual						
	list of spare parts						

From the findings of the research it can be seen that five of the six companies surveyed exhibit a trend towards increased application of terotechnological practices with increasing mechanisation. Table 5 summarises the findings and illustrates this trend. The next chapter presents the findings of the research into the application of terotechnological practices during the next phase, that of design of a physical asset's life-cycle.

CHAPTER 8

TEROTECHNOLOGICAL PRACTICE IN THE DESIGN OF PHYSICAL ASSETS.

8.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices during the design phase of a physical asset's life-cycle. The results are presented in the same manner as the previous chapter.

8.2 Employees Interviewed.

Within each company a person responsible for designing plant and equipment was interviewed. Table 6 shows the title of each employee within each company.

8.3 Terotechnological Practices.

8.31 General Care. In Chapter 5 it was proposed that three terotechnological design practices could be associated with a level of general-care. They were stated as; a system to allow plant modifications, the use of journals and conferences etc. to keep up to date with design practice and developments and the scheduling of the work load to be completed during the project.

All companies surveyed operated a system whereby plant could be modified in use. In the case of companies B and D this practice was carried out by the writing of a memo to

TABLE 6
EMPLOYEES INTERVIEWED WITH RESPECT TO
TO DESIGN PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	ENGINEERING MANAGER
B	DESIGN ENGINEER
C	DESIGN ENGINEER
D	ENGINEERING MANAGER
E	CHIEF DESIGN DRAUGHTSMAN
F	CHIEF DEVELOPMENT ENGINEER

the engineering managers which would then be considered at a meeting. In the case of company A the design department had to charge the production and maintenance departments for their services. Commenting on this system of internal accounting, the engineering manager stated, " this system hinders the performance of the plant and departmental cooperation ". In company E the system for plant modifications was the responsibility of the area engineers within each factory zone. A formal "plant improvement" document was submitted to the chief development engineer and a project team would then be designated to examine the suggested improvement. In company C a project team would also be established to examine a proposed modification. The interviewees in companies A and C commented that product changes or developments caused the majority of modifications to plant.

All companies except company D made use of reports, journals and conferences to keep up to date with design developments. In all the other companies there was a regular circulation of several engineering journals. Only company F had its own 'house journal'.

The third practice at the level of general-care was the formal scheduling of work to facilitate project planning. This practice was adopted by all the companies surveyed except company D. In company E a draughtsman was responsible for this task. In all cases the 'bar-chart' was the most frequently used technique.

8.32 Moderate Care. Three practices were proposed at this level-of-care. The first of these practices, that of designers discussing problems with maintenance engineers, did not occur in companies A, B, C and D. In company E discussions would be held between designers and the area maintenance engineers responsible for the zone of the factory in which the plant would be located. In company F a maintenance engineer formed part of the project design team and all design drawings were examined by the maintenance engineer. In addition, the maintenance engineer was given responsibility for designing the layout of the maintenance workshops.

The second practice proposed was the analysis of maintenance costs in order to identify the high cost items or characteristics. This practice was not found in companies A, B, C and D. In company E this practice was carried out by an industrial engineer who then submitted the findings of his analysis to the designers and project engineers. In company F it was stated that "no major plant would be selected without an investigation into its maintenance characteristics either from cost data within the company or as a result of visits to other companies."

The third practice at the level of moderate-care was the analysis of breakdown data and information given by fitters on job cards and other primary information sources. This practice was not adopted by companies A, B, C and D. In company E

this practice was carried out by the secondment of a maintenance fitter to the project team. The fitter then examined breakdown data, from the historical records, in order to establish weak points in the design of the existing plant. This practice was found also in company F.

8.33 Advanced Care. Company F was the only company found to utilise any of the practices associated with advanced-care in the design of plant.

The first practice, that of using ^a of system of information feedback to design, was operated both within the company and to major suppliers of plant. A 'complaints procedure' was used also by designers in order to gain information about the 'on-going' problems of operating the plant.

The second practice of designing-in condition monitoring equipment was also found. Equipment such as load-cells, oil analys^zers and vibration monitors were designed-in to major plant in the production process. The information generated by this equipment was fed back to a central control panel in the plant control room.

The third practice, that of utilising historical information on plant repair times, was used. The company had detailed plant history records which were analysed in order to produce a standard for "average job length". This was stated as 1.75 hours. In addition, designers visited other companies in order to gain further information about maintenance problems, repair times and other characteristics.

The fourth practice proposed at the level of advanced-care was the use of a data bank of information for designers. Again this was only found in company F. The system relied on manual input and record keeping, but the information was stored on computer.

8.34 Intensive Care. In Chapter 5, four practices were proposed at the level of intensive-care when designing physical assets. However, it was found that none of the companies surveyed adopted any of the four practices proposed.

8.4 Summary.

This chapter has presented the findings of the industrial research into the use of terotechnological practices during the design of physical assets. It has been found that company D utilised only one of the fifteen practices and consequently cannot be described as even reaching a level of general-care when designing its plant. Companies A, B and C adopted all of the practices associated with general-care. Company E adopted all the practices proposed at the level of moderate-care. Company F was the only company surveyed which was found to practice at the level of advanced-care. None of the companies surveyed utilised the practices proposed at the level of intensive-care.

Table 7 summarises the findings of the research described in this chapter. The findings have shown that the companies with the lowest and highest levels of production system

TABLE 7
THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN DESIGNING PLANT RELATED TO THE AVERAGE
LEVEL OF PRODUCTION SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	DESIGNING	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	trade-off studies						
	cost-effec. analysis						
	life-cycle costing						
	reliability and maintainability analysis						
ADVANCED	design data bank						
	historical information on M.T.B.F.						
	historical information on M.T.T.R.						
	condition monitoring						
	information feedback to design						
MODERATE	analysis of breakdown data & job cards						
	analysis of maintenance costs						
	discussions with maintenance						
GENERAL	scheduling of work						
	reviews of reports, journals etc						
	plant modification system						

mechanisation have the lowest and highest levels of application of terotechnological practices respectively. It has been found that design practice in four of the six companies was operating at the level of general-care or lower. However, the findings show that there is a 'tendency' towards the increasing application of terotechnological practices during design being mechanisation dependent.

The next chapter presents the findings of the research into the application of terotechnological practices during the financial evaluation of physical assets.

CHAPTER 9

TEROTECHNOLOGICAL PRACTICE IN THE FINANCIAL EVALUATION OF PHYSICAL ASSETS

9.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices during the financial evaluation of physical assets.

9.2 Employees Interviewed.

Within each company a person responsible for the financial evaluation of plant was interviewed. Table 8 shows the title of the position held by each interviewee in each company.

9.3 The Terotechnological Practices.

9.31 General-Care. In Chapter 5 it was proposed that the practice of budgeting for a procurement should be associated with this level-of-care. All the companies surveyed adopted this practice. However, company D did not extend its practices beyond this level.

9.32 Moderate-Care. The practice proposed at this level was that of carrying out an investment appraisal of the plant under consideration. All companies, except company D, utilised investment appraisal techniques. In company C the return-on-investment method was used for plant up to £100,000. For plant up to £1,000,000, then discounted cash flow was

TABLE 8
EMPLOYEES INTERVIEWED WITH RESPECT
TO FINANCIAL EVALUATION PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	DIVISIONAL ACCOUNTANT
B	COST ACCOUNTANT
C	COMPANY ACCOUNTANT
D	COMPANY SECRETARY
E	COST & MANAGEMENT ACCOUNTANT
F	PROJECT ACCOUNTANT

adopted also. In company A the discounted cash flow method was adopted also. Additionally, company A used the pay-back period method on occasions. Company E used the discounted cash flow method and in company F the discounted cash flow, pay-back period and return-on-investment methods were all used as required.

9.33 Advanced-Care. Two practices were proposed at the level of advanced-care. The first practice was the use of quantitative techniques to predict future cost trends. Only companies B, E and F used this practice. In company B linear regression analysis was used to predict costs. In company E a firm of forecasting specialists was used to supply regular reports on cost trends in their sector of manufacturing industry. Company F had a headquarters team of specialists to supply cost indices for labour and materials. These were further analysed into different industry sectors. Companies E and F made use also of risk analysis when evaluating projects.

The second practice was the use of plant performance analysis using financial criteria. This practice was only found in companies E and F. In company E a measure of plant 'efficiency' was used, expressed as a percentage of actual operating time against the budgeted operating time. Actual against budget comparisons were made for plant running costs and maintenance costs. In company F a similar procedure was

found. In addition, company F analysed plant stoppages by nature of stoppage and amount of lost-time attributable to that cause.

9.34 Intensive-Care. Only companies E and F operated at this level. Furthermore, of the three practices proposed in Chapter 5 only the first was used by the two companies. The first practice was the use of post-completion-auditing in order to evaluate the performance of the plant and assess the success of the decisions made at the time of the initial evaluation. In company E post-completion-auditing was a formal requirement with a manual provided to show the method to adopt and points to be covered when submitting the audit. The post-completion-audit was usually carried out at the end of the second or third year of the plant's life. The actual timing being dependent on the type of plant under review. The post-completion-audit was carried out by an industrial engineer together with other members of the project team as required. The audit was then submitted to the highest level of engineering management in the company.

In company F the post-completion-audit was also a formal requirement. In this company it was called a 'post-completion-review'. Three such reviews were stipulated. The first review had to be submitted after the plant had been installed. The second after twelve months running experience and the third after two years running experience.

Each member of the project team submitted a section of the post-completion-review and one such review, examined by the researcher, extended to over 100 pages in length . As with company E, company F also submitted the post-completion-review to the highest level of engineering management in the company.

The other two practices proposed at the level of intensive-care were not applied by any of the companies surveyed.

9.4 Summary.

This chapter has presented the findings of the industrial research into the application of terotechnological practices during the financial evaluation of a physical asset.

All the companies surveyed, practised at the level of general-care. Company D did not exceed the level of general care. Companies A and C did not practise beyond the level of moderate-care and company B used one of the practices proposed at the level of advanced-care. Companies E and F used both practices at the level of advanced-care and the first practice at the level of intensive-care. None of the six companies surveyed operated beyond the first practice at the level of intensive-care.

Table 9 summarises the findings of this part of the industrial research. It can be seen from this table that financial practice is slightly more standardised

TABLE 9

THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN PERFORMING THE FINANCIAL EVALUATION
OF PLANT RELATED TO THE AVERAGE LEVEL OF PRODUCTION
SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	FINANCIAL EVALUATION	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	trade-off studies & optimisation						
	Life-cycle costing						
	Post completion auditing						
ADVANCED	performance analysis						
	use of quantitative techniques						
MODERATE	investment appraisal						
GENERAL	budgets						

across the sample than other practices performed during a plant's life-cycle. Again the company with the lowest level of terotechnological practice also has the lowest level of production system mechanisation. The companies with the highest levels of practice have also the highest levels of mechanisation. However, company F with a level of mechanisation nearly three points higher than company E had not adopted any more intensive a level of practice.

With the exception of company B the findings again indicate the 'tendency towards' the level of application of terotechnological practice being dependent upon the average level of production system mechanisation within a company. The reason for the accelerated level of practice found in company B is again attributed to the fact that as a small company, the accountant was responsible directly to the owner of the company and this had tended to 'promote' the application of higher level techniques in order to assist in the decision making process.

The next chapter presents the findings of the research into the application of terotechnological practices during the procurement of physical assets.

CHAPTER 10

TEROTECHNOLOGICAL PRACTICE IN THE PROCUREMENT OF PHYSICAL ASSETS

10.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices during the procurement of physical assets.

10.2 Employees Interviewed.

Within each company a person responsible for the procurement of plant was interviewed. Table 10 shows the title of the position held by each interviewee within each company.

10.3 The Terotechnological Practices.

10.31 General-Care. In Chapter 5 it was proposed that the practice of progressing purchases should be associated with the level of general-care. All the companies surveyed adopted this practice. In the case of company A an escalation system for progressing late deliveries was in use. In this case a buyer would refer a supplier's poor performance to a senior buyer, who in turn would escalate the problem to the assistant chief buyer and finally to the chief buyer. A formal 'exception report' was produced

TABLE 10
EMPLOYEES INTERVIEWED WITH RESPECT
TO PROCUREMENT PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	CHIEF BUYER
B	WORKS' MANAGER
C	PURCHASING OFFICER
D	PURCHASING OFFICER
E	SENIOR PROJECT ENGINEER
F	PROGRESS & INSPECTION ENGINEER

on a regular basis. In company B the system was not as formal, the interviewee commented, "most companies keep us informed". In company C suppliers were progressed approximately every two weeks until delivery took place. In company D progressing was carried out by clerks. Any problems were then referred to the purchasing officer. In company E the project engineer was responsible for ensuring that suppliers met the required delivery dates. In company F progress chasers reported to planning engineers who in turn were required to report information to the interviewee. Formal progress sheets were written for all orders.

10.32 Moderate-Care. The practice proposed at the level of moderate-care was that of using a system of receipt inspection to ensure that procured items were delivered according to the specification required. All the companies surveyed operated a system of receipt inspection as a standard practice .

10.33 Advanced-Care. Two practices were proposed at the level of advanced-care.

The first practice was the use of a system of supplier vetting in order to ensure that only reputable and efficient suppliers were used by a company. This practice was not adopted by companies B and D. In company C references were asked for as a means of assessment. In company A an assessment of a supplier was made on the basis of the buyer's experience. In addition, an analysis of the suppliers' viability was also carried out using the

basis of the buyer's experience. In addition, an analysis of a company's viability was also carried out using the 'Telegraph Exchange' company information service. Other considerations, such as a willingness to negotiate on the price and the method of payment, were also taken into account. Furthermore, within company A, for large procurements the company's accountants would also review the suppliers' profit and loss accounts and balance sheets. For overseas suppliers the vetting took the forms described above but in addition personal visits would be made to undertake a general "approval investigation". In companies E and F an assessment was made also on the basis of reputation and viability. The interviewee in company F commented that "some companies are black-listed".

The second practice proposed at the advanced level-of-care was that of using penalty clauses for late delivery of plant because of the disruption that this could cause. This practice was not found in companies A, B, C and D. In company E a percentage of the value of the contract was withheld until delivery took place. In company F a penalty of $\frac{1}{2}$ % of the capital value of the plant per week of late delivery was imposed on the supplier.

10.34 Intensive-Care. Two practices were proposed at the level of intensive-care. These were the use of approved supplier listings such as those used for government contracting and the use of incentive contracting to promulgate increased reliability and maintainability in procured plant. None of the companies surveyed adopted these practices.

10.4 Summary.

This chapter has presented the findings of the research into the use of terotechnological practices during the procurement of plant . All of the companies surveyed operated up to the level of moderate-care. However, companies B and D did not exceed this level. Companies A and C adopted the first practice at the level of advanced-care and companies E and F were found to use both practices at this level. None of the companies surveyed were found to operate at the level of intensive-care.

The findings show a trend towards an increased application of terotechnological practice with increasing mechanisation.

Table 11 summarises the findings of this work. The next chapter presents the findings of the research into the application of terotechnological practices during the installation phase of a physical asset's life-cycle.

TABLE 11

THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN PROCURING PLANT RELATED TO THE AVERAGE
LEVEL OF PRODUCTION SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	PROCUREMENT	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	incentive contracting						
	approved supplier listings						
ADVANCED	late delivery penalties						
	formal supplier vetting						
MODERATE	receipt inspection						
GENERAL	progressing						

CHAPTER 11

TEROTECHNOLOGICAL PRACTICE IN THE INSTALLATION OF PHYSICAL ASSETS

11.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices during the installation of physical assets.

11.2 Employees Interviewed.

Within each company a person responsible for the installation of plant was interviewed. Table 12 shows the title of the position held by each employee within each company.

11.3 The Terotechnological Practices.

11.31 General-Care. At this level-of-care three practices were proposed. These were, the use of site layouts, services' layouts and the scheduling of the installation project in order that an assessment could be made of the time required to complete the installation. All of these practices were adopted by each company surveyed.

11.32 Moderate-Care. The first practice proposed at this level-of-care was the forward planning for equipment needed during the installation phase. All of the companies surveyed

TABLE 12
EMPLOYEES INTERVIEWED WITH RESPECT TO
INSTALLATION PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	ENGINEERING MANAGER
B	MAINTENANCE FOREMAN
C	INSTALLATION ENGINEER
D	WORKS' ENGINEER
E	INSTALLATION MANAGER
F	PROJECT PLANNING ENGINEER

were found to adopt this practice.

The second practice was that of budgeting for the cost of the installation phase. This was carried out by all companies except company D. In the case of company C the interviewee commented, " installation budgets are established in great detail even down to each nut & bolt and weld ".

The third practice was that of planning the work load required in each task during the installation. Companies D and B did not adopt this practice. All the other companies in the survey did utilise this practice. In company C a general procedure for carrying out a task was laid down. In company A the task planning was generally carried out by the plant designer. In company E the installation manager drew up procedures and instructions for the project and in company F a detailed card system was used. This operated in such a way that as each item of equipment was delivered an installation card was issued. As each item was subsequently installed the card was completed by a site engineer or contractor.

11.33 Advanced-Care. The first practice proposed at this level-of-care was the forward planning of manpower requirements during the installation phase. This was found to be in use by all companies except D and B.

The second practice was the use of network analysis to facilitate installation planning. Only companies D & B did not adopt this technique. In company C a planning

assistant was employed to prepare networks together with detailed bar-charts and flow sheets. In company A bar-charts were more often used than networks. In company E the initial network was drawn-up by a project engineer, the installation manager and a project technician. The network would then be computerised and the critical path established. In company F the network was also computer based with regular up-dating and re-issuing of the installation plan.

The third practice was that of recording installation problems relating to the plant. This practice was only found in companies E and F. In both cases the reporting was carried out via regular meetings during installation. In company E these were termed " project control meetings" whilst in company F they were termed "co-ordination meetings".

11.34 Intensive-Care. Two practices were proposed at the level of intensive-care.

The first practice was that of recording the problems encountered when installing the services. Companies E and F both adopted this practice. In the case of company E this was carried out using formal reports to the " project control meetings". In the case of company F the problems would be recorded and reported to the regular "co-ordination meetings ".

The second practice associated with intensive-care was that of carrying out a formal review of the installation phase and feeding back information to facilitate improvements

to future installation projects. This practice was only found in companies E and F. In company E this was done in a formal manner. At the end of the installation project the Installation Manager of company E would be responsible for writing a report to the project control committee. In addition, all the points raised during the installation phase would be recorded in the formal minutes of each meeting. In company F a similar procedure was found. However, in this case further meetings were held with consultants, contractors and between design, installation, production and maintenance personnel. In addition, a noteworthy practice was found also in that the installation engineers appointed were appointed with their suitability to become subsequently maintenance engineers on the plant. Hence, feedback was directly achieved.

11.35 Summary.

This chapter has presented the findings of the industrial research into the extent to which terotechnological practices were found to be applied when installing physical assets. The findings are summarised in Table 13. All the companies surveyed were found to operate above the level of general-care. Company D was found to use one practice at the level of moderate-care and company B two practices at this level. Companies C, A, E and F adopted all the practices associated with moderate-care. Companies C and A were found to use two practices at the level of advanced-care whilst companies

E and F were found to adopt all of the practices at this level. Companies E and F were the only companies found to be operating at the level of intensive-care and both of the practices proposed at this level were in use.

The findings as shown by Table 13 indicate a tendency towards an increasing application of terotechnological practice during the installation of plant with increasing mechanisation of the production system.

The following chapter presents the findings of the reserach into the application of terotechnological practices during the commissioning phase of the life-cycle.

TABLE 13

THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN INSTALLING PLANT RELATED TO THE
AVERAGE LEVEL OF PRODUCTION SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	INSTALLATION	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	review and information feedback						
	recording of problems with services						
ADVANCED	recording problems with plant						
	use of network analysis						
	manpower planning						
MODERATE	task planning						
	budgeting						
	equipment planning						
GENERAL	work scheduling						
	services' layouts						
	site layouts						

CHAPTER 12

TEROTECHNOLOGICAL PRACTICE IN THE COMMISSIONING OF PHYSICAL ASSETS

12.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices during the commissioning phase of the life-cycle.

12.2 Employees Interviewed.

Within each company a person responsible for the commissioning of plant was interviewed. Table 14 shows the title of the position held by each interviewee within each company.

12.3 The Terotechnological Practices.

12.31 General-Care. In Chapter 5 Table 1, four practices were proposed at this level. They were, the use of a formal commissioning schedule, tests of performance of the plant to ensure that it functions, the production of actual components to determine the plant's capability to produce and finally a detailed evaluation of the operation of the plant against the specification laid down for it. The survey found that all companies adopted these practices.

12.32 Moderate-Care. Four practices were proposed at this level-of-care.

The first practice was the use of a formal acceptance

TABLE 14
EMPLOYEES INTERVIEWED WITH RESPECT TO
COMMISSIONING PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	ENGINEERING MANAGER
B	MAINTENANCE FOREMAN
C	PROCESS ENGINEER
D	CHIEF PRODUCTION ENGINEER
E	INSTALLATION MANAGER
F	PROJECT PLANNING ENGINEER

procedure. This was found to be in use in all of the companies surveyed. In the case of company C the acceptance sheets were signed by each engineer in the project team. In addition, plant and process data were written up and handed over to the process engineers and plant managers. In company E a 40 shift commissioning run would be carried out and if production were then satisfied with the plant it would be accepted formally by the company.

The second practice was that of training plant operators during the commissioning period. Only company B did not adopt this practice, the interviewee commenting, "the plant is not complicated enough to justify it". In the case of company A detailed operating instructions were given to operators prior to starting on a plant. In company C operators attended training lectures and 'on-plant' training. In company F the operators were attached to experienced operators of similar plant for up to 3 months prior to working on the new plant. In addition, courses were held at the company's own training schools and residential weekend seminars were used also to establish a rapport between management and operators.

The third practice proposed at this level-of-care was the training of production management. This was carried out by companies D, C, A, E and F. In company A the production manager would be involved in a plant project from its initial conception and would follow the project through until he became responsible for the plant when put into full operational use. In company C management attended

a series of lectures on the new plant and examined flow process sheets and other layouts of the new plant complex. In companies E and F a production manager would be seconded to the project team.

The fourth practice was the recording of plant faults during the commissioning period. This practice was found in companies C,A,E and F. In company C formal commissioning data sheets were completed together with daily meetings to discuss the performance of the plant. In company F a "commissioning card" system was used in the same way as the "installation card" system. As each plant became available to commission, a card was drawn-up with the commissioning procedure laid down. As each procedure was completed, the card was signed and comments made in the space adjacent to the task.

12.33 Advanced-Care. The first practice proposed at this level-of-care was that of recording faults that occur on auxiliary equipment. This practice was found in companies C,A,E and F .

The second practice was the adoption of formal reviews and information feedback during commissioning. This was found in companies C,A,E and F. In company A formal meetings were held between design and production. In company C regular meetings of the project team were held with contractors, consultants and designers. This type of procedure was also adopted by companies E and F.

The third practice at the level of advanced-care was the adoption of a training programme for maintenance management in order to familiarise them with the new plant. This practice was only found in companies E and F. As with production management, the maintenance engineer, who would be ultimately responsible for the plant, would be a member of the project team and would have been familiar with the plant almost from its conception. In company F the departmental engineer was responsible for vetting designs, approving installation and commissioning procedures and for recruiting installation and commissioning engineers to be subsequently transferred to posts in maintenance supervision.

12.34 Intensive-Care. Three practices were proposed at the level of intensive-care.

The first practice was the training of maintenance fitters and electricians during the commissioning period. This practice was only found in companies E and F. In company E maintenance craftsmen were given an appreciation of the plant during its initial design stages. Subsequently, the craftsmen would be involved in 'on-the-job' training during the commissioning period. In addition, the maintenance craftsmen carried out a two day check of the plant during which time notes of possible modifications would be made. Further training took place because the craftsmen assisted the supplier in the task of completing the commissioning schedule and generally 'de-bugging' the plant. In company F

the training of maintenance craftsmen was conducted in a slightly different way. Initially, specific skill requirements were identified using a "skills matrix". Training programmes were then devised to provide the craftsmen with these skills. Training extended over a 61 day period for each fitter. Specialised courses were run on fault location, fault diagnosis, use of documentation and reporting systems, condition monitoring equipment and computerised data systems.

The two remaining practices at the level of intensive-care were not found in any of the companies surveyed.

12.4 Summary.

This chapter has presented the findings of the industrial research into the application of terotechnological practices during the commissioning of plant. The findings are summarised in Table 15 . It is notable from these findings that the position of companies D and B has been reversed from that which might be expected if the proposition stated in Chapter 6 was to be true in all cases. More detailed analysis of the reasons for the enhanced level of practice in company D or conversely the depressed level of practice found in company B reveal that in company B management's attitude towards the production process was that it was "unsophisticated" and simple in nature. They regarded the operation of the plant as a straightforward task. However, in company D the management regarded the process as quite complex and "fiddily" and consequently felt that training for operatives and supervision was required in order to ensure satisfactory

operation and quality. This finding led to another possible factor affecting the level of management practice being applied in a particular company. That is the perception of the complexity or sophistication of the production process in the minds of management.

All the companies surveyed operated above the level of general-care. Company B adopted only one practice at the level of moderate-care whilst company D was found to adopt three of the practices at this level. Companies C, A, E and F all operated above the level of moderate-care. Companies C and A were found to adopt two practices at advanced-care and companies E and F utilised all the advanced practices. Only companies E and F were found to be practising at the level of intensive-care, both adopting the first practice only. The findings summarised in Table 15 show that there is an indication towards the application of terotechnological practice being dependent on the attitude of management towards the complexity of the process. For the remaining four companies the findings show that there was a tendency towards the application of terotechnological practices increasing with increasing mechanisation of the production process. The following chapter presents the findings of the industrial research into the application of terotechnological practices when maintaining plant.

TABLE 15

THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN COMMISSIONING PLANT RELATED TO THE
AVERAGE LEVEL OF PRODUCTION SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	COMMISSIONING	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	reliability testing						
	maintainability testing						
	maintenance fitter training						
ADVANCED	maintenance management training						
	formal reviews & information feedback						
	recording of auxiliary equipment faults						
MODERATE	recording plant faults						
	training of production management						
	training of operators						
	formal acceptance procedure						
GENERAL	evaluation of operation against spec.						
	production of comps.						
	tests of performance						
	commissioning schedule						

CHAPTER 13

TEROTECHNOLOGICAL PRACTICE IN THE MAINTENANCE OF PHYSICAL ASSETS

13.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices when maintaining physical assets.

13.2 Employees Interviewed.

Within each company a person responsible for the maintenance of plant was interviewed. Table 16 shows the title of the position held by each employee within each company.

13.3 The Terotechnological Practices.

13.31 General-Care. Four practices were proposed at this level-of-care. They were breakdown maintenance, lubrication maintenance, the stocking of spare parts and the allocation of priorities to different types of maintenance work and plant. All of the companies surveyed were found to adopt these practices. In companies D and B the maintenance workforce was found to be centralised whereas in companies C, A, E and F the workforces were found to be decentralised but supported by central workshops. In companies D and B lubrication schedules were decided upon by the maintenance

TABLE 16
EMPLOYEES INTERVIEWED WITH RESPECT TO
MAINTENANCE PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	ASSISTANT FACTORY MANAGER
B	MAINTENANCE FOREMAN
C	WORKS' ENGINEER
D	WORKS' ENGINEER
E	MAINTENANCE SYSTEMS' MANAGER
F	DEPARTMENTAL ENGINEER

crews. In company C the works' engineer was in the process of arranging for an oil company to examine the lubrication requirements of the plant. In companies A, E and F oil companies were already used to determine the lubrication schedules and select the oils.

In companies A and C priorities were decided upon by the plant managers. In company B by the works' manager and in company D by the production supervisor. Only in companies E and F were the priorities determined by the maintenance engineers. In company F a lubrication engineer was on the site permanently and company E had recently started discussions with the National Tribology Centre at Leeds University in order to further develop the company's knowledge of lubrication.

13.32 Moderate-Care. Four practices were proposed at the level of moderate-care.

The first of these practices was the overhauling of plant. This practice was found in all the companies surveyed. Overhauls were carried out either on a time scale basis (every one or two years) or on a production-run basis (after x million units of production).

The second practice was that of using a system of budgetary control for maintenance. This practice was not found in companies D and B. In company A the assistant factory manager derived the budget, in company C the works' engineer, in company E the area engineers laid down their own area

budgets and in company F the departmental engineer was responsible for the setting of the maintenance budget.

The third practice was that of carrying out preventive maintenance inspections on a regular basis. This practice was not found in companies D, B and C. In company A preventive maintenance was the task of two semi-skilled fitters. They used a formal checking and inspection schedule derived by the maintenance foreman. The schedules were updated, at intervals, in order to take account of changes in the plant inventory or other circumstances. In fact, at the time of the visit to this company, the maintenance foreman was in the process of re-writing all the preventive maintenance schedules. In company E preventive maintenance was carried out by the day shift crews only, each crew reporting to an area engineer. The schedules were derived on the basis of experience and, at the time of the researcher's visit, were in the process of being put onto computer. In company F the preventive maintenance schedules were written initially by the maintenance staff and were then put onto computer and issued as required on a daily, weekly, monthly or half yearly basis. Some examples of the preventive maintenance schedules, used by company F, are given in Appendix 4.

The fourth practice at the level of moderate-care was the use of job cards to record information during maintenance work. This practice was found only in companies E and F. In both companies clerical staff were employed to check job cards and to transfer information from them to plant

history cards. In addition to job cards both companies were found to use shift reports and maintenance record sheets. These were used by the maintenance engineers to enter detailed information of any task that was carried out during their shift. Examples of these documents are given in Appendix 4.

13.33 Advanced-Care. At this level-of-care four practices were proposed in Chapter 5 Table 1.

The first of these practices was the use of a standard costing system in order to establish more accurate budgets and cost estimates. This practice was found only in companies E and F. In company E industrial engineers derived standard costs for labour, materials and overheads. In company F they were derived by a cost accountant.

The second practice proposed was the use of a system of data management to collect, collate, analyse and report maintenance data. Again this practice was found only in companies E and F. In both cases the source documents were job cards and shift reports. These were fed-back to administration departments for detailed recording, collation and analysis. In company E clerical staff entered the information onto plant history cards, technicians and a cost analyst were employed to examine the data and issue reports. At the time of the research visit company E was in the process of designing a computer based data management system. In company F the administration staff transferred information onto a computer for storage.

The third practice was the use of performance measurement for the plant. This was found only in companies E and F. In company E a standard for production efficiency was established as actual production per shift over possible production per shift expressed as a percentage. If this target was not achieved then the reasons for the shortfall in performance were examined in detail. In addition, the company operated a " Management Performance Improvement Programme - MPIP ", in which short and long term performance targets for general increases in efficiency would be set. In company F performance was measured in terms of " Engineering Delays ". In this case a standard was set for engineering delays of 5.4% . The engineering delays were plotted on a wall chart and " design attributed delays " were also identified and plotted separately. The availability of major plant was measured also and recorded on a wall chart displayed in the departmental engineer's office. In addition, both companies used variance analysis for comparison of actual/budget cost and material consumption. Examples of some the documentation used to record performance are shown in Appendix 4 . .

The fourth practice at the level of advanced-care was the use of a system of in-company data feedback to ensure that data were fed-back to production, design and development and to top management. This practice was found only in companies E and F. In company E a formal " Plant Services Report " was issued on a regular basis. In this report each

engineer contributed a section about the plant for which he was responsible. The report had seven sections dealing with personnel, training, developments in systems and procedures, plant modifications, projects, general comments and equipment causing concern, together with major breakdowns and the resulting delay times. This report was circulated to all levels of management. In company F " Period Reports " were issued giving summaries of engineering performance. The reports covered engineering delays, availability, safety, accidents and they analysed trends in performance. Detailed reports would be issued as required . For example, design attributed delays were identified and the cause of these faults would be reported to design engineering or to the supplier. In addition, company F operated what was termed a "follow-on" book. This was used to define the responsibility for solving a particular problem and then ensuring that the problem had been followed up and action taken. Shift report sheets were examined by management on a daily basis in both companies. Furthermore both companies used post-completion-reviews as a means of information feedback. Examples of some documentation mentioned here are given in Appendix 4.

13.34 Intensive-Care. Four practices were proposed at this level-of-care. They were a system of ex-company data feedback , use of fault diagnosis systems, condition monitoring systems and maintenance optimisation studies. Only company F was found to operate at the level of intensive-care.

The first practice was found to be in use with several of the company's suppliers. A formal system of data feedback had been set up between the departmental engineer and major plant manufacturers. An additional source of ex-company data feedback was that the company published regularly in the professional journals for the industry.

The second practice was the use of fault diagnosis systems. In this case company F had developed its own type of system known as, "Functional Systems Documentation-FSD" - this being an adaptation of a system in use by the Royal Navy. A department was established within the company in order to develop the FSD documentation and procedures and the two major suppliers of plant also set up new departments in order to incorporate the FSD into the new plant designs. Detailed training was given to fitters, electricians, technicians, supervisors and managers in order to familiarise them with the use of fault diagnosis systems.

The third practice at the level of intensive-care was the use of condition monitoring systems. Here again company F had designed-in condition monitoring equipment which included oil analysers, vibration monitors and load cells. Information from the condition monitoring equipment was fed back to the central control room where instruments recorded the condition of the plant. If a fault was detected by the monitoring systems then the fault was relayed to a " faults' computer "

attached to a visual display unit-VDU. For example, if a fault occurred then the control room engineer would type-in the plant number and the readings from the monitoring equipment. The computer would then display on the VDU a list of possible remedies which the fitter or electrician could then try out. The purpose of this system was to increase the speed of location of a fault, its diagnosis and repair so that production could be resumed as soon as possible.

The fourth practice at the level of intensive-care was not found in any of the companies surveyed.

13.4 Summary.

This chapter has presented the findings of the industrial research into the application of terotechnological practices when maintaining plant. The findings which are summarised in Table 17, show that all the companies surveyed operated above the level of general-care. However, companies D and B were found to adopt only one practice at the level of moderate-care, whilst company C adopted two practices and company A three practices at this level-of-care. Only companies E and F operated at the level of advanced-care. Company F was the only company in the survey to operate at the level of intensive care when maintaining its physical assets.

The findings indicate that there is a tendency towards the level of application of terotechnological practices increasing with increasing mechanisation of the production

TABLE 17

THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN MAINTAINING PLANT RELATED TO THE
AVERAGE LEVEL OF PRODUCTION SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	MAINTENANCE	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	optimisation studies						
	condition monitoring						
	fault diagnosis						
	ex-company data feedback						
ADVANCED	in-company data feedback						
	performance measurement						
	data management						
	standard costing						
MODERATE	job cards						
	preventive maintenance inspections						
	budgets						
	overhauls						
GENERAL	priority allocation						
	spare parts						
	lubrication						
	breakdowns						

system. The next chapter presents the findings of the industrial research into the application of terotechnological practices during the removal of plant at the end of its life-cycle.

CHAPTER 14
TEROTECHNOLOGICAL PRACTICE IN THE
REMOVAL OF PHYSICAL ASSETS

14.1 Introduction.

This chapter presents the findings of the industrial research into the application of terotechnological practices when removing physical assets at the end of their life.

14.2 Employees Interviewed.

Within each company a person responsible for the removal of plant was interviewed. Table 18 shows the position held by each interviewee within each company.

14.3 The Terotechnological Practices.

14.31 General-Care. Three practices were proposed at this level-of-care.

The first of these practices was the assessment of the market potential for the new product which is to be manufactured by the new machine. All the companies in the survey were found to adopt this practice when considering the removal of an old plant for replacement by a new one.

The second practice proposed was to carry out an assessment of the operational performance requirements (ie.speed,feed,capacity etc.) for the new plant. Again all the companies in the survey were found to adopt this practice.

TABLE-18
EMPLOYEES INTERVIEWED WITH RESPECT TO
REMOVAL PRACTICES

COMPANY	TITLE OF INTERVIEWEE
A	TECHNICAL & PLANT ENGINEER
B	WORKS' MANAGER
C	CHIEF ENGINEER
D	WORKS' ENGINEER
E	INSTALLATION MANAGER
F	CHIEF DEVELOPMENT ENGINEER

The third practice was that of making an assessment of the residual value of the old plant. This was found in all the companies surveyed. In company B the plant was usually scrapped off. In company F the plant would be advertised internally to other divisions of the company, otherwise the accountants' book value or the scrap value would be used. This was also the method used in companies A, C, D and E.

14.32 Moderate-Care. Three practices were proposed at this level-of-care.

The first of these was the preparation of a budget for the removal project. This was found to be adopted by all of the companies surveyed. In all cases it was found that the interviewees were responsible for preparing the budget.

The second practice was the formal planning of the removal project. This was not found in companies D and B. In companies C and F network analysis was used as well as bar-charting. In companies A and E bar-charting was the only technique adopted.

The third practice was to review the maintainability problems of the plant being removed in order to ensure that they were not carried on into the new plant design. This practice was found only in companies E and F. In company E, prior to the design of a new plant, the poor maintainability features of the existing plant were highlighted and fed-back

to the designers. One example was quoted in which some 60 points had been raised by the maintenance engineers which added several months to the design time of the new plant. In company F a similar procedure was found in which the maintenance engineer would highlight the poor aspects of the old plant to ensure that these features were not repeated in the new plant wherever possible.

14.33 Advanced-Care. The first practice proposed at this level-of-care was to carry out a review of the reliability problems associated with the old plant. This practice was only found in companies E and F. In both companies a similar procedure was adopted to that for assessing maintainability problems.

The second practice was to assess the maintainability requirements of the new plant. This was found only in companies E and F. In company E this was carried out by the area engineers who were responsible for highlighting the features that they wished to be incorporated in a new plant. For example, one case was given in which a specific number of preventive maintenance hours were stipulated by the area engineers. It was mentioned also that several new maintainability ideas were tried out on development plant before being incorporated into new plant designs. In company F the departmental engineer estimated the "average job length"

for a maintenance task and reviewed also other characteristics such as fault location aids, fault diagnosis aids, condition monitoring equipment, workshop layouts and special equipment.

The third practice was to assess the life of the new plant. This was found only in companies E and F. In company E this was assessed as ten years and in company F as fifteen years. However, in both cases the interviewees admitted that these lives were arbitrary and based more on accounting convenience than on engineering estimates.

14.34 Intensive-Care. Two practices were proposed at the level of intensive care. The first was the recording and feed-back of experience gained during the life of a plant to the plant manufacturer. This was not found as a practice in any of the companies surveyed. However, company F had established a system of feed-back of information which they hoped would still be in existence at the end of the plant's life. Because this practice was established recently it has not been credited to the company because it has not existed long enough to apply to any plant that they are considering removing from operation.

The second practice was to carry out an assessment of the reliability required of a new plant. This practice was not found in any of the companies surveyed.

14.4 Summary.

This chapter has presented the findings of the research

into the application of terotechnological practices when removing plant from operational use and replacing it with a new plant. All the companies surveyed were found to adopt the practices associated with general-care. The first practice at the level of moderate-care was utilised also by all companies in the survey. However, companies D and B did not exceed this level of practice. Companies C and A adopted two practices at the level of moderate-care and companies E and F adopted all of the practices at this level. Only companies E and F were found to adopt practices associated with advanced-care of their physical assets. Table 19 summarises the findings presented in this chapter. The table indicates that the findings show a tendency towards the increasing application of terotechnology being dependent on the increasing level of mechanisation of the production system.

The next chapter presents a summary and draws some conclusions from the research findings which have been presented in the foregoing chapters.

THE APPLICATION OF TEROTECHNOLOGICAL
PRACTICES WHEN REMOVING PLANT RELATED TO THE
AVERAGE LEVEL OF PRODUCTION SYSTEM MECHANISATION

LEVEL-OF-CARE	THE PROPOSED TEROTECHNOLOGICAL PRACTICES	COMPANY CODE LETTER					
		AVERAGE LEVEL OF MECHANISATION					
		D	B	C	A	E	F
	REMOVAL	3.2	3.5	3.8	5.2	7.4	10.3
INTENSIVE	assess reliability of new plant						
	recording and feedback of experience						
ADVANCED	assess life of new plant						
	assess maintainability of new plant						
	review reliability of old plant						
MODERATE	review maintainability of old plant						
	formal plans for removal						
	budget for removal						
GENERAL	assess residual value of plant						
	assess operating requirements for plant						
	assess market for product						

CHAPTER 15

SUMMARY AND CONCLUSIONS

15.1 Introduction.

This chapter presents an overview of the research work detailed in the foregoing chapters. It then draws some conclusions based on the findings of this work into the concept and practice of terotechnology.

15.2 Overview of the Research Work.

Chapter 1 of this dissertation set out the broad objectives of the work. It outlined the justifications for pursuing the work, it described the setting and limitations surrounding both the conceptual and field research work and finally it described the structure of the dissertation.

Chapter 2 was concerned with establishing the historical development of terotechnology as a concept and the evolution of the formal definition.

Chapter 3 examined the literature in two areas of concern to the development of this research. These areas were examined and conclusions arrived at as a result of the analysis of the literature. However, because the literature presented a confused picture of the way terotechnology should be interpreted, Chapter 4 presented a detailed examination

of the definition in order to develop a generalised interpretation of the role that terotechnology should adopt within a manufacturing organisational system.

Chapter 5 was concerned with developing a conceptual model based on the concept of 'caring-for' physical assets. The chapter developed a 'level-of-care' framework for each of the eight phases in the terotechnological life-cycle. This model facilitated a praxeological description of the nature of 'terotechnological practices'. In total 95 such practices were identified and associated with levels of care described as general, moderate, advanced and intensive.

Chapter 6 examined the objectives of the industrial field research, it described the alternative research methodologies available and the reasons for selecting the descriptive survey methodology. The research design was then described in detail together with details of the response rate and participating companies. The basis for comparative analysis was given and the method adopted to present the findings of the industrial research was stated.

Chapters 7 to 14 presented the findings of the industrial research into the application of terotechnological practices over the life-cycle of physical assets. That is, when specifying, designing, financially evaluating, procuring, installing, commissioning, maintaining and finally removing physical assets. The following section presents the conclusions drawn from this research work.

15.3 Conclusions.

This section presents the conclusions that the author considers justifiable as a result of this research into the concept and practice of terotechnology. The first part considers the conclusions drawn as a result of the work which examined the concept of terotechnology and the second part deals with the practice of terotechnology.

15.31 The Concept of Terotechnology.

In Chapter 1, page 1 the objective for this part of the research was stated as follows:-

To investigate the historical development of terotechnology and to examine the way in which the concept should be interpreted.

As a result of the work carried out in Chapters 2 to 5 this dissertation draws the following conclusions:-

- 1) It concludes that to the author's knowledge, until this research was undertaken, no single work had attempted to establish the historical development of terotechnology. The concept was evolved as a result of two government reports which attempted to establish how maintenance engineering was being practised and the cost to the country of those practices.
- 2) It concludes that despite the attention given to maintenance, the government working party interestingly omitted the word maintenance from the first definition given in 1972 and it was not until 1974 that this omission was rectified.

- 3) It concludes that the word terotechnology was chosen by Dr.H.P.Jost and the late Sir Richard Clarke one Sunday after dinner in Dr.Jost's sitting room and that as a result of this the government set up a working party to investigate how the concept of terotechnology could be disseminated to industry,education,research and the media.
- 4) It concludes that early work in the literature on terotechnology was confused about the concept,some describing it as inter-disciplinary and others as multi-disciplinary. This work suggests that the correct interpretation should be that terotechnology is a multi-disciplinary concept.
- 5) It concludes that again the literature was confused about the possible role that terotechnology could adopt in manufacturing industry. The descriptions ranging from "absurdly naive" to "multi-disciplined science". This work has developed a generalised interpretation of the role of terotechnology as follows:-

Terotechnology can be considered to operate as a subsystem of an organisation responsible for the non-operational life-cycle management, engineering,financial and other practices applied to that organisation's physical assets in order to pursue cost-effective life-cycle costs for those assets. It exists as one of a number of subsystems in a total organisational system, which when combined,are responsible for pursuing the business objectives of that organisation.
(Chapter 4,pages 27 and 28)

6) It concludes that whilst the literature frequently referred to the application of 'terotechnological practices' no attempt had been made to identify what these practices were. This research has developed a conceptual model based on progressive development of a 'caring' attitude towards the life-cycle management of physical assets. This has resulted in a model which describes four levels-of-care. These being; general-care, moderate-care, advanced-care and intensive-care. The model then identified 95 separate terotechnological practices over the eight phases of the life-cycle. These 95 practices formed the basis around which the industrial field research could be conducted.

This section has stated the conclusions drawn from the work presented in Chapters 2 to 5. The following section states the conclusions drawn from the industrial research.

15.32 The Practice of Terotechnology.

In Chapter 6, page 53 and 54 the objectives for this part of the research were stated and are summarised as follows:-

1. To investigate the extent to which terotechnological practices, as identified within this dissertation, were applied in a small sample of manufacturing organisations.
2. To suggest, as a result of this investigation, those areas of management practice where special emphasis should be placed in order to improve the level-of-care applied to industrial plant and equipment.

These objectives were applied to each of the eight phases

in the life-cycle that were identified in Chapter 5. As stated in Chapter 6, page 65 the conclusions have been bound as formulations in terms of 'tendencies' when dealing with all the companies in the survey and in terms of an 'indication towards' when dealing with an individual company.

In Chapter 6, page 66 the method of comparative organisational analysis was stated. This was the use of Bright's (op.cit) mechanisation profile. The average level of production system mechanisation was determined for each company and the results of the research were presented in Chapters 7 to 14 from which the following conclusions about the application of terotechnology are drawn.

- 1) This research concludes that when specifying plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average 43% of practices, proposed in Chapter 5, Table 1, were found to be in use.
- 2) This research concludes that when designing plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average, 30% of the practices, proposed in Chapter 5, Table 1, were found to be in use.

- 3) This research concludes that when performing the financial evaluation of plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average 43% of the practices, proposed in Chapter 5, Table 1, were found to be in use in the companies surveyed.
- 4) This research concludes that when procuring plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average 50% of the practices, proposed in Chapter 5, Table 1, were found to be in use in the companies surveyed.
- 5) This research concludes that when installing plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average 71% of the practices, proposed in Chapter 5, Table 1, were found to be in use in the companies surveyed.
- 6) This research concludes that when commissioning plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average 67% of the practices, proposed in Chapter 5, Table 1, were found in use in the companies surveyed.

- 7) This research concludes that when maintaining plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average, 52% of the practices, proposed in Chapter 5, Table 1, were found in use in the companies surveyed.
- 8) This research concludes that when removing plant there is a tendency towards an increasing application of terotechnological practices with increasing mechanisation of the production system. On average, 54% of the practices, proposed in Chapter 5, Table 1, were found in use in the companies surveyed.
- 9) This research concludes that there is an indication towards other factors affecting the application of terotechnological practices. For example, it was found that in companies D and B, whilst they had the lowest levels of mechanisation in the survey, they could adopt higher level practices. In company B the indications were that because it was owner managed the senior management who reported directly to the owner tended to take more 'care' over the setting of specifications and the financial evaluation of possible plant procurements. In company D, which had the lowest level of mechanisation, the management regarded their plant as sophisticated and 'fiddily' to use. As a consequence they adopted higher

level practices when commissioning plant than might have been expected if variations in the application of terotechnological practices could be entirely explained by the mechanisation of the production system.

- 10) This research concludes that it was noticeable that during the early phases in the life-cycle, that is when specifying, designing and carrying out the financial evaluation, the lowest levels of practice were found. This, it is suggested, is a most significant finding in that during these phases of the life-cycle approximately 70% of the total life-cycle cost of the plant could already have been committed, but perhaps only as much as 5% will have been incurred. This finding is depicted in Figure 5. In this figure the life-cycle is the horizontal axis and the percentage life-cycle cost is the vertical axis. It can be seen that it is most important to adopt terotechnological practices to a very high level as early in the project as possible, because the cost incurred in doing so is small in comparison to the cost committed during the early stages in the life-cycle.
- 11) As a result of the conclusion drawn in 10 above, it is further concluded that emphasis needs to be placed on the development of a wider and deeper understanding of the importance of setting specifications to include as

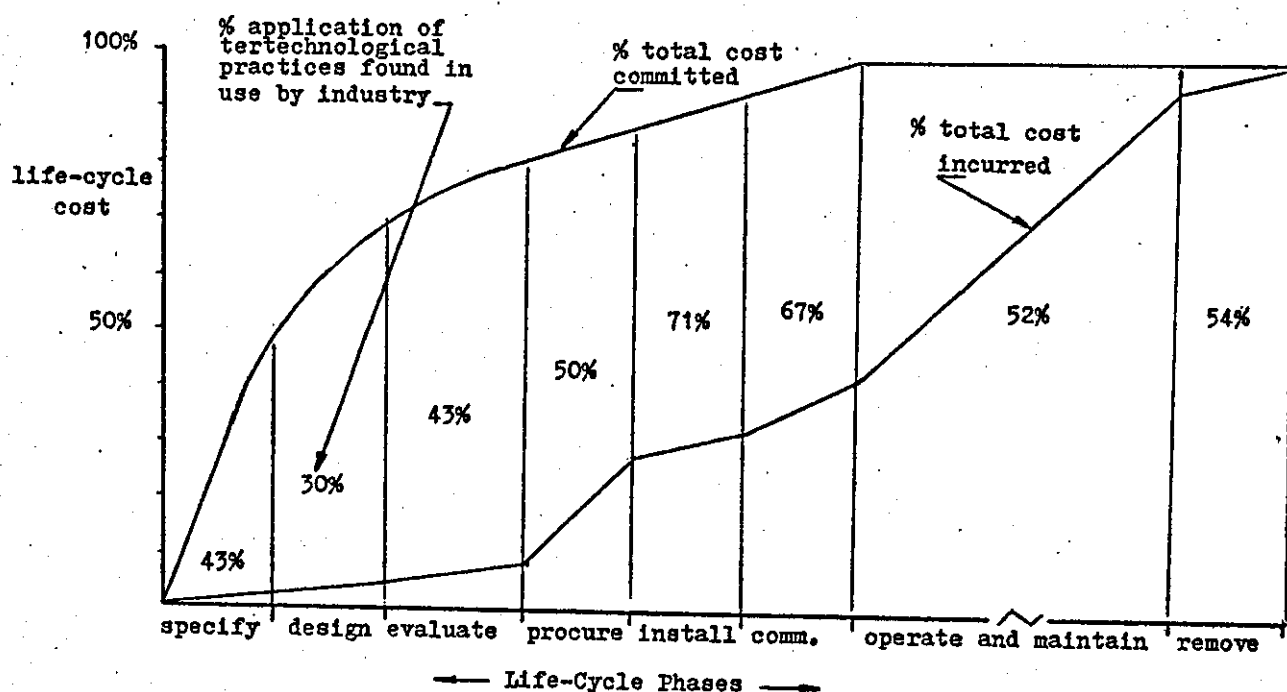


Figure 5 - An Idealised Representation of Committed/Incurred Life-Cycle Cost showing the Overall % Application of Terotechnological Practice found during each Phase of the Life-Cycle

*This figure has been adapted from a similar one proposed by Brigadier General J.O.Arman (74).

many terotechnological features as justifiable in order to pursue cost-effective life-cycle costs.

- 12) This research concludes that special emphasis should be placed on the design of physical assets. In particular the development of a wider and deeper understanding of terotechnological aspects of design such as those suggested in Chapter 5, Table 1.
- 13) This research concludes that special emphasis should be placed on financial evaluation as an important and distinct phase in the life-cycle of a physical asset. It was found that none of the companies surveyed had heard of life-cycle costing. Further attention should be given to this technique if the application of terotechnological practice is to improve and to be seen to be cost-effective.
- 14) This research concludes that the level of application of terotechnological practice during the maintenance phase was also at a low level when compared to the other post-procurement phases. Yet maintenance is probably the greatest cost incurring phase during an assets' life-cycle. Special emphasis should be placed on improving the application of terotechnological practices during maintenance.

15) This research concludes that on the basis of the findings, which are summarised in Table 20, over the six companies surveyed in this work for all the phases in the life-cycle of plant the application of terotechnological practices was found to increase with increasing mechanisation of the production system. The application of linear multiple regression analysis indicated that there was an overall correlation coefficient (r) of 0.976 between the average level of production system mechanisation and the overall percentage of terotechnological practices found in each of the six companies. This result gave a coefficient of determination (r^2) of 0.955 . This suggests that 95% of the variation between the application of terotechnological practices and the mechanisation of the production system could be explained by a linear relationship between the two variables. The print - out from the multiple regression correlation package (MULREG) is given in Appendix 5 .

15.4 Summary.

This chapter has presented an overview of the work carried out in this section of the dissertation. The conclusions drawn, as a result of the research carried out into the concept and practice of terotechnology, have been

TABLE 20
SUMMARY OF THE FINDINGS OF THE RESEARCH
INTO THE APPLICATION OF TEROTECHNOLOGICAL PRACTICES

LIFE-CYCLE PHASE	THE NUMBER OF TEROTECHNOLOGICAL PRACTICES PROPOSED BY THE MODEL IN CHAPTER 5 TABLE 1	MECHANISATION INCREASING→						THE % OVERALL AVERAGE IN USE
		THE No.OF PRACTICES IN USE						
		THE % OF PRACTICES IN USE						
		D	B	C	A	E	F	
		3.2	3.5	3.8	5.2	7.4	10.3	
SPECIFYING	15	2 13%	6 40%	3 20%	7 47%	9 60%	12 80%	43%
DESIGNING	15	1 6%	3 20%	3 20%	3 20%	6 40%	11 73%	30%
FINANCIAL EVALUATION	7	1 14%	3 43%	2 28%	2 28%	5 72%	5 72%	43%
PROCURING	6	2 33%	2 33%	3 50%	3 50%	4 67%	4 67%	50%
INSTALLING	11	4 36%	5 45%	8 72%	8 72%	11 100	11 100	71%
COMMISSIONING	14	7 50%	5 36%	10 72%	10 72%	12 86%	12 86%	67%
MAINTAINING	16	5 31%	5 31%	6 37%	7 44%	12 75%	15 94%	52%
REMOVING	11	4 36%	4 36%	5 45%	5 45%	9 82%	9 82%	54%
TOTAL NUMBER OF PRACTICES PROPOSED DURING THE LIFE-CYCLE		95	95	95	95	95	95	
TOTAL NUMBER OF PRACTICES FOUND IN USE IN EACH COMPANY		26	33	40	45	68	79	
THE OVERALL % OF PRACTICES FOUND IN USE IN EACH COMPANY		29%	35%	42%	47%	72%	83%	51%

stated. The next chapter examines other work which has been carried out in this field in order to establish if any comparisons can be made between them and the conclusions drawn in this chapter.

CHAPTER 16

COMPARISONS WITH OTHER WORK

16.1 Introduction.

This chapter examines the comparisons which can be made with other research work that has been pursued in the area covered by the work presented in this dissertation.

However, it should be understood that to the authors' knowledge no directly comparable research has ever been conducted. Therefore, directly relevant comparisons cannot be made and the comparisons presented in this chapter are of a general nature only.

16.2 Identification of Other Work.

No other research work has been identified which investigated the extent of application of terotechnological practice in relation to the level of production system mechanisation. However, Bright (op.cit.) in 1954 carried out research in the United States to examine the general impact of automation on management within 13 manufacturing organisations. In addition, between 1973 and 1975, the Small Business Centre of the University of Aston carried out a survey of companies employing less than 200 people. The survey was conducted in order to determine

the terotechnological practices adopted by small companies. 116 companies were surveyed and the findings of the work were published in March 1976,(42). In 1968 the Ministry of Technology commissioned P.A.Management Consultants Limited to carry out a survey of maintenance practices in manufacturing industry. Some of the findings of these three works can be compared, but only in the most general way. The next section describes some of the comparisons which can be made with the findings of the research presented within this dissertation.

16.3 Some Comparisons.

The first comparison which can be drawn is with the Aston Survey. The survey found that 53% of the firms in the sample used investment appraisal techniques. In this research 84% of the sample used such techniques. The Aston Survey found that 52% of the companies bought second-hand plant. In this survey only 17% were found to adopt this practice. The Aston Survey found that 27% of the companies visited used historical records to assist in plant purchasing decisions, whereas in this survey 33% of the companies used this practice.

Bright found that automation brought considerable planning problems during installation and that manpower planning, equipment planning and task planning were all carried out in detail. In this survey equipment planning

was found in all companies, whilst task planning and manpower planning were found only in companies C,A,E and F. So that the more highly mechanised plants were found to carry out more planning. Bright found also that considerable use was made of the commissioning phase as a training tool. This practice was found also in five of the companies surveyed by this work.

Bright found that " no meaningful records " existed to enable him to judge how routine maintenance was affected by automation. However, in this study it was found that routine maintenance work was organised more formally in the more mechanised plants. For example job cards were used and maintenance was decentralised with groups of engineers responsible for maintaining zones or areas of plant. Automatic lubrication systems were found in both studies. Bright found that organised preventive maintenance was strongly advised by experienced maintainers of automated plant. This was found also in this survey in which the three more mechanised companies operated detailed preventive maintenance systems. Bright found also one company in his survey that had a separate housekeeping organisation. Coincidentally, only one company(E) was found to have a separate housekeeping department in this survey. Another interesting finding, which compares with this work,

was that Bright found decentralisation of the maintenance force was a desirable feature in automated plants. This was also noticeable in this work. All the companies in the survey, except D and B, used decentralised maintenance organisations. Bright comments on the rising level of automaticity by saying that " there is a strong economic spur to raise activities off levels 1,2 and 3 ". He goes on to say " But in many cases there is literally neither necessity nor economic advantage in achieving mechanisation above, say level 6, with an occasional use of levels 8,9 and 10 where needed." This conclusion may well be the one which most dates the findings of Bright's work. As can be seen from Table 21, the average level of production system mechanisation observed in the seven mechanisation profiles given in Chapter 4 of his book show that they ranged from 3.5 up to 6.8. Whereas, in this survey the range was from 3.2 up to 10.3 despite the fact that most of the companies in this survey were much smaller than those in Bright's survey. Certainly, the management of companies C, E and F saw no halt in the desire to increase the mechanisation of their production systems still further. However, it was noticeable that the management of companies B and D could see no incentive for further increasing the mechanisation of their production systems. This leads to the proposition that it could be a function of size and management attitudes towards

TABLE 21
COMPARISONS BETWEEN AVERAGE
LEVELS OF PRODUCTION SYSTEM MECHANISATION

BRIGHT SURVEY(1954-55)		HARVEY SURVEY(1975-76)	
company	average level of production mechanisation ¹	company	average level of production mechanisation
Burton Oil Seals	3.5	D	3.2
Rubberfoam	4.2	B	3.5
Ovenflow	4.6	C	3.8
Growmore	4.6	A	5.2
Queens Motors	4.7		
Ford Motor Company	6.1	E	7.4
Northland Oil Refinery	6.8	F	10.3
Range	3.5 to 6.8		3.2 to 10.3
Overall Average	4.9		5.6

¹Computed from the mechanisation profiles given in exhibits 4.3 to 4.10 chapter 4.

the plant which could affect the desire to increase the mechanisation of production.

Another note-worthy comparison between this work and the findings of Bright are the conclusions he draws regarding the need for integrated organisational systems.

Bright states:-

... under automation it becomes a job of management to create superior teamwork. Automation is literally integration of the physical plant. Its counterpart for management is integration of the organisation. The plant and its people may no longer be unrelated elements, each proceeding with little regard to the others actions. An effective automation design team that knits together the requirements, plans and adaptations of marketing, sales, product design, process design, purchasing and manufacturing ~~person~~ personnel to the total business goals is the first management step towards successful automation. (Bright, ibid, page 234)

It was found in this survey that companies E and F paid particular attention to the integration of their organisation structures when setting up plant projects. In company E project teams consisted of marketing, product research and development, process development, project engineering, design engineering, industrial engineering, maintenance engineering, production management and other specialist disciplines as were considered necessary by the project manager. In company F new plant project teams were designed also to fulfil the needs of an integrated approach to the consideration of new proposals. They consisted of accounting, production,

personnel, safety, site engineering, maintenance, progress and inspection, electrical engineering, design engineering, process control, planning, installations, and many other support functions . This form of organisational integration was not found in any of the other companies with much lower levels of mechanisation.

The need for a terotechnological approach to the management of plant is highlighted also by Bright when he concludes:-

Managers must become "machine designers". ... No longer can management simply "run" the plant to make whatever it is selling. Now management must decide well in advance exactly what it wants to make, how much it wants to make, at what rate it is to be made and over what period. This is a far cry from traditional practice ... Therefore, an extremely careful planning job, which means laying down a clear set of requirements of input, output, and operating characteristics for the supermachine must be done. Only management can do this.
(Bright, ibid, page 234)

This conclusion must be as true in 1978 as it was in 1955. The importance of planning and determining the detailed characteristics of the production system are central to the terotechnological approach to the life-cycle management of physical assets. Bright makes a further comment on the need for terotechnological characteristics in the management of plant when he concludes:-

Management must provide the "feedback" from market to supermachine, from technological frontiers to the plant. ... Once management has collected data and

identified trends, it must make a realistic and hard-boiled decision about scrapping or changing the supermachine. How can management do this sensing, balancing, data-relating and interpreting job? The complexities of the relationships are so much greater and more significant under automation that all facets of the organisation must be intimately conscious of what is happening in other parts of the business.
(Bright, *ibid*, page 234)

It could be argued that Bright was suggesting that what is needed to cope with automation is a terotechnological approach to plant management although of course the concept did not exist at the time he carried out his work.

Returning to some of the findings of the Aston survey, it found that 24% of companies carried out regular lubrication of plant. In this survey 100% of the companies adopted this practice. Regular preventive maintenance inspection was found in 32% of the Aston survey and 50% of the companies in this survey. 86% of the companies surveyed in the Aston study kept spare parts, whereas all the companies in this survey were found to hold stocks of spares. Overhauls were carried out in 22% of the Aston survey and 100% in this survey. In the Aston survey 23% of companies had records of machine breakdowns whereas 33% of companies in this survey kept such records. Only 11% of the companies in the Aston survey had heard of terotechnology whereas 50% of the companies in this survey had done so.

The P.A. Management Consultant's report(op.cit.)

found that 41% of the respondents used budgetary control in maintenance whereas in this study 67% of the companies adopted this practice. The P.A. study found that on average, throughout manufacturing industry, 7% of all employees were employed on maintenance work. In this study the overall average for all six companies was 10%.

It must be clearly stated again that the comparisons that have been made in this chapter are formulated in the most general way because as was stated at the introduction to this chapter no directly comparable work has ever been conducted.

Having reiterated the limitations on these comparisons, some general statements can be postulated regarding the application of terotechnology and its relationship to mechanisation, based on the comparisons of the four studies noted in this chapter.

- 1). It would appear that in comparison to the findings of the Aston survey in 1973 to 1975 and the P.A. survey in 1968, that terotechnological practices are applied to a greater extent than these surveys might suggest.*
- 2). Based on the findings of the Aston survey into companies employing up to 200 people, it could be suggested that the enhanced levels of practice

* This conclusion was seen to be doubtful in the eyes of the thesis examiners

found to be in use in the six companies surveyed by this research existed for reasons other than simply the mechanisation of the production system.

(For example, size, management attitudes and so on)

- 3). More than twenty years ago companies in the U.S.A. were approaching the challenge of managing production systems with ever increasing levels of mechanisation by adopting what are now described as terotechnological practices.
- 4). If the management of a company are considering further mechanisation then they would be strongly advised to consider a terotechnological approach if their move towards increased mechanisation is to be successful.

16.4 Summary.

This chapter has presented some comparisons with other work that has been carried out in the field of terotechnology and automation. It has been pointed out that the connection between the three studies mentioned and this work is very loose and that the comparisons are made in a most general way. The comparisons have not enabled any definitive validation of the findings of the work presented in the foregoing chapters of this dissertation but nevertheless were interesting to note.

This chapter concludes the work on the concept and practice of terotechnology. Part 2 follows this chapter.

This deals with the concept and practice of life-cycle costing, a technique which is central to the development and application of a terotechnological approach to physical asset management.

PART 2

LIFE-CYCLE COSTING

CHAPTER 17

LIFE-CYCLE COSTING--AN OVERVIEW

17.1 Introduction.

This chapter presents an overview of the technique of life-cycle costing. It states the definition of a life-cycle cost and it reviews the literature in order to establish the historical development of the technique on an international basis. In addition, the literature is examined in order to establish what benefits and limitations have been associated with the application of life-cycle costing to the economic evaluation of engineered systems.

17.2 The Definition.

Several authors have chosen to place slightly different interpretations on the definition of a life-cycle cost. For example, Kaufman(43), Ebenfelt and Ogren(44), White and Oswald(45), Murden(46) and Brode(47). However, the majority of writers have chosen to adopt the definition given by the Logistics Management Institute of the U.S.A.

It is the total cost of ownership of a system during its operational life. It embraces all the costs associated with the feasibility studies, research, development, design and production, and all support training and operating costs generated by acquisition of the equipment. (Life-Cycle Costing in Equipment Procurement, IMI, April 1965)

Within the United Kingdom some writers have chosen to use the definition offered by the Department of Industry. This is stated as follows:-

It includes the costs associated with acquiring, using, caring for and disposing of physical assets, including the feasibility studies, research, design, development, production, maintenance, replacement and disposal, as well as support, training and operating costs generated by the acquisition, use, maintenance and replacement of permanent physical assets. (Terotechnology-An Introduction to the Management of Physical Resources, Dept. of Industry, 1975, page 3.)

It is this definition which has been adopted throughout this dissertation.

17.3 The Historical Development.

The origin of the life-cycle costing (LCC) technique can be traced back to the early 1960's. At this time the United States' Department of Defense became concerned about the implications for on-going expenditure incurred by the government if it continued to award contracts on the basis of lowest purchase price only. As a result of this concern, in 1963 the then Assistant Secretary for Defense (Installations and Logistics) contracted the Logistics Management Institute (LMI) of the U.S.A. to investigate the consequences and feasibility of a change in procurement policy from the use of the 'low-bid' to a policy which took account of the on-going costs of ownership and their impact on government expenditure.

The Logistics Management Institute reported in April 1965 (48). The report stated that "operating and support costs were often a substantial part of the total cost of a piece of equipment over its expected life". The report found that, "those operating and support costs, as well as the purchase price, can vary significantly among various suppliers." The report concluded that techniques could be devised to allow the government to predict and measure operating and support costs to a degree that would allow their use in evaluating alternative procurements.

On the 10th. July 1965, the Assistant Secretary for Defense issued a memorandum to his assistant secretaries of the military departments. The memorandum stated that:-

It is important that we develop an improved capability to identify and evaluate logistics costs, other than price, in awarding contracts for equipment. There is general agreement that a well organised approach should be undertaken particularly to ensure communication of information and experience between organisational elements in the departments engaged in this work. Co-ordination with industry is desirable especially to familiarise defense contractors with the general concept and our intentions to develop procedures to exploit it.. (taken from Peratino, G.S., Air Force Approach to Life-Cycle Costing, Procs. 1968 Reliability Symposium Boston, Mass. Jan. 16-18th. 1968.)

In addition, the Secretary proposed the setting up of a Department of Defense life-cycle costing steering group together with several life-cycle costing task groups. The task groups were composed of representatives from

procurement, engineering, maintenance, supply and training. As the work of the task groups continued, it became evident that the role of engineering personnel was critical. In a letter dated the 4th. June 1966, to the Director of Defense Research and Engineering (ODDR&E), the Assistant Secretary of Defense (Installations and Logistics), (49) stated:-

It is clear ... much of the initiative for employing this concept [life-cycle costing] rests with personnel representing engineering. In fact, it is likely that criteria for evaluation of logistics factors should be written into equipment specifications.
(taken from L.C.C. in Equipment Procurement, LMI., Feb. 1967, page 8)

The Director of Defense Research and Engineering replied:-

I believe there is considerable promise in the concept of life-cycle costing in equipment procurement and that participation is desirable.
(ibid, page 8)

At this time doubts still existed about the compatibility of financial procedures to the application of life-cycle costing. However, on the 30th. June 1966 the Assistant Secretary for Defense (Comptroller) said:-

Life-cycle costing ... is certainly a concept that should be fully exploited in the interest of providing for more complete evaluations of the economic impact of defense programs before they are approved for programming and execution. I do not foresee that our current program/budget procedures should interfere with the execution of decisions reached as the result of application of life-cycle costing analyses ...
(ibid. page 9)

Peratino (50) , has suggested that the level of acceptance gained by the Department of Defense's efforts to promote life-cycle costing can be judged from a statement issued by the Deputy Assistant Secretary of Defense(Procurement), on the 21st.June 1966.

The statement read:-

The concept of life-cycle costing in equipment procurement has the endorsement of top level Department of Defense management. Some of our defense contractors and many representatives of Department of Defense technical disciplines have urged this course of action for some time ... The logic of this concept is so compelling that we intend to make whatever investment is necessary to exploit it to the fullest possible extent.(ibid).

Following these initiatives the Department of Defense conducted several trial procurements and from this experience an initial life-cycle costing policy evolved.

Several examples of the application of life-cycle costing to equipment procurements were performed by each of the armed forces. For example, Sternlight(51) has described the application of LCC to the design and economic analysis of a Fast Deployment Logistics Ship. However, Pedrick(52) has suggested that the progress made in the use of reliability and maintainability analysis had been disappointing. He suggests that at this time most of the emphasis was placed on inventory mangement costs and on estimating the useful life of non-repairable equipment.

Further work was carried out by the Department of Defense and in 1970 an interim report was issued(53). This guide represented the first attempt to establish procedures for employing the LCC concept to military procurements. The guide stated that:-

Implementation of life-cycle costing involves the application of knowledge from a broad range of disciplines. ... Included in the assigned responsibility should be the effective utilisation of personnel operating in teams, who collectively possess the materiel management, engineering, cost analysis, procurement and legal expertise needed in the execution of life-cycle costing procurements.... (Department of Defense Guide, LCC 1, July 1970, page 1.)

Since the publication of this procedural guide, life-cycle costing has become a common evaluation technique within the United States Armed Forces. For example, Boren(54), Fiorello(55), Nelson(56), Balaban and Nomer(57), Brode(58), Dixon and Anderson(59), Duhan and Catlin (60), Fagan(61), Fiorello and Konoske-Dey(62), Fragola and Spahn(63), Gansler(64), Giordano and Sacks (65), Harty(66), Langwost(67), Rush et al(68), Sadler(69), Stehle et al(70) and Watts(71) all describe the application of LCC to the evaluation of military systems.

From the literature it is clear that the Swedish government have also used life-cycle costing. For example, Ebenfelt and Ogren(72), Ebenfelt and Waak(73), Arman (74), and Dahlberg and Westlund(75) all describe the application of life-cycle costing to Swedish military

systems.

In the United Kingdom, the origins of life-cycle costing stem from work carried out by the admiralty department¹ in late 1967. At this time the admiralty were becoming increasingly concerned with the impact that on-going costs of operating and logistics support were making on the total costs of vessels in the operational fleet. In addition, it was recognised that some vessels were suffering from down-time of unacceptable proportions. Hence, in late 1967 a working party of four admiralty staff(three engineers and one accountant) was set-up to investigate ways of reducing expenditure incurred as a result of the on-going operation and support of the fleet. The working party analysed maintenance costs, logistics costs, reliability and maintainability characteristics and so on.

Further work continued in the late 1960's and early 1970's within what is now termed the Navy Department. In approximately 1971 the Army and Air Force began to take an interest in the use of life-cycle costing. In the same year the Management and Technical Information Service² (MANTIS) department of the Procurement Executive set-up a working party to develop a procedural guide to the use of life-cycle costing in the Ministry of Defence. In 1974 they produced a guide entitled " Defence Life-Cycle Costing-Introduction and Guide"(76). In 1973 the Army

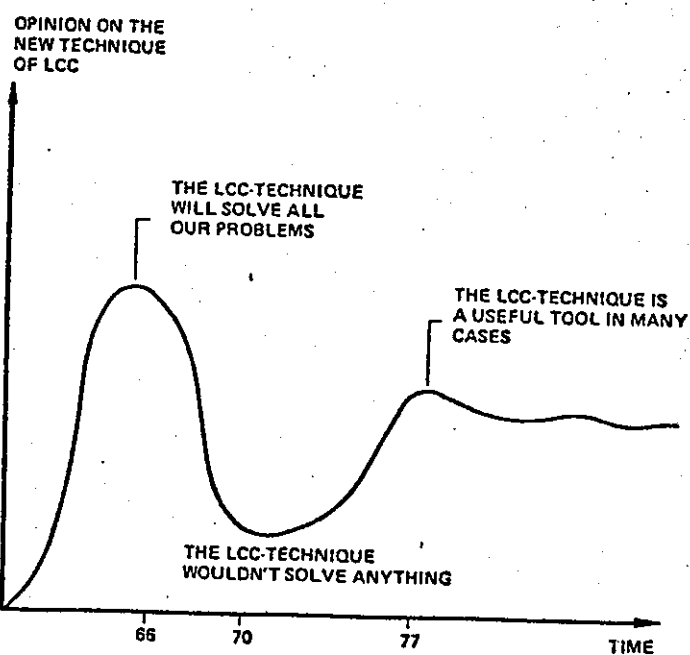
commissioned a firm of consultants to investigate the feasibility of using life-cycle costing on army equipment. In 1973 the Air Force established a working party which looked at the use of trade-off analyses, particularly for aero-engine performance against cost characteristics. In December 1975 the Navy Department produced a report outlining the procedure for application of LCC to naval equipment. Other work, particularly in the fields of parametric cost estimating, trade-off and simulation work is being carried out by the Defence Operational Analysis Department. In 1977 three case studies were presented at a conference in London in which members of the Procurement Executive gave detailed accounts of the work that has been pursued by them. (77).

In 1976 the Department of Industry set-up a life-cycle costing working party with the task of promoting the general level of awareness and encouraging application of life-cycle costing within manufacturing industry generally. The working party commissioned a firm of consultants to produce an accountants' guide to life-cycle costing and this was published in 1977 (78).

The concept of terotechnology allied to life-cycle costing, as a means of economic evaluation for manufacturing plant, has received more and more interest from industry.

The author has held discussions with several senior managers in manufacturing industry including Hart³, Clarke⁴, Sharrock⁵, Powell⁶, Moss⁷, Sadler⁸, Riddell⁹, Hodgkinson¹¹, Blunn¹², Davies¹³, Darnell¹⁴ and Fenwick¹⁵. These discussions have indicated that there is considerable interest in testing the feasibility of life-cycle costing. However, they all have one problem which is tending to prevent implementation. That is, no procedural model has been developed to enable industry to pick-up the technique and understand how to proceed with its application. However, opinion on the value of the technique does seem to have increased, with many manufacturing organisations expressing interest in the technique, research being conducted and the literature becoming more expansive. In 1977 the 2nd. International Conference on Life-Cycle Costing was held in London and early in 1978 the third conference was held in the Netherlands. Arman (op.cit.) expressed the current situation well in his paper and his figure is reproduced in Figure 6. The figure attempts to illustrate the initial extreme fluctuations when a new technique is introduced and as time passes the level of opinion settles down to a steady state. Arman is suggesting that in 1978 the technique has reached a stage where it is regarded as a useful tool for application in many cases.

OPINION ON A NEW TECHNIQUE



THE FLUCTUATION OF OPINION ON LIFE-CYCLE
COSTING

Figure 6

(taken from Arman, J.O. (74))

17.4 The Benefits from Application.

The application of life-cycle costing could produce many desirable benefits to industry. However, little work has been carried out to establish what those benefits are in relation to the application of life-cycle costing as an economic evaluation technique for manufacturing plant and equipment. The literature expounding the benefits which have accrued to the military sector is considerable. In this section those benefits, which the author perceives as being relevant to manufacturing industry, are brought together from the wide ranging military orientated literature.

Peace(79) says of life-cycle costing "it is a valuable tool in all phases of program development and operations ... and it has the highest pay-off early in the program". Kaufman(op.cit)who is one of the few writers to have examined the application of LCC to manufacturing plant says " life-cycle costing reinforces the point that profits are maximised by minimising overall or life-cycle costs and not just initial costs".

McCullough(80) says "The use of life-cycle costing highlights the distinctions that can be made in the allocation of resources over the life-cycle of the asset". Earles(81) suggests that life-cycle costing can be used as four things "... a costing discipline, a procurement technique, an acquisition consideration and a design

trade-off tool". Ryan(82) says, "The objective of LCC procurement is to avoid the so called "low-bid fallacy". Ryan goes on to state, " LCC represents a more scientific approach to the source selection process than those predicated upon acquisition price alone." Bryson(83) says that " designing to life-cycle cost brings improved management." Harrison (84.) says, "LCC is a valuable tool in reducing support costs".

More detailed analyses of the value of life-cycle costing are found in work by Sternlight,(op.cit), Ebenfelt(85) and the Logistics Management Institute. For example,Ebenfelt states:-

Life-cycle costing has three roles; the first in budgeting and planning, the second in communicating priorities and the third as a basis to support trade-offs. The life-cycle costing technique is a trademark implying that a decision has been supported by relevant user orientated utility and cost concepts. (Ebenfelt,H.2nd.Int.Conf.on Design-to-Cost-Life-Cycle Cost,London,1977,pages 94-95)

The Logistics Management Institute (op.cit.)says of life-cycle costing:-

Life-Cycle Costing ... encourages a more advantageous distribution of technical effort among ... equipment design, support equipment design and operation and support precepts. Since LCC award criteria are more comprehensive than acquisition cost criterion, a better balance of ... innovative effort should result. (Life-Cycle Costing in Equipment Procurement-Supplemental Report,Task 66-3,IMI,Washington D.C.,Feb.1967)

Perhaps the most comprehensive analysis of the value of life-cycle costing has come from Sternlight(op.cit.) He describes, in detail, the way in which life-cycle costing was of value to the design and economic evaluation of the Fast Deployment Logistic Ship project. Because his analysis is so detailed and central to arguments for encouraging the use of life-cycle costing within manufacturing industry, two long quotations are included here for completeness of this section. Sternlight states:-

As a result of the complete, coherent application of life-cycle cost analysis as an engineering decision making tool from system to component a step-by-step economic justification of the entire system and the rationale for its selection exists. It is possible to see how decisions at any stage affect and are affected by previous and subsequent decisions. It is also possible to explore the decision chain when changes to the system are contemplated in order to provide an efficient method for the analysis of the economic affect of these changes. (Sternlight, D. Fast Deployment Logistics Ship Project: Economic Design and Decision Technique, NRLQ, Vol. 17 1970, pages 374-375)

When summarising the application of life-cycle costing to this project Sternlight goes on to say:-

The benefits from life-cycle cost and economic analysis integrated into major physical system planning and design are so significant that we have adopted these same techniques for many other systems which are currently under in-house study and design ... The technique of formally applied, integrated life-cycle cost analysis is being applied ... from the design of resistors to that of major systems, substantial savings are possible in overall life-cycle costs. At the same time

more reliable, more maintainable systems will be produced, with the higher investment costs fully justified by the reduction in total life-cycle costs. To assure these benefits, contractors must rise to the responsibility of developing data bases on their products' costs and performance.(ibid,page 387)

The benefits then are thought to be considerable, if it is possible to transfer experience from the military sector of industry to manufacturing industry in general. However, several problems exist with respect to establishing the technique within manufacturing industry.

It is suggested that the first requirement in order to commence the application of life-cycle costing should be to develop a procedural methodology. Indeed this was the first step taken by both the United States Department of Defense and the British Ministry of Defence. To the author's knowledge no procedural model exists to facilitate the wider dissemination and application of the technique at the time of writing. It is the objective of later chapters to attempt to develop such a model.

17.5 The Problems and Limitations of Application.

The first problem, which was highlighted above, is the lack of any procedural model at the present time. Another problem associated with attempting to apply the LCC technique in manufacturing industry is that not enough is yet known about the actual mechanics of performing a life-cycle costing analysis. For example,

is LCC performed by engineers or accountants or are LCC analysts required who are specially trained? Is inflation included in the analyses? Is discounting included? Are computers required? What combinations of knowledge and experience are desirable? What management and organisational implications stem from the use of life-cycle costing? What limitations do experienced practitioners see in the application of the technique ? and so on. Before any meaningful detailed analysis of the technique can begin, it was considered necessary to seek answers to these fundamental questions. Therefore a survey of experienced practitioners was conducted and this work is described in detail in the next chapter.

17.6 Summary.

This chapter has presented an overview of the the technique of life-cycle costing. The definitions used in the U.S.A and the U.K. have been stated. The historical development of the technique has been established and the advantages and limitations that can be associated with the application of the technique within manufacturing industry have been stated. The next chapter presents the research design, objectives, survey response and the findings of the field research conducted in order to provide some base of fundamental information so that a procedural model can then be designed.

- ¹ This was determined after a visit to the Procurement Executive in 1976.
- ² This was determined after a further visit to the Procurement Executive in which the manager of MANTIS was interviewed.
- ³ Discussions held with Mr. J. Hart, Manager Maintenance and Operations Division, Greater London Council.
- ⁴ Discussions with Mr. D. Clarke, Manager, Vehicle Maintenance Costing, National Bus Company.
- ⁵ Discussions with Mr. G. Sharrock, Chief Engineer, Pearl Assurance Company.
- ⁶ Discussions with Mr. Powell, Chief Development Engineer, Pedigree Petfoods Limited.
- ⁷ Discussions with Mr. R. Moss, Manager, Systems Reliability Service Data Bank, UKAEA.
- ⁸ Discussions with Mr. J. Sadler, Head of Engineering Economics, British Steel Corporation.
- ⁹ Discussions with Mr. H. Riddell, Maintenance Adviser, ICI Organics Division, Manchester.
- ¹⁰ Discussions with Mr. A. Hodgkinson, Plant Services Manager, Pedigree Petfoods Limited.
- ¹¹ Discussions with Mr. M. Blunn, Manager, Value Engineering, Pilkingtons Glass Limited.
- ¹² Discussions with Mr. D. Davies, Chief Maintenance Engineer, Pilkingtons Glass Limited.
- ¹³ Discussions with Mr. H. Darnell, Director of Engineering, British Steel Corporation.
- ¹⁴ Discussions with Mr. Fenwick, Production Manager, Ferodo Limited.

CHAPTER 18

LIFE-CYCLE COSTING:

ESTABLISHING SOME FUNDAMENTAL PRECEPTS

18.1 Introduction.

This chapter presents the field research design, objectives and findings. The field research into the practice of life-cycle costing was carried out in order to establish answers to important questions regarding some of the fundamental aspects of life-cycle costing. Some of these questions were listed in Chapter 17. It was considered essential to attempt to establish a base of fundamental knowledge before any realistic attempt could be made to design a procedural model of the life-cycle costing process.

18.2 Research Objectives.

The field research was designed with the following four areas of concern in mind. The research objectives were to determine:-

- 1)What qualifications and experience are sought of personnel employed on life-cycle costing analyses?
- 2)What quantitative and accounting techniques are utilised within life-cycle costing analyses?
- 3)What management and organisational considerations stem from the application of life-cycle costing?

- 4)What limitations and other important issues do existing practitioners associate with the use of life-cycle costing?

18.3 Research Design.

This research was intended to seek the views of experienced practitioners in life-cycle costing. The literature showed that the vast majority of experienced professionals were located in the United States and Sweden. Consequently, a postal questionnaire survey was considered the most appropriate method to adopt. Analysis of the writers who had published papers in 1975 and 1976 showed that twenty eight had done so and given a correspondence address. It was felt that to send a questionnaire to writers who had published earlier than 1975 would probably result in a lot of returns as "address unknown" and would be a waste of time and resources.

18.31 Questionnaire Design.

The questionnaire was designed to cover the four objectives stated earlier. It included both open and closed questions. Thirty seven questions were asked and the questionnaire can be found in Appendix 6 . To introduce the research an introductory letter was enclosed together with an international reply coupon and self addressed envelope.

18.32 Response Rate.

The twenty eight companies selected were all located in Sweden or the United States. The response pattern is given in Table 22 below. Table 23 gives details of the respondents.

TABLE 22
RESPONSE PATTERN

	UNITED STATES	SWEDEN	TOTALS
QUESTIONNAIRES POSTED	22	6	28
RESPONSE	7	1	8
RETURNED ADDRESS UNKNOWN		1	(1)
RESPONSE RATE			30%

As can be seen from the table a total of eight completed questionnaires were returned, giving a 30% response rate.

18.33 Limitations of Results.

The following limitations on the findings of the postal survey are recognised:-

- 1) The sample was very small.
- 2) The experience of the respondents is very specialised and there may be limitations on the degree to which their experiences are applicable to the use of life-cycle costing as an economic evaluation technique for manufacturing plant.

TABLE 23
DETAILS OF RESPONDENTS

RESPONDENT NAME/COMPANY/COUNTRY	ORGANISATION CODE*
R.A.Eberhard, Chief Technology Engineer, Operations Analysis, Mc Donnell Aircraft, U.S.A.	G
Staff Engineer, U.S.A. (asked to remain anonymous)	H
S.O.Nilsson, Manager, Reliability Group, Sweden. (asked for company to remain anonymous)	I
D.R.Earles, Manager of Life-Cycle Analysis, Raytheon Company, U.S.A.	J
Director of Support Technology, U.S.A. (asked to remain anonymous)	K
J.H.Witt, Principal Engineer, ARINC Research Corporation, U.S.A.	L
D.D.Gregor, Manager System Support, Northrop Corporation, U.S.A.	M
H.A.Brode, Cost Analyst, Hughes Aircraft Company, U.S.A.	N

*
Used to refer to each respondent within the text.

3) There may be misunderstandings with language used in the questionnaire and in the replies.

4) All the respondents worked for very large international organisations with considerable resources at their disposal. Hence, some of the replies may exaggerate the degree of depth or breadth actually necessary to adopt the practice at a minimum level of sophistication. Despite these inherent limitations on the findings of the survey, the results give some interesting insights into the fundamental knowledge and skills required in order to adopt the life-cycle costing technique. The findings of the survey are given in the next section.

18.4 Survey Findings.

The findings of the survey are divided into four groups under the same headings as the objectives were stated. That is, the survey findings are presented below under (1) Qualifications and Experience, (2) Quantitative and Accounting Techniques, (3) Management and Organisational Considerations and (4) Limitations and Other Important Issues.

18.41 Qualifications and Experience.

Four questions were asked in this section dealing with academic qualifications, industrial experience, the ideal combination of knowledge and skills and at what academic level did respondents think that life-cycle costing should be introduced.

Academic Qualifications. Respondent G required a Bachelor of Science degree in maths., physics or engineering. Respondent H stated, "an engineering degree with a masters in business is desirable but not mandatory.". Respondent I did not specify any qualifications and respondent J required "industrial engineering". Respondent K required a "good engineering background" and respondent M required "advanced degrees in economics, accounting, business administration or equivalent". Respondent L replied, "staff ... generally have engineering, mathematics or operations research backgrounds". Respondent N replied simply, "a university degree". From these findings it would appear that the most frequently required qualification is a degree in engineering with additional qualifications in economics, business, operational research and accounting being generally desirable.

Industrial Experience. Respondent G replied that experience is required in "design, maintenance engineering and reliability". Respondent H stated, "design, government requirements and cost estimating". Respondent I replied, "knowledge of product cost, manufacturing cost and calculating principles, knowledge of product users cost principles, specific knowledge of maintenance costs and related subjects". Respondent J required experience in "design engineering, product assurance and support engineering". Respondent K stated that "military

systems experience" was required, and experience in cost analysis was required by respondent M. Respondent L required "general knowledge of DoD procedures, procurement, costing categories and operating and support philosophies". Respondent N required "experience in the use of computer programs and ability to work with systems engineers". From these findings it would appear that experience in design engineering, cost estimating, maintenance engineering and computing would be most relevant to the needs of the life-cycle costing analyst.

The Ideal Combination of Knowledge and Skills. Respondent

G replied that the following would be ideal:-

1. Familiarity with system design and function.
2. Experience with system operational characteristics.
3. Knowledge of customer's planned utilisation of system.
4. Experience in maintenance and reliability.
5. Manufacturing/production cost estimation and support concepts.
6. Ability to explain LCC methodology and results to the customer.

Respondent H gave the following reply:-

The best combination is an engineer with design and test experience with either a knowledge of cost estimating or an interest therein. A "value engineer" makes an excellent life-cycle cost analyst.

The respondent I suggested two alternatives. Firstly a team consisting of:-

1. Leader- with an academic degree in technology combined with knowledge of economics.
2. Economist- maybe with a bachelors degree, with practical experience of product use and knowledge of computer programming.

3. Engineer- with practical experience of maintaining and using the products.
4. Engineer- with experience from production and or design of the products.

The respondent suggested a second alternative in that an individual LCC analyst should be "an engineer with some practical experience combined with knoweldge of economics". Respondent J suggested, "accounting and engineering is ideal". and respondent K suggested, "engineers with some operational research knowledge". Respondent M suggested that " an engineering degree and advanced degree in economics or business administration with experience in computer sciences and operation of systems ". Respondent L suggested that " a basic education in engineering or mathematics and operational research is all that is required" and respondent N stated, " an engineering background, or anyone with an analytical mind has the potential to be an LCC analyst."

From these replies the 'ideal' combination of knowledge and experience can be summarised as engineering experience, particularly design and maintenance, with knowledge of the product and its operational environment. Further experience in economics, cost estimating and computing would also be desirable. A team of LCC analysts would also provide a very comprehensive range of abilities and skills if the combination of disciplines suggested by respondent 'I' could be integrated effectively.

At What Academic Level Should LCC be Taught? Respondents

G,H,I,J,M and N all replied that LCC should be taught at bachelors degree level. Respondent G commented, "LCC should be treated with more depth and the practical or engineering aspects incorporated". Respondent H replied :-

The undergraduate must be exposed to LCC to be certain that the student will consider systematically, all parameters in decision making, once employed. Students naturally have a tendency to over emphasise their own speciality. LCC tends to neutralise this tendency.

Respondent J suggested that " a general introduction to the subject at undergraduate level work ... more specialised considerations at graduate level". Respondent M replied that " The introduction to the methodology should be at an early level", and respondent N replied, "it may be appropriate to introduce LCC as a concept as part of a bachelors degree in engineering or finance". However, respondent L suggested that "LCC should be taught on post-experience short courses or as part of an MBA", and respondent K thought that it should be taught at the masters' degree level. From these findings the majority view was found to be that LCC should be introduced at bachelor degree level and that it is important that exposure to the concepts of life-cycle costing should be introduced as early as possible. In addition, the view was expressed that LCC could fit also into masters and post-experience courses as appropriate.

18.42 Quantitative and Accounting Techniques.

This section presents the findings relating to the application of various quantitative and accounting techniques when performing life-cycle costing analyses. The questionnaire covered the topics of post-completion auditing, discounting, inflation, risk and sensitivity analysis, cost estimating relationships, cost-effectiveness analysis and trade-off analysis.

Post Completion Auditing (PCA). Respondents G, L, J, K & N did not use PCA in conjunction with life-cycle costing studies, whereas respondents H, I and M were found to adopt PCA. Respondent H applied PCA analysis after 2 to 4 years of an asset's life and respondent M commented that PCA was applied "during a major portion of the asset's life".

Discounting. Discounting was not used by respondents N and G. Respondent I did not answer the question. Respondents L, M, K, J, and H were all found to use discounting when performing LCC analyses. The discount rate chosen at the time of the survey was found to be between 7% and 10%.

Inflation. Allowance for inflation was included in LCC analyses by respondents G, H, J, L, M, and N. It was not included by respondents I and K. Respondent G stated that "all costs are inflated" and respondent H stated that "labour and materials are inflated". Respondent K stated

PART 3

FUTURE DEVELOPMENTS

that "a general across-the-board inflation factor was used" and respondent L commented that "generally inflation is included at different rates for RDT&E, procurement, labour, materials and construction". Respondent M replied that "an overall inflation factor was used of 10%" and respondent N stated that "all cost elements are inflated".

Risk and Sensitivity Analysis. All respondents except I were found to use risk and sensitivity analysis in conjunction with life-cycle costing studies.

Cost Estimating Relationships (CERs). All respondents except I were found to apply cost estimating relationships within their LCC analyses. Respondent J stated, "all costs are calculated using CERs" and respondent K replied that "only R&D costs use CERs". In the case of respondent L the reply was, "CERs are used for acquisition costs, and the prediction of MTBF and MTTR which in turn are then used in support cost equations to predict future support costs". Respondent M used CERs for "fuel consumption, installation costs, equipment costs, spares costs, support equipment costs and manpower requirements" and respondent N used CERs to calculate direct labour and material costs.

The cost estimating relationships were generally derived from multiple linear regression analysis of

historical data. In addition, where historical data did not exist, respondents stated that information and estimates, derived by experts in each field, would be used.

Cost-Effectiveness Analysis. The use of cost-effectiveness analysis in conjunction with LCC analysis was found to be used by all respondents except N. Typical measures of cost-effectiveness found to be used by the respondents were :-

- 1) Cost to achieve a given level of effectiveness.
- 2) Cost per unit of reliability.
- 3) Cost per pound of pay-load.
- 4) Cost per risk unit.
- 5) Cost per performance unit.
- 6) Relationship between on-going maintenance cost and manufacturing cost.
- 7) Probability of survival v production cost.
- 8) Reliability v operating and support costs.
- 9) Availability v operating and support costs.
- 10) Availability v life-cycle cost.

More respondents were found to use measures 8, 9 and 10 than any of the other more specialised ones.

Trade-Off Analyses. All respondents except I were found to apply trade-off analyses in conjunction with life-cycle costing studies. Typical trade-offs mentioned by the respondents to the survey were between the

following :-

- 1) Reliability and cost
- 2) Performance and production cost
- 3) Acquisition cost and operating and support costs
- 4) Cost and availability
- 5) Reliability and performance
- 6) MTBF and acquisition and support costs
- 7) Acquisition costs and support costs
- 8) Design costs and manufacturing costs
- 9) What design will meet performance requirements at minimum cost.

Trade-offs were carried out using both manual analysis, as in the case of respondents G, H, J and K, and computer based analysis, as in the case of respondents M and N. Respondents G, H, J, K and L used both manual and computer based methods of analysis.

From the findings given in this section on quantitative and accounting techniques it has been found that most respondents use discounting, inflation allowances, risk and sensitivity analyses, cost estimating relationships and cost-effectiveness analysis. Only three respondents were found to use post-completion-auditing whereas most respondents applied trade-off analyses to their LCC studies.

18.43 Management and Organisational Considerations.

This section presents the findings of the survey which are related to some of the management and organisational considerations which should be recognised when adopting life-cycle costing. The survey covered; the use of computers, the use of LCC as a contractual requirement, the basis used for decision making, the work performed by life-cycle costing analysts or staff, the use of data banks, and organisational design.

Use of Computers. All respondents except I used computers in order to perform LCC analyses. All of the respondents had computer systems which facilitated cost summations and calculations. Some of the respondents had also systems which allowed optimisation studies to be carried out.

LCC as a Contractual Requirement. Respondents G,H, I,K,L and M all required LCC analyses to be carried out, as a contractual requirement, on a percentage of projects. For respondent G it was 50%, for H 75%, for I less than 10%, for K 100%, for L 100% and for respondent M 50% of projects were required to perform LCC analyses as part of the contract for the system under study.

The Basis for Decision Making. It was thought that it would be of interest to determine whether or not the use of life-cycle costing determines the way in which decisions are made regarding particular projects. It was

found that when using life-cycle costing analyses respondents H,M and N used minimum life-cycle cost as the basis for determining which system to procure or manufacture. Respondent G used maximum cost effectiveness and respondent L stated that each method was used in about equal proportions depending on the project under study. In addition, respondent L stated that many projects are now using Design-to-Cost or Design-to-Life-Cycle Cost (DTC and DTLCC) as a decision making requirement.

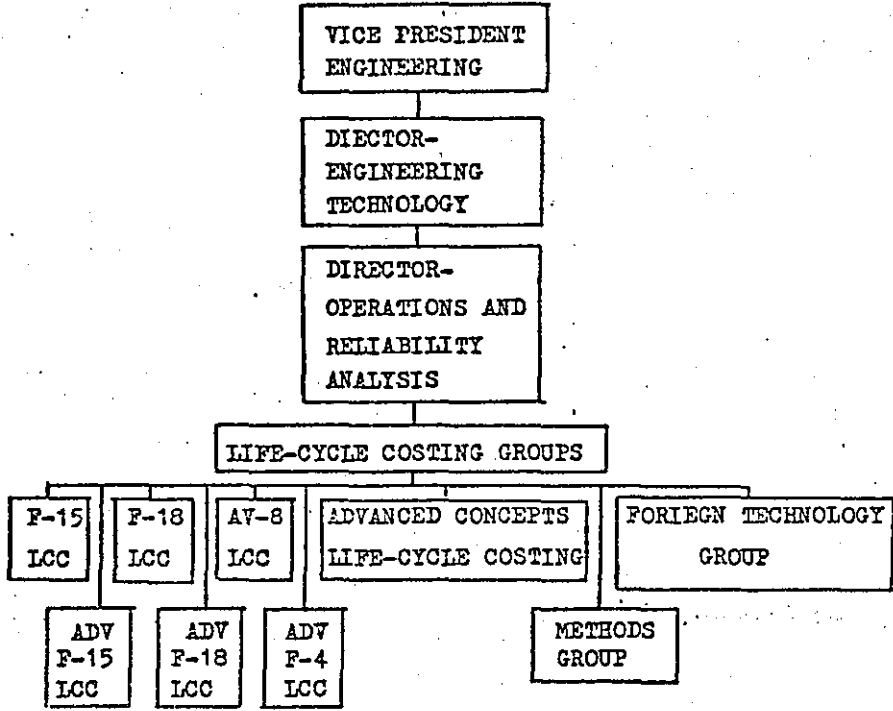
Work Performed by LCC Analysts and Staff. Respondents G,H,J and M all replied that their LCC analysts worked entirely on life-cycle costing projects. Respondent I stated that in his organisation they are employed also on reliability studies and follow-up work on maintenance costs. Respondent K commented that his LCC staff work also on systems' engineering, whilst respondent L replied that they were employed also on operations research, operations analysis and engineering analyses projects. In the case of respondent N the LCC analysts were also employed on 5 year budget planning.

Use of Data Banks. All the respondents were found to have data banks of historical information. The data banks were both computer and manually based. Respondents H and N use manual data banks only, whilst respondents

G,I,J,K and L used both manual and computer based data banks. In all cases respondents stated that data banks were updated regularly.

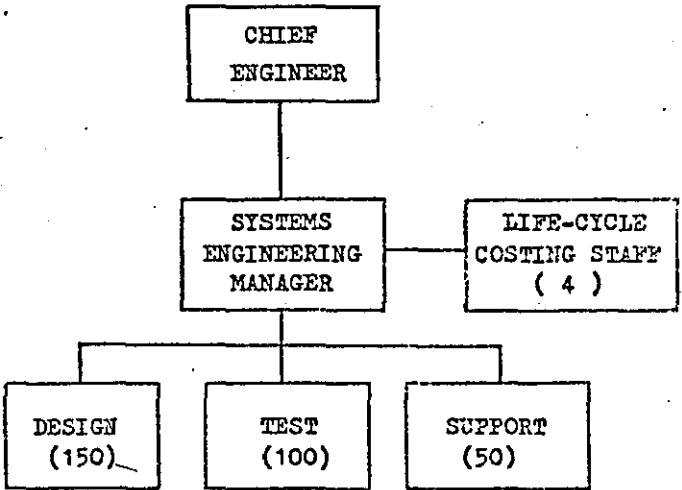
Organisation Design. In all cases life-cycle costing staff were located in engineering organisations and functions. In organisation G, the LCC staff reported to the "Chief Technology Engineer-Operations Analysis" and in organisation H, the LCC staff reported to the "Systems Engineering Manager". In organisation I, LCC analysts formed part of the "Product Planning Department" and in organisation J, they were part of the "Industrial Engineering Department". In organisation K, LCC staff were part of "Support Technology" and in organisation L, they were part of "Project Engineering". In organisation N, they were part of the cost analysis staff reporting to the "Assistant Engineering Program Manager". Each respondent was asked to sketch the organisation structure in which the life-cycle costing staff were situated and these organisation structures are shown in Figures 7 to 14 .

The findings, from this section of the survey, indicate that in the majority of cases computers were used to perform LCC analyses and all respondents utilised some form of formal data bank of historical information. Many of the respondents were required to carry out LCC analyses



ORGANISATION STRUCTURE 'G' SHOWING LOCATION
OF LCC STAFF

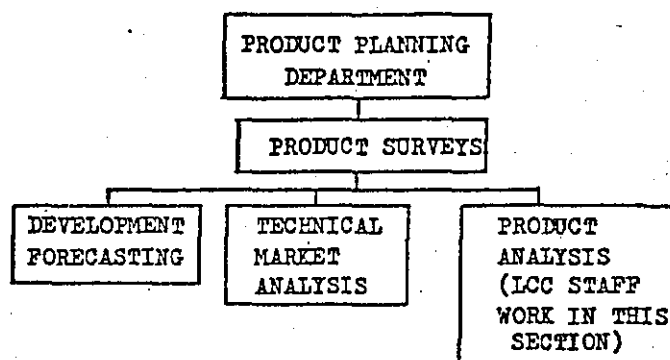
Figure 7



ORGANISATION STRUCTURE 'H' GIVING LOCATION
OF LCC STAFF

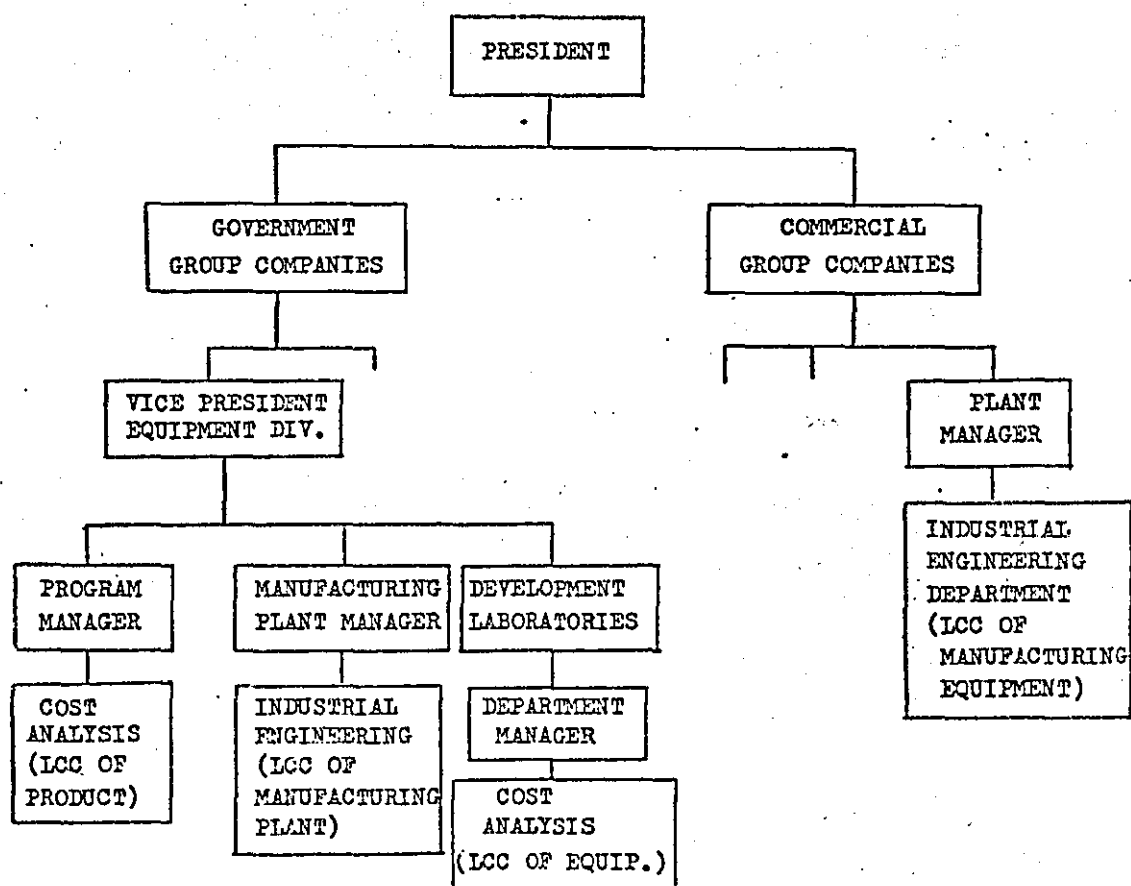
Figure 8

FIGURES IN PARENTHESIS DENOTE
NUMBERS EMPLOYED IN EACH FUNCTION



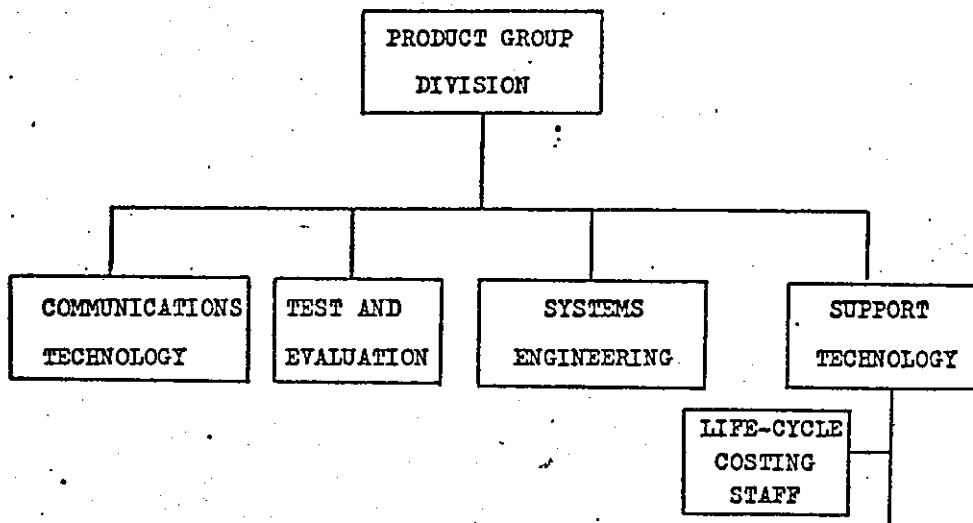
ORGANISATION 'I' SHOWING LOCATION
OF LCC STAFF

Figure 9

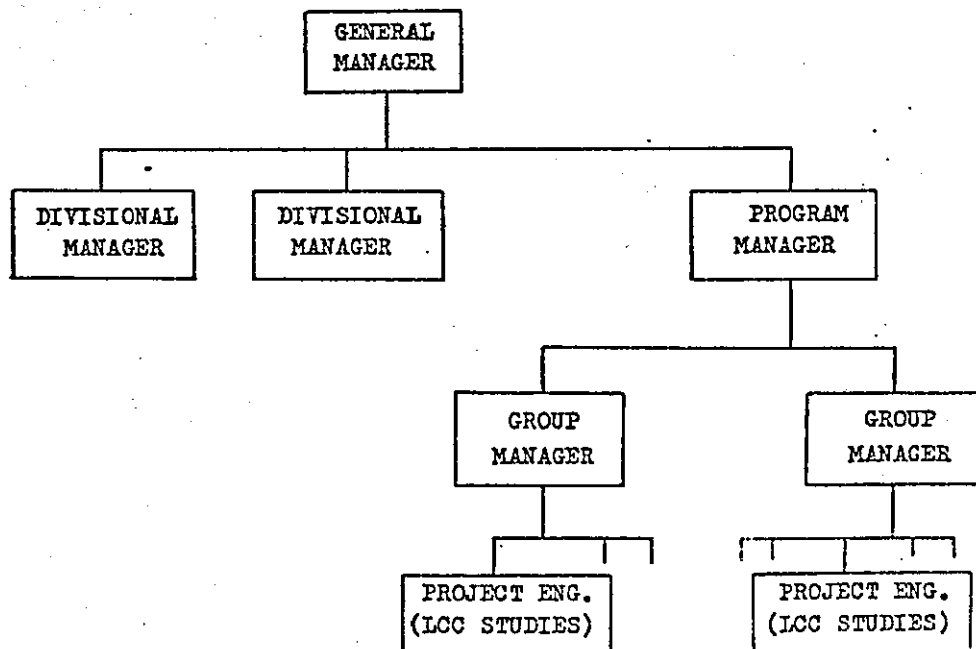


ORGANISATION STRUCTURE 'J' SHOWING LOCATION
OF LCC STAFF

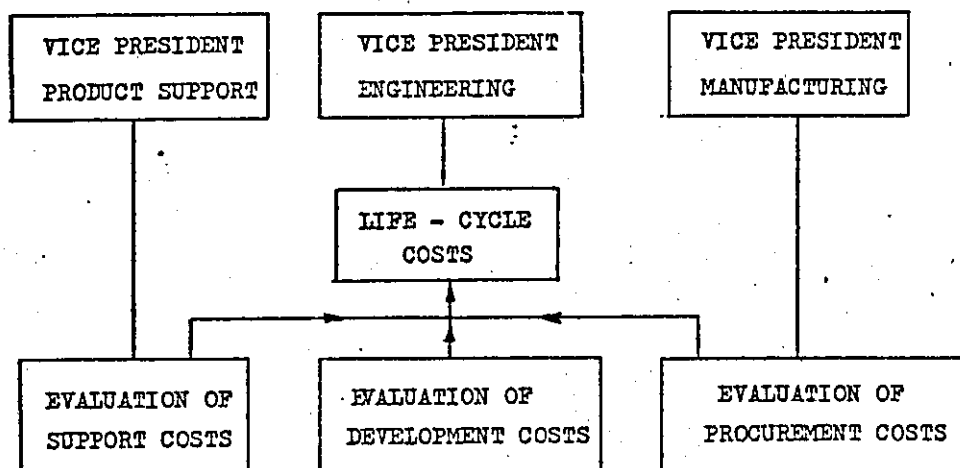
Figure 10



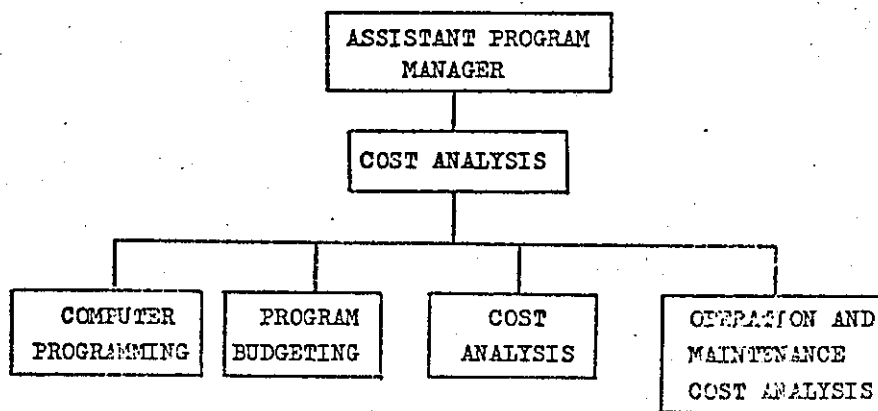
ORGANISATION STRUCTURE 'K' SHOWING LOCATION
OF LCC STAFF
 Figure 11



ORGANISATION STRUCTURE 'L' SHOWING LOCATION
OF LCC STAFF
 Figure 12



ORGANISATION STRUCTURE 'M' SHOWING LOCATION
OF LCC STAFF
 Figure 13



ORGANISATION STRUCTURE 'N' SHOWING LOCATION
OF LCC STAFF
 Figure 14

as a condition of the project on which they were employed. Decision making was found to be based on a mixture of criteria. Minimum LCC, Maximum cost-effectiveness and more recently design-to-cost and design-to-life-cycle cost criteria were now being applied. The majority of respondents stated that LCC analysts were employed entirely on life-cycle costing work. Other work performed by LCC staff included long term planning, operations' analysis and operations' research, together with reliability studies, maintenance cost analysis and engineering analyses. LCC analysts were found to be employed in engineering departments and several examples of organisation structures are given in Figures 7 to 14.

18.44 Limitations and Other Important Issues.

This section presents the findings of the survey in which the respondents were invited to make any comments based on their experience in the use of LCC which would be of value to the successful application of the technique. No comments were offered by respondents G and N. However, respondent H commented:-

Visibility is the key to successful application of life-cycle costing effort. The program personnel must know their cost goals once they have been established by trade-off studies. Goals and predicted/actual performance must be compared periodically and corrective action taken if necessary.

Respondent I commented:-

Design engineers must have an understanding of economic design criteria.

Respondent K commented:-

The most important thing is to realise that current tools are good enough for "ball-park" estimates for comparison of alternative systems and logistics systems. They do not give "exact" answers.

Respondent L commented:-

I believe that no "general" life-cycle cost analysis model can be developed which is truly meaningful. The analysis model must be tailored to the specific system and its users, reflecting the peculiarities of its operation and support within the using environment as well as the users' policies and procedures.

Respondent M made several detailed and valuable comments:-

In our experience, life-cycle costing remains an art relying upon the experience of the analyst rather than a strict scientific discipline. There are three observations I would like to make concerning the ability of the analyst to produce an accurate and useful product. They are:-

1. Familiarity with the hardware is of prime importance. Any cost is associated with some task and some set of resources. Unless the analyst has an intimate knowledge of what is being accomplished and what resources are required, the analyses may become no more than an accounting exercise.
2. Familiarity with the using organisation is also required. The objectives, policies and structure of the using organisation may have as much impact upon life-cycle cost as the equipment being provided.
3. The life-cycle cost analysis model must be compatible with the accounting procedures of the producer and user. Too many models require estimates to be made at a detailed level for which no cost or resource requirements records are available. Such estimates are subject to gross errors which are seldom detected and cannot be verified.

The general comments made by the respondents indicate that despite many years of experience in the application of life-cycle costing it is regarded still as an "art". Its primary value is in giving "ball-park" comparisons for mutually exclusive systems in order that a decision can be made on the basis of some visibility of future cost flows. It would seem also that familiarity with the system under study and the organisation, in which the system will operate, is also of considerable importance in developing meaningful LCC analyses.

18.5 Summary.

This chapter has presented the findings of the postal questionnaire survey of experienced LCC practitioners in the United States and Sweden. The objectives of the survey were stated, the survey design and response rate were discussed. The response was found to be 30% which whilst low was acceptable for the purposes of this work. The knowledge gained as a result of this survey enabled the second part of the research work into life-cycle costing to be carried out. The findings were presented under the headings of qualifications and experience, quantitative and accounting techniques, management and organisation and limitations and other issues. Considerable insight has been gained into the practice of life-cycle costing as a consequence of this survey. The following chapter is concerned with the development of a generalised

procedural model in order to facilitate the conducting of a life-cycle costing study within a manufacturing organisation.

CHAPTER 19

A PROCEDURAL MODEL FOR LIFE-CYCLE COSTING

19.1 Introduction.

This chapter develops a procedural model intended to facilitate the application of life-cycle costing as an economic evaluation technique for manufacturing plant and equipment. The objectives in developing a procedural model are stated, the assumptions made in order to develop the model are described, the model itself is developed and the limitations of such a model are outlined.

19.2 The Objectives of Developing a Procedural Model.

The considerable number of industrial visits and discussions held with directors, managers, engineers and accountants, which had been carried out whilst pursuing this research work, indicated that one of the biggest problems facing application of life-cycle costing was the lack of any guide to indicate how LCC could be adopted. Further evidence of the need to develop firstly procedural models, before analytical models, is found in the work of the United States Department of Defense and the Ministry of Defence in the United Kingdom. In both cases the first reports that these organisations issued were concerned

with establishing procedures for adopting the LCC technique, as an evaluation tool, for military equipment. Numerous analytical models then followed. The specific objectives in developing a generalised procedural model are stated below :-

1. To facilitate the application, by manufacturing industry, of the LCC technique by providing a procedural model which can be adapted to suit specific company environments.
2. To provide a check list of cost elements that could be used by an LCC analyst when evaluating an item of manufacturing plant.
3. To identify and give some examples of the types of cost structure that could be utilised when performing life-cycle costing analyses.
4. To describe some of the cost estimating relationships that could be adopted according to the nature of the estimating situation.
5. To develop a generalised procedural flow chart to describe the methodology which should be adopted in order to evaluate finally the life-cycle cost of the systems under study.

19.3 The Assumptions Made in the Development of the Model.

In order to develop any type of model of a system it is necessary to establish what assumptions or 'start-points'

have been made. In the case of this model, the following assumptions were made in order to proceed further:-

1. That the organisation understands the concept of terotechnology and wishes to apply the life-cycle costing technique to the economic evaluation of its manufacturing plant.
2. That the type of experienced and qualified personnel, as described in Chapter 18, are available within the company or will be recruited.
3. That senior company management are sufficiently committed to the application of life-cycle costing that there would be little or no restrictions imposed on the investment of resources required in order to develop and implement the necessary procedures.
4. The procedural model is intended only to facilitate the analysis of life-cycle costs of those assets under study. It is not intended to be a 'profitability' or 'industrial dynamics' type of model in which sales revenue, profit and other variables are considered also. (This type of model is mentioned later in suggestions for further work)

19.4 Development of Model Characteristics.

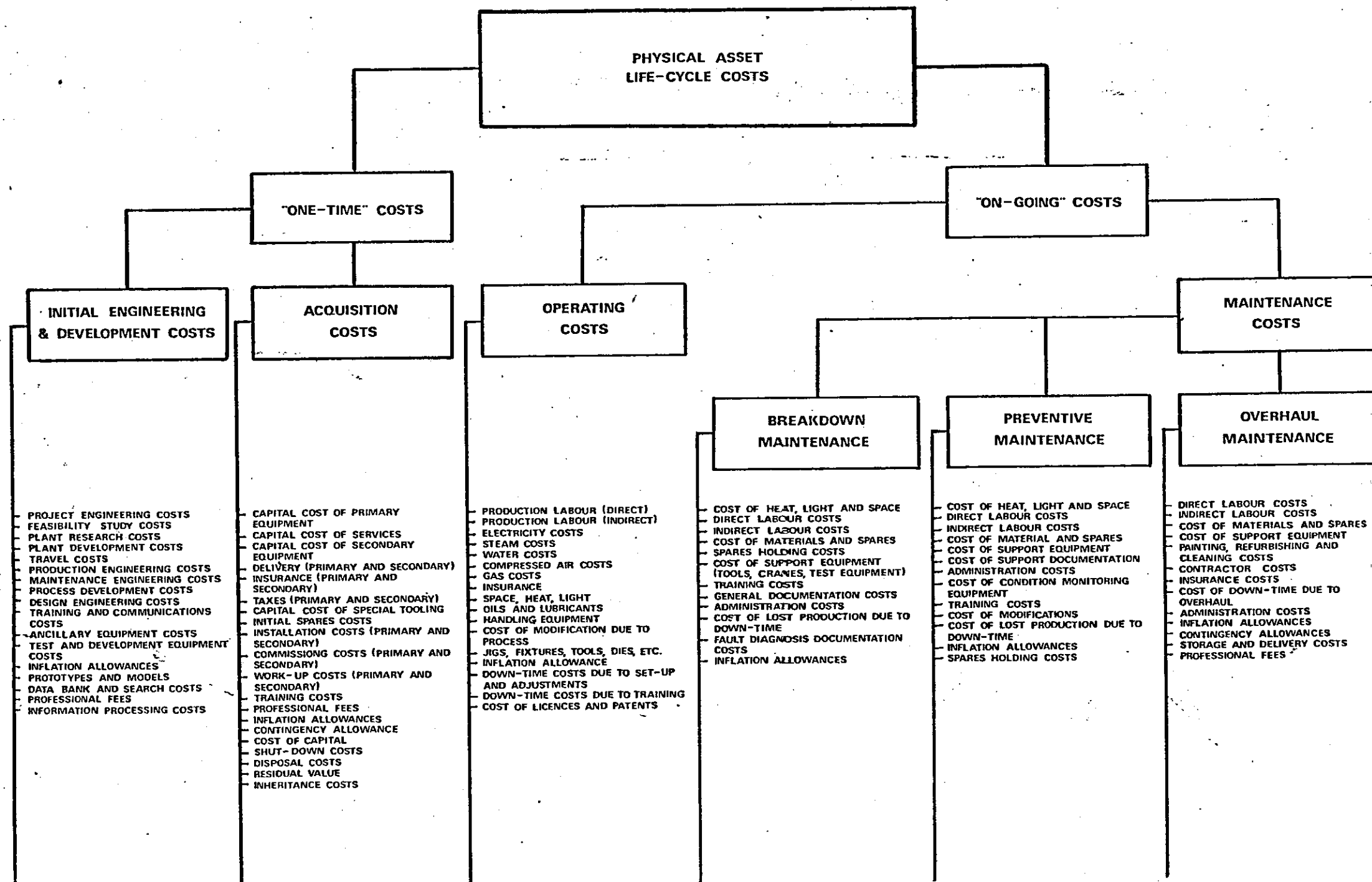
The types of models that have been developed by the military users of life-cycle costing have been very

detailed extending in some cases to over two hundred pages of description. To develop such a detailed type of model for use by manufacturing industry was thought to be unnecessary and would probably be counter-productive. Consequently, the characteristics of the model were developed in order to ensure that the model would be simple to understand yet general enough to be modified to suit individual company environments and objectives. The model has twenty two procedural stages and these are described below:-

Stage 1. Identify Cost Elements of Interest.

This is the first stage in the procedural model. The individual cost elements that are important to a particular organisation must be identified in detail. This task is carried out most effectively using "cost element check lists". Initial screening of the cost elements is not necessary. The important point is to list as many cost elements as can be thought of. Kaufman(cp.cit) suggests "every conceivable cost" should be identified only then can discrimination between significant and insignificant cost elements take place. A life-cycle cost element check list is given in Figure 15. This check list consists of 92 cost elements which could be considered when evaluating the life-cycle cost of manufacturing plant. The check list is not exhaustive but is intended to be representative of

AN L.C.C. COST-ELEMENT CHECK LIST



A LIFE-CYCLE COST ELEMENT CHECK LIST FOR MANUFACTURING PLANT

the type of check list that should be aimed at.

Stage 2. Commence the Collection of Historical Data.

The technique of life-cycle costing relies heavily on the availability of historical information. This is required in order to identify the significant cost elements, to design appropriate cost structures and to establish the cost estimating relationships. Consequently, once the organisation has derived an initial cost element check list, it is then necessary to collect data on each cost element. The collection of historical data is most effectively carried out by using standard source documents that already exist in the organisation. In this way less inertia should be experienced in the collection of detailed information. Typically, the source documents could be maintenance job cards, project cost control cards, materials' consumption records, time sheets, invoices, overhead cost records, general accounting records, plant history records and so on. The important point about all these source documents is that life-cycle costing requires that they become 'plant specific' and not department or factory specific as is generally the case with many data collection systems. Therefore, the design and implementation of a system of data collection in order to establish historical information on the cost elements, identified as important to the organisation, is an essential part of the procedure to bring life-cycle costing into use in an organisation.

Stage 3. Establish a Data Bank of Historical Information.

Having installed a system of data collection using standard source documentation, the next stage is to develop a data bank of historical information. Efforts to develop such a data bank must begin long before it becomes necessary to use the data for LCC studies. For example, it took the British Army Data Centre three years in order to establish an adequate base of historical information.¹ The data bank must be established in order to fulfil the needs of a range of investigative procedures allied to the application of a terotechnological approach to physical asset management. For example, life-cycle costing analyses, level-of-care studies, cost effectiveness analysis and trade-off analyses.

A data bank should have the following minimum characteristics:-

1. Well planned source documentation.
2. A system of regular data collection.
3. A system of indexing and classifying cost information, and other operational and design information.
4. A facility for storage of the historical information with sufficient capacity to hold data for many years.
5. A system which allows simple and quick access to data by data users.

6. A facility for updating the data base to take account of recently acquired data.
7. A facility for storage of cost-estimating relationships, cost indices and other standard costing data as used within the organisations' accounting system.
8. A system of data analysis and periodic or ad-hoc reporting.

These basic characteristics of a data bank for life-cycle costing should then be integrated with the needs of users in terms of both data retrieval and data analysis which form the next stages of the procedure.

Stage 4. Establish a Data Retrieval and Update Procedure.

This is a very important stage in the procedural model. If data is difficult to obtain and becomes out of date then the system falls into disuse and the process of implementing life-cycle costing will be very difficult to pursue. Therefore, it is important that access to the data by the LCC analyst and other users is efficient, regular and simple. The updating of data should be carried out on a regular basis so that the latest information is always available to a user. The frequency of updating will depend on the frequency of data collection, the uses to which data are put and the nature of the data. For example, maintenance cost data could be updated monthly, whereas the updating of a cost estimating relationship may only take place once a year.

Stage 5. Establish a Data Analysis and Reporting Procedure.

In addition to the need for regular updating and simplicity of data retrieval, there is another feature which should be incorporated into the procedure. That is, data analysis and reporting. Because of the nature of the task, life-cycle costing analyses will require many smaller or lower level analyses to be carried out. Therefore, provision should be made in order to facilitate small amounts of data analysis outside the main life-cycle costing analysis. For example, a user may wish to examine the trend of maintenance labour costs against operator labour costs over several years in order to give some further detail. Therefore the user should be able to request this type of low level analysis from the data bank without a long and detailed search of the data. Such an analysis should then be forwarded to the user as an output report from the data bank. Additionally, regular reports should also be a desirable feature of the ICC procedural model. Such reports may take the form of monthly digests of information such as cost indices, lists of references, research data and information about work of other departments which may affect the work of the ICC analysts (ie. design changes, material changes, performance changes etc.). The important point to make here is that the organisation must consider if this aspect of the model is required in order to satisfy

the objectives of the particular system that is being established.

Stage 6. Identify the Cost Structures* of Interest.

The procedural model has now reached a stage where the cost elements have been identified, a system of data management has been established in order to collect, store, update, access, analyse and report on the characteristics of these cost elements. The next stage is to identify the forms of LCC cost structure which are appropriate to the organisations' objectives. The purpose of establishing a cost structure is to enable trade-offs to be carried out between the different phases in an assets' life-cycle. It ensures also that comparisons between alternative plant systems are compared on an equal basis and ensures that cost elements are positioned correctly within a particular phase of the plant's life. This separation of cost elements into an aggregated cost structure enables system level, subsystem level and component level trade-offs and detailed life-cycle costing analyses to be performed. The specific nature of an LCC cost structure will depend on the objectives of the study, the organisation, the plant itself and the availability of historical information. Several types of life-cycle cost structure can be envisaged and some examples are given in Figures 16 to 20.

The structure shown in Figure 16 is a generalised one,

* The term "cost structure" used throughout this section of the thesis could be more accurately described as "cost breakdown structure".

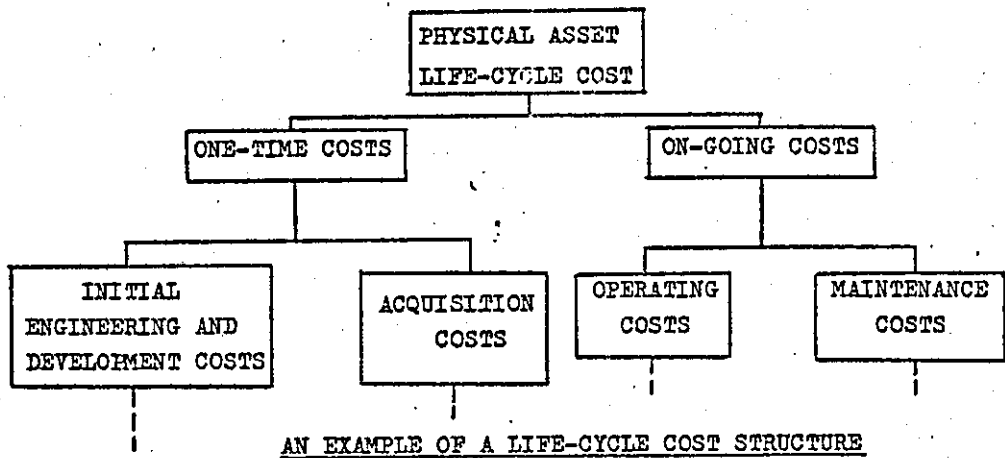


Figure 16

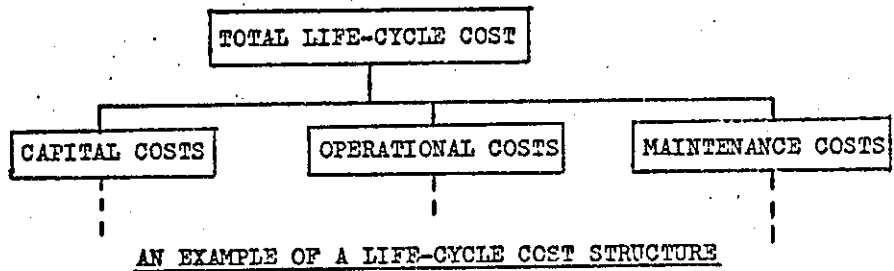


Figure 17

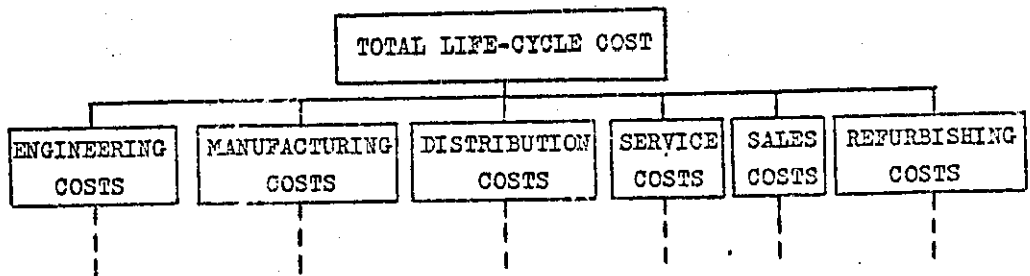


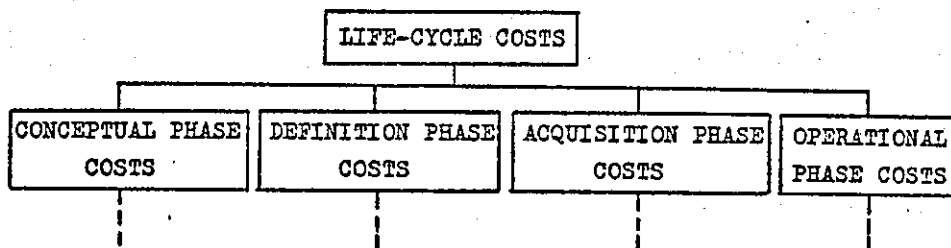
Figure 18

in which an organisation would be concerned with identifying the cost impact of 'one-time' costs of initial engineering and development and acquisition costs against the cost impact of 'on-going' costs which in this case have been identified as operating and maintenance costs.

Figure 17 shows the cost structure used by Blunn (86), in his LCC work. Figure 18 shows the cost structure adopted within Jeffrey's organisation (87). Figure 19 shows the LCC cost structure used by Stordahl and Short(88), and Figure 20 provides a further variation in the structure used by Sternlight(op.cit.). An important consideration in the design of the life-cycle cost structure is that it must be designed to suit the objectives of the study and once defined the cost elements must be allocated to each branch of the structure as necessary.

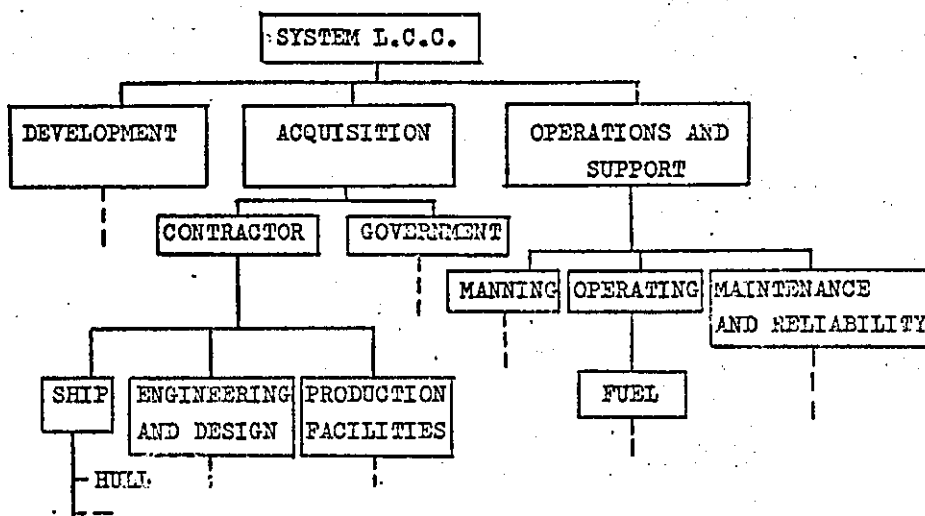
Stage 7. Develop Cost Estimating Relationships (CERS).

This stage is dependent largely on the availability of historical information and the quality of that information. It is one of the primary objectives, in holding considerable historical data, to facilitate the development of cost-estimating relationships. There are many types of cost estimating relationships and the literature gives several descriptions of these types. For example, McCullough(op.cit.) Sternlight(op.cit.) and Seiler(89) describe two types whilst Jones (90) describes five different types. However, for use on the evaluation of manufacturing plant six



AN EXAMPLE OF A LIFE-CYCLE COST STRUCTURE

Figure 19



AN EXAMPLE OF A LIFE-CYCLE COST STRUCTURE

Figure 20

forms of CER can be identified as being useful to the LCC analyst.

1. Cost Factor Estimating Relationships.

Here the item to be costed is identified as a specific type and quantity from an 'off-the-shelf' catalogue, or other source. Therefore, the analyst simply multiplies the catalogue price by the required quantity; adding delivery, insurance etc. to obtain a total cost. For example, the cost of 100 litres of lubricating oil might be expressed as :-

$$100.L_c + D_c + I_c = TC$$

Where

L_c = cost per litre

D_c = delivery charge

I_c = insurance cost

TC = total cost

2. Cost-To-Cost Estimating Relationships.

In this method cost is estimated as a function(eg.a percentage) of another cost. For example a delivery charge may be expressed as a % of the purchase price. Many other examples of this type of CER are given in Earles(op.cit page 78).For example:-

Program Management Costs = 1.04(Test Hardware Fab.Cost)

System Engineering Costs = 2.2 "

Design Costs = 5.5 "

Data Costs = 0.20 "

Another example could be that maintenance costs are

expressed as a percentage of total production costs, eg.:-

$$\text{Maintenance Costs} = 0.15(\text{Production Costs})$$

3. Parametric Estimating Relationships.

In this method cost is estimated as a function of one or more non-cost parameters of the plant. For example, age, capacity, weight, output rate, etc.. They describe the relationship between elements of cost and plant characteristics. Sternlight(op.cit.) gives an example of such a CER in which installation labour costs for plant type G are stated as:-

$$= A.B.(\text{SHP}_G)^C$$

where A = Cost factor per man hour

B, C = Historical data regression coefficients

SHP = Design horsepower, plant type G.

Many other examples of this type of CER are given in Rush et al(op.cit.), Levenson (91) and Watts (op.cit.). Statistical correlation analysis is required to develop this type of estimating relationship. For example, Sternlight used linear regression, Rush used a weighted linear regression technique and Levenson used multiple regression analysis.

4. Specific Analogy Estimating Relationships.

In this method costs are estimated by means of an analogy to some specific previous item of plant. The new and analogous plants are compared on the basis of their

performance, design, intended use, operating environment and so on. This type of estimating relationship could have wide application in LCC analyses of manufacturing plant. For example, for estimating routine lubrication maintenance tasks on comparable plant, for estimating design costs and for estimating material and labour costs for the design and manufacture of analogous plant. Figure 21 gives an example of a specific analogy cost estimating relationship taken from Earles (op.cit. page 80).

5. Expert Opinion.

In the absence of historical information or specifically analogous plant, a company can derive cost estimates for use in the LCC analysis by consulting expert opinion. Such estimates may be made by maintenance engineers, production engineers, designers, cost estimators, life-cycle cost analysts, consultants and so on. For example, such an estimate may be derived for the cost of the first overhaul of a plant or for the cost of a modification. In both of these cases it could be that historical information and analogous plant do not exist.

6. Accounting Relationships.

In this method the cost of an element may be determined by mathematical summation of the various lower level elements in the cost structure so that all summary elements (mechanical totals) are identified properly.

For example, research and development costs could be expressed by the CER:-

$$R\&D = (E_s + E_a + E_r + E_m + E_d + E_t)$$

Where E_s = Engineering, specification costs
 E_a = " , administration costs
 E_r = " , reliability costs
 E_m = " , maintainability costs
 E_d = " , design costs
 E_t = " , testing costs

From the six methods of developing cost-estimating relationships described above, it is clear that historical information is essential if the relationships are to be developed with confidence. It is necessary also to establish a correlation between the parameters of a CER before the relationship is put to use. Therefore, when establishing a linear regression equation, it should be tested also for correlation and significance. If a reasonable correlation is not obtained then further data must be collected until the CER is acceptable. Once acceptable CERS have been derived the next stage in the procedure can follow.

Stage 8 . Decide on Plants to be Studied.

Stages 1 to 7 have provided the organisation with a method of data collection, storage, analysis, reporting and updating. In addition, the appropriate cost structures have been identified and the cost elements of interest

to the organisation have been selected. From this base the cost-estimating relationships have been established and tested for reliability. The organisation is now in a position to begin to adopt life-cycle costing as an economic evaluation technique for manufacturing plant. Consequently, stage 8 is concerned with the selection of the particular project(s) to which an LCC analysis is to be applied. It is necessary to establish that the plants, under study, are comparable in terms of their basic performance characteristics and intended use. It is then necessary to ensure that the LCC analysts are familiar with the characteristics of the plants and that they gain as much information about their operating conditions and maintenance problems as possible. Having selected the plants to be studied the next stage can follow.

Stage 9. Select Appropriate Cost Elements.

From the original list of cost elements, derived at stage 1, a 'plant' or 'study-specific' list can now be derived which identifies those cost elements considered appropriate to the plant under study.

Stage 10. Design an Appropriate Cost Structure.

Again, from an earlier stage in the procedure (stage 6) a cost structure can be selected which suits the specific objectives to be met in the study.

Stage 11. Allocate Cost Elements to Cost Structure.

At this stage is it necessary to identify within each branch of the cost structure all those cost elements that should be allocated to it. At this stage in the analysis, the analyst should now have a structure established similar to that shown in Figure 15. This figure gives an example of a cost structure with cost elements allocated to each branch within the structure.

Stage 12. Select Appropriate CERS From Data Bank.

Having identified the cost elements of interest, and designed the appropriate cost structure it is now possible to begin evaluating the magnitude of each cost element. This can be carried out using one of the cost estimating methods described at stage 7. If historical information has been built-up then cost estimating relationships may already exist on file in the data bank. In which case it will be necessary to establish which ones are the most appropriate for the plant under study.

Stage 13. Estimate the Value of each Cost Element.

At this stage all the cost elements are evaluated. This can be done using computer based analytical models or by manual analysis. From the findings of the field survey presented in Chapter 18 it would seem that discounting and inflation should be included in the

evaluations.

Stage 14. Aggregate Cost Elements to Cost Structure.

Having estimated the value of each cost element within the cost structure, each of these estimates can now be summated to obtain each sub-total for each branch of the cost structure. This would result, for example taking Figure 15, in the summation of 92 cost elements into a 4 phase cost structure of "Initial Engineering and Development Costs", "Acquisition Costs", "Operating Costs" and "Maintenance Costs". In this particular case maintenance costs were sub-divided also into breakdown maintenance costs, preventive maintenance costs and overhaul maintenance costs. This would be a desirable feature of a cost structure when lower level policy decisions are being determined or when trade-offs between different types of maintainability characteristics are being considered.

Stage 15. Evaluate Each Cost Structure Sub-Total.

The life-cycle costing procedure has now reached an advanced stage in the analysis of a particular plant under study. This stage is included in order to emphasise the need to examine the implications to the company of the particular levels of resources which will need to be committed to each phase in the life-cycle of the plant.

It is at this stage where decisions about plant performance characteristics and company policy can be seen in terms of the amount of capital the company requires and the on-going commitment that it will incur if a decision is taken to proceed with the project. If the company is satisfied with the estimated value of each phase of the cost structure then the next stage can follow.

Stage 16. Evaluate Total Life-Cycle Cost.

This is performed simply by summing each of the cost structure sub-totals in order to determine the total life-cycle cost of the plant under study.

Stage 17. Repeat Stages 12 to 16 for Each Plant Under Study.

The procedure has now enabled the analyst to estimate the life-cycle cost of the first plant under study. As the LCC technique has its greatest value as a comparative tool, it will now be necessary to repeat the evaluation procedure from stage 12 through to stage 16 for each plant or plant configuration that is under consideration.

Stage 18. Compare The Life-Cycle Costs.

Having now evaluated the life-cycle costs for several plants, each of these can be compared and a decision taken. It is important at this stage of the procedure to take account of the assumptions that were made in the analyses. These should be examined to ensure that these assumptions

still hold and that radical changes in the market for the product or in the availability of finance and other variables have not taken place. This procedure then leads to a decision to proceed as the next stage.

Stage 19. Select Plant With Lowest Life-Cycle Cost.

This stage is concerned with actually making a decision to proceed with the project. The findings of the field survey indicate that this is generally carried out on the basis of the 'lowest life-cycle cost' criterion. However, this may not be the only criterion for a plant project within a commercial manufacturing organisation. The procedure described in this chapter has been concerned only with the evaluation of the life-cycle cost. It may now be necessary to evaluate revenue and carry out profitability analyses of each of the plants studied. A decision could then be taken on the basis of maximum cost-effectiveness, where effectiveness is measured in terms of profit or sales' revenue or some other variable. However, for the purposes of this work, the decision criterion has been assumed to be that of lowest life-cycle cost.

Stage 20. Acquire Plant and Operate.

Once the decision has been taken then the plant can be acquired and installed, commissioned and put into full scale operational use. The plant should then enter a system

of on-going terotechnologically based management.

Stage 21. Collect Operational Information.

As part of the system of terotechnologically based management, the plant should enter a regular and detailed system of source data collection. This data will be derived from the standard documentation used by production and maintenance personnel and should be designed to continue throughout the life of the plant.

Stage 22. Feed - back Operational Information.

This is the final stage in the procedural model. At this stage the plant is in use and data are being collected on a regular basis. The data should then be fed-back to the data bank via stage 2 of the procedure described earlier. In this way the process of life-cycle costing becomes a cyclical and iterative procedure in which data are being built - up and used to improve the characteristics of future plant and as a consequence to improve the life-cycle cost effectiveness of those plants.

19.5 Summary.

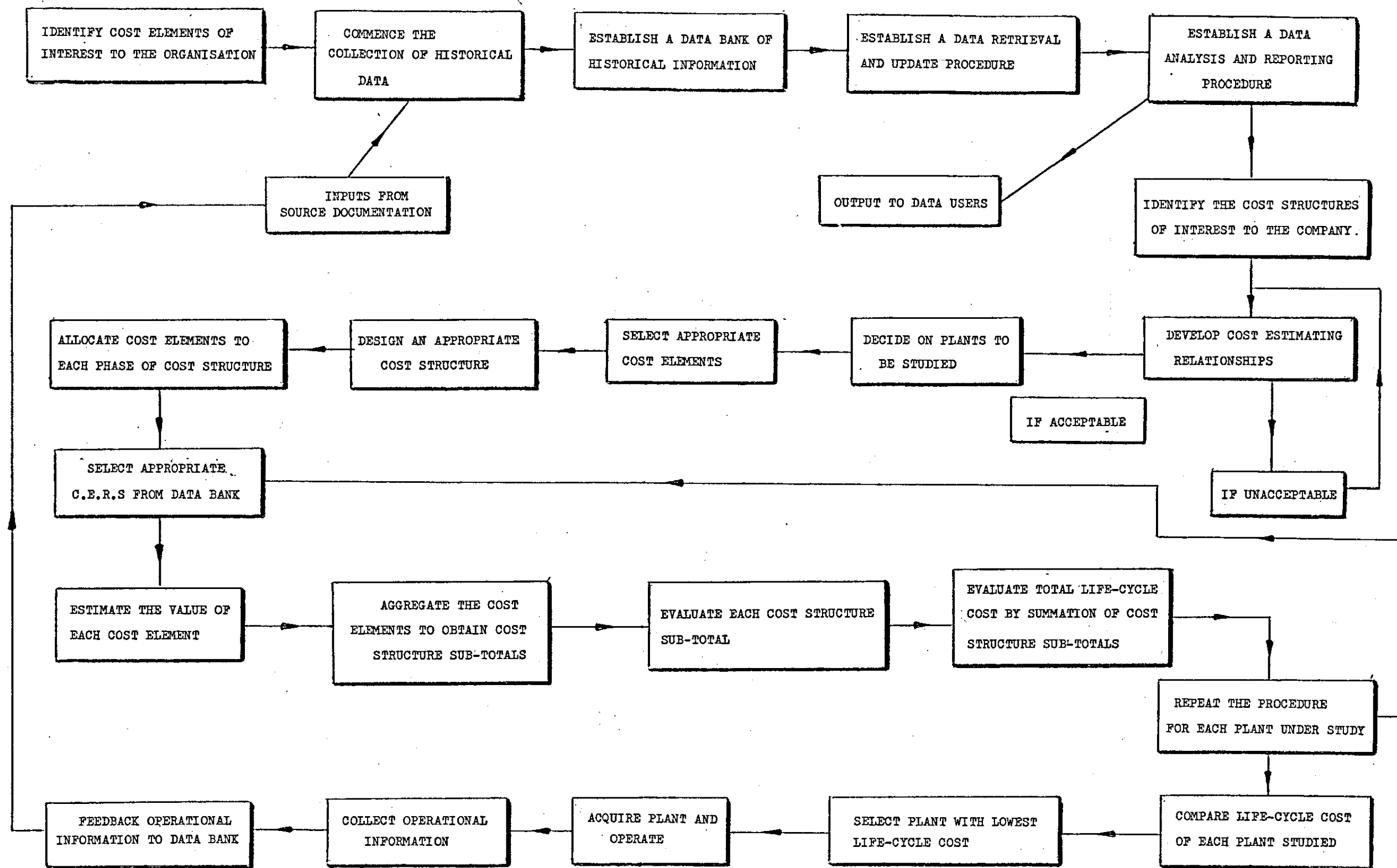
This chapter has developed a procedural model for life-cycle costing. The objectives of developing such a model were stated and the assumptions made, in order to develop the model, were described. The characteristics of the procedural model were then described. The procedure consisted of twenty two different stages in which the

company is required firstly to identify those cost elements that are important to it, then to set-up a data collection system and progress through the procedure until the life-cycle cost of a particular plant can be estimated using the base of historical information in order to provide more reliable estimates. From this, several plants can be studied and a decision taken to acquire a plant and operate it. On-going information regarding the plant's design, performance and cost characteristics is then fed-back to a data bank and used to estimate the characteristics of future plant systems.

The procedural model is summarised by Figure 22 which illustrates the path of the procedure from stage 1 through to stage 22. From stage 22 the procedure then feeds into stage 2 for the second and subsequent cycles.

The following chapter presents an example of the application of this procedural model.

¹Information obtained during a visit to the REME Data Centre, Woolwich, 1976.



A GENERALISED PROCEDURAL MODEL FOR LIFE-CYCLE COSTING

Figure 22

CHAPTER 20
THE LCC PROCEDURAL MODEL
AN EXAMPLE OF ITS APPLICATION

20.1 Introduction.

This chapter presents a case-study in the use of the procedural model developed in the last chapter. The case-study is based on data collected from company E of the industrial research into the application of terotechnological practices described in Part 1 of this dissertation.

20.2 The Limitations of this Case-Study.

The case-study developed in this chapter is based on real data collected from the historical records made available to the author. Some cost data were not available for examination by the author. For example, management salaries, the contribution to income per unit of output and the general fixed overheads. Therefore, this case-study is not exhaustive and is intended only to indicate the way in which the procedural model could be applied. It was considered to be important to use real data, despite its limitations, because the data could then be subjected to analysis in order to determine if it was feasible to

develop cost estimating relationships on the basis of raw data collected from the records available within the company. Further limitations are seen in that it was not possible to obtain an engineering estimate of the plant's life. Hence, from data available in Jelen (92), an average life of plant within manufacturing industry was found to be twelve years and this life was assumed here. Inflation was assumed to be at 5% per annum (merely for simplicity) and the discounting rate was assumed to be 10%, again chosen only for simplicity in this hypothetical example.

20.3 Background and Data Sources.

The company was experiencing increased demand for its products and wished to establish a new manufacturing facility. The major item of capital expenditure was the sterilising plant and its associated secondary plant such as water treatment and conveyors. The company was anxious not to repeat a mistake made some years ago when a plant was procured which has given consistently poor performance. For the type of plant under consideration two manufacturers were available. The company had experience with both makes of plant. The company wished to evaluate these two makes on the basis of life-cycle cost rather than adopting the company's conventional practice of considering capital costs only. It was assumed that both makes of plant would meet the minimum operational

performance requirements.

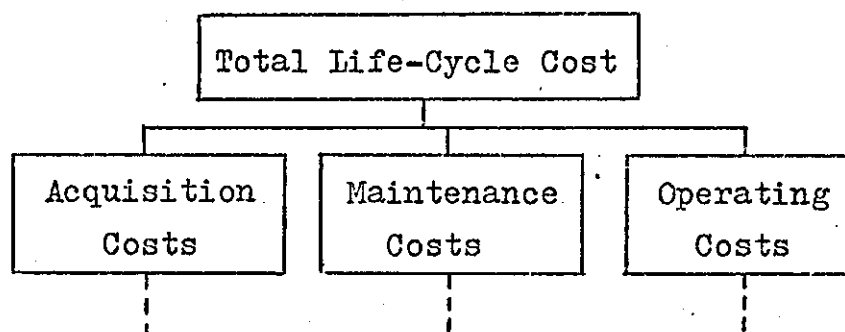
The data sources available to the researcher were plant history record cards, computer files on maintenance man-hours for breakdown maintenance and preventive maintenance, computer files for maintenance materials' expenditure, shift data, operator costs per annum by grade of operator, the hourly cost of maintenance craftsmen, the capital costs of each plant and an industrial engineering report which included data on project engineering costs, delivery costs, initial spares' costs, installation and commissioning costs and an estimate for a half-life overhaul.

20.4 Applying the Procedural Model.

This particular company had an established data management system for the collection of operational information. A maintenance administration manager was employed together with a staff of three clerks, two technical assistants and a cost analyst. Data were collected at the end of each shift and then entered onto the plant history cards and inputted to the computer data base. Regular reports were issued from the computer giving details of maintenance man-hours expended by plant number and maintenance materials' costs by plant number. Hence, stages two up to five of the procedural model were already

in existence. For stage one a check list was derived which identified the cost elements of interest to the company. This is shown in Table 24. Stage 6 was the next item of the procedure. This stage required the identification of the cost structure of interest to the company in order to facilitate analysis between different phases of the life-cycle. In this case a three phase cost structure was chosen, consisting of "acquisition cost", "on-going maintenance costs" and "on-going operating costs".

This structure is shown in Figure 23 below.



An LCC Cost-Structure Appropriate
To The Company
Figure 23

The cost elements identified earlier could then be allocated to each branch of the structure. The structure used here involved only the direct costs associated with the plant under study. As was mentioned earlier, indirect costs and overheads could not be considered due to the lack of data.

TABLE 24
AN LCC COST-ELEMENT CHECK LIST SUITABLE
FOR STUDIES IN COMPANY E

NUMBER	COST-ELEMENT
1	Initial Engineering & Development
2	Purchase Price
3	Delivery
4	Initial Spares
5	Training
6	Information Processing
7	Manuals
8	Installation
9	Commissioning
10	Removal
11	Contingency
12	Overhauls
13	Management Costs
14	Preventive Maintenance Labour Cost
15	Breakdown Maintenance Labour Cost
16	Maintenance Material Cost
17	Maintenance Stock Holding Cost
18	Electricity Cost
19	Steam Consumption Cost
20	Operator Labour Cost
21	Water Treatment Cost
22	Maintenance Administration Cost

Having identified the cost-elements of interest and an appropriate cost-structure for use in an LCC study, the next stage could follow. This was stage 7 in which the cost estimating relationships should be derived and tested. In order to derive the CERS data was collected over a six year period in the case of plant A and a five year period in the case of plant B. This was the maximum amount of historical data available. Unfortunately, because the company was not practising life-cycle costing, historical data was kept only on a year-end basis. Therefore, the CERS were derived using six data points for plant A and five data points for plant B. Data were available for maintenance man-hours per year on preventive maintenance and breakdown maintenance, maintenance material costs per year, operator labour costs per year at 1975 values only and electricity and steam costs per year at 1975 values only. The data collected are shown in Appendix 7. From this data, multiple regression analysis was carried out using a standard computer package (MULREG) which gave the regression equation and its correlation coefficient. The resulting cost estimating relationships* are shown in Table 25 and the print out of the MULREG programme is given in Appendix 8 .

* The cost estimating relationships derived using the Mulreg program data, were, in some cases, not found to be statistically significant. Therefore it should be understood that the cost estimating relationship shown in table 25 merely illustrates the types of CER which could be derived if historical data were available.

TABLE 25
COST ESTIMATING RELATIONSHIPS
DEVELOPED FROM COMPANY DATA

COST ELEMENT	COST-ESTIMATING RELATIONSHIP	
	PLANT A	PLANT B
Preventive Maintenance Labour Cost	$\sum_{a=1}^{a=n} \left[\frac{(198 + 268a) C_1 \phi_1}{(1+r)^a} \right]$	$\sum_{a=1}^{a=n} \left[\frac{(718 + 243a) C_1 \phi_1}{(1+r)^a} \right]$
Breakdown Maintenance Labour Cost	$\sum_{a=1}^{a=n} \left[\frac{(301 + 15a) C_2 \phi_1}{(1+r)^a} \right]$	$\sum_{a=1}^{a=n} \left[\frac{(530 + 242a) C_2 \phi_1}{(1+r)^a} \right]$
Maintenance Material Costs	$\sum_{a=1}^{a=n} \left[\frac{(2692a - 1482)}{(1+r)^a} \right]$	$\sum_{a=1}^{a=n} \left[\frac{(10,062a - 11,884)}{(1+r)^a} \right]$
Maintenance Logistics Costs	$\sum_{a=1}^{a=n} \left[\frac{(2692a - 1482)}{(1+r)^a} \right]_{0.1}$	$\sum_{a=1}^{a=n} \left[\frac{(10,062a - 11,884)}{(1+r)^a} \right]_{0.1}$
Operating Labour Cost	$\sum_{a=1}^{a=n} \left[\frac{C_3 \cdot N \cdot \phi_1}{(1+r)^a} \right]$	$\sum_{a=1}^{a=n} \left[\frac{C_3 \cdot N \cdot \phi_1}{(1+r)^a} \right]$
Electricity Costs	$\sum_{a=1}^{a=n} \left[\frac{C_4 \cdot \phi_1}{(1+r)^a} \right]$	$\sum_{a=1}^{a=n} \left[\frac{C_4 \cdot \phi_1}{(1+r)^a} \right]$
Steam Costs	$\sum_{a=1}^{a=n} \left[\frac{C_5 \cdot \phi_1}{(1+r)^a} \right]$	$\sum_{a=1}^{a=n} \left[\frac{C_5 \cdot \phi_1}{(1+r)^a} \right]$

where:-

a = plant life in years 1,2 ... n
 c_1 = preventive maintenance labour cost factor (£/hr)
 c_2 = breakdown maintenance labour cost factor (£/hr)
 c_3 = operator labour costs/shift/year (£)
 c_4 = annual cost of electricity at base year (£)
 c_5 = annual cost of steam at base year (£)
 ϕ_1 = assumed inflation factor(%/year)
 r = assumed discount factor(%/year)
 N = number of shifts/year

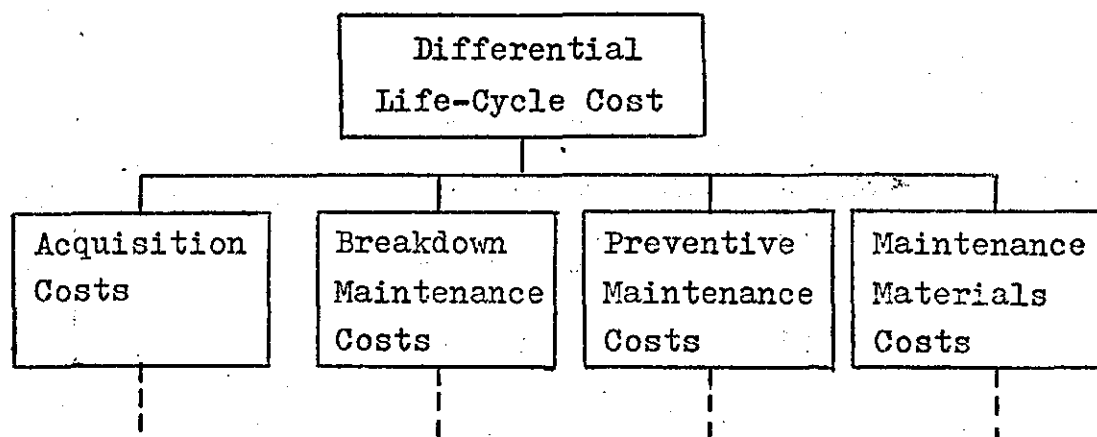
Stage 8 of the procedural model could now follow.

In this particular case-study two different makes of hydrostatic sterilisers were to be analysed. Each plant was manufactured overseas and the company had six years operating experience with plant A and five years operating experience with plant B. As stated at the introduction to this case-study, the purpose of the new procurement is for expansion of the production facility and the choice is between plant A or B on the basis of lowest life-cycle cost.

Stage 9 involved the selection of the appropriate cost elements for the study. From the check list derived at stage 1, cost elements 1,2,3,4,8,9,10,11,12,13,14,15, 16, and 17 were selected. In addition training, information processing and manuals (cost elements 5,6 and 7) were combined into one cost element as insufficient data were available to justify separating them. Cost elements 18, 19,20,21 and 22 were considered to be equal for both plants and were therefore not included in the comparative LCC analyses. As a consequence of this, the LCC case-study became a differential LCC case-study in which only those cost elements, thought to be different between the two mutually exclusive plants, were considered.

Stage 10 was concerned with the design of an appropriate cost structure to facilitate comparison of the alternatives.

For this particular study a four phase cost structure, as shown in Figure 24, was chosen.



The Life-Cycle Cost Structure

Figure 24

Having selected an appropriate cost structure to suit the objectives of the study and the limitations of the available data, the next stage was to allocate the cost elements to each branch of the structure. Cost elements were allocated to each branch and these are detailed in the working sheets shown in Appendix 9 .

Stage 12 consisted of selecting the appropriate cost estimating relationships from the data bank. From the bank of CERS derived earlier in this chapter and given in Table 25, four appropriate CERS were chosen. These were CERS to estimate preventive maintenance labour costs, breakdown maintenance labour costs, maintenance material

costs and what has been described as maintenance logistics costs. This CER was derived in order to estimate the stock holding costs together with the costs associated with holding small stocks of parts on the plant itself in order to improve repair times for simple tasks such as changing drive belts, replacing filters etc.

Stage 13 was concerned with the actual calculation of the value of each cost element. The working sheets for these calculations are given in Appendix 9. Each cost element was estimated either from company data for capital costs or from the CERS using company data for labour rates at 1975 levels. Table 26 presents a summary of the results of this LCC case-study.

The study has now reached stage 18 of the procedural model. At this stage a comparison between the plants under study should take place. This comparison indicates that plant B has an initial capital cost which represents only 78% of the capital cost of plant A. However, because plant B has poorer reliability and maintainability characteristics, it has a total direct maintenance cost some 2.30 times greater than plant A. Table 26 shows that plant B is estimated to have over 5 times more breakdown hours than plant A and to require approximately twice as many maintenance craftsmen to be employed to maintain it.

TABLE 26
SUMMARY OF ESTIMATED LCC

COST ELEMENT	PLANT A	PLANT B	B/A
ACQUISITION COSTS	808,150	632,500	.78
$\frac{1}{2}$ LIFE OVERHAUL COST	50,000	80,000	1.60
REMOVAL COSTS	50,000	60,000	1.20
BREAKDOWN MAINT.COST	33,860	169,663	5.00
PREVENTIVE MAINT.COST	148,117	178,889	1.21
MAINT.MATERIALS COST	88,777	291,639	3.30
MAINT.LOGISTICS COST	8,877	29,164	3.30
TOTAL DIRECT MAINT.COST	329,631	759,355	2.30
TOTAL LIFE-CYCLE COST (as considered here)	1,187,781	1,441,855	1.25
SUMMARY OF OTHER DATA			
TOTAL BREAKDOWN HOURS	4,812	25,236	5.24
TOTAL PREVENTIVE MAINT. HOURS	23,280	27,520	1.20
MAINTENANCE MANPOWER YR.1	.5 man	1.0 man	2.00
MAINTENANCE MANPOWER YR.12	2.3 men	4.2 men	1.83
RATIO $\frac{\text{LIFE-CYCLE COST}}{\text{ACQUISITION COSTS}}$	1.47	2.26	1.40

The procedural model has been followed in this case-study and as a consequence the life-cycle cost analysis has been reduced rationally to a consideration between capital costs and on-going direct maintenance costs. Whilst this case-study has been extensively simplified it illustrates the impact that reliability and maintainability characteristics can have on the cost of owning plant and the potential losses in revenue which stem from owning plant with many thousands of hours of breakdown time during its life-cycle.

Stage 19 would require that plant A be procured despite its higher capital cost. As a result of this type of analysis it can be seen that the company would probably never again procure plant type B. In this way, ~~and thereby~~ the company will be reducing its future on-going costs of operating and maintaining its production plant. Experience gained in operating plant A can now be fed-back to the manufacturer and improvements in reliability and maintainability could be introduced into the plant. Thereby further reducing the levels of breakdowns and preventive maintenance activities. Future plant designs would therefore benefit from this data feedback thus indicating the cyclic and iterative nature of the procedural model proposed in Chapter 19.

20.5 Summary.

This chapter has presented an example of the application of the procedural model developed in the previous chapter. The example was hypothetical in that the situation described did not actually take place within the company. However, actual historical data collected from company records, were used in order to estimate the magnitude of the cost elements. Furthermore, the example is realistic in the sense that the type of situation described is not untypical of the type of decision which faces the managements of manufacturing companies. The application of the procedural model facilitates a step-by-step analysis and justification for the selection of a particular item of plant.

The example has many limitations, as were described in the text, and such considerations as investment allowances and grants, taxation, depreciation and of course the estimated revenue must now be taken into account in order to convert the calculation of the life-cycle cost into a comprehensive investment appraisal. The important point about the application of the procedural model is that it provides a detailed economic evaluation technique based on the engineering characteristics of a plant.

The following chapter presents a summary of the research work into the concept and practice of life-cycle costing.

CHAPTER 21
SUMMARY AND CONCLUSIONS ON RESEARCH
INTO LIFE-CYCLE COSTING

21.1 Introduction.

This chapter presents firstly a summary of the research work carried out into the technique of life-cycle costing. It then draws some conclusions that can be made regarding the application of life-cycle costing within manufacturing industry. Conclusions are also drawn from the findings of the postal questionnaire survey of experienced practitioners in the United States and Sweden.

21.2 An Overview of the Research Work.

The research work carried out into the concept and practice of life-cycle costing has been presented in Chapters 17, 18, 19 and 20 of this dissertation. Chapter 17 was concerned with establishing the historical development of life-cycle costing on an international basis. This chapter stated also some of the definitions of life-cycle costing. The definition offered by the Department of Industry is the one which was assumed throughout this research work. The advantages and problems

associated with the use of life-cycle costing were outlined also.

Chapter 18 presented the industrial research. This chapter covered the objectives of the research, the approach to the participants, the response from the postal questionnaire and then described the findings of the research in detail.

Chapter 19 was concerned with the development of a procedural model to facilitate the application of life-cycle costing as an economic evaluation technique for manufacturing plant and equipment. The objectives of developing such a model were described together with the assumptions made. The model was then described in detail as a twenty two stage procedural model which was both cyclical and iterative in nature. Cost element check lists, examples of cost structures and cost estimating relationships were given. A general schema of the procedural model was presented in Figure 22.

Chapter 20 presented a brief case-study in the use of the procedural model. In this case-study data were acquired from source documentation within company E of the industrial research described in part 1 of this dissertation. The case-study was hypothetical in nature because company E had not in fact even heard of life-cycle costing at the time of the research visit. Therefore,

the case-study gives only an indication of the way in which the model could be applied.

21.3 Conclusions.

This section presents the conclusions drawn from the work described in the foregoing chapters . The conclusions are presented in three sections. The first considers the conclusions relating to the development of the technique of life-cycle costing. The second section deals with the findings of the survey of practitioners in the USA and Sweden and the third section draws some conclusions regarding the development of the procedural model and its applications.

21.31 The Development of Life-Cycle Costing.

In Chapter 1 page 1 the objective of this part of the research into life-cycle costing was stated as follows:-

To investigate the historical development of life-cycle costing.

As a result of the work presented in Chapter 17 of this dissertation, the following conclusions are drawn.

- 1) That life-cycle costing developed due to an increasing concern expressed by the military authorities that the on-going costs of supporting military equipment were becoming excessive and that a more effective method than the 'low-bid' must be developed as a means of equipment selection.
- 2) The military authorities were concerned also that

the availability of some items of equipment was poor in relation to its desired level and that more attention needed to be given to reliability and maintainability characteristics as important parameters in system design.

- 3) The technique of life-cycle costing should be developed within manufacturing industry for the same reasons that it was developed within the military environment. This author concludes that the justifications for developing life-cycle costing as an integral part of the appraisal of equipment procurement and design is applicable equally to the procedures which should be adopted to evaluate manufacturing plant and equipment.
- 4) Life-cycle costing has developed into a standard evaluation technique within the American, Swedish and British Defence industries and that this level of commitment to the technique should reinforce the view that the technique should be considered seriously by those engineers, managers, accountants and directors who are responsible for the effective allocation of resources within their organisations.
- 5) The application of the technique has certain limitations which must be understood by users and its greatest value is in the comparative evaluation of mutually exclusive

assets and when great accuracy is not required.

21.32 Establishing Some Fundamental Precepts.

In Chapter 1 page 1 the objective for this part of the research into life-cycle costing was stated as follows:-

To investigate some of the fundamental precepts surrounding the technique of life-cycle costing. In particular the qualifications and experience required, the use of accounting and quantitative techniques, the management and organisational considerations and the limitations and other important issues which are associated with application of life-cycle costing.

In order to achieve this objective a postal survey of experienced practitioners was conducted. The survey obtained the experiences of eight life-cycle costing practitioners seven of whom were from the United States and one from Sweden. As a result of this survey the following conclusions are drawn.

- 1) That life-cycle costing is performed by engineers as a tool for the evaluation of the engineering characteristics of a system .
- 2) That life-cycle costing analysts do exist, most of whom have bachelor degrees in engineering, with some analysts having higher degrees in business, economics operations research and mathematics.
- 3) That within the context of manufacturing industry, a value engineer or industrial engineer would have a suitable combination of knowledge and skill to become a life-cycle costing analyst.

- 4) That experience of the user organisation and familiarity with the plant under study is of vital importance to the successful application of life-cycle costing.
- 5) That life-cycle costing should be introduced into the curriculum of bachelor degrees in engineering and finance. It should be introduced also at masters degree level and where appropriate on short courses as part of post-experience development within companies.
- 6) That ideally life-cycle costing should not be performed by a single 'expert' but that a combination of skills is required if the technique is to be exploited to the full.
- 7) That as a result of the opinions expressed in the questionnaires, the following quantitative and accounting techniques were found to be used in conjunction with life-cycle costing:-
 - (a) three respondents used post-completion auditing.
 - (b) five respondents used discounting.
 - (c) six respondents used inflation indices.
 - (d) all respondents used risk and sensitivity analyses.
 - (e) seven respondents used cost estimating relationships.
 - (f) seven respondents used cost-effectiveness analysis.
 - (g) seven respondents used trade-off analyses.

These findings indicate the complexity and depth of analyses carried out when using life-cycle costing

as an evaluation procedure for engineered systems.

- 8) That as a result of the findings from the postal questionnaire survey the following management and organisational considerations stemmed from the use of life-cycle costing:-
- (a) seven respondents used computers to perform life-cycle costing analyses.
 - (b) six respondents required life-cycle costing to be carried out as part of a contractual commitment
 - (c) four respondents used minimum life-cycle cost as a basis for decision making.
 - (d) one respondent used maximum cost effectiveness and one respondent used design-to-cost and design-to-life-cycle cost as a basis for decision making.
 - (e) four respondents employed LCC analysts who worked entirely on life-cycle costing studies.
 - (f) the remaining four respondents stated that LCC analysts were employed on a variety of other work such as reliability studies, maintenance cost analysis, operations research, operations analysis, engineering projects and five year budget planning.
 - (g) All respondents were found to use data banks of historical information which were regularly updated.

- (h) In all the organisations in which the respondents were employed the LCC analysts were located in engineering departments.
- (i) That an important feature of life-cycle costing is to recognise that the technique only produces 'ball-park' estimates for comparison of alternative systems under study.
- (j) That familiarity with the user organisation and the policies, procedures and structure of the organisation are important.
- (k) That familiarity with the plant is of prime importance.
- (l) That the life-cycle cost model must be compatible with the accounting procedures of the user organisation.
- (m) That life-cycle cost analysis models of a generalised nature are unlikely to be meaningful. Analytical models must be tailored to the specific type of study under consideration.
- (n) That the development of procedural guidelines should be the first stage in an organisation's strategy for the implementation of life-cycle costing as an integrated economic evaluation technique for manufacturing plant and equipment.

20.33 The Development of a Procedural Model.

In Chapter 1 page 2 the objective for this part of the research was stated as follows:-

To develop a generalised procedural model to facilitate the use of life-cycle costing as an economic evaluation technique for manufacturing systems.

This objective was met by the work carried out in Chapter 19 of this dissertation. As a result of this research work the following conclusions are drawn:-

- 1) That no procedural model existed to facilitate the application of life-cycle costing within manufacturing industry. This dissertation is to the author's knowledge the first attempt at such a procedural model.
- 2) That a procedural model should be the first task of any organisation wishing to implement life-cycle costing.
- 3) That once a procedural system has been introduced then specific analytical models can be developed in order to evaluate life-cycle costs, perform trade-off analyses, cost-effectiveness analyses and so on.
- 4) That a procedure of the type developed in Chapter 19 can be regarded as sufficiently comprehensive to enable manufacturing organisations to adopt the life-cycle costing technique as an integrated part of their evaluation procedures for new plant designs and procurements.

- 5) The example given in Chapter 20 of this dissertation illustrates the way in which the technique of life-cycle costing could be applied to the evaluation of manufacturing plant. It is concluded here that this type of application could improve greatly the decision making ability of those engineers, managers and directors responsible for the allocation of resources within manufacturing organisations. The technique should be of particular value when attempting to justify the increased allocation of resources to improve the reliability and maintainability characteristics of plant.
- 6) The application of the procedural model should provide a complete, coherent and step-by-step economic justification for an item of manufacturing plant. Furthermore, it should be possible to identify and examine the way in which decisions were arrived at and to explore the decision chain in order to ensure that all the relevant parameters, concerning the plant under study, have been considered.

20.4 Summary.

This chapter has presented an overview of the work carried out in this section of the dissertation. The conclusions drawn as a result of the research carried out

in Chapters 17 to 20 have been stated.

This chapter concludes the research work carried out into the concept and practice of terotechnology and life-cycle costing. The next chapter is the first of the three chapters under part 3 of this dissertation. This part is concerned with postulating some future developments for terotechnology and life-cycle costing and with outlining some suggestions for further research work.

CHAPTER 22

FUTURE DEVELOPMENTS IN THE CONCEPT AND PRACTICE OF TEROTECHNOLOGY

22.1 Introduction.

This chapter attempts to outline some of the possible future developments in the concept and practice of terotechnology. These speculations have been based firstly on a consideration of the current state-of-the-art within those companies that the researcher perceived to be leaders in the application of terotechnological practices. Secondly, they have been based on the findings of one day visits to 16 organisations within manufacturing industry, local government, the armed forces and passenger vehicle operators. Thirdly, they have been based purely on the author's evaluation of the way in which the concept and practice of terotechnology may develop in the future. Therefore, the background to these speculations has consisted of interviews with over 90 directors, managers, engineers and accountants in 22 organisations within the United Kingdom.

22.2 Some Possible Developments

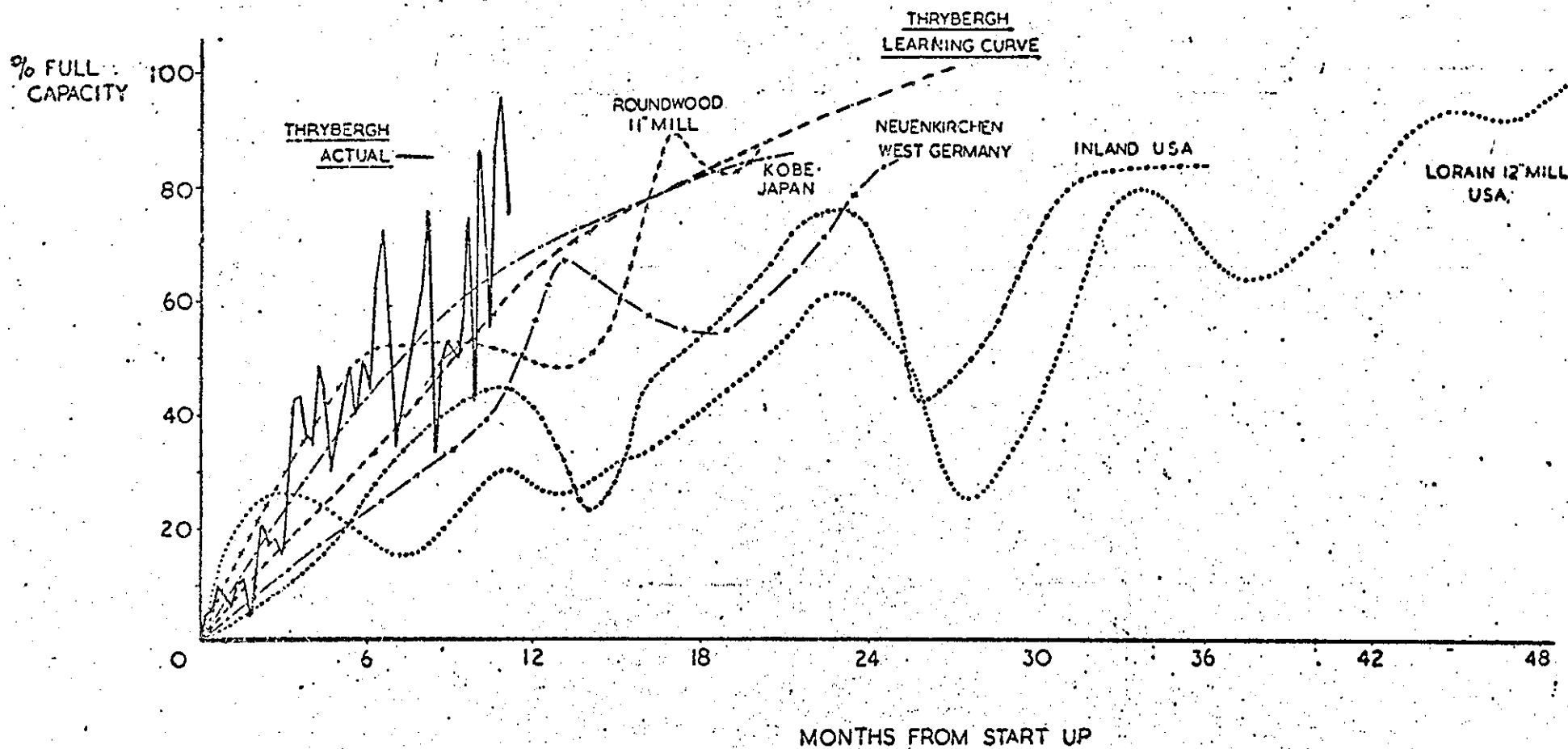
These developments are outlined in the two following sections. The first considers the concept of terotechnology and the second deals with the practice of terotechnology.

22.21 Developments in the Concept.

Discussions with many personnel in the organisations visited, revealed that the word terotechnology was disliked. Many felt that the development of a new word was counter-productive. The understanding of the definition of the word varied considerably. From these findings it is postulated here that the word terotechnology will fall into disuse. The researcher's view is that the term 'life-cycle management' is much preferred within industry and the services. It was found also that using this term enabled discussion of life-cycle costing to take place directly and naturally as an associated concept to that of life-cycle management.

The concept of 'caring-for' plant and equipment was found to be well received. The interpretation placed on the word terotechnology was very varied and only one organisation was found to have developed its own ideas on the way in which the concept could be interpreted. In general, it was found that industry preferred self defining terms such as life-cycle management and physical asset management to the word terotechnology. It is suggested here that it will be the term life-cycle management which supercedes eventually the word terotechnology.

The way in which the concept of terotechnology is interpreted will be subject to considerable change over the next few years. One organisation is known to have formulated a view on the way in which the concept applies to their particular requirements. This view has been expressed by the the organisation's director of engineering, Mr.H.Darnell,in two papers referred to in Chapter 3 of this dissertation. The British Steel Corporation have, under Mr. Darnell's leadership,developed comprehensive terotechnological procedures based on his concept that terotechnology can be considered as a subsystem of an organisation concerned with the application of business objectives to the management of its permanent physical resources. British Steel have formed a special department of terotechnology at the London headquarters with the task of developing a terotechnological approach to the management of the organisation's plant and equipment. One result of this work has been described by Harvey(93). This was the Thybergh Bar Mill project which was designed with many terotechnological features and at the time of the author's visit had surpassed all previously recorded performance figures for steel plant throughout the world. Figure 25 shows the work-up performance of the Thrybergh Bar Mill in comparison to other recent installations.



A Comparison of Work - Up Rates For Recent Bar Mill Installations

Figure 25

Other examples of the application of terotechnological concepts and the benefits accrued from such application are described by Weigel (94) and Rappini (95). What is clear in the author's view, from these examples, is that there needs to be an integrated organisational system established to ensure that terotechnologically orientated ideas can be considered and put into practice within the organisation. That is to say that the interpretation of terotechnology, developed in Chapter 4 of this dissertation, is likely to become the accepted way in which a detailed, integrated and conscious attempt to develop terotechnological practices within an organisation could be achieved.

Further development of the concept is seen in the education and training of engineers and accountants and so on. Educational establishments have been actively encouraged to introduce terotechnology into courses and this effort is resulting slowly in several new courses and modifications to existing ones. This effort will continue to develop but once again it is the author's view that the word terotechnology is likely to be replaced by more widely acceptable terms such as those mentioned earlier.

The author is a member of a working party of the Chemical and Allied Products Industry Training Board

This working party has the task of developing training recommendations for the introduction of terotechnological concepts and practices within the industry. Such developments as these will continue but their impact is of course long term.

In the author's view one of the most significant contributions that the development of the new word has made is in terms of awareness. This awareness has been demonstrated by the high levels of attendance at conferences, the interest shown by government and educational establishments and by the level of interest shown by the personnel that have been interviewed during the course of this research work. In particular, industry seems to have become more aware of the need to increase the reliability and maintainability characteristics of plant and to consider on-going costs of operating and maintaining plant in greater depth than has hitherto been the practice. It is felt that this increasing awareness will continue and in particular there will be a demand to integrate engineering considerations with economic analysis to a much greater extent than is the current practice.

To summarise the possible future developments in the concept of terotechnology, the author considers

that firstly, the word terotechnology will be replaced by the term 'life-cycle management'. Secondly, that whilst organisations will need to develop their own interpretation of terotechnology, the kind of interpretation developed in this dissertation should be considered as one possible way to move forward. Thirdly, that there will be greater integration amongst those disciplines concerned with the life-cycle management of plant and equipment.

Further developments will take place in education and training which will provide a medium and long term development of the concept which will become eventually an accepted and integral part of industrial life.

Finally, the level of awareness for reliability and maintainability as important plant characteristics will continue. Furthermore, it may well be the case that 'directives' or 'codes of practice' may be introduced which will promote the detailed consideration of reliability and maintainability together with the pursuit of economic life-cycle costs within equipment procurement contracts and so on.

22.22 Developments in Practice.

The first development that is needed in the practice of terotechnology is in the collection, analysis,

reporting and use of data on plant design, performance and cost characteristics. Some of the organisations visited are carrying out projects in this field. For example, one organisation was developing a rationalised data collection system for the 40 locations throughout the U.K. in which maintenance work was carried out. Another organisation had developed a system of data feedback to its plant suppliers and two other organisations were investigating the nature of data collection which would be most appropriate to their needs.

Improved maintenance practices are seen also as vital future developments. Again several companies were examining their existing practices very closely and at the time of one visit a firm of management consultants had been called in to make a presentation to the company's engineering staff. Another company had set up a project team to examine the maintenance characteristics of major plant. As a result of this study, 64 maintenance problems were highlighted.

Within manufacturing industry, the role of the production engineer should be given more attention in the development of technological practices. This possible role was described by Harvey (96) in which the production engineer is seen as a central figure in the design, selection,

technical and economic appraisal and on-going use of manufacturing plant. It is suggested that this role be examined more closely in the future and resources allocated in order to allow the production engineer to avoid the 'low-bid' procurement practice.

Further developments should be pursued in the design of manufacturing plant. Design for reliability and design for maintainability were found to be little known terms. Currently, these expressions seem to have meaning only in the military sectors of industry. It is suggested that these practices must be developed if significant improvements in operational performance are to be obtained from manufacturing plant. It was found that, in general, the pressure to purchase or design to a low initial cost far outweighed the desirability of increasing the initial costs in order to reduce the life-cycle cost.

This leads to the need for a further important future development. That is the development of attitudes. Top management must change their attitude towards capital expenditure if the practice of terotechnology is to be successful. Designers and plant selectors must be prepared to propose plant procurements on the basis of life-cycle cost rather than purchase price, and what is more important they must be able to defend the logic of this approach.

A further important development is seen in the need to establish much better plant specifications and contractual commitments. Specified reliability and maintainability characteristics, specified functional systems documentation, specified condition monitoring equipment and so on would soon make plant designers and manufacturers take some notice of industry's commitment to the application of terotechnological practices. This was again highlighted by the British Steel Corporation when they decided to incorporate functional systems' documentation as a designed-in feature of the plant for Thrybergh Bar Mill. As a result of their action two major suppliers had to set-up new departments in order to supply the fault diagnosis systems specified by BSC. Specified reliability and maintainability is again now a common practice in the military sector of industry. Furthermore, some military procurements are now based on 'incentive contracting' in which incentives are offered to suppliers to exceed the specified minimum level of performance . However, if the specified level of performance is not met then the supplier faces penalties. It is suggested that these types of practices should be examined and if they can be applied to general manufacturing industry then they should be encouraged as desirable improvements in the way in which contracts and specifications are laid down.

To summarise the developments in the practice of terotechnology as perceived by the author . Firstly, data management will need to be improved greatly before terotechnology can even begin to have an effect on plant performance. Secondly, maintenance practices will need to be improved and the role of the maintenance engineer , in the decision making process, needs to be recognised. Thirdly, the role of other disciplines needs to be examined and consideration given to the contribution that they could make to the successful application of terotechnological practices. In addition, the need to improve design for reliability and design for maintainability is of paramount importance in the future development of terotechnology. Emphasis on low initial costs must be shifted towards low life-cycle costs. However, this task is largely dependent on the commitment to terotechnology by top management who issue policy directives and sanction procurement decisions. Lower levels of management and engineering must be provided with the skills and knowledge to adopt and defend decisions based on life-cycle cost. Plant contracts and specifications must be improved and techniques currently in use by the military establishment should be examined and applied to manufacturing plant , wherever applicable.

22.3 Summary.

This chapter has outlined some of the possible future developments in the concept and practice of terotechnology. Some of these developments that have been suggested are in fact already in use in the military sector of industry or in the major manufacturing organisations of the U.K. It is the author's opinion that practices adopted by the defence organisations have often been applied successfully in general manufacturing industry and given time the same will be true of advanced life-cycle management practices of the types suggested in this chapter.

The following chapter considers some possible future developments in the application of life-cycle costing within manufacturing industry.

CHAPTER 23

FUTURE DEVELOPMENTS IN THE APPLICATION OF LIFE-CYCLE COSTING

23.1 Introduction.

This chapter attempts to outline some of the possible future developments in the technique of life-cycle costing as applied to the evaluation of manufacturing plant and equipment. As with the speculations regarding terotechnology, the developments proposed in this chapter have been based on the research within a total of 22 organisations. In addition, the views expressed by the eight respondents to the postal questionnaire on life-cycle costing have also been taken into account.

23.2 Some Possible Developments.

These developments are outlined in the following three sections. The first deals with the need to have a transference of experience from the experienced military users of the technique to the perhaps sceptical industrial users. The second considers the need to test the technique thoroughly before it can become standard practice and the third section outlines some of the attempts that are already being made by major companies to utilise

the technique.

23.21 The Need to Transfer Experience.

A major development which the author suggests as vital to the successful development of life-cycle costing is that the considerable amount of experience, within the defence industries and armed forces, should be transferred to manufacturing industry. The armed forces now have over twenty years' experience in the use of life-cycle costing. To some extent this transfer of knowledge is taking place already in that two major international conferences were held in late 1977 and early 1978. In both cases all the speakers were from the defence industries and armed forces. The author has visited senior members of the Ministry of Defence Procurement Executive and members of the army's data management centre at Woolwich. The experience held within these organisations and others should be disseminated so that manufacturing industry may learn from the experience of the defence industries and thereby accelerate the detailed appraisal of the technique necessary before it can become standard practice within manufacturing industry. Knowledge is building up also in the airline operating companies and in some rental based organisations such as Rank Xerox. The experience of the author indicates that these organisations are very willing to

discuss their experiences in the use of life-cycle costing. However what is needed is some form of central or governmental incentive to disseminate their knowledge on a wider scale.

The educational and research establishments have a major role to play in this transference of knowledge and it is the author's view that further resources need to be allocated to enable research, short courses, publications and so on to be mounted.

23.22 Establishing the Validity of the Technique.

Another important development, which needs to take place, is that of validating the applicability of the technique to the environment in which investments must be made within manufacturing industry. The author has heard often the complaint that the defence industries have a 'bottomless pot of gold' and that such sophisticated techniques as life-cycle costing, cost-effectiveness analysis and trade-off analyses would be too expensive for most manufacturing organisations. However, as has already been pointed out in Chapter 19, what is needed in manufacturing industry are simplified procedures which facilitate the same process of analysis but at a level of depth which is appropriate to the needs of the particular study being undertaken. The professional institutions should establish their policies regarding

the validity of life-cycle costing as a method of economic analysis for manufacturing plant.

The validity of the technique should also be tested by conducting case-studies and developing and testing analytical models of life-cycle costing. Over 200 analytical models have been developed by the military organisations and some which the author has seen extend to over 200 pages of explanation, computer programmes and eventually the printouts of the results of the evaluation. Such models would in the author's view be counter-productive for manufacturing industry.

23.23 Future Developments in Industry.

Of the 22 organisations visited during the course of this research (between 1975 and 1976) six organisations are known to be using life-cycle costing or examining the applicability of the technique. In one company internal seminars and lectures have been held in order to introduce life-cycle costing to project engineers, accountants, maintenance engineers and other members of the management structure. In another company an on-going project has been established to create a data collection system, test out life-cycle costing on a pilot basis and several internal courses have been run. In another company case-studies have been conducted and examples of the work that this company has carried out

were presented at the Tero 77 Conference(97) by Mr.S.E.Kay. This development should continue to gather momentum and other companies will almost certainly begin to investigate the use of the technique.

However, the author has serious doubts about the way in which the technique is being taken up by industry before standardised procedures and definitions have been developed and published . What appears to be happening at the moment is that each company is adopting its own definitions and procedures so that numerous varieties of life-cycle costing techniques may become established. What is considered to be a more desirable course is for a standardised procedure to be developed and supported by the institutions so that it can then be applied to each company environment as their needs dictate. The need for a standardised approach is particularly important of course if the technique becomes part of a contractual requirement as is the case in many defence contracts. If each supplier submits a proposal for the design and manufacture of an item of manufacturing plant based on life-cycle costing, then it is essential that they are all using the same procedure, definitions and assumptions.

To summarise the developments seen to be required by the author. The first development should be in the

field of wider dissemination of knowledge and experience in the use of life-cycle costing. The second is seen in terms of encouraging more detailed research into the use of the technique as a means of appraisal for manufacturing plant. The third is seen in terms of a need to establish the validity of the technique and the feasibility of adopting such in-depth procedures within a commercial industrial environment. The fourth and perhaps most important development should be in the development of simple standardised procedures for the implementation of the technique. The fifth development seen as important by the author is to ensure that the technique has the support of the institutions and that this leads to wider use of what should become a standard evaluation procedure for manufacturing plant and equipment.

23.3 Summary.

This chapter has described some of the future developments considered to be desirable by the author. Some of these developments are already under way within industry and most of them are standard practice in the defence industries. If the potential benefits, as described in Chapter 17, are to be realised then these

speculative ideas must become reality. The technique has a long way to go but the extent of the interest shown by industry has been remarkable for such a new technique.

The following chapter outlines some suggestions for further research work in terotechnology and life-cycle costing.

CHAPTER 24

SUGGESTIONS FOR FURTHER WORK

24.1 Introduction.

This chapter describes some suggestions for carrying out further research work in the fields of terotechnology and life-cycle costing. The findings of the research, presented in this dissertation, leave many unanswered questions about the way in which terotechnology and life-cycle costing should be applied to manufacturing industry. The suggestions are presented in two sections. The first considers further work in terotechnology and the second describes some suggestions for further work in life-cycle costing.

24.2 Suggestions for Further Research in Terotechnology.

The findings of this research highlighted the following ideas for further research endeavour.

- 1) To carry out industrial research to establish the way in which the concept of terotechnology has been interpreted by engineers, managers and accountants.
- 2) To carry out industrial research to establish if the word terotechnology is actually in regular use

as a managerial or engineering term.

- 3) To carry out industrial research into the application of terotechnology to determine what effect such application has on the financial performance of a company.
- 4) To carry out industrial research to establish the value of using the terotechnology concept as a product marketing tool.
- 5) To carry out research which will provide detailed case-studies in the application of terotechnological practices and their subsequent effect on the performance of the product.
- 6) To carry out research into methods of assessing the 'pay-off' to be gained from applying terotechnology to a plant design(ie. increasing its reliability and maintainability characteristics) against the cost and time involved in applying techniques to improve these characteristics.
- 7) To carry out research into the way in which the application of terotechnological practices varies according to the industrial sector.(ie. what differences exist between practices adopted by the chemical industry and say the vehicle manufacturing industry)
- 8) To carry out research into the training implications of introducing terotechnology into an organisation.

- 9) To perform a replication of the research work carried out in this dissertation in order to determine if the findings of this work hold true for a different sample of organisations.
- 10) To carry out research into the sociological problems associated with the need to have greater interaction between professional disciplines within an organisation and methods of breaking down specialist barriers to communication.

These suggestions are not exhaustive in nature, but do indicate those areas which should receive attention from researchers endeavouring to advance our knowledge about the concept and practice of terotechnology.

24.3 Suggestions for Further Research into Life-Cycle Costing.

The findings of this research work into life-cycle costing highlighted the following ideas for further research endeavour.

- 1) Industrial research to establish, in detail, the way in which those companies who are applying LCC have done so and the reasons why they decided to utilise the technique.
- 2) Research into the way in which the Ministry of Defence have applied life-cycle costing and their experiences in the use of the technique. This work should then be disseminated to industry in general in order to stimulate interest and application of LCC.

- 3) Research, on a case-study basis, to investigate the cost of implementation of a life-cycle costing procedure within a manufacturing organisation.
- 4) Research into the possible application of life-cycle costing to other environments such as local government, hospital equipment, buildings services' plant and buildings.
- 5) Research into the problem of applying discounting techniques to long-life systems and the way in which such systems should be treated from a life-cycle cost viewpoint.
- 6) Research to carry out long term 'follow-up' analyses of projects, selected on the basis of their low life-cycle cost, to determine the accuracy of the forecasting ability of cost-estimating relationships and predicted reliability and maintainability characteristics.
- 7) Research to establish how life-cycle costing can be integrated with conventional investment appraisal techniques for manufacturing plant.
- ✓ 8) Research to establish how to cost for lost production from breakdowns and the validity of including such a cost element in an LCC analysis.
- ✓ 9) Research to develop specific analytical models for the evaluation of a life-cycle cost for particular types of manufacturing plant.

- 10) Research to establish the most effective way of introducing life-cycle costing into an organisation. (ie. should one engineer or accountant be trained in the technique or should it be performed by a team?)
- 11) Research to develop a range of life-cycle costing case-studies for wide dissemination within industry and education.

Again these suggestions are not intended as an exhaustive list but as an indication of the direction in which research should be developed.

24.4 Summary.

This chapter has outlined some of the suggestions for further research that this work has highlighted. Inevitably all the ideas proposed in this chapter would require considerable time and commitment of resources. Nevertheless, the effort would be well rewarded by wider understanding and application of life-cycle costing as a technique for the economic evaluation of engineered systems. The suggestions for further research into the concept and practice of terotechnology would probably be even more difficult to pursue but again the rewards could be substantial if such research led to a wider understanding and application of terotechnological practices.

This chapter concludes the work presented in this dissertation. The appendices and list of works cited follow this chapter.

APPENDICES

APPENDIX 1

- (a) Industrial research letter of introduction
- (b) The research brochure.

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DEPARTMENT OF ENGINEERING PRODUCTION

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Professor T. M. HUSBAND, Ph.D., British United Shoe Machinery Professor of Manufacturing Organisation

I am currently engaged on postgraduate research which is being funded by the Science Research Council. My research is aimed at investigating how companies manage the life - cycles of their plant and equipment. That is, how plant is specified, designed, installed, commissioned, used and maintained. The objective is to determine what relationships exist between various physical asset management practices and plant performance.

I am writing to ask if you would be willing to assist me in this research work. I would very much like to use your company as one of my case studies. This will simply involve me in visiting your company for a short period of time to collect data and interview several of your management personnel.

Please find enclosed a short brochure which outlines the objectives of my research and covers some other points that you may be interested in having clarified at this stage.

If you would like to assist me in this research work and would like to discuss it further, please let me know. I look forward to hearing from you.

Yours faithfully

Graham Harvey.

Postgraduate Research Student.

PRACTICAL RESEARCH INTO THE PHYSICAL ASSET
MANAGEMENT PRACTICES OF INDUSTRY.

A RESEARCH PROJECT FUNDED BY THE SCIENCE RESEARCH COUNCIL.

GRAHAM HARVEY.
DEPARTMENT OF ENGINEERING PRODUCTION
LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY.

TELEPHONE.

LOUGHBOROUGH 63171 EXT. 328.

SEPTEMBER 1975.

PRACTICAL RESEARCH INTO THE PHYSICAL ASSET MANAGEMENT PRACTICES OF INDUSTRY.INTRODUCTION.

These notes are for the information and guidance of potential 'host' companies. I hope that managers and engineers who read these notes will be encouraged to collaborate with the university in this research work. Hopefully, the project should produce results of value to the host companies as well as providing essential knowledge about the general nature of physical asset management practices within manufacturing industry.

The management of industry's physical assets has recently begun to receive a great deal of attention from government departments, institutions, consultants and educational establishments as well as from industry itself.

The growth in interest in this 'cinderella' area of management was sparked off by a government report which was published in 1970. This report was centred around an investigation into the maintenance practices of British manufacturing industry. However the report also highlighted the fact that an asset requires managing from its initial specification and design, to its installation, commissioning, operation, maintenance and eventual removal and replacement. A copy of the report summary is included on page 5. This whole - life management approach has been given the name Terotechnology. It is suggested that British industry could save approx. £500 million by the adoption of improved maintenance and life - cycle management practices (at 1970 cost levels).

However very little is known about the whole - life physical asset management techniques that are employed by companies in order to ensure that their plant and equipment is working effectively throughout its economic life.

THE OBJECTIVES OF MY RESEARCH.

- i) To investigate the whole-life physical asset management practices of manufacturing industry.
- ii) To investigate the relationships that exist (if any) between various physical asset management practices, plant performance and the overall company performance.
- iii) To investigate how the 'need' for whole - life physical asset management varies according to the complexity of the production process.

WHAT DATA WILL BE COLLECTED.?

I would like to collect data on the following aspects of the company's organisation. (a) the general organisation structure, (b) how the company specifies, designs, installs, commissions, operates, maintains and replaces its plant and equipment. (c) data relating to the company's performance, eg. sales, profit, assets employed etc. (d) data relating to the plant's performance eg. no. of breakdowns, operating costs, scrap levels etc. (e) a general description of the production process.

HOW WILL THE DATA BE COLLECTED ?

I shall collect the data within the host company. I shall visit the host company at any time convenient to it. I would like to talk to several managers and other personnel who hold the data that I wish to collect. Data will be entered onto coded data collection sheets, or onto questionnaires.

HOW CONFIDENTIAL WILL THE STUDY BE?

No documents or records of any kind will be removed by me from the host company's premises. No publication of the results of my study will proceed without the written consent of the company concerned. However it is desirable that the company will allow me to use the data, in an anonymous form, within the content of my thesis. Such a reference will take the form of the following example:-

Data collected from company 'X' small batch production.

WHAT ASSISTANCE IS REQUIRED FROM THE HOST COMPANY.?

I would like to be able to interview, quite briefly, various managers and engineers who are associated with the management of the company's physical assets, eg. Chief designer, Production manager, Maintenance manager, Accountant, etc. I would also require initial guidance in the interpretation of company data.

There will be no cost to the company. The project is financed by the Science Research Council.

WHAT BENEFITS CAN THE HOST COMPANY EXPECT FROM THIS STUDY?

When I have collected and analysed the data from several different companies I should then be able to carry out several comparative analyses. These will probably take the form of comparing the practices of each company with the other companies, and relating this to the success of the company's financial and operational performance. This should enable conclusions to be drawn regarding those management practices that can be associated with high levels of plant performance and company success.

From this and other forms of analysis, I shall prepare a report for each company. This will outline the findings of my research, in general terms and as related to your particular company. It may also be possible to suggest improvements or modifications to existing practice which have been shown to be successfully applied in other companies.

WHAT BENEFITS WILL THE UNIVERSITY GAIN?

I am carrying out this research work in order to submit a thesis for the degree of Ph.D. In addition the university will gain a much clearer understanding of the practical problems that have to be solved when managing a company's physical assets. It is hoped that information regarding the problems that face those managers concerned with asset management will enable future teaching and training courses to be modified to include this knowledge.

APPENDIX 2

The industrial research questionnaires

STRICTLY CONFIDENTIAL.INDUSTRIAL RESEARCH INTO THE PHYSICAL ASSET LIFE - CYCLE MANAGEMENTPRACTICES OF MANUFACTURING INDUSTRY. (BY CASE-STUDY)GENERAL QUESTIONNAIRE. COMPANYLOCATION.

NOTES. This questionnaire is to be used to collect general information about the participating companies. This includes the nature of products, type of production system, analysis of the production process, number of employees and other general organisational information.

- 1) Classification of industry _____
- 2) Nature of products _____
- 3) Type of production system (see operation sequence and mechanisation profile) _____
- 4) Type of organisation _____
- 5) Total number of employees at the location under study _____
- 6) Company organisation structure (see separate sheets) _____
- 7) The number of levels of hierarchy in the organisation. _____
- 8) The number of executives responsible (directly reporting) to the chief executive. _____
- 9) The operational and financial performance of the company (see separate sheet) _____
- 10) The functional responsibilities for the life - cycle management of plant and equipment.
 - a) Responsible for the specification of plant _____
 - b) Responsible for the design of plant _____
 - c) Responsible for the installation of plant _____
 - d) Responsible for the commissioning of plant _____
 - e) Responsible for the manufacture of plant (if 'in house') _____
 - f) Responsible for the operation of the plant _____
 - g) Responsible for the maintenance of plant _____
 - h) Responsible for the removal of plant _____
 - i) Responsible for the financial evaluation of the plant _____
 - j) Responsible for the decision to invest in plant _____
 - k) Responsible for the procurement of plant _____
 - l) Responsible for personnel selection recruitment and training. _____
 - m) Responsible for the provision of management information. _____

FIELD RESEARCH : QUESTIONNAIRE No. I.THE SPECIFYING OF PHYSICAL ASSETS (PLANT AND EQUIPMENT ONLY)INTERVIEWER'S POSITION:-

NOTES. This questionnaire looks at the factors that could be included when attempting to set specifications terotechnologically. Would you please confine your answers to those practices that you adopt with respect to the specifying of major items of capital equipment. This does not include buildings and structures. If you feel unable to answer any question accurately or feel it is not relevant please say so rather than just giving a NO answer.

Are any of the following factors included when laying down the specification for an asset against which it will be subsequently designed or procured?

	YES	NO	COMMENTS
1) The working speeds and feeds of the plant ?	<input type="checkbox"/>	<input type="checkbox"/>	
2) The capacity of the plant (size or work piece etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
3) A measure of the product quality that is required?	<input type="checkbox"/>	<input type="checkbox"/>	
4) The degree of plant accuracy required ?	<input type="checkbox"/>	<input type="checkbox"/>	
5) The degree of plant repeatability required?	<input type="checkbox"/>	<input type="checkbox"/>	
6) The skill level required of the operator (ie. skilled, s/s, u/s)?	<input type="checkbox"/>	<input type="checkbox"/>	
7) The approximate cost of the plant ?	<input type="checkbox"/>	<input type="checkbox"/>	
8) The operating profile of the plant (ie. hrs. in use/week etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
9) The utilisation factors of the plant (ie. pumps etc. that only need to operate occasionally)?	<input type="checkbox"/>	<input type="checkbox"/>	
10) The geographic location of the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
11) The working environment of the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
12) The safety requirements of the plant (ie. must supply fully guarded etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
13) The mean time to repair a failure that is required?	<input type="checkbox"/>	<input type="checkbox"/>	
14) The delivery date?	<input type="checkbox"/>	<input type="checkbox"/>	
15) The mean time between failures of the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
16) The need to be supplied with preventive maintenance schedules?	<input type="checkbox"/>	<input type="checkbox"/>	
17) The need to be provided with plant overhaul schedules?	<input type="checkbox"/>	<input type="checkbox"/>	
18) The need to be supplied with a maintenance manual?	<input type="checkbox"/>	<input type="checkbox"/>	
19) The need to be supplied with a list of recommended spares?	<input type="checkbox"/>	<input type="checkbox"/>	
20) The need to be supplied with fault diagnosis data?	<input type="checkbox"/>	<input type="checkbox"/>	
21) The need to provide training programmes for maintenance and production operators?	<input type="checkbox"/>	<input type="checkbox"/>	

	YES	NO	COMMENTS
22)The need to provide training programmes for maintenance and production supervision ?	<input type="checkbox"/>	<input type="checkbox"/>	
23)The need to provide instruments and controls that are readily accessible to the operator and maintenance fitter?	<input type="checkbox"/>	<input type="checkbox"/>	
24)The need to ensure that there is good access to internal parts of the plant that will require maintenance ?	<input type="checkbox"/>	<input type="checkbox"/>	
25)A penalty clause for late delivery?	<input type="checkbox"/>	<input type="checkbox"/>	
26)A penalty clause for plant reliability being below the specified level for a given period or time (ie. guarantee period or agreed number of operating hours) ?	<input type="checkbox"/>	<input type="checkbox"/>	
27)The need to be provided with 'expected life' data for specified plant components?	<input type="checkbox"/>	<input type="checkbox"/>	
28)Do you have any historical data which you use in order to make decisions on plant reliability and maintainability when you are specifying a new item or plant?	<input type="checkbox"/>	<input type="checkbox"/>	
29)Do you specify the need to be supplied with data or information on the transportation, packaging and storage requirements of the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
30)Do you specify the anticipated life - cycle of the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
31)Do you specify the need for modular construction or plant to facilitate ease of maintenance and replacement?	<input type="checkbox"/>	<input type="checkbox"/>	
32)Do you use network analysis to plan a new plant project?	<input type="checkbox"/>	<input type="checkbox"/>	
33)Do you over specify certain requirements in order to give you margins of safety?	<input type="checkbox"/>	<input type="checkbox"/>	
34)Is a review of the plants performance spec carried out?	<input type="checkbox"/>	<input type="checkbox"/>	
35)Is a review of the plants reliability spec carried out?	<input type="checkbox"/>	<input type="checkbox"/>	
36)Is a review of the plants maintainability spec carried out?	<input type="checkbox"/>	<input type="checkbox"/>	
37)Is a review of the plants final specification carried out in the light of historical data and information ?	<input type="checkbox"/>	<input type="checkbox"/>	
38)In which department is the interviewee located?			
39)At what level of management is the interviewee situated?			
40)What qualifications does the interviewee hold?			
41)What do you find gives you the biggest problems when developing a plant specification?			

FIELD RESEARCH : QUESTIONNAIRE No.2.

THE DESIGNING OF PHYSICAL ASSETS (PLANT AND EQUIPMENT ONLY)INTERVIEWERS POSITION:-

NOTES. This questionnaire looks at the factors that could be included when attempting to design plant systems terotechnologically. Would you please confine your answers to those practices that you adopt with respect to the designing of major items of capital equipment. This does not include buildings and structures. If you feel unable to answer any question accurately or feel it is not relevant please say so rather than just giving a NO answer.

Are any of the following factors included when designing a new item of plant.?

	YES	NO	COMMENTS
1)The use of historical data on plant performance (ie, speeds, feeds, quality, accuracy, repeatability etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
2)The use of historical data to determine a plants MTR?	<input type="checkbox"/>	<input type="checkbox"/>	
3)The use of historical data to determine a plants MTEF?	<input type="checkbox"/>	<input type="checkbox"/>	
4)The use of historical data to determine the degree of preventive maintenance applied to a plant?	<input type="checkbox"/>	<input type="checkbox"/>	
5)The examination of breakdown reports etc. to determine the comments made by the operator or maintenance fitter at the time of a breakdown?	<input type="checkbox"/>	<input type="checkbox"/>	
6)The holding of discussions with maintenance personnel to determine their suggestions for improvements in the plants maintainability?	<input type="checkbox"/>	<input type="checkbox"/>	
7)The analysis of maintenance costs, downtime records, spares usage records to locate high cost areas?	<input type="checkbox"/>	<input type="checkbox"/>	
8)The use of network analysis to plan the design project?	<input type="checkbox"/>	<input type="checkbox"/>	
9)The use of value engineering studies?	<input type="checkbox"/>	<input type="checkbox"/>	
10)The use of statistical analysis on historical data?	<input type="checkbox"/>	<input type="checkbox"/>	
11)The use of trade - offs between plant cost and operational performance (ie, speed to cost, capacity to cost etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
12)The use of trade-offs between different forms of control systems (ie, mech/elect/hyd/pne etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
13)Do you use any form of cost effectiveness criteria to evaluate alternative designs?	<input type="checkbox"/>	<input type="checkbox"/>	
14)Do you use Life - Cycle Costing to evaluate designs?	<input type="checkbox"/>	<input type="checkbox"/>	
15)Do you use trade - offs between the different elements of cost in the life of the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
16)Do you use reliability and maintainability criteria to evaluate alternative plant designs?	<input type="checkbox"/>	<input type="checkbox"/>	
17)Do you derive a detailed operating profile for the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
18)Do you derive utilisation factors for the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
19)Do you identify critical cost parameters in the plant design?	<input type="checkbox"/>	<input type="checkbox"/>	
20)Do you make use of reports, journals, conferences etc to keep up to date with engineering developments?	<input type="checkbox"/>	<input type="checkbox"/>	
21)Do you write schedules for the manufacture, installation, and commissioning of plant?	<input type="checkbox"/>	<input type="checkbox"/>	
22)Do you write lubrication maintenance schedules for plant?	<input type="checkbox"/>	<input type="checkbox"/>	
23)Do you write overhaul schedules for plant?	<input type="checkbox"/>	<input type="checkbox"/>	
24)Do you write schedules for preventive maintenance of plant?	<input type="checkbox"/>	<input type="checkbox"/>	
25)Do you write schedules for preventive replacement of components?	<input type="checkbox"/>	<input type="checkbox"/>	

- 26) Do you write out fault diagnosis and repair sheets? ☐ ☐
- 27) Is there a formal data feedback document to the design dept. from the other phases in the plants life? ☐ ☐
- 28) Do you receive any form of feedback information during a plants life - cycle which provides you with some data on plant performance, reliability, maintainability and costs? ☐ ☐
- 29) Do you have a data bank of historical information on plant performance within the design dept.? ☐ ☐
- 30) If yes is it a computerised system? ☐ ☐
- 31) What reports and types of information can you obtain from the system? ☐ ☐
- 32) What delay is there between requesting and receiving information? ☐ ☐
- 33) Do you design in condition monitoring equipment? ☐ ☐
- 34) Is there a system for modifying plant whilst in service. (ie. from suggestion schemas etc.)? ☐ ☐
- 35) If yes how does the system operate? ☐ ☐
- 36) How many design alternatives are taken to the final stages of evaluation before a decision is made? ☐ ☐
- 37) Who decides which design is the 'best'? ☐ ☐
- 38) What criteria is used to determine the best design? ☐ ☐
- 39) What particular aspect of plant design gives you the greatest problems? ☐ ☐
- 40) What do you consider to be the most important consideration in the design of a new item or plant? ☐ ☐
- 41) Please rank the following design criteria in order of importance to you as the company's plant designer
- a) Design for longest plant life ☐
 - b) Design for ease of operational use ☐
 - c) Design for ease of maintenance ☐
 - d) Design for maximum reliability ☐
 - e) Design for maximum product quality ☐
 - f) Design for maximum engineering quality of the plant ☐
 - g) Design for lowest initial investment cost ☐
 - h) Design for maximum plant availability ☐
 - i) Design for lowest ongoing operating costs ☐
 - j) Design for lowest life - cycle costs ☐
 - k) Design for an optimum mix between plant performance, costs, quality, availability and life. ☐
- The use of quantitative techniques in the design of plant
- 42) Do you use critical path analysis? ☐ ☐
- 43) Do you use risk and sensitivity analysis? ☐ ☐
- 44) Do you use O.R. techniques to predict reliability? ☐ ☐
- 45) Do you use O.R. techniques to predict maintainability? ☐ ☐
- 46) Do you use cost effectiveness analysis? ☐ ☐
- 47) Do you use discounted cash flow analysis? ☐ ☐

- 48) Do you use O.R. techniques to predict optimum inspection frequencies? ☐ ☐
- 49) Do you use O.R. techniques to predict optimum overhaul freqs? ☐ ☐
- 50) Do you use O.R. techniques to predict optimum maint. crew sizes? ☐ ☐
- 51) Do you use regression analysis on historical data? ☐ ☐
- 52) Do you use linear programming? ☐ ☐
- 53) Do you use life - cycle costing? ☐ ☐
- 54) Do you use component stress analysis? ☐ ☐
- 55) Do you use vibration analysis? ☐ ☐
- 56) Do you use simulation? ☐ ☐
- 57) Do you use any rules of thumb for designers? ☐ ☐
- 58) Do you use a lowest cost only decision rule? ☐ ☐
- 59) Do you use ergonomics? ☐ ☐

- 60) In which department is the interviewee located? _____
- 61) At what level of management is the interviewee situated? _____
- 62) What qualifications does the interviewee hold? _____
- 63) What is the organisation structure of the design department? _____

FIELD RESEARCH : QUESTIONNAIRE No.3.THE INSTALLATION OF PHYSICAL ASSETS(PLANT AND EQUIPMENT ONLY)INTERVIEWEE'S POSITION:-

NOTES .This questionnaire looks at the factors that could be included when attempting to install plant terotechnologically.Would you please confine your answers to those practices that you adopt with respect to installing major items of capital equipment. This does not include buildings and structures.If you feel unable to answer any question accurately or feel it is not relevant please say so rather than just giving a NO answer.

Are any of the following included when installing a new item or plant.?

	YES	NO	COMMENTS
1)Do you have a formal layout of the site where the the plant is to be installed?	<input type="checkbox"/>	<input type="checkbox"/>	
2)Do you have a formal layout of the site services?	<input type="checkbox"/>	<input type="checkbox"/>	
3)Do you derive an installation project plan using network analysis?	<input type="checkbox"/>	<input type="checkbox"/>	
4)Do you develop job descriptions for each installation task?	<input type="checkbox"/>	<input type="checkbox"/>	
5)Do you use contractors to install plant?	<input type="checkbox"/>	<input type="checkbox"/>	
6)Do you use contractors to install the services?	<input type="checkbox"/>	<input type="checkbox"/>	
7)Do you carry out any forward planning or manpower requirements,?	<input type="checkbox"/>	<input type="checkbox"/>	
8)Do you carry out any forward planning or auxiliary equipment requirements?	<input type="checkbox"/>	<input type="checkbox"/>	
9)Do you record the problems encountered when installing the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
10)Do you record the problems encountered when installing the services?	<input type="checkbox"/>	<input type="checkbox"/>	
11)Do you have any formal reporting documents for recording installation problems?	<input type="checkbox"/>	<input type="checkbox"/>	
12)Do you establish an installation budget?	<input type="checkbox"/>	<input type="checkbox"/>	
13)Do you establish an installation project time schedule?	<input type="checkbox"/>	<input type="checkbox"/>	
14)On completion of plant installation are there any formal meetings between design,prod.,maintenance,commissioning, accounting etc.to review problems/costs with you.?	<input type="checkbox"/>	<input type="checkbox"/>	

15)What particular aspects of plant installation give you the biggest problems?

16)What do you consider to be the most important aspect in the installation of a new item or plant?

17)In which department is the interviewee located?

18)At what level of management is the interviewee situated?

19)What qualifications does the interviewee hold?

FIELD RESEARCH : QUESTIONNAIRE No. 1.THE COMMISSIONING OF PHYSICAL ASSETS (PLANT AND EQUIPMENT ONLY)INTERVIEWEE'S POSITION:-

NOTES. This questionnaire looks at the factors that could be included when attempting to commission a plant technologically. Would you please confine your answers to those practices the you adopt with respect to commissioning major items of capital equipment. This does not include buildings and structures. If you feel unable to answer any question accurately or feel it is not relevant please say so rather than just giving a NO answer.

Are any of the following included when commissioning a new item or plant?

	YES	NO	COMMENTS
1) The use of a formal commissioning schedule?	<input type="checkbox"/>	<input type="checkbox"/>	
2) Formal tests for plant performance (ie positioning, repeatability, quality of output etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
3) Formal tests for plant reliability (ie. determination of M.T.B.F.)?	<input type="checkbox"/>	<input type="checkbox"/>	
4) Formal tests of plant maintainability (ie. carrying out prev. maint. routines to specified times etc.)?	<input type="checkbox"/>	<input type="checkbox"/>	
5) A formal training programme for plant operators?	<input type="checkbox"/>	<input type="checkbox"/>	
6) A formal training programme for production supervision?	<input type="checkbox"/>	<input type="checkbox"/>	
7) A formal training programme for maintenance fitters?	<input type="checkbox"/>	<input type="checkbox"/>	
8) A formal training programme for maintenance supervision?	<input type="checkbox"/>	<input type="checkbox"/>	
9) The production of actual components?	<input type="checkbox"/>	<input type="checkbox"/>	
10) The evaluation of components for compliance with the specification?	<input type="checkbox"/>	<input type="checkbox"/>	
11) The evaluation of plant performance against that specified?	<input type="checkbox"/>	<input type="checkbox"/>	
12) The recording of all plant faults during the commissioning period?	<input type="checkbox"/>	<input type="checkbox"/>	
13) The recording of all auxiliary equipment and services faults during the commissioning period?	<input type="checkbox"/>	<input type="checkbox"/>	
14) Are any formal reporting documents used?	<input type="checkbox"/>	<input type="checkbox"/>	
15) Is there a formal acceptance of the plant as complying with the specification?	<input type="checkbox"/>	<input type="checkbox"/>	
16) Is there any formal discussion between design, prod., maint., instal., commissioning, supplier etc to discuss problems that have occurred during commissioning?	<input type="checkbox"/>	<input type="checkbox"/>	
17) What do you consider to be the most important activity carried out when you commission a new item of plant?			
18) What particular commissioning activity gives the biggest problems?			
19) In which department is the interviewee located?			
20) At what level of management is the interviewee situated?			
21) What qualifications does the interviewee hold?			

FIELD RESEARCH: QUESTIONNAIRE No. 6.

THE MAINTENANCE OF PHYSICAL ASSETS (PLANT AND EQUIPMENT ONLY)

INTERVIEWEES POSITION. _____

NOTES. This questionnaire looks at the factors that could be included when attempting to maintain plant and equipment technologically. Would you please confine your answers to those practices that you adopt with respect to major items of capital equipment. This does not include buildings and structures. If you feel unable to answer any question accurately or feel that it is not relevant please say so rather than just giving a NO answer.

Are any of the following included when maintaining the plant and equipment used within the manufacturing process.

	YES	NO	COMMENTS
1) Do you carry out any training of maintenance fitters when a new item of plant is installed?	<input type="checkbox"/>	<input type="checkbox"/>	_____
2) Do you carry out any training of maintenance supervision when a new item of plant is installed?	<input type="checkbox"/>	<input type="checkbox"/>	_____
3) Are any data recording documents used by the maintenance dept.? If yes, what data is recorded on these documents?	<input type="checkbox"/>	<input type="checkbox"/>	_____
4) Are any production operators used on maintenance work? If yes, in what capacity?	<input type="checkbox"/>	<input type="checkbox"/>	_____
5) Is there a maintenance fitters incentive scheme?	<input type="checkbox"/>	<input type="checkbox"/>	_____
6) Do you allocate priority to maintenance jobs?	<input type="checkbox"/>	<input type="checkbox"/>	_____
7) What is the basis of the priority allocation?	<input type="checkbox"/>	<input type="checkbox"/>	_____
8) Is there a lubrication maintenance schedule?	<input type="checkbox"/>	<input type="checkbox"/>	_____
9) Is the schedule supplied by an oil company?	<input type="checkbox"/>	<input type="checkbox"/>	_____
10) Is there a preventive maintenance programme in use? If yes how does it operate?	<input type="checkbox"/>	<input type="checkbox"/>	_____
II) Is there a before-failure parts replacement programme in use? If yes, how does it operate?	<input type="checkbox"/>	<input type="checkbox"/>	_____
12) Are any formal reports written when a plant break down occurs? If yes, do you use formal reporting documents?	<input type="checkbox"/>	<input type="checkbox"/>	_____
13) Do you use maintenance job cards?	<input type="checkbox"/>	<input type="checkbox"/>	_____

YES NO COMMENTS

14) If yes, what information is collected on the job card?

15) To what use is this information put? _____

16) How do you update the preventive maintenance schedules? _____

17) Are fault diagnosis sheets used by the maintenance fitter? ☐ ☐

18) If yes, who creates these diagnosis sheets? _____

19) Is there a computerised system of maintenance data manipulation and reporting? ☐ ☐

If yes, how does it operate? _____

20) How is the data interpreted? _____

21) Who interprets the data? _____

22) What reports are issued on the basis of reviewing the maintenance data? _____

23) Do you have cost recovery rates for maintenance work? ☐ ☐

If yes, does the maintenance dept calculate them? _____

24) Is there a standard costing system in use in the maintenance department? ☐ ☐25) Is there a budgetary control system in use in the maintenance department? ☐ ☐

If yes, do you set your own budgets? _____

How are they set? _____

26) Do you set performance standards for the maintenance department? ☐ ☐

If yes, how do you do this and what measurements do you use? _____

	YES	NO	COMMENTS
27) Is there any system of maintenance data feedback to other departments in the company or to the plant manufacturers?	<input type="checkbox"/>	<input type="checkbox"/>	
If yes, how is this done?			
28) Is network analysis used within the maintenance department?	<input type="checkbox"/>	<input type="checkbox"/>	
If yes, what is it used for?			
29) Do you overhaul plant?	<input type="checkbox"/>	<input type="checkbox"/>	
If yes, do you use contractors?			
30) How do you decide that a plant needs to be overhauled?			
31) Have you heard of terotechnology (before my arrival at the company)?	<input type="checkbox"/>	<input type="checkbox"/>	
If yes, what is your understanding of the word?			
32) Do you hold spare parts for plant and equipment?	<input type="checkbox"/>	<input type="checkbox"/>	
If yes, on what basis do you decide if a part should be held in inventory?			
33) Do you know how much maintenance costs your company?	<input type="checkbox"/>	<input type="checkbox"/>	
34) What practices do you think would have an adverse effect (decrease) on the expected life of plant?			
35) What practices do you think would have a favourable effect (increase) on the expected life of plant?			
36) What types of plant suffer most failures?			
37) What are the major causes of failure?			
38) What do you consider to be the most important activity carried out by your maintenance dept.?			
39) What particular aspect of maintenance gives you the biggest problems?			

40) Are any of the following techniques used by the maintenance dept.

	YES	NO
1) Critical path analysis.	<input type="checkbox"/>	<input type="checkbox"/>
2) Sensitivity analysis.	<input type="checkbox"/>	<input type="checkbox"/>
3) Prediction of plant availability.	<input type="checkbox"/>	<input type="checkbox"/>
4) Prediction of plant reliability.	<input type="checkbox"/>	<input type="checkbox"/>
5) Prediction of plant maintainability.	<input type="checkbox"/>	<input type="checkbox"/>
6) Simulation.	<input type="checkbox"/>	<input type="checkbox"/>
7) Determination of optimum inspection freq.	<input type="checkbox"/>	<input type="checkbox"/>
8) " " " overhaul "	<input type="checkbox"/>	<input type="checkbox"/>
9) " " " maint. crew sizes.	<input type="checkbox"/>	<input type="checkbox"/>
10) Cost effectiveness analysis.	<input type="checkbox"/>	<input type="checkbox"/>
11) Ratio analysis. (i.e. avail./cost.)	<input type="checkbox"/>	<input type="checkbox"/>
12) Discounted cash flow analysis.	<input type="checkbox"/>	<input type="checkbox"/>
13) Evaluation of a plant figure of merit.	<input type="checkbox"/>	<input type="checkbox"/>
14) Development of relationships between maint. cost and plant performance.	<input type="checkbox"/>	<input type="checkbox"/>
15) Linear programming.	<input type="checkbox"/>	<input type="checkbox"/>
16) Regression analysis.	<input type="checkbox"/>	<input type="checkbox"/>
17) Probability analysis.	<input type="checkbox"/>	<input type="checkbox"/>
18) Analysis of risk and uncertainty.	<input type="checkbox"/>	<input type="checkbox"/>
19) Standard costing.	<input type="checkbox"/>	<input type="checkbox"/>
20) Optimum stock holding levels.	<input type="checkbox"/>	<input type="checkbox"/>
21) Optimum re - order levels.	<input type="checkbox"/>	<input type="checkbox"/>
22) Optimum ordering quantities.	<input type="checkbox"/>	<input type="checkbox"/>
23) Determination of an optimum spares mix.	<input type="checkbox"/>	<input type="checkbox"/>
24) Evaluation of life - cycle support costs.	<input type="checkbox"/>	<input type="checkbox"/>
25) Life - cycle costing.	<input type="checkbox"/>	<input type="checkbox"/>
26) Any other techniques used by the maintenance dept.	<input type="checkbox"/>	<input type="checkbox"/>

FIELD RESEARCH: QUESTIONNAIRE No. 7.THE REMOVAL AND REPLACEMENT OF PHYSICAL ASSETS (PLANT AND EQUIPMENT ONLY)INTERVIEWEES POSITION. _____

NOTES. This questionnaire looks at the factors that could be included when applying terotechnology to the removal and replacement of plant and equipment. This does not include buildings and structures. Would you please confine your answers to those practices that you adopt with respect to major items of capital equipment. If you feel unable to answer any question accurately or feel that it is not relevant please say so rather than just giving a NO answer.

Are any of the following included when removing and replacing an item of plant?

	YES	NO	COMMENTS
1)An assessment of the residual value of the old plant?	<input type="checkbox"/>	<input type="checkbox"/>	_____
2)A review of the life-cycle costs of the old plant?	<input type="checkbox"/>	<input type="checkbox"/>	_____
3)A review of the maintenance problems associated with the old plant?	<input type="checkbox"/>	<input type="checkbox"/>	_____
4)A review of the reliability problems associated with the old plant?	<input type="checkbox"/>	<input type="checkbox"/>	_____
5)An assessment of the future market requirements for the product that is to be produced from the new plant?	<input type="checkbox"/>	<input type="checkbox"/>	_____
6)An assessment of the operational performance requirements of the new plant (speeds, feeds, capacity etc)?	<input type="checkbox"/>	<input type="checkbox"/>	_____
7)An assessment of the life-cycle that the new plant must be selected for?	<input type="checkbox"/>	<input type="checkbox"/>	_____
8)An assessment of the maintainability requirements of the new plant? (MTR, PM, CH, etc)	<input type="checkbox"/>	<input type="checkbox"/>	_____
9)An assessment of the reliability requirements of the new plant? (MTBF, system, s/s etc)	<input type="checkbox"/>	<input type="checkbox"/>	_____
10) If a new item of plant is to be purchased 'off the shelf' do you carry out any investment appraisal analysis?	<input type="checkbox"/>	<input type="checkbox"/>	_____

If yes, what method do you use?

II) Do you use network analysis to plan a removal project?

☐ ☐

I2) Do you derive a budget for the removal project?

☐ ☐

I3) Do you use contractors to remove plant?

☐ ☐

41) In which department is the interviewee situated? _____

42) At what level of management is the interviewee located? _____

43) What qualifications does the interviewee hold? _____

FIELD RESEARCH: QUESTIONNAIRE No. 8.THE FINANCIAL MANAGEMENT OF PHYSICAL ASSETS (PLANT AND EQUIPMENT ONLY)INTERVIEWEES POSITION. _____

NOTES. This questionnaire looks at the factors that could be included when applying terotechnology to the financial management of plant and equipment. Would you please confine your answers to those practices that you adopt with respect to major items of capital equipment only. This does not include buildings and structures. If you feel unable to answer any question accurately or feel it is not relevant please say so rather than just giving a NO answer.

Are any of the following included within the financial management of the company's plant and equipment?

	YES	NO	COMMENTS
I) Do you establish budgets for any of the following:-			
a) The setting of the plant specification?	<input type="checkbox"/>	<input type="checkbox"/>	
b) The design of the plant ?	<input type="checkbox"/>	<input type="checkbox"/>	
c) The cost of purchasing the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
d) The cost of installing the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
e) The cost of commissioning the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
f) The cost of operating the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
g) The cost of maintaining the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
h) The cost of removing the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
i) The cost of initial spares for the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
j) The training of production and maintenance personnel?	<input type="checkbox"/>	<input type="checkbox"/>	
k) The cost of providing management information relating to the plant throughout its life?	<input type="checkbox"/>	<input type="checkbox"/>	
2) Are actual costs recorded?	<input type="checkbox"/>	<input type="checkbox"/>	
3) If yes, do you produce any management information from them?			
If yes, what form does this take?			
4) Do you calculate the life cycle cost of the plant?	<input type="checkbox"/>	<input type="checkbox"/>	
5) What methods of investment appraisal are used to evaluate plant investment decisions?			
6) Is the accounting system computerised?	<input type="checkbox"/>	<input type="checkbox"/>	

14) Do you write a formal report regarding the problems that were encountered in the removal of the plant?

YES

NO

COMMENTS

☐☐

15) What data do you collect during the removal of a piece of plant?

16) What particular activity gives you the biggest problem when removing plant?

17) In which department is the interviewee located?

18) At what level of management is the interviewee situated?

19) What qualifications does the interviewee hold?

FIELD RESEARCH: QUESTIONNAIRE No. 9.

THE PROCUREMENT OF PHYSICAL ASSETS (PLANT AND EQUIPMENT ONLY)INTERVIEWEES POSITION. _____

NOTES. This questionnaire looks at the factors that could be included when applying terotechnology to the procurement of physical assets. This does not include buildings and structures. Would you please confine your answers, unless otherwise requested, to those practices that you adopt with respect to major items of capital equipment. If you feel unable to answer any question accurately or feel it is not relevant please say so rather than giving a NO answer.

Are any of the following included when procuring plant and equipment?

	YES	NO	COMMENTS
1) Do you include penalty clauses for late delivery of plant?	<input type="checkbox"/>	<input type="checkbox"/>	_____
2) Do you progress suppliers before the delivery date expires?	<input type="checkbox"/>	<input type="checkbox"/>	_____
3) Do you progress suppliers when delivery is overdue?	<input type="checkbox"/>	<input type="checkbox"/>	_____
4) Are any particular criteria used to select suppliers of plant?	<input type="checkbox"/>	<input type="checkbox"/>	_____
5) Is there any system of supplier vetting in operation?	<input type="checkbox"/>	<input type="checkbox"/>	_____
If yes, how does this operate?			
6) Do you carry out a receipt inspection?	<input type="checkbox"/>	<input type="checkbox"/>	_____
7) Do you calculate economic ordering quantities for large usage items?	<input type="checkbox"/>	<input type="checkbox"/>	_____
8) How do you plan your forward stock requirements?			_____
9) What do you consider to be the most important activity performed by the procurement department?			_____ _____
10) What particular activity gives you the biggest problems?			_____ _____
11) In which department is the interviewee situated?			_____ _____
12) At what level of management is the interviewee located?			_____ _____
13) What qualifications does the interviewee hold?			_____ _____

	YES	NO	COMMENTS
7) If yes, what accounting routines are on the computer?			
8) Is there a system of plant performance reporting?	<input type="checkbox"/>	<input type="checkbox"/>	
If yes, what criteria are used to measure and evaluate plant performance?			
9) If none are used what criteria would you consider to be good measures of plant performance?			
10) Do you carry out a post-completion-audit of a plant's life - cycle?	<input type="checkbox"/>	<input type="checkbox"/>	
If yes, what form does this take?			
11) Are any quantitative techniques used to predict future cost trends?	<input type="checkbox"/>	<input type="checkbox"/>	
12) When a new item of plant is being specified do you perform any financial analysis to determine the optimum specification?	<input type="checkbox"/>	<input type="checkbox"/>	
13) When a new item of plant is being designed do you perform any financial analysis to determine an optimum design configuration?	<input type="checkbox"/>	<input type="checkbox"/>	
14) What do you consider to be the most important activity carried out within the financial management of plant and equipment?			
15) What particular aspect of the financial management of plant and equipment give you the biggest problems?			
16) In which department is the interviewee located?			
17) At what level of management is the interviewee situated?			
18) What qualifications does the interviewee hold?			

APPENDIX 3

- (a) Bright's mechanisation profile
- (b) The mechanisation profiles of each company in the field research survey.

THE MECHANISATION PROFILE

In 1954 Professor J.R. Bright initiated a project to investigate the effect of automation on the management of several manufacturing organisations in the United States. As part of this research he devised the concept of a 'mechanisation profile' as a means by which the mechanisation of a production system could be assessed.

Seventeen levels of mechanisation were identified in ascending order from level 1 (hand) to level 17 when a machine would be able to "anticipate action required and adjust to provide it". The table over is taken from page 45 of his book 'Automation and Management'. Bright applied this profile technique to thirteen manufacturing companies and the resulting mechanisation profiles are given on pages 47 to 56 of his book. The profile is really only of use in assessing the level of mechanisation. Bright also identified the characteristics of 'span' and 'penetration' and these are defined on pages 40 and 41 of his book. However, for the purposes of the research presented in this dissertation only the level of mechanisation was assessed.

Initiating Control Source		Type of Machine Response		Power Source	Level Number	LEVEL OF MECHANIZATION	
From a variable in the environment		Responds with action		Mechanical (Nonmanual)			
From a control mechanism that directs a predetermined pattern of action	Fixed within the machine	Responds with signal	Selects from a limited range of possible pre-fixed actions		17		Anticipates action required and adjusts to provide it.
					16		Corrects performance while operating.
					15		Corrects performance after operating.
					14		Identifies and selects appropriate set of actions.
					13		Segregates or rejects according to measurement.
		Responds with action	Modifies own action over a wide range of variation		12		Changes speed, position, direction according to measurement signal.
					11		Records performance.
					10		Signals preselected values of measurement. (Includes error detection)
					9		Measures characteristic of work.
				8	Actuated by introduction of work piece or material.		
From man	Variable		Manual	7	Power Tool System, Remote Controlled		
				6	Power Tool, Program Control (sequence of fixed functions).		
				5	Power Tool, Fixed Cycle (single function).		
				4	Power Tool, Hand Control.		
				3	Powered Hand Tool.		
				2	Hand Tool.		
				1	Hand.		

Bright's Seventeen Levels of
Mechanisation

(taken from 'Automation and Management'
page 45)

Method of Application of the Mechanisation Profile.

One of the reasons given in Chapter 6 of this dissertation for the selection of Bright's mechanisation profile technique was that he gave detailed instructions on the way in which the profile should be used. Taking these factors into account the following method was adopted within the six companies included in this research.

1. The operation sequence was identified and listed.

This was done with the assistance of an experienced member of the production management of the company.

2. The method adopted by Bright was used to evaluate the level of mechanisation. That is, all 'primary' actions within the production process were plotted.

What was considered 'primary' was essentially a subjective assessment but was left to the production manager to determine. This method was used on a consistent basis throughout the six companies.

3. The mechanisation profile was then plotted and a simple average of all the primary actions was computed. This 'simple average level of mechanisation' was then used as the basis for the subsequent comparative analyses of the terotechnology practices found in use in the six companies.

The resulting mechanisation profiles for companies A, B, C, D, E and F are shown in this appendix.

The Mechanisation Profiles.

Company A. This company operated two equally important production lines for the manufacture of its product lines. Consequently, in order to assess the level of mechanisation of the company's production system, both production lines were examined and an average of the two profiles was taken. For production line 1, the average level of mechanisation was 4.76 and for line 2, the average was 5.61. Therefore, the overall average was 5.2.

Company B. The same situation was found in this company as was found in company A. Therefore two profiles were plotted. The first averaged 3.45 and the second 3.55. Therefore the overall average was 3.5.

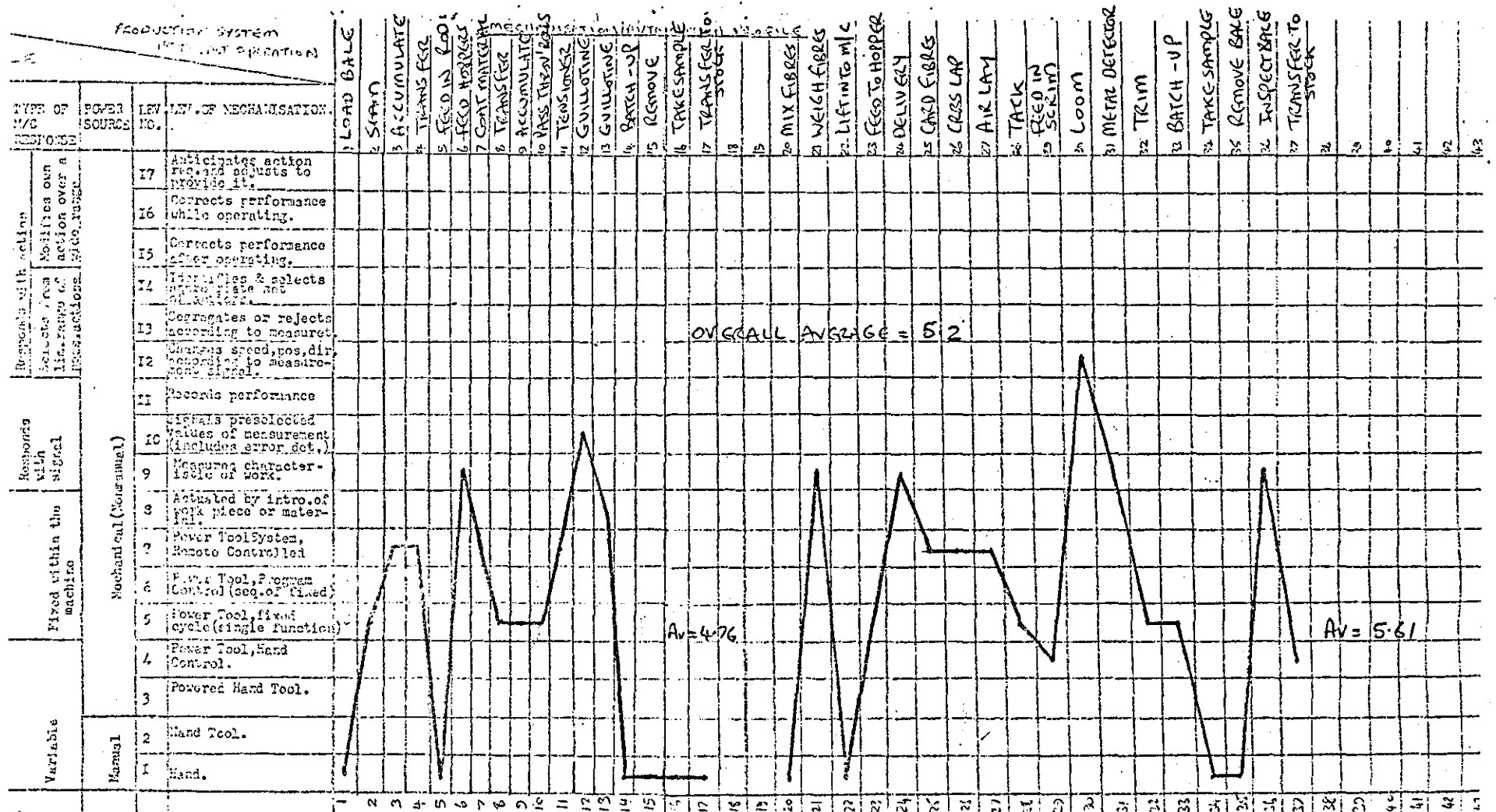
Company C. This company operated a single production line, as shown in profile C. The overall average level of mechanisation was found to be 3.8.

Company D. This company operated three production lines all considered of equal importance. Therefore, three profiles were plotted with averages of 4.6, 1.4 and 3.5 with the overall average being 3.2.

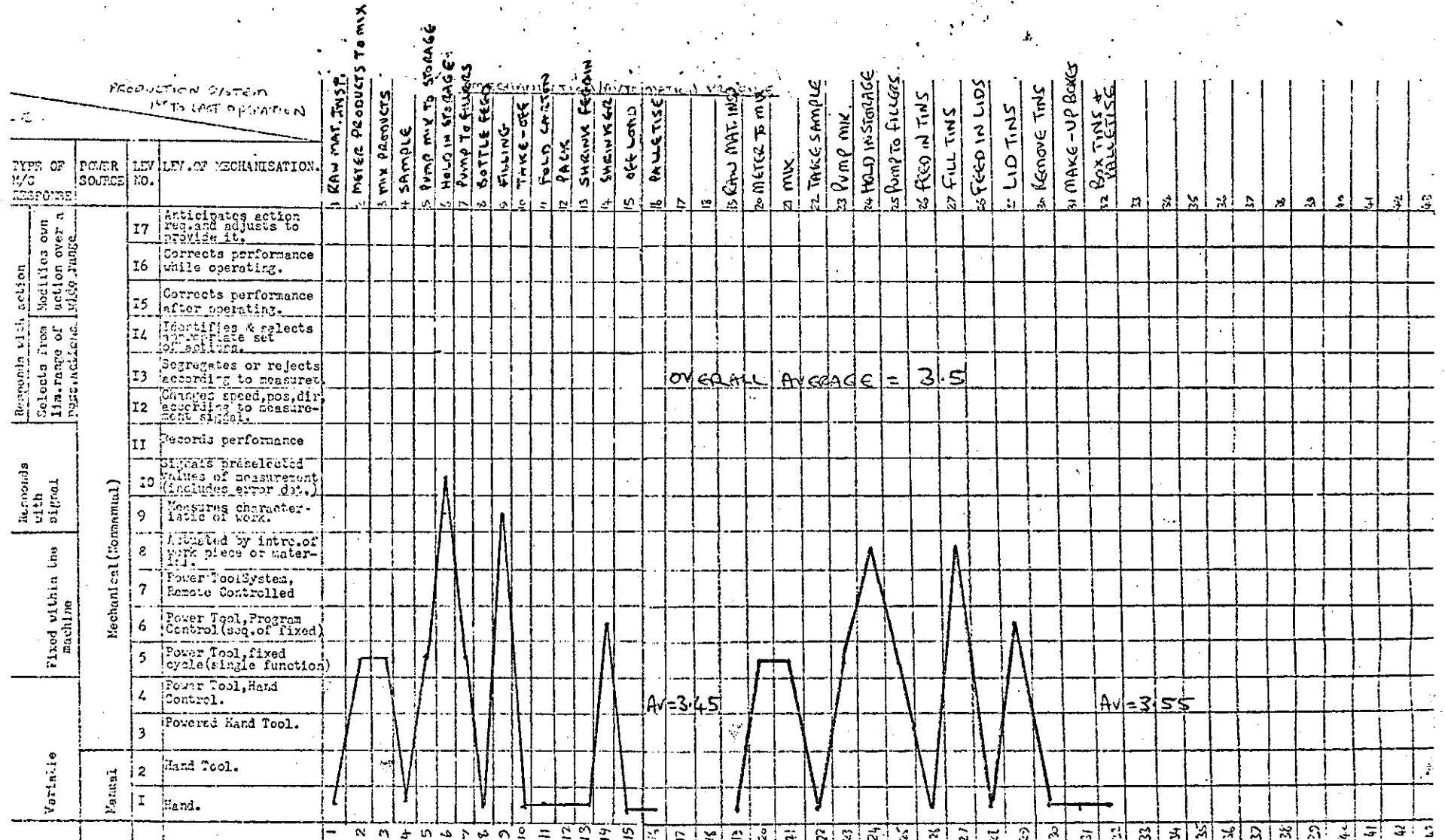
Company E. This company operated a single production line, as shown in profile E. The overall average level of mechanisation was found to be 7.4.

Company F. This company operated a single production line, as shown in profile F, giving an overall average of 10.3.

MECHANISATION PROFILE: A.



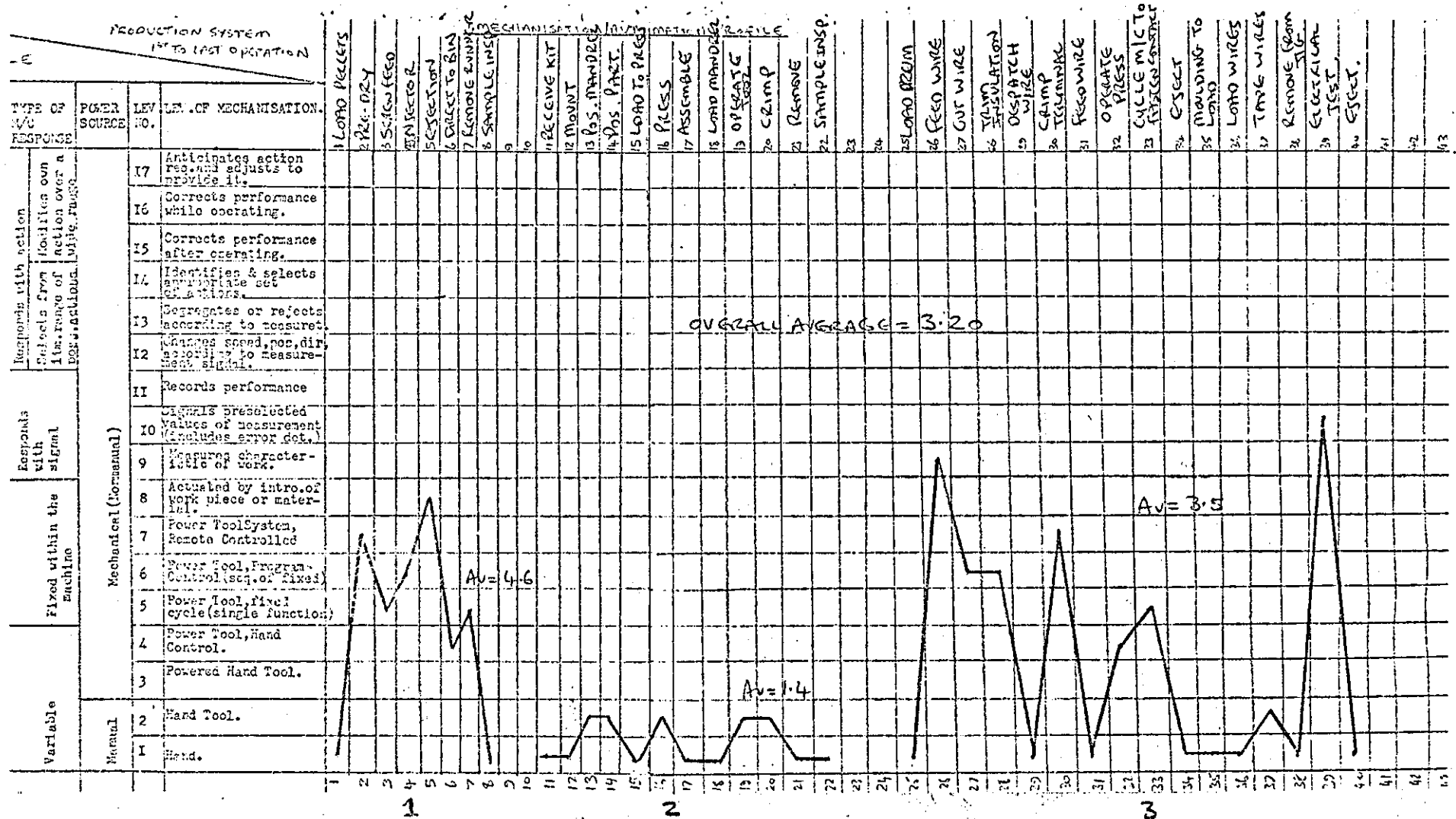
MECHANISATION PROFILE: B.



MECHANISATION PROFILE: COMPANY C

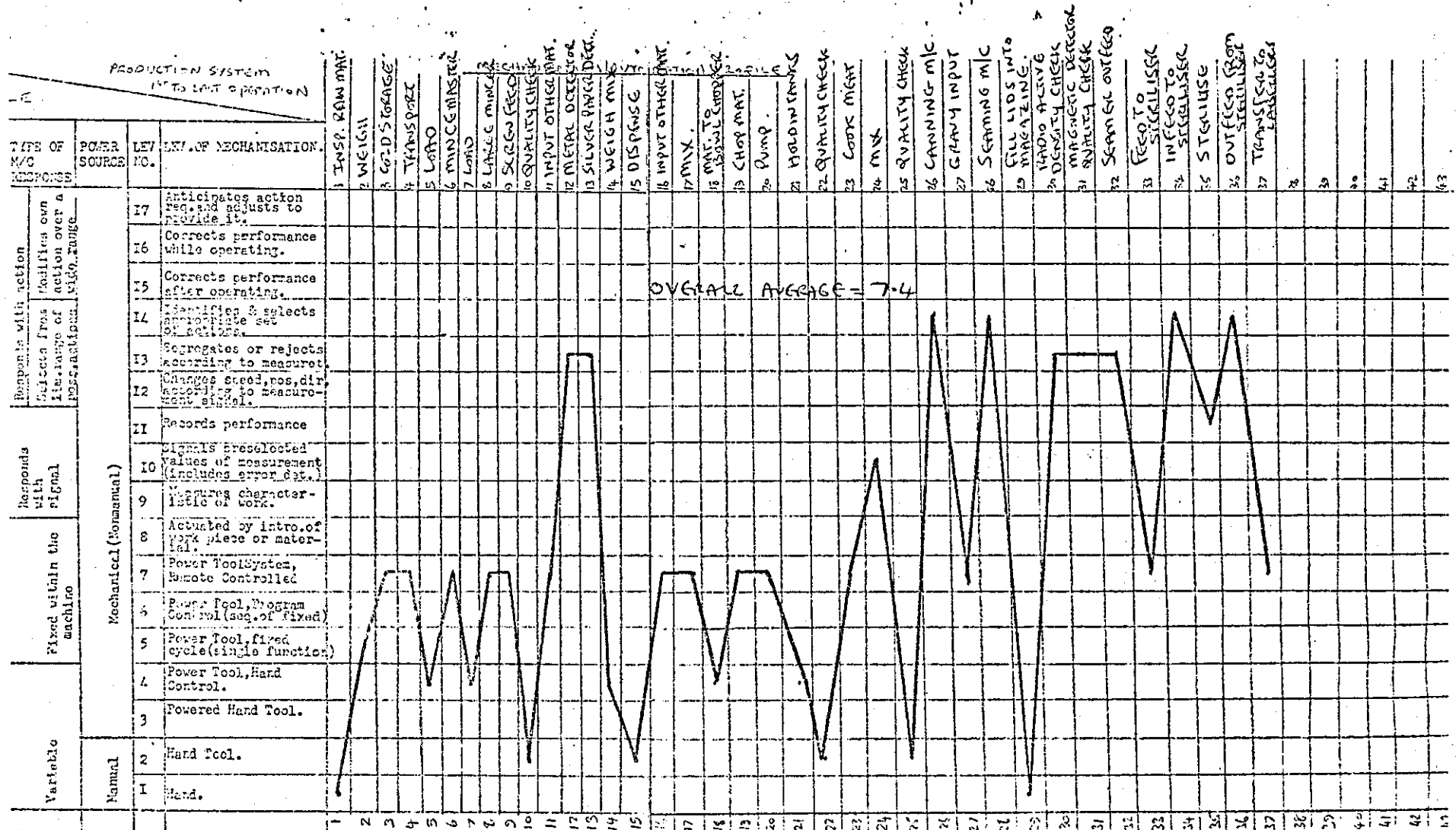


MECHANISATION PROFILE: D.

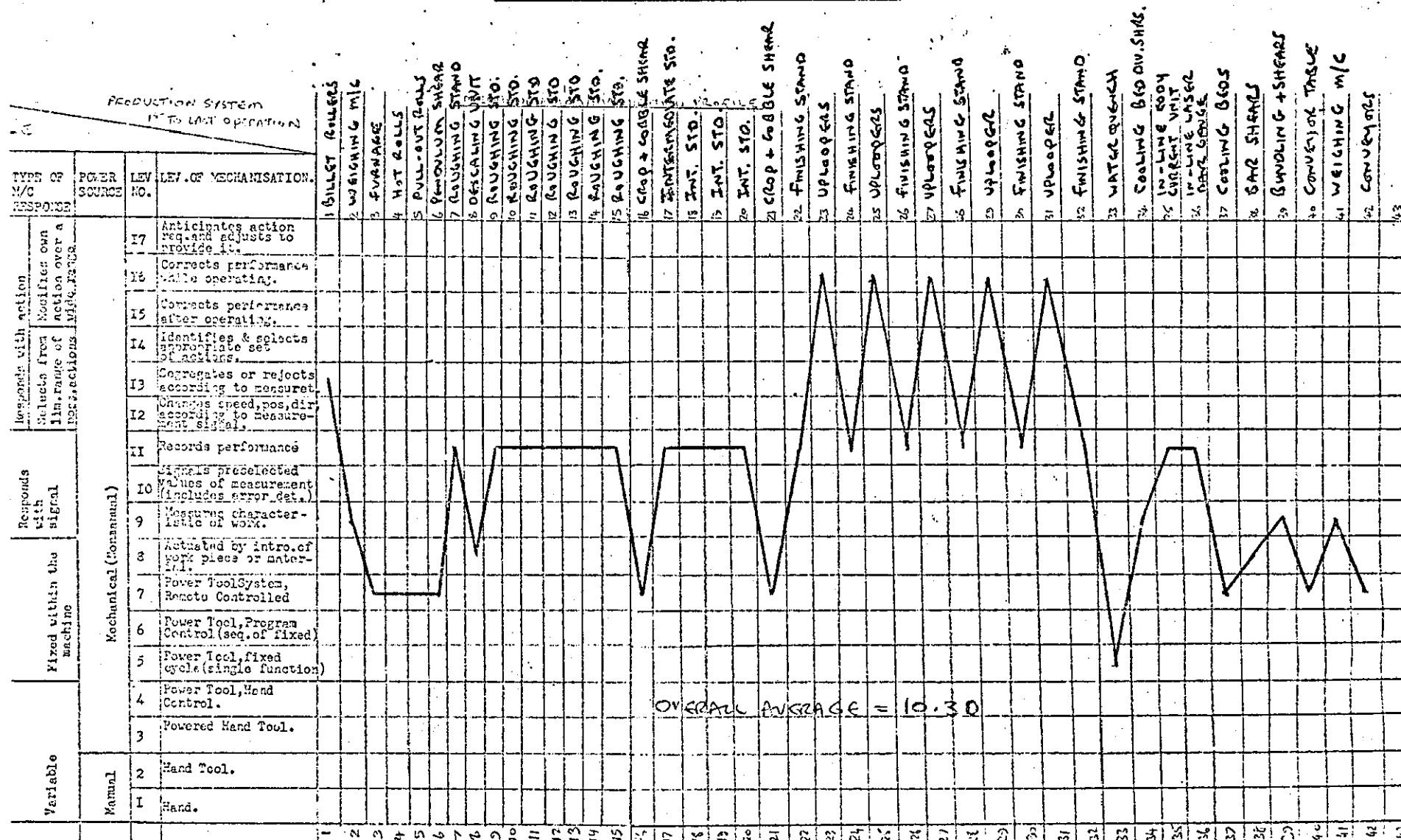


MECHANISATION PROFILES: COMPANY D.

MECHANISATION PROFILE : E.



MECHANISATION PROFILE : A.



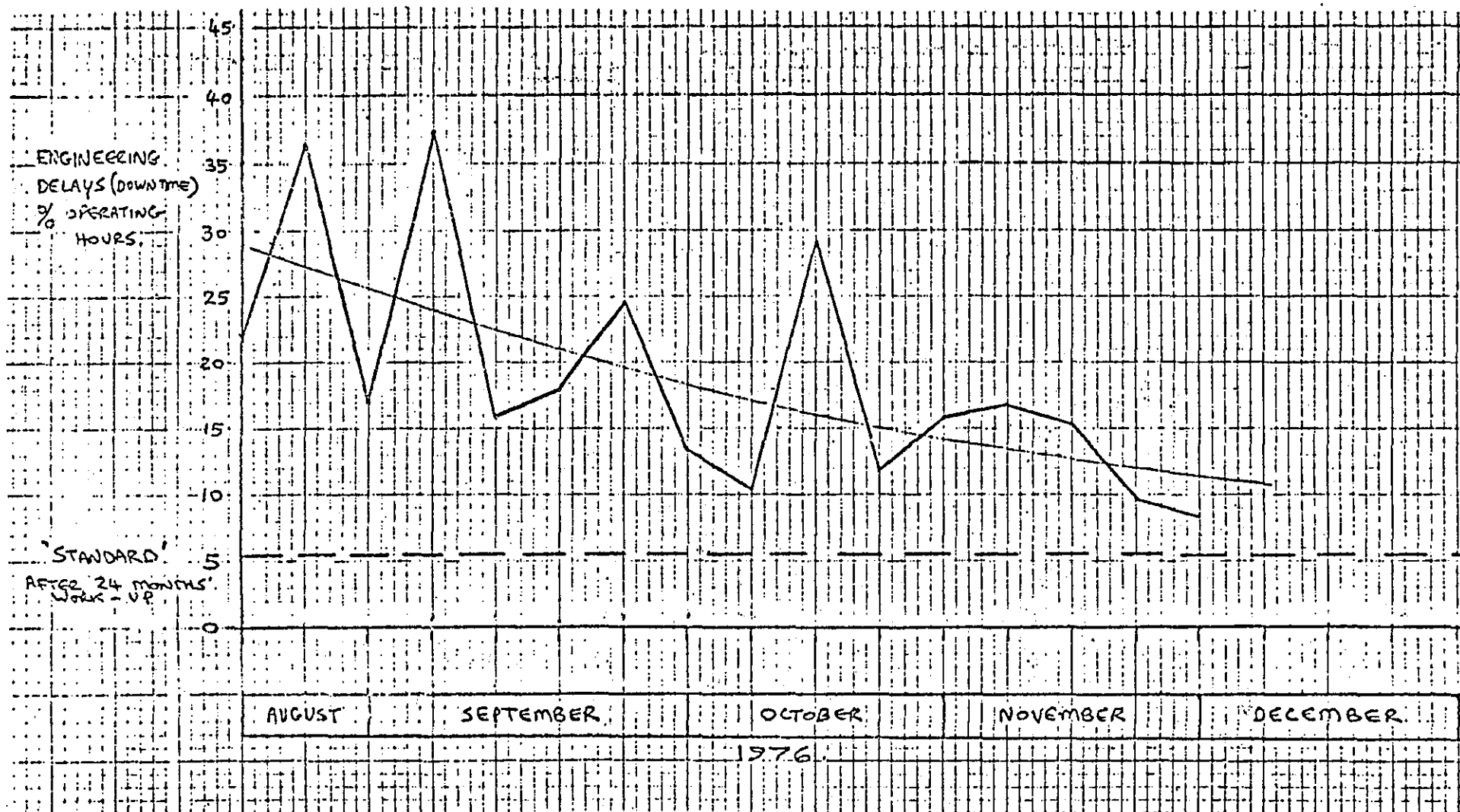
MECHANISATION PROFILE : COMPANY F.

APPENDIX 4

Examples of documentation collected

Company F

An example of the type of documentation
used to measure performance.



Engineering Delays(downtime)as a percentage of
Operating Hours.

Company A
An example of the type of documentation
used to measure performance.

	Team Working Hours	Research	F A C T O R Y			% Idle Hours	ANALYSIS OF IDLE HOURS					STANDARDS \$
			Working Hours	Prod. Hours	Idle Hours		Prep. & Cleaning	Mechan. Break- downs.	Supply Failures	Recounts and Rewash	Meal Breaks	Idle Hours Allowed in Costs
PLANT 1	571.00	3.00	568.00	430.75	137.25	24	82.00	5.00	0.50	28.50	21.25	11.2
PLANT 2	264.75	-	264.75	233.00	31.75	12	29.75	0.75	1.25	-	-	12.6
PLANT 4												
PLANT 5	306.75	15.50	291.25	263.75	27.50	9	20.50	4.25	2.75	-	-	12.0
PLANT 7	200.00	-	200.00	140.00	60.00	30	25.00	1.25	-	33.75	-	7.1
PLANT 8	476.00	-	476.00	404.25	71.75	15	40.25	12.00	0.25	2.25	17.00	10.7
PLANT 10	367.50	2.25	365.25	310.25	55.00	15	41.00	6.25	1.00	-	6.75	8.3
PLANT 11	632.00	9.00	623.00	477.75	145.25	23	110.50	32.50	1.50	-	0.75	7.2

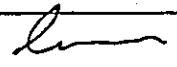
MAINTENANCE RECORD SHEET

SHIFT		DATE:-		
E	DAYS	TWO SHIFTS		
A	Blue	TIME		TRADE
B	Green	Morning	Mech.	
C	Black	Afternoon	Elec.	
D	Red	Night	SERV.	

[illegible]

Company E

PLANNED MAINTENANCE TASK SHEET

Job Charge No.	Job Ref.	Job Description	Allowed Hours	Date Completed	Craftmans Signature
17542419	001	INSPECT CROP & COBBLE SHEAR DRIVE MOTOR 12 V	2.00	2/12/76	

Op. No.	Task No.	Operation/Task Description	Remarks/Details of Work Done	Plant History ✓/X
1		DRIVE MOTOR		
	1	CHECK FOR SECURITY, WEAR, DAMAGE		
	2	CHECK FOR CLEANLINESS, OVERHATING		
	3	CHECK WIRING, TERMINATIONS		
	4	CHECK BRUSHES, BRUSHGEAR, COMMUTATOR		
	5	CHANGE OR ADJUST BRUSHES & BRUSHGEAR		
	6	CHECK COUPLING		
	7	CHECK BEARINGS		
2		TACHO GENERATOR		
	1	REPEAT TASKS 1 TO 7 OPEATION 1		
3		COOLING MOTOR		
	1	CHECK FOR SECURITY, WEAR, DAMAGE		
	2	CHECK FOR CLEANLINESS, OVERHATING		
	3	CHECK WIRING & TERMINATIONS		
	4	CHECK BEARINGS		
4		COOLING MOTOR FILTER		
	1	CHECK FOR SECURITY, WEAR, DAMAGE		
	2	CHECK FOR CLEANLINESS		

Completed.

Filter Changed.

Company F

In-company data feed-back report
Company E.

PLANT SERVICES DEPARTMENT

DEPARTMENT:-

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BI-MONTHLY REPORT PERIODS

MANAGER:-

1. Personnel (Vacancies, transfers, recruitment, promotions).

2. Training (Courses completed, familiarisation with new equipment)

3. Developments in systems and control procedures

4. Noteworthy plant modifications

5. Projects Status of maintenance preparation for forthcoming projects, progress on installed projects.

6. General comments (difficulties, successes, techniques).

7. Equipment causing concern (investigations, action plans) - Area Engineer.
On major breakdowns, by Area, and delay times - Shift Engineer.

APPENDIX 5

The printout from the MUIREG programme

Variable Identification

The variables inputted to the correlation programme were given the following identifications:-

x = average level of production system mechanisation.

y_1 = the percentage application of terotechnological practices found in use when specifying plant

y_2 = as y_1 but for design practice

y_3 = as y_1 but for financial evaluation practices

y_4 = as y_1 but for procurement practices.

y_5 = as y_1 but for installation practices.

y_6 = as y_1 but for commissioning practices.

y_7 = as y_1 but for maintenance practices.

y_8 = as y_1 but for removal practices.

y_9 = the overall average percentage application of terotechnological practices found in each company.

VAR OBS = 1,2,3,4,5,6 these refer to each company from company A to F respectively.

The data were taken from Table 20 page 147.

*** M U L R E G ***

CORRELATION ANALYSIS FOR INDUSTRIAL RESEARCH DATA.

MULTIPLE LINEAR REGRESSION ANALYSIS

	X	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇	Y ₈	Y ₉
VAR	1	2	3	4	5	6	7	8	9	10
OBS										
1	3.200	13.000	6.500	14.000	33.000	36.000	50.000	31.000	36.000	29.000
2	3.500	40.000	20.000	43.000	33.000	45.000	36.000	31.000	36.000	35.000
3	3.800	20.000	20.000	28.000	50.000	72.000	72.000	37.000	45.000	42.000
4	5.200	47.000	20.000	28.000	50.000	72.000	72.000	44.000	45.000	47.000
5	7.400	60.000	40.000	72.000	67.000	100.000	86.000	75.000	82.000	72.000
6	10.300	80.000	73.000	72.000	67.000	100.000	86.000	94.000	82.000	83.000

CORRELATION MATRIX

COL	X	Y ₁	Y ₂	Y ₃	Y ₄	Y ₅	Y ₆	Y ₇
ROW	1	2	3	4	5	6	7	8
1	1.000000000							
Y ₁ 2	.927562642	1.000000000						
Y ₂ 3	.967916558	.909885994	1.000000000					
Y ₃ 4	.855991808	.894794260	.872709290	1.000000000				
Y ₄ 5	.881911735	.779858816	.817171363	.797818267	1.000000000			
Y ₅ 6	.876027710	.801069405	.820292441	.816913568	.993762218	1.000000000		
Y ₆ 7	.778797369	.611591602	.679223070	.589375381	.956264162	.933399209	1.000000000	
Y ₇ 8	.990325337	.898890927	.953282637	.884699105	.909002003	.891909839	.804066755	1.000000000
Y ₈ 9	.930248867	.836934754	.878548422	.908921809	.943436755	.926361926	.838320124	.969793401
	1.000000000							
Y ₉ 10	.977572618	.911607974	.942563192	.906221536	.948465706	.943622869	.839997230	.988864323
	.976617835	1.000000000						

APPENDIX 6

- (a) The letter of introduction for the postal survey of life-cycle costing practitioners.
- (b) The life-cycle costing questionnaire

26th July 1976

Dear Sir

Research into Life-Cycle Costing

I am carrying out research into the theory and practice of life-cycle costing (L C C). Since you have worthwhile experience in this field I would be very grateful if you could find time to assist me by answering the enclosed questionnaire. This information is intended to provide some insight into the basic knowledge and expertise required for the application of L C C in practical situations.

All information you provide will, of course, be treated in the strictest confidence and no publication of the information will proceed without your prior written approval. The research is being sponsored by the Science Research Council of Great Britain.

Could you please return the completed questionnaire in the envelope provided. The international reply coupon is also enclosed to enable you to obtain a refund of the postage charge.

With many thanks for your help.

Yours faithfully

Tom Husband.

Professor T M Husband

LIFE - CYCLE COSTING QUESTIONNAIRE.

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1) Do you carry out Life Cycle costing analyses on all capital investment projects and feasibility studies?

YES

NO

2) If NO, on what basis do you select projects that will be subjected to L.C.C. analyses?

3) If NO, on what % of projects do you carry out an L.C.C. analysis?

4) At what stage in the life of the project is L.C.C. analysis carried out?

a) The specification stage

b) The design stage

c) The procurement stage

d) The operation and support stage

e) At any other stage in the life - cycle

(please specify)

5) Do you employ L.C.C. analysts who work solely on Life-Cycle Costing studies?

YES

NO

6) If NO, on what other work are they employed?

7) What academic qualifications do you require of an L.C.C. analyst?

8) What industrial/commercial/other experience do you require of an L.C.C. analyst?

9) Do you feel that L.C.C. analysts should be accountants or economists or engineers or technologists or O.R. scientists or some combination of these? Please specify and comment on your view of the ideal combination of knowledge and skill that would best serve the needs of an L.C.C. analyst / team.

10) At what academic level do you think it is appropriate to introduce the teaching of Life-Cycle Costing?

- a) Bachelors degree
- b) Masters degree
- c) Post-experience short courses
- d) Professional accounting examinations
- e) Doctoral research only
- f) Any other level (please specify)

These courses are, of course, not necessarily mutually exclusive. Hence, would you please expand on the reasons for your choice. If you do not feel strongly towards any one level of course then please indicate your order of preference by ranking from first to last.

11) Do you have a 'data bank' of information on reliability/maintainability/cost - estimating relationships/ cost factors and functions etc. that the L.C.C. analyst employs?

YES

NO

12) If NO to question (11), how does the L.C.C. analyst collate the necessary information and data to perform the L.C.C. analysis?

13) If YES to question (11) is the data-bank created and managed using a computer or, manually-based creating, updating, storing and retrieval system?

a) computer

b) manual

c) mixture (please specify what is computerised)

14) Do you carry out Post-Completion-Audits on the capital projects where Life-Cycle Costing was carried out?

YES

NO

15) If YES at what stage in the life-cycle is the Post-Completion-Audit carried out?

first 2 years

2 to 4 years

4 to 6 years

6 to 8 years

8 to 10 years

any other time (please specify)

16) Do you use D.C.F. within an L.C.C. analysis?

YES

NO

17) If YES what discount rate do you use and why?

18) Do you use any other forms or investment appraisal techniques in conjunction with L.C.C.? (i.e. payback period, rate of return, N.P.V. etc.).

19) Do you take inflation into account in an L.C.C. analysis?

YES

NO

20) If YES which costs do you inflate and what % rate or other basis do you use to escalate costs?

21) Do you use risk and sensitivity analysis within the L.C.C. analysis?

YES

NO

22) Do you use cost-estimating relationships (C.E.R.s) within the L.C.C. analysis?

YES

NO

23) If YES which costs do you calculate using C.E.R.s?

24) How are the C.E.R.s derived?

25) Do you produce control information during the operational phase in the
life - cycle?

YES

NO

26) If YES what form does this take and to what use is it put?

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27) Do you use cost effectiveness criteria (i.e. figures of merit, ratios etc.)
in association with an L.C.C. Analysis?

YES

NO

28) If YES please give some examples of the types of cost effectiveness criteria
you employ.

29) On what basis do you make the decision to select a particular project
submission?

- a) Minimum Life-Cycle Cost
- b) Maximum Cost - Effectiveness
- c) Maximum Life - Cycle profit
- d) Other (please specify)

If more than one method is used please specify the % distribution and the
reasons for employing different criteria.

30) Do you carry out 'trade-off' studies?

YES

NO

31) If YES which parameters and/or costs do you trade-off?

32) If YES how are the trade-off studies carried out? (i.e. do you use computer simulation, manual, analysis, system/subsystem/component level 'trade-offs' etc.)

33) Do you use a computerised model for evaluating L.C.C.?

YES

NO

34) If YES is this a 'number crunching' computer program for cost summations and calculations or is it a simulation program which enables optimisation studies to be carried out?

35) Would you be kind enough to sketch the organisation structure for the department within which Life - Cycle Costing analyses are carried out. Please indicate the breakdown of any special responsibilities carried out by members of the department. Please indicate the line of command from your department to the senior levels of management within the organisation. (titles should be given, not individual's names).

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36) Do you have any projects in which Life-Cycle Costing is a contractual requirement?

YES

NO

If YES what % are these of your total L.C.C. analyses?

- 37) Please make any further comments on the theory and practice of Life-Cycle Costing that you feel are important to the successful application of the technique. 328

Thank you very much indeed for your valuable cooperation and time. When completed would you please return the questionnaire in the stamped addressed envelope provided.

NOTE: ACKNOWLEDGEMENTS. If you would prefer your response to remain anonymous please tick the box. ☐

Otherwise please give your name, position, qualifications, company and address in order that a full acknowledgement can be made.

APPENDIX 7

The historical data collected from
company E

DATA COLLECTION SHEET 1

PLANT A+B: MAINTENANCE MAN HOURS PER YEAR

YEAR	PREVENTIVE		BREAKDOWN	
	PLANT A	PLANT B	PLANT A	PLANT B
1970	467	—	314	—
1971	551	391	240	208
1972	1,331	1,453	527	884
1973	1,039	2,287	295	2,006
1974	1,726	1,548	353	2,643
1975	1,694	1,560	400	539

DATA COLLECTION SHEET 2.

PLANT A + B MAINTENANCE MATERIALS
COSTS PER YEAR.

YEAR	MATERIALS EXPENDITURE £'s	
	PLANT A	PLANT B
1970	1,700	-
1971	1,287	252
1972	8,955	9,542
1973	10,455	7,445
1974	10,582	37,882
1975	-	36,396

APPENDIX 8

The printout from the MULREG programme
for the derivation of the LCC cost-
estimating relationships.

*** M U L R E G ***

MULTIPLE LINEAR REGRESSION ANALYSIS

VAR	1	2	3	4	5
CBS					
1	1.000	391.000	208.000	1700.000	252.000
2	2.000	1453.000	834.000	1287.000	9542.000
3	3.000	2287.000	2006.000	8955.000	7445.000
4	4.000	1548.000	2643.000	10445.000	37882.000
5	5.000	1560.000	539.000	10582.000	36396.000

DATA CODES

- 1 = PLANT AGE.
- 2 = PLANT B PREV. MAINT. MAN HRS.
- 3 = PLANT B BREAKDOWN MAN. HRS.
- 4 = PLANT A MAINT. MATLS. COSTS
- 5 = PLANT B MAINT. MATLS COSTS.

CORRELATION MATRIX

COL	1	2	3	4	5
ROW					
1	1.000000000				
2	.566620667	1.000000000			
3	.371931704	.641690221	1.000000000		
4	.905361185	.623342175	.586679569	1.000000000	
5	.906895318	.291966727	.390669102	.778162845	1.000000000

SELECTION INDEP 1 DEP 5
 PLANT B MAINTENANCE MATERIALS C.E.R.

VAR	MEAN	STANDARD DEVIATION	CORRELATION X Y	REGRESSION COEFFICIENT	STD ERROR REG COEFF	COMPUTED T VALUE
1	3.000000000	1.581138830	.906895818	10062.799999000	2699.285936400	3.727948886

DEPENDENT

5	18303.400000000	17544.114222000
---	-----------------	-----------------

INTERCEPT	-11884.999999000
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MULT CORRELATION	.906895818
------------------	------------

STD ERROR ESTIMATE	8535.891615100
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ANOVAR	DF	SUM OF SQUARES	MEAN SQUARES	F VALUE
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REGRESSION	1	1.0125994383e09	1.0125994383e09	13.397602896
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RESIDUALS	3	218584337.000000000	72861445.666000000
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TOTAL	4	1.2311837753e09
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SELECTION INDEP 1 DEP 2 = PLANT B. PREVENTIVE MAINTENANCE LABOUR C.E.R.

VAR	MEAN	STANDARD DEVIATION	CORRELATION X Y	REGRESSION COEFFICIENT	STD ERROR REG COEFF	COMPUTED T VALUE
1	3.600000000	1.581138330	.566620667	243.299999990	204.270237670	1.191069255

DEPENDENT

2 1447.800000000 678.921713610

INTERCEPT 717.900000010

MULT CORRELATION .566620667

STD ERROR ESTIMATE 645.959

SELECTION INDEP 1 DEP 3

PLANT B. BREAKDOWN MAINTENANCE LABOUR C.E.R.

VAR	MEAN	STANDARD DEVIATION	CORRELATION X Y	REGRESSION COEFFICIENT	STD ERROR REG COEFF	COMPUTED T VALUE
1	3.000000000	1.581138830	.371931704	242.099999990	348.851539560	.693991490

DEPENDENT

3 1256.000000000 1029.204304300

INTERCEPT 529.700000020

MULT CORRELATION .371931704

STD ERROR ESTIMATE 1103.165430300

SELECTION	INDEP	1	DEP	4	PLANT A MAINTENANCE MATERIALS CRT. C.C.R.		
VAR	MEAN	STANDARD DEVIATION	CORRELATION X Y		REGRESSION COEFFICIENT	STD ERROR REG COEFF	COMPUTED T VALUE
1	3.00000000	1.581138830	.905361184		2692.199999900	729.034576200	3.692828965
DEPENDENT							
4	6593.800000000	4701.705828600					
INTERCEPT		-1482.799999900					
MULT CORRELATION		.905361184					
STD ERROR ESTIMATE		2305.409753800					
ANOVAR	DF	SUM OF SQUARES					

SELECTION INDEP 1 DEP 2

PLANT A PREVENTIVE MAINTENANCE LABOUR C.E.R.

VAR	MEAN	STANDARD DEVIATION	CORRELATION X Y	REGRESSION COEFFICIENT	STD ERROR REG COEFF	COMPUTED T VALUE
1	3.500000000	1.370828693	.915238649	267.657142850	58.914863060	4.543117457

DEPENDENT

2	1134.666666600	547.114856930
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INTERCEPT 197.866666660

MULT CORRELATION .915238649

STD ERROR ESTIMATE 246.453554440

ANOVAR	DF	SUM OF SQUARES	MEAN SQUARES	F VALUE
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REGRESSION	1	1253706.057100000	1253706.057100000	20.639916229
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RESIDUALS	4	242967.276250000	60741.819062000
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TOTAL	5	1496673.333300000
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SELECTION INDEP 1 DEP 3

PLANT A BREAKDOWN MAINTENANCE LABOUR C.E.R.

VAR	MEAN	STANDARD DEVIATION	CORRELATION X - Y	REGRESSION COEFFICIENT	STD. ERROR REG COEFF	COMPUTED T VALUE
1	3.500000000	1.370828693	.286698083	15.342857143	25.634596097	.598521509

DEPENDENT

3	354.833333330	100.118762610
---	---------------	---------------

INTERCEPT 301.133333330

MULT CORRELATION .286698083

STD. ERROR ESTIMATE 107.237209250

ANOVAR	DF	SUM OF SQUARES	MEAN SQUARES	F VALUE
REGRESSION	1	4119.557142600	4119.557142600	.358227996
RESIDUALS	4	45999.276192000	11499.819048000	
TOTAL	5	50118.833335000		

SOFTWARE GROUP
W A N G - EUROPE

APPENDIX 9

The working sheets for the estimation
of the life-cycle cost.

Life-Cycle Costing Model: Data Sheet LCC 0.'One-Time' Cost Inputs

Cost Element	Plant A	Plant B
Initial Engineering and Development Costs	16,000	8,000
Purchase Price	700,000	550,000
Delivery Costs	10,000	8,500
Initial Spares	15,000	25,000
Training/Information/Manuals etc. Costs	7,000	2,000
Installation Costs	14,500	12,500
Commissioning Costs	28,650	17,500
Removal Costs (END OF LIFE)	50,000	50,000
'One-Time' Contingency Costs	5,000	4,000
Overhaul Costs ($\frac{1}{2}$ LIFE)	50,000	80,000
Management Costs	12,000	5,000
Totals	908,150	762,500

PLANT A

Life - Cycle Costing Model: Data Sheet LCC I.Preventive Maintenance.

Plant age	Estimated Prev. Maint. Hours	Prev. Maint. Cost Factor £/hr.	Inflation Factors	Prev. Maint. Labour Cost	Discount Factors	Total P.M. Discounted Labour Cost	Manpower Reqsnts.
1	466	9.66	—	4,501	0.909	4,091	0.28
2	734	10.14	1.05	7,445	0.826	6,149	0.43
3	1,002	10.64	"	10,661	0.751	8,006	0.59
4	1,270	11.19	"	14,211	0.683	9,706	0.75
5	1,538	11.75	"	18,071	0.621	11,222	0.91
6	1,806	12.33	"	22,267	0.564	12,558	1.10
7	2,074	12.94	"	26,837	0.513	13,767	1.23
8	2,342	13.59	"	31,829	0.467	14,864	1.39
9	2,610	14.27	"	37,245	0.424	15,791	1.54
10	2,878	14.98	"	43,112	0.386	16,641	1.70
11	3,146	15.74	"	49,518	0.350	17,331	1.86
12	3,414	16.52	"	56,399	0.319	17,991	2.02
Totals	23,280			322,096		148,117	

Cost Estimating Relationship(CER)=

Discount Rate

= 10%

Standard Labour Hours/year

= 1,690

PLANT A.

Life-Cycle Costing Model: Data Sheet LCC 2Breakdown Maintenance.

Plant age	Estimated Breakdown Maint. Hours	Breakdown Maint. Lab. Cost factor £/hr	Inflation Factors	Breakdown Maint. Lab. Cost	Discount Factors	Total B.M. Discounted Labour Cost	Manpower Reqs.
I	316	10.07	-	3,182	0.909	2,892	0.18
2	332	10.57	1.05	3,509	0.826	2,898	0.19
3	347	11.10	"	3,852	0.751	2,893	0.20
4	362	11.66	"	4,221	0.683	2,883	0.21
5	378	12.24	"	4,627	0.621	2,873	0.22
6	393	12.85	"	5,050	0.564	2,853	0.23
7	409	13.49	"	5,517	0.513	2,830	0.24
8	424	14.17	"	6,008	0.467	2,806	0.25
9	440	14.87	"	6,530	0.424	2,766	0.26
10	455	15.62	"	7,107	0.386	2,743	0.27
11	470	16.40	"	7,708	0.350	2,697	0.28
12	486	17.22	"	8,369	0.319	2,670	0.29
Totals	4,812			65,680		33,860	

Cost Estimating Relationship(CER)=

Discount Rate

= 10%

Standard Labour Hours/year

= 1,690

PLANT A.

Life - Cycle Costing Model: Data Sheet LCC 3.Maintenance Materials Costs/LogisticsCosts.

Plant age	Estimated Maintenance Materials Costs	Discount Factors	Total Discounted Maintenance Materials Costs	Maintenance Logistics Costs.	Discounted Logistics Costs	Total Maintenance Materials and Logistics Costs. (Discounted)
I	1,210	0.909	1,099	121	109	1,208
2	3,902	0.826	3,222	390	326	3,588
3	6,594	0.751	4,952	659	495	5,447
4	9,286	0.683	6,342	928	634	6,976
5	11,978	0.621	7,438	1,197	743	8,181
6	14,670	0.564	8,273	1,467	827	9,100
7	17,362	0.513	8,906	1,736	890	9,796
8	20,054	0.467	9,365	2,005	936	10,301
9	22,746	0.424	9,644	2,274	964	10,609
10	25,438	0.386	9,819	2,543	981	10,800
II	28,130	0.350	9,845	2,813	984	10,829
12	30,822	0.313	9,832	3,082	983	10,815
Totals	192,192		88,777	19,219	8877	97,654

Cost Estimating Relationship(CER)=

Discount Rate

= 10%

Logistics Costs Estimating Relationship(CER)= 10% of MATERIAL COST.

PLANT B

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Life - Cycle Costing Model: Data Sheet LCC I.

Preventive Maintenance.

Plant age	Estimated Prev. Maint. Hours	Prev. Maint. Cost Factor £/hr.	Inflation Factors	Prev. Maint. Labour Cost	Discount Factors	Total P.M. Discounted Labour Cost	Manpower Reqs.
1	961	9.46		9,283	0.909	8,438	0.57
2	1,204	10.14	1.05	12,208	0.826	10,083	0.71
3	1,447	10.64	"	15,396	0.751	11,562	0.86
4	1,690	11.19	"	18,911	0.683	12,916	1.00
5	1,933	11.75	"	22,712	0.621	14,014	1.14
6	2,176	12.33	"	26,830	0.564	15,132	1.29
7	2,419	12.94	"	31,310	0.513	16,062	1.43
8	2,662	13.53	"	36,176	0.467	16,894	1.57
9	2,905	14.27	"	41,454	0.424	17,576	1.72
10	3,148	14.98	"	47,157	0.386	18,202	1.86
11	3,391	15.74	"	53,374	0.350	18,680	2.00
12	3,634	16.52	"	60,033	0.319	19,150	2.15
Totals	27,570			374,844		178,889	

Cost Estimating Relationship(CER)=

Discount Rate

= 10%

Standard Labour Hours/year

= 1,690

PLANT B

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Life-Cycle Costing Model: Data Sheet LCC 2

Breakdown Maintenance.

Plant age	Estimated Breakdown Maint. Hours	Breakdown Maint. Lab. Cost factor £/hr	Inflation Factors	Breakdown Maint. Lab. Cost	Discount Factors	Total B.M. Discounted Labour Cost	Manpower Reqs.
I	772	10.07	-	7774	0.909	7066	0.45
2	1014	10.57	1.05	10718	0.826	8853	0.60
3	1256	11.10	"	13941	0.751	10469	0.74
4	1428	11.66	"	17467	0.683	11929	0.88
5	1740	12.24	"	21297	0.621	13225	1.03
6	1982	12.85	"	25467	0.564	14364	1.17
7	2224	13.49	"	30001	0.513	15390	1.32
8	2466	14.17	"	34943	0.467	16318	1.46
9	2708	14.87	"	40282	0.424	17079	1.60
10	2950	15.62	"	46079	0.386	17786	1.75
11	3192	16.40	"	52348	0.350	18321	1.88
12	3434	17.22	"	59133	0.319	18863	2.03
Totals	25,236			359,426		169,663	

Cost Estimating Relationship(CER)=

Discount Rate

= 10%

Standard Labour Hours/year

= 1,690

PLANT B

Life - Cycle Costing Model: Data Sheet LCC 3.Maintenance Materials Costs/Logistics Costs.

Plant age	Estimated Maintenance Materials Costs	Discount Factors	Total Discounted Maintenance Materials Costs	Maintenance Logistics Costs.	Discounted Logistics Costs	Total Maintenance Materials and Logistics Costs. (DISCOUNTED)
I	1,822	0.909	1,656	182	165	1821
2	8,240	0.826	6,806	824	680	7,486
3	18,302	0.751	13,744	1830	1374	15,118
4	28,364	0.683	19,372	2836	1937	21,309
5	38,426	0.621	23,862	3842	2386	26,248
6	48,488	0.564	27,347	4848	2734	30,081
7	58,550	0.513	30,036	5855	3,003	33,039
8	68,162	0.467	31,831	6816	3,183	35,014
9	78,674	0.424	33,357	7867	3335	36,692
10	88,740	0.386	34,253	8874	3,425	37,678
11	98,998	0.350	34,649	9899	3,465	38,114
12	108,860	0.319	34,726	10,886	3,473	38,199
Totals	645,625		291,639	64,562	29,164	320,803

Cost Estimating Relationship(CER)=

Discount Rate

= 10%

Logistics Costs Estimating Relationship(CER)= = 10% OF MAINT MATERIALS COST.

PLANT A + PLANT B

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Life-Cycle Costing Model: Data Sheet LCC 4

Life-Cycle Operating Costs

Plant age	Estimated Electricity Consumption Costs	Est. Gas/Fuel Oil Consumption Costs	Estimated Air/Steam Consumption Costs	Estimated Direct Labour Requirement Costs	Estimated Supervisory Labour Costs	Totals (Discounted)
I	7,030	—	48,507	165,331	—	200,763
2	7,381	—	50,926	173,597	—	191,552
3	7,750	—	53,472	182,277	—	182,867
4	8,138	—	56,145	191,391	—	174,626
5	8,545	—	58,953	200,960	—	166,712
6	8,972	—	61,900	211,009	—	158,980
7	9,420	—	64,995	221,559	—	151,834
8	9,891	—	68,245	232,637	—	145,130
9	10,386	—	71,658	244,269	—	138,356
10	10,905	—	75,240	254,482	—	131,482
11	11,451	—	79,003	269,306	—	125,916
12	12,023	—	82,953	282,772	—	120,507
Totals	111,892		772,291	2,629,590		1,888,739

PLANT A .

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Life - Cycle Costing Model:Data Sheet LCC 5

Life-Cycle Cost Summary Sheet.

Plant age	One-Time Cost Impact	Total Discounted Maintenance Cost Impact	Total Discounted Operating Cost Impact	Total Life-Cycle Cost Impact
0	808,150			808,150
I		8,191	200,763	
2		12,635	191,552	
3		16,346	182,867	
4		19,565	174,626	
5		22,276	166,712	
6	50,000	24,511	158,980	
7		26,393	151,834	
8		27,971	145,130	
9		29,168	138,356	
10		30,184	131,482	
11		30,857	125,916	
12	50,000	31,476	120,507	
Totals	908,150	279,631	1,888,739	3,076,520

PLANT B.

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Life - Cycle Costing Model: Data Sheet LCC 5

Life-Cycle Cost Summary Sheet.

Plant age	One-Time Cost Impact	Total Discounted Maintenance Cost Impact	Total Discounted Operating Cost Impact	Total Life-Cycle Cost Impact
0	632,500			632,500
I		17,325	200,763	
2		26,422	191,552	
3		37,149	182,867	
4		46,154	174,626	
5		53,487	166,712	
6	80,000	59,847	158,980	
7		64,491	151,834	
8		68,226	145,130	
9		71,347	138,356	
10		73,666	131,482	
II		75,115	125,916	
12	60,000	76,212	120,507	
Totals	712,500	669,355	1,888,739	3,330,594

LIST OF REFERENCES

1. Atkinson, L. Sir., Committee for Terotechnology: Report to the Secretary of State 1970-1972. Department of Trade and Industry, London, June 1973.
2. Maddock, I., Report by the Working Party on Maintenance Engineering, Ministry of Technology, H.M.S.O., London, 1970.
3. P.A. Management Consultants Ltd., Study of Engineering Maintenance in Manufacturing Industry. Ministry of Technology, London, April 1969.
4. Parkes, D., Terotechnology- The Changing Face of Plant Engineering, Proceedings of the International Plant Engineering Conference, U.S.A., 1971.
5. Jost, H.P., Personal correspondence to the researcher, 14th. July, 1975.
6. Department of Industry., Terotechnology: Concept and Practice. H.M.S.O., London, July 1974, page 3.
7. Department of Industry., Terotechnology: An Introduction to the Management of Physical Resources, H.M.S.O., London, November, 1975, page 2.
8. Department of Industry., Terotechnology: Concept and Practice, H.M.S.O., London, 1975.
9. Department of Industry., The Committee for Terotechnology, London, August, 1974, page 3.
10. Department of Industry., Committee for Terotechnology: First Report on Education and Training, TT103, London, May, 1974, page 13.
11. Department of Industry., Committee for Terotechnology. Terotechnology Education and Training: Teaching Terotechnology, London, 1975, pages 1 and 4.
12. Partington, E.V., Terotechnology and the Executive Engineer, The Executive Engineer, Vol. 55, No. 1, January, 1975, pp. 31-32.

13. Westlake, F.J., Terotechnology-Turning a Dream into a Reality, The Plant Engineer, April, 1976, pp.31-34.
14. Venton, A.O.F., How Numerate is Terotechnology, Trans.Inst.of Marine Engineers, Vol.87, 1975, pp.1-14.
15. Husband, T.M., Research Objectives in the Organisation of Maintenance, Management Education and Development, Vol.6, part 1, April, 1975, pp.3-11.
16. McCallum, P., A Way of Thinking and Little Else So Far- Thats Terotechnology, The Engineer, 15th. November, 1973, pp.51-53.
17. Atkinson, L.Sir., Terotechnology-A New Approach to an Old Problem, New Technology, No.44, March, 1971.
18. Department of Industry., The total cost of ownership- Terotechnology, H.M.S.O., London, 1975, p.3.
19. Department of Industry., Committee for Terotechnology, Teaching Terotechnology 1, London, 1975, page 3.
20. Finniston, M., The Terotechnology Way, The Engineer, 20th. March, 1975, pp.32-33-35-82.
21. Darnell, H., Terotechnology, Metals and Materials, September, 1973, pp395-400.
22. White, E.N., Terotechnology(Physical Asset Management), Mining Technology, August, 1975, pp.293-297.
23. Perry, J.C., Terotechnology and Design, Engineering Designer, No.1, 1975, pp.8-9.
24. DelaMare, R.F., Terotechnology-1, Chemical Processing, January, 1974, pp.81-84.
25. McCallum, P., op.cit., pp.51-53.
26. Atkinson, L.Sir., op.cit.
27. Chartered Mechanical Engineer, Down With Maintenance?, Chartered Mechanical Engineer, Editorial, April, 1972, pp.50-53.
28. Jost, H.P., Thoughts on Terotechnology, Chartered Mechanical Engineer, April, 1972, page 53.

29. Weigel, H., Functional Maintenance: A Systems Approach, Metals Technology, January, 1974, pp. 6-12.
30. Darnell, H. and Smith, M., Management Aspects of Terotechnology, Conf. University of Durham, September, 1975.
31. Wahlin, A., et. al., Intensive Care, John Wiley & Sons, London, 1972, page 20. (English translation of the third Swedish revision).
32. Norton, D., et. al., An Investigation of Geriatric Nursing Problems in Hospital, Churchill Livingstone, London, 1962, pp. 38-41.
33. Woodward, J., Industrial Organisation-Theory and Practice, Oxford University Press, London, 1965.
34. Leedy, P. D., Practical Research: Planning and Design, Macmillan Publishing Co., London, 1974.
35. Oppenheim, A. N., Questionnaire Design and Attitude Measurement, Heinemann, London, 1966.
36. Barnes, L. B., Organisation Design and Research, Editors J. D. Thompson and V. H. Vroom, Univ. of Pittsburgh Press, Pittsburgh, 1971. pp. 77-78.
37. Kelly Trade Directory of Company Information, London, 1975.
38. Central Office of Information., Business Monitor, PA1003, H.M.S.O., London, 1973.
39. Lockyer, K. G., Factory Management, Sir Isaac Pitman and Sons., London, 1969.
40. Bright, J. R., Automation and Management, Plimpton Press, Massachusetts, USA., 1958.
41. Amber, G. H. and Amber, P. S., Anatomy of Automation, Prentice Hall, New Jersey, 1962.
42. Department of Industry, Guide to the Terotechnological Practices of Small Firms, Committee for Terotechnology, London, March, 1976.
43. Kaufman, R. J., Life-Cycle Costing: A Decision Making Tool for Capital Equipment Acquisition, Cost and Management Accountant (Canada), March-April 1970.

44. Ebenfelt, H and Ogren, S., Some Experiences from the use of an L.C.C. approach, Procs. Reliability and Maintainability Symp., Los Angeles, California, 1974, pp. 142-146.
45. White, G.E. and Oswald, P.F., Life-Cycle Costing, Management Accounting (USA), January, 1976.
46. Murden, W.P., Operations Analysis-1, Procs., Annual Reliability and Maintainability Symp., Washington D.C., 28th-30th. January, 1975, pp. 55-59.
47. Brode, H.A., Cost of Ownership-An Overview, Procs., 1975, Annual Reliability and Maintainability Symp., Washington, D.C., pp. 212-216.
48. Logistics Management Institute, Life-Cycle Costing in Equipment Procurement, Washington, D.C., April, 1965.
49. Logistics Management Institute, Life-Cycle Costing in Equipment Procurement-Supplemental Report, Task 66-3, Washington, D.C., February, 1967.
50. Peratino, G.S., Air Force Approach to Life-Cycle Costing, Procs., 1968, Reliability Symposium, Boston, Massachusetts, January, 1968.
51. Sternlight, D., The Fast Deployment Logistics Ship Project: Economic Design and Decision Technique, Naval Research Logistics Quarterly, Vol. 17., 1970, pp. 373-387.
52. Pedrick, P.C., Survey of Life-Cycle Costing Practices of Non-Defense Industry, Procs., 1968 Reliability Symposium, Boston, Massachusetts, January, 1968, pp. 188-192.
53. Department of Defense, Life-Cycle Costing Procurement Guide LCC-1, Washington, D.C., July, 1970.
54. Boren, H.E., DAPCA: A Computer Program for Determining Aircraft Development and Production Costs, Rand Corporation, Santa Monica, California, February, 1967.
55. Fiorello, M.R., Estimating Life-Cycle Costs: A Case-Study of the A-7D, Rand Corporation, Santa Monica, California, February, 1975.

56. Nelson, J.R., et.al., A Weapon-System Life-Cycle Overview: The A-7D Experience, Rand Corporation, Santa Monica, California, October, 1974.
57. Balaban, H.S. and Nomer, F.J., Warranty Procurement- A Case History, Procs., 1975 Reliability and Maintainability Symp., Washington, D.C., January, 1975, pp.543-548.
58. Brode, H.A., op.cit.
59. Dixon, T.E. and Anderson, R.H., Implementation of the Design-to-Cost Concept, Procs., 1976 Reliability and Maintainability Symp., Las Vegas, Nevada, January, 1976, pp.224-229.
60. Duhan, S. and Catlin, J.C., Total Life-Cycle Cost and the Ilities, Procs., 1973 Reliability and Maintainability Symp., U.S.A., pp.491-495.
61. Fagan, T.L., A Computerised Cost Model for Space Systems, Procs., 1969 Reliability and Maintainability Symp., Denver, Colorado, July, 1969, pp.85-89.
62. Fiorello, M.R. and Konoske-Dey, P., An Appraisal of Logistics Support Costs used in the Air Force IROS Program, Rand Corporation, Santa Monica, California, February, 1975.
63. Fragola, J.R. and Spahn, J.F., Economic Models for Satellite System Effectiveness, Procs., 1973 Reliability and Maintainability Symp., U.S.A., pp.167-176.
64. Gansler, J.S., Application of Life-Cycle Costing to the D.O.D. System Acquisition Decision Process, Procs., 1974 Annual Reliability and Maintainability Symp., Los Angeles, California, 1974, pp.147-148.
65. Giordano, P.J. and Sacks, J., Reliability and Maintainability Considerations for Total Ship Systems, Procs., 1968 Reliability Symp., Boston, Massachusetts, January, 1968.
66. Harty, J.C., A Practical ICC/Cost of Ownership Type Procurement via Long Term/Multi-Year Failure Free Warranty (FFW). Showing Trial Procurement Results, Annals of 10th. Reliability and Maintainability Conf., Anaheim, California, June, 1971.

67. Langwost, C.H., LCC Applied in Evaluating Alternative Short Take-Off and Landing (STOL) Aircraft & Tracked Air Cushion Vehicles (TACV) as modes of Transportation, Annals of the 10th. Reliability and Maintainability Conf., Anaheim, California, June, 1971.
68. Rush, R.C., et.al., A Nonlinear Programming Model for Launch Vehicle Design and Costing, Operations Research, Vol. 15, March-April, 1967, pp185-210.
69. Sadler, G.C., An Evaluation of Weapon System Life-Cycle Analysis Models, Procs., 1974 Reliability and Maintainability Symp., Los Angeles, California, January, 1974.
70. Stehle, F., et.al., The Development and Application of a Cost-Effectiveness Assessment Procedure for Shipboard Electronic Equipments, Procs., 1966 Reliability and Maintainability Conf., New York, July, 1966, pp. 61-74.
71. Watts, A.F., Aircraft Turbine Engines-Development and Procurement Costs, Rand Corporation, Santa Monica, California, November, 1965.
72. Ebenfelt, H. and Ogren, S., op.cit.
73. Ebenfelt, H. and Waak, O., LCC-Defense Application, Procs., 1975 Reliability and Maintainability Symp., Washington, D.C., January, 1975, pp. 63-72.
74. Arman, J.O., Design to Life-Cycle Cost in Swedish Defense Programs: Some Problems and Achievements, Procs., 1977 International Conference, Design to Cost-Life Cycle Cost and Logistics Alternatives, London, December, 1977, pp. 13-17.
75. Dahlberg, L.E., and Westlund, S.E., Viggen Aircraft Maintainability, Procs., 1975 Reliability and Maintainability Symp., Washington, D.C., January, 1975.
76. Procurement Executive, Ministry of Defence, Defence Life-Cycle Costing: Introduction and Guide, April, 1974.
77. Several Authors, Procs., 1977 International Conference, Design to Cost-Life Cycle Cost and Logistics Alternatives, December, 1977, London.
78. Beauprez, R., Life Cycle Costing in the Management of Assets: a Practical Guide, Department of Industry, May, 1977.

79. Peace, T.E., Controlling Life-Cycle Cost in the F-16 Program, Procs., 1977 International Conference, Design to Cost-Life Cycle Cost and Logistics Alternatives, December, 1977, pp37-46.
80. McCullough, Estimating Systems Costs, in Cost Effectiveness Analysis: New Approaches in Decision Making, Ed., T.A. Goldman, F.A. Praeger Pub., Ltd., New York, 1967, pp. 69-90.
81. Earles, D.R., L.C.C.-Commercial Application: Ten Years of Life-Cycle Costing, Procs., 1975 Annual Reliability and Maintainability Symp., Washington, D.C., January, 1975, pp. 74-85.
82. Ryan, W.J., Procurement Views of Life-Cycle Costing, Procs., 1968 Reliability Symp., Boston, Massachusetts, January, 1968.
83. Bryson, L.S., Designing to Life Cost in the Ministry of Defence, Procs., 1977 International Conference Design to Cost-Life Cycle Cost and Logistics Alternatives, December, 1977, pp. 55-59, London.
84. Harrison, J.E.A., Reducing Royal Air Force Support Costs, 1977 International Conference on Design to Cost-Life Cycle Cost and Logistics Alternatives, December, 1977, pp. 73-81, London.
85. Ebenfelt, H., LCC - Its Roles and Shapes, 1977 International Conference on Design to Cost-Life Cycle Cost and Logistics Alternatives, London, December, 1977. pp. 83-95.
86. Blunn, M., Terotechnology and Life-Cycle Costing- Approach in Pilkingtons, paper presented at a short course at Loughborough University, March, 1977.
87. Jeffrey, T.D., Terotechnology in the Maintenance of Office Copying Machines, paper presented at a short course at Loughborough University, April, 1975.
88. Stordahl, N.C. and Short, J.L., The Impact and Structure of Life-Cycle Costing, Procs., 1968 Reliability Symposium, Boston, Massachusetts, January, 1968.
89. Seiler, K., Introduction to Systems Cost-Effectiveness, Wiley-Interscience, New York, 1969.
90. Jones, M.V., Estimating Methods and Data Sources Used in Costing Military Systems, Technical Report No. ESD-TR-65-396, Mitre Corporation, USA., December, 1965.

91. Levenson, G.S. and Barro, S.M., Cost Estimating Relationships for Aircraft Airframes, Rand Corporation Memorandum, RM 4845 PR(abridged), Santa Monica, California, May, 1966.
92. Jelen, F.C., Cost and Optimisation Engineering, McGraw-Hill Book Company, New York, 1970, Chapter 3, pp.44-45.
93. Harvey, G., Terotechnology: A Case-Study in the Application of the Concept, Research Paper, Department of Engineering Production, Loughborough University of Technology, March, 1977.
94. Weigel, H., Functional Maintenance-A Systems Approach, Procs., 1972 Terotechnology in Iron and Steelworks, Conference, London, 3-4 May, 1972, pp.36-43.
95. Rappini, G.E., Some Aspects of Terotechnology at Italsider, Procs., 1972 Terotechnology in Iron and Steelworks Conference, London, 3-4 May, 1972, pp.57-74.
96. Harvey, G., Terotechnology-What is the Production Engineer's Role?, The Production Engineer, July-August, 1977, pp.36-39.
97. Kay, S.E., Terotechnology in the Flat Glass Industry, Procs., Tero 77 Conference, Profit Through Care, London, 2-6th. May, 1977, pp.9-24.

