DEVELOPMENT OF A COMPUTING AND INFORMATION SYSTEMS
INFRASTRUCTURE FOR CAPM IN A COMPUTER INTEGRATED
MANUFACTURING ENVIRONMENT

by

Neil Weston
B.A. (Hons), M.Sc.

Submitted to the Council for National Academic Awards in partial
fulfilment of the requirements for the degree of Doctor of Philosophy

Polytechnic South West in collaboration with Davy Computing Ltd and
PA Computers and Telecommunications.

February 1991
<table>
<thead>
<tr>
<th>Item No.</th>
<th>9000 467860</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class No.</td>
<td>T-670.42WES</td>
</tr>
<tr>
<td>Cont'l No.</td>
<td>X 70 2449007</td>
</tr>
</tbody>
</table>
Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other C.N.A.A. or University award. None of the material herein has been used in any other submission for an academic award.

The work carried out by the author in completing this thesis formed part of the CAFM methodology developed by all the members of the Polytechnic South West and Sheffield Business School team. In the thesis a clear distinction is made between the work as a whole and the author's individual work on the computing and information systems aspects of CAFM.

A programme of advanced study was undertaken in partial fulfilment of the requirements, including literature reviews of previous research and in-company visits (under the direction of Professor D. R. Hughes); attendance and presentation of papers written by the author of this thesis at relevant conferences and seminars. Briefly these consisted of:

Conferences

10th International Conference on Production Research, The University of Nottingham, August 1989.


ACME CAFM Conference, Birmingham, September, 1990.


Programme of Studies

CIM Course, CIM Institute, Polytechnic South West, March 1988.

Within the thesis
Acknowledgements

I dedicate this thesis to my mother.

I would also like to thank my friends, Alison, Darrell, Andrew and Geoffrey for all the support and kindness they have shown during the last few years.

Special thanks are due to Darryl Hughes for all the kind hospitality provided and to the efforts of Professor D R Hughes, Director of Studies, Professor D R Tranfield, Professor S Smith and Dr R M Maull in completing this thesis.
DEVELOPMENT OF A COMPUTING AND INFORMATION SYSTEMS INFRASTRUCTURE FOR CAfM IN A COMPUTER INTEGRATED MANUFACTURING ENVIRONMENT

by NEIL WESTON. B.A. (Hons), M.Sc.

ABSTRACT

The continuing failure of many CAfM implementations in the UK, despite the availability of a large and growing supply of software, gave rise to concern within the academic and user community and highlighted a need for a concerted research effort into the causes of failure. The Science and Engineering Research Council responded to this need by sponsoring a major research initiative into CAfM through its ACME (Application of Computers to Manufacturing Engineering) Directorate. The findings reported in this thesis result from the work carried out for ACME by the author as part of the joint Polytechnic South West/Sheffield Business School research programme under the direction of professors D R Hughes, I S Smith and D R Tranfield.

The extent of the work included surveying a large number of manufacturing firms, interviewing suppliers of CAfM systems and services and analysing the data collected from these activities. This resulted in the identification of a number of causes of CAfM failure. A major component of the work then concerned developing an appropriate CAfM design and implementation methodology to address the issues and concerns identified as significant.

A clear distinction is made in the thesis between the work carried out by the author as part of the ACME team and the author's own work. The results from the joint effort of the research team are explained together with the author's unique contribution.

The concepts of operational performance envelopes and contextually bound computing and information systems infrastructures provide the theoretical foundation to the author's approach. These concepts are utilised within an approach developed by the author which offers a wider ranging approach than is currently available. Existing approaches focus on the development of single point solutions and aim to address particular and current problems only. Such solutions are inappropriate where requirements are subject to rapid and frequent change, as in the manufacturing sector. In contrast the author's approach focuses on the development of a computing and information systems capability with the necessary flexibility to accommodate changing requirements and priorities. In this way a more resilient solution is obtainable.
TABLE OF CONTENTS

1.0 INTRODUCTION TO THE RESEARCH (1)
   1.1 Introduction (1)
   1.2 The ACME CAPM Research Initiative (2)
   1.3 The ACME Team Research Project (5)
   1.4 Additional Supporting Work (5)
       1.4.1 CIM Centre, Kingston upon Thames (7)
   1.5 The Aim and Scope of the Author's Research (10)
   1.6 Contribution to Knowledge (14)
   1.7 Significance of the Research (19)
   1.8 Conclusion (20)

2.0 RESEARCH METHODOLOGY (22)
   2.1 Introduction (22)
   2.2 Theoretical Analysis (22)
   2.3 Data Collection and Company Visits (23)
   2.4 Continuous Validation (27)
   2.5 Analysis and synthesis (27)
   2.6 Dissemination and Commercial Exploitation (28)
   2.7 Conclusion (29)

3.0 THE ELECTRONICS SECTOR (30)
   3.1 Introduction (30)
   3.2 Industrial Classification (31)
       3.2.1 Segmenting the Electronics Sector by Existing Schemes (33)
       3.2.2 ICL's Electronics Market Segmentation Project (34)
   3.3 Supporting Studies (36)
   3.4 Implications for the Development of a Generic Methodology (38)
   3.5 Environmental Characteristics (39)
   3.6 Bringing About Change (43)
   3.7 The Need for New Methodologies (44)
   3.8 Conclusion (45)

4.0 CAPM SYSTEMS (47)
   4.1 Introduction (47)
   4.2 CAPM Systems (48)
       4.2.1 The Nature and Extent of Computer Support for CAPM systems (53)
   4.3 CAPM Packages (55)
   4.4 Technological Factors (58)
   4.5 Computerised or Manual Production Management Systems? (60)
       4.5.1 High Level PPP's (71)
   4.6 Flexibility and "fit" (75)
   4.7 Enhancements to Accommodate Changing Requirements (76)
   4.8 Conclusions (77)
5.0 THE RESULTS OF THE IN-COMPANY FIELD WORK ANALYSIS (78)

5.1 Introduction (78)
5.2 Data Collection (78)
5.3 Current Approaches (84)
5.4 Examples of Failures (87)
   5.4.1 Examples (88)
5.5 Conclusion (92)

6.0 REQUIREMENTS FOR A CAPM METHODOLOGY (94)

6.1 Introduction (94)
6.2 Issues, Concerns and Requirements (95)
6.3 Summary of Requirements (102)
6.4 Conclusion (105)

7.0 THE CAPM METHODOLOGY (106)

7.1 Introduction (106)
7.2 Overall Framework (109)
7.3 Content, Structure and Stages of the CAPM Methodology (112)
   7.3.1 Strategic Analysis (113)
   7.3.1.1 Strategic Audit (114)
   7.3.1.2 Financial Evaluation (116)
   7.3.1.3 Product Portfolio (117)
   7.3.1.4 Competitive Audit (119)
   7.3.2 Manufacturing analysis (120)
      7.3.2.1 Manufacturing Audit (120)
      7.3.2.2 Resources Impact Analysis (121)
7.4 Conclusion (122)

8.0 REQUIREMENTS FOR A COMPUTING AND INFORMATION SYSTEMS INFRASTRUCTURE APPROACH TO CAPM (124)

8.1 Introduction (124)
8.2 Issues, Concerns and Requirements (125)
8.3 Addressing the Issues (127)
   8.3.1 Discrete Applications (128)
   8.3.2 Turnkey (128)
   8.3.3 Blueprint (128)
   8.3.4 Planned Evolution (129)
8.4 Modelling Techniques (130)
   8.4.1 Critique of Modelling Approaches (133)
8.5 Conceptual and Reference Models (135)
8.6 Dealing With Changing Requirements (138)
   8.6.1 The Infrastructure Approach (139)
   8.6.2 Operational Performance Envelopes (OPE's) and Computing and Information Systems Infrastructures. (140)
8.7 Computing and Information Systems Infrastructure Components (146)
   8.7.1 Strategy (147)
   8.7.2 Technology (155)
   8.7.3 People (158)
8.7.4 Manual or Computerised Tasks (158)
8.8 Conclusion (161)
9.0 DEVELOPING A COMPUTING AND INFORMATION SYSTEMS INFRASTRUCTURE FOR CAPM (163)

9.1 Introduction (163)
9.2 Structure and Stages of the Computing and Information Systems Infrastructure Approach (164)
9.3 Strategic Analysis (168)
9.4 Manufacturing Analysis (169)
9.5 IT Appraisal and IT Internal Audit (170)
   9.5.1 First Cut Physical Design (173)
   9.6 Infrastructure Requirements (176)
9.7 Infrastructure Solution (179)
9.8 Choosing the Most Appropriate CAPM Package (179)
   9.8.1 Customisation (181)
   9.8.2 Policies, Practices and Procedures (181)
   9.8.3 Installation (181)
9.9 Decisions Involved in the Development of a Resilient Computing and Information Systems Infrastructure for CAPM (182)
9.10 Conclusions (184)

10 SUMMARY AND CONCLUSIONS (185)
10.1 Summary (185)
10.2 Conclusions (185)
10.3 Further Work (185)

REFERENCES (188)
Figures

Figure 1.1 Outline and Stages of the Process Methodology (11)
Figure 1.2 Activities Involved in the Author's Work (12)
Figure 2.1 Companies Visited (24)
Figure 4.1 Production Management Functions (54)
Figure 5.1 Causes of CAPM Systems Failure (80)
Figure 5.2 Types of Failure due to Changing Requirements (81)
Figure 5.3 Failure Modes (83)
Figure 5.4 Vendor Led Approaches (85)
Figure 6.1 Validation Criteria (99)
Figure 6.2 Summary of Requirements for the CAPM Methodology (104)
Figure 6.3 Summary of Requirements for the Author's Approach (104)
Figure 7.1 The Stratagem Process Methodology (108)
Figure 7.2 Amended Mendelow Stakeholder Analysis (115)
Figure 7.3 Boston Consultancy Group 1 Financial Evaluation (116)
Figure 7.4 Boston Consultancy Group 2 Portfolio Development (117)
Figure 7.5 Resource Impact Matrix (121)
Figure 8.1 Operating Performance Envelopes (142)
Figure 8.2 CAPM Operating Performance Envelope (144)
Figure 8.3 Derivation of the Computing and Information Systems Infrastructure (145)
Figure 8.4 Levels of CAPM Integration (146)
Figure 8.5 USA, European and UK architecture approaches (149)
Figure 8.6 CAPM Package Flexibility Parameters (155)
Figure 9.1 The CAPM Methodology and the Computing and Information Systems Infrastructure Sub-stages (165)
Figure 9.2 Data, Sources of Data and Use of Data (167)
Figure 9.3 Technological Constraints (172)
Figure 9.4 Decisions Required to Develop a CAPM Computing and Information Systems Infrastructure (183)
Appendices

APPENDIX A

Paper presented to the 10th International Conference on Production Research, The University of Nottingham, August 1989. The Design of an Implementation Methodology for CIM systems in the Electronic's Sector (1-7)

APPENDIX B


APPENDIX C


APPENDIX D

Paper presented to the School of Management, UWIST, Cardiff 1988 (1-7)

APPENDIX E

Paper presented to the ACME CAPM Conference, Birmingham, September 3, 1990 (1-6)

APPENDIX F


APPENDIX G

Summary of the CAPM Systems of Companies Visited (1-2)

APPENDIX H

CAPM software package features (1-10)

APPENDIX I

Examples of Pro-formas (1-6)
CHAPTER 1

INTRODUCTION TO THE RESEARCH

1.1 Introduction

This chapter provides an introduction to the research work undertaken by the author. Details are provided of the Application of Computers to Manufacturing Engineering (ACME) Computer Aided Production Management (CAPM) research initiative and the programme of work carried out jointly by members of the Polytechnic South West and Sheffield Business School from 1987 to-date, of which the work presented here formed a part. This joint effort is referred to as the ACME team from this point on in the thesis.

The aims and objectives of the specific work carried out by the author are defined in this chapter and the research methodology devised for undertaking the work, both by the ACME team and for the author's individual work, is described and fully explained in chapter two. The contribution to knowledge arising from the author's work, and the ACME team's work, is discussed as providing an original, theoretically sound, usable and cost effective design and implementation methodology for CAPM. The significance of the work undertaken by both the ACME team and the author is discussed as providing a methodology for CAPM which, by assisting in the implementation of more resilient CAPM systems, will make a contribution towards the revitalisation of those UK manufacturing companies that are currently being out performed by fierce and
competitively motivated foreign competition. The 1990 balance of trade figures for the UK testify to the need for such methodologies if this much needed revitalisation is to be brought about.

1.2 The ACME CAPM Research Initiative

The findings presented in this thesis result in the most part from the research carried out by the author for the ACME Directorate of the Science and Engineering Research Council under its directed research initiative in CAPM (1986). In addition the work undertaken between 1985 and 1987 for the CIM Centre, Kingston upon Thames and for IBM between 1988 and 1990 is also reported and its relevance explained accordingly.

The CAPM initiative was set up to meet the need for research to produce practical, user-led methodologies for the specification, design, implementation and operation of CAPM systems. The ACME CAPM Midterm Report (Clouder-Richards 1989) explains the reason for the initiative as arising out of a recognition that:

1. "the potential available in many companies to improve their industrial performance through reductions in stock holding and lead times was not being fully exploited;

2. general concern at the poor quality of CAPM practice and knowledge of relevant production management techniques within UK industry;
an academic research community keen to take a broader based and more academic oriented approach to CAPM research".

These three factors were regarded as significant and sufficiently meritorious to warrant further investigation.

It was recognised by ACME that significant gains in industrial manufacturing performance could be made with low capital investment, by making better use of CAPM. A study into the state-of-the-art in computer-aided production management (Waterlow and Monniot 1986) was commissioned and this set out to determine what the problems were for industry in the adoption of CAPM and whether solutions could be found through academic research. The data on which the study's conclusions were based was collected from conducting in-depth interviews with 33 manufacturing firms and from discussions with 5 suppliers of CAPM systems. The study confirmed that CAPM users were not, in general, gaining the maximum benefit from CAPM use. In addition the adoption process was frequently very long, expensive and difficult and the key issues at successive stages of CAPM integration were different. Four stages of integration were identified by Waterlow and Monniot ranging from no CAPM to CAPM systems fully integrated with other systems. These stages are discussed in more depth in chapter eight and shown in figure 8.4.

It was also noted that previous academic research on CAPM had been of limited practical benefit. Waterlow and Monniot (1986) therefore recommended that future research into CAPM should:
be undertaken with a computer integrated manufacturing (CIM)
perspective and adopt a systems perspective;

that the research should be concentrated around industry sectors;

a multi-disciplinary approach should be adopted.

The author's work aims to fill this gap in current knowledge
identified by Waterlow and Monniot by focusing on the computing and
information systems aspects of CAPM within an integrated, CIM
framework and by developing a generic approach based on the most
volatile of all the manufacturing sectors, the electronics sector.

In addition, Waterlow and Monniot observed that research was needed
to help firms determine their needs and select CAPM packages which
matched these. The importance of selecting a package which closely
matched the user's manufacturing environment and management practices
was noted as significant for achieving a high degree of integration.
Again this deficiency in our knowledge of CAPM systems has been
addressed by the ACME team as a whole and specifically by the
author's work in matching CAPM packages to user requirements.
Techniques have been provided for this purpose and are discussed in
chapters eight and nine.

User involvement and user-led approaches were stressed by Waterlow
and Monniot as significant for the successful introduction and
development of CAPM. These and other concepts provided an initial
framework for both the ACME team and for the author's research and have been fully investigated. The usefulness and relevance of these concepts has been evaluated and techniques have been developed to incorporate these into a fully workable CAFM methodology. These aspects are dealt with in detail in chapters six, seven, eight and nine.

1.3 The ACME Team Research Project

The ACME team project (1987) initially concentrated on investigating CAFM implementations in the electronics manufacturing sector but was subsequently extended to encompass all manufacturing industry. The project was specifically designed to investigate the premise that the key to the successful implementation of CAFM in the electronics sector lay in the development of a practical, user led methodology. To achieve this aim the research work involved an investigation of the organisational, business, technological and human factors affecting the design and implementation of CAFM systems. Much of the initial work focused on gaining an understanding of the relative importance of these factors to the success or failure of CAFM implementations.

1.4 Additional Supporting Work

In addition to the work carried out under the ACME CAFM initiative the author also undertook, with Professor D. R. Hughes, work for IBM under their Study Grant scheme. This work was carried out between 1988 and 1990 and involved an investigation of the data linkages between the office automation system and other manufacturing and
business systems. The work integrated with the author's interest in the area of data and information integration and the development of company wide CIM systems.

Specifically, the aims of the Study Grant included:

- "to establish a 'front-office' of a manufacturing business in order to demonstrate to business, engineering and computing students the value of integrating office and industrial systems; provide hands on experience of an advanced office automation product;

- to research into the nature and extent of the required linkages between office automation, desktop publishing, order processing, CAPM, Engineering Change Control (ECC), financial and administrative systems;

- to demonstrate the value of such integration in deriving and maintaining a competitive advantage" (Hughes, Weston and Maull 1988).

A number of issues were investigated including the introduction of new technology and the problems associated with this. For example, a fundamental re-think of the business and systems and a redistribution of activities and intelligence may be required before any significant gains are realised from the introduction of new technologies.
Integration problems were examined and specifically the issue of incompatibility arising from the use of heterogeneous equipment from different vendors. The emergence of standards were investigated as one potential cure for alleviating this problem. The problems surrounding the transfer of data within companies was also investigated and specifically the problem caused through the development of incompatible data structures. Data communications and problems arising from the use of non-standard communications protocols was researched.

1.4.1 CIM Centre, Kingston upon Thames

From 1985 to 1987 the author undertook a programme of research for the CIM Centre, Kingston upon Thames. The focus of this work was on investigating the use and effectiveness of structured systems analysis and design methodologies, tools and techniques for developing computer integrated manufacturing (CIM) systems. The work provided an opportunity for the author to conduct action research (Checkland 1983; Warmington 1980) over a significant period of time in a local aerospace manufacturer. The level of involvement of the author was that of an external analyst and the scope of the work that was specified extended to defining the initial CIM requirements at the site. The content of the work included developing data flow diagrams of the current activities and processes, and specifically those concerned with CAPP, prior to designing a new and more fully integrated system. The work was carried out using the company's in-house design methodology, a derivative of the Structured Systems Analysis and Design Methodology (SSADM). The project sought to
firstly upgrade the existing CAPM system, secondly to develop a fully operational direct numerically controlled (DNC) system from the computer numerically controlled (CNC) machines on the site and thirdly to integrate the DNC system with the new CAPM system.

The work carried out by the author necessitated spending a considerable period of time collecting data on, and modelling, the existing factory architecture at the site. As a result of undertaking this work a number of important insights into the problems and issues surrounding the development of the 'traditional' factory architecture were gained. In particular the piecemeal and incremental approach, which is characteristic of the traditional approach, poses a potential problem for subsequent attempts to rejuvenate and integrate the architecture. The result is all too often apparent in the form of the so called "islands of automation".

The research also highlighted a number of technological and methodological problems associated with the introduction of new information technology. For example, difficulties of achieving a high level of "fit" (see section 4.6) and sufficient flexibility may result if a wholly technological solution is sought without considering the benefits from incorporating manual practices, policies and procedures into the overall solution. At a methodological level it would seem essential to provide the means for users to debate any difference of perception concerning the functioning of the existing system and the required functions of the new system.
On the issue of design, integrating previously free standing applications into a fully integrated system should not be attempted without the prior existence of a company wide information strategy and the adoption of company wide standards for data structures and communications protocols. In addition simplification and rationalisation of processes are an essential pre-requisite if the implementation of information technology is to be effective. This aspect has been developed in the current research programme together with techniques for harnessing the best of the technology and the policies, practices, and procedures to enhance the "fit" of the system (Weston and Maull 1990).

Much of the work carried out in the company remains confidential, although the relevant findings from this work are reported in later chapters of the thesis. The work culminated in a requirements definition report (1986) which was presented to the Board of Directors of the company for approval. This was granted and the work proceeded to the next, functional specification, stage.

1.5 The Aim and Scope of the Author's Research
The overall aim of the ACME team's project was to develop a practical, usable and cost effective methodology for the design and implementation of CAFM systems, capable of addressing the factors responsible for CAFM systems failure. Although this work initially concentrated on the requirements of the electronics sector, it was
subsequently developed into a generic methodology for more widespread use in all manufacturing sectors.

Within the framework provided by the ACME team's project, the author's individual work has fulfilled the PhD requirements of originality, significance and contribution to knowledge. This has been achieved by focusing on those aspects of the design of computing and information systems for CAPM which have previously proved problematical. Specifically, the issue of providing a long term, resilient computing and information systems capability for CAPM has proved difficult to achieve. This has been addressed both in content and process. The content has been addressed through developing techniques for the matching of current and future functional, processing and information integration requirements to the available CAPM packages, thereby ensuring that only the appropriate package is selected. The process of defining a resilient capability has been addressed by the development of an approach which enables the user to identify the nature and extent of flexibility required. This is achieved by providing techniques for carrying out an environmental analysis and an internal appraisal of, for example, the current computing capability of a company.

The author's work forms an integral part of the overall Polytechnic South West/Sheffield Business School project and the more wider ranging, CAPM methodology, devised by the team as a whole.

The stages of the overall CAPM methodology are shown in figure 1.1
The methodology devised consists of four stages.

The stages of the overall methodology, and particularly the strategic and manufacturing analysis stages, are described in chapter 7 of this thesis. The final two stages are described in detail in chapter nine.

The focus of the author's work culminates in the final two stages of the CAPM methodology. The specific activities covered by the author's work on the computing and information systems aspects of CAPM are shown in Figure 1.2.
The content of the author's work includes new techniques for selecting a package that most closely fits the dynamic and functional requirements of a company. The selection process fully considers all the relevant technological constraints which may exist and the customisation requirements to enhance the "fit". These activities are undertaken within a framework which aims to provide a solution with a highly resilient capability.

The process mechanisms relate to the way the approach is used in practice to allow the users to define the requirements of each individual application. In addition, these mechanisms serve to enlist the full support of all the company personnel involved in the design and implementation of the CAPM system. The concept and role of the

<table>
<thead>
<tr>
<th>Process Mechanisms</th>
<th>CAPM Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workshops</td>
<td>Requirements Definition</td>
</tr>
<tr>
<td>Pre-work and Pro-formas</td>
<td>Functional Specification</td>
</tr>
<tr>
<td>Technical Briefings</td>
<td>Selection of Candidate</td>
</tr>
<tr>
<td>Information Sheets</td>
<td>Packages</td>
</tr>
<tr>
<td></td>
<td>Selection of best &quot;fit&quot;</td>
</tr>
<tr>
<td></td>
<td>Package</td>
</tr>
<tr>
<td></td>
<td>Customisation</td>
</tr>
</tbody>
</table>
facilitator "who guides and manages the entire process" is reported in Weston and Maull (1990).

The process based methodology was developed through the joint effort of all the members of the ACME team and governs the whole of the Polytechnic South West/Sheffield Business school project as well as the author's individual work. The process refers to how the structure and stages of the methodology (see figure 1.1) and the techniques and supporting documentation are applied in practice. Although traditional structured development methodologies, such as SSADM, provide the analyst with detailed instruction on the use of technique in analysing and designing information systems, the role of the user in this process is often, at best, neglected or at worst misunderstood.

Focusing on the process of applying the methodology in practice and clearly establishing the role of the analyst as facilitator and the user as the provider of knowledge at the company level ensures that requirements are captured and commitment to the solution generated is achieved, thereby increasing the chances of a successful implementation. In addition resilience is ensured by the top down approach which begins with an appraisal of the relevant environmental characteristics affecting all existing and future systems, including the computing and information systems aspects of CAPM, and proceeds through the next, audit stage, where the internal company processes and systems are examined and documented. The results of these two stages provide the detail necessary for the CAPM requirements to be
defined and a functional specification developed for matching against the available software packages.

1.6 Contribution to knowledge

The dynamic environment of the 1990's, that many manufacturing companies worldwide now face, requires the development of practical and usable tools and techniques which are underpinned by a sound and rigorously established theoretical foundation. The author has developed a number of such tools and techniques from undertaking the research described in this thesis. Concepts and techniques have been created to define, measure and communicate the dimensions of change which affect both the current and future performance of the CAPM computing and information system. For example, the concept of an operational performance envelope (Weston and Hughes 1989) provides a powerful tool for communicating that a variety of potential and unpredictable demands may be placed on the manufacturing system.

Operational performance envelopes depict the range of conditions likely to be experienced by a company and the boundary of the envelope indicates the likely extreme conditions that may arise. A number of such envelopes may be envisaged at the strategic, manufacturing and application level as discussed in Weston and Maull (1990).

Specifically, in terms of the author's work, the operational performance envelope at the CAPM level is circumscribed by the three variables of information integration, data storage and processing and
manufacturing philosophy requirements. Within the dimensions of this envelope a sufficiently flexible solution must be defined to accommodate as many of the potential requirements as is economically and technically feasible.

The complementary concept of "contextually bounded" infrastructures provides a way of expressing that in any manufacturing situation there are a number of alternative strategies that could be adopted and a variety of means by which the strategies could be implemented. Creating a capability to respond to the potential demands by providing unlimited flexibility would, however, be prohibitively expensive (Weston, Maull and Childe 1988). Therefore, there is a need to restrict the number of possibilities that could realistically be addressed by a particular company.

An appropriate contextually bounded computing and information systems infrastructure for CAPM is that solution which, through adjusting the variables governing the extent of the systems flexibility, meets all the potential requirements within the operational performance envelope and at an acceptable cost. Although it is now technically possible to cater for change by developing a computer based data dictionary system which holds "data about data" and which contains powerful applications generators for automatically creating new applications (Van Duyn 1984) for most installations the time, effort and cost of establishing such a system may far exceed the value derived. The author's work, and that of the ACME teams's, therefore focuses on selecting the most appropriate CAPM package and the
continual enhancement of this by customisation of the software and by the use of practices, procedures and policies (PPP's) to maintain a high level of "fit".

One major finding by the ACME team was that in order to define the requirements of the lower level CAFM system it was first necessary to undertake an analysis at the strategic and manufacturing levels as diagrammatically portrayed in figure 1.1. A similar requirement emerged for the author's work which, although forming an integral part of the overall CAFM methodology, focused specifically on the computing and information systems aspects of CAFM. The reader is directed to figure 9.1 which shows the structure and stages of both the CAFM methodology and the authors approach.

It was found that to define the computing and information systems configuration for CAFM a necessary pre-requisite was to investigate the external, technological environment within which the company's CAFM system operated. The external environment comprises, for example, relevant developments in the areas of software, hardware and data communications. This aspect of the work is covered in chapter eight where the role and importance of international standards for CIM are explained e.g. those currently being developed through the CIM-OSA project (Kosannke 1990; Jorysz and Vernadat 1990; Klittich 1990). The next pre-requisite in developing a computing and information systems infrastructure for CAFM concerns auditing the company's current internal computing capability. This stage is carried out in parallel with the manufacturing analysis stage of the overall CAFM
methodology shown in figure 1.1 and utilises an output from this, the manufacturing philosophy requirements, which define the control requirements for the supporting computing and information systems infrastructure for CAFM. The control requirements may be for a materials requirements planning (MRP) system, a just in time (JIT) system or some combination of both of these etc.

The contribution to knowledge of the author's work stems, in part, from the application of the concepts and frameworks developed by the ACME team as a whole to the specific area of computing and information systems for CAFM and from the new techniques developed by the author. A computing and information systems infrastructure, in the context of the author's research, is the "contextually bound" information processing capability required to support the range of potential CAFM conditions. This concept clearly challenges traditional, single point, approaches to the design and implementation of CAFM systems. Single point approaches are aimed at providing a solution to meet a particular and a current problem.

In contrast, embodied in the infrastructure approach is the notion that attempting to meet only the current requirements is impractical. It is impractical because these requirement will change. Equally impractical is the notion that future requirements can be predicted with any degree of precision. The approach offered by the ACME team and applied to the author's research recognises, instead, that it is only possible to identify in broad terms likely future requirements. It is, however possible to cater for change, through designing an
appropriate infrastructure is a system with a flexible capability to meet future requirements.

Flexibility can be accommodated in a number of ways. Firstly the inherent customisation capabilities of the package may be exploited to enhance the level of "fit" and provide a higher degree of functional correspondence. Secondly the overall fit may be enhanced further by providing a partly computerised and partly manual system. Adjusting the manual policies, practices and procedures as changing requirements dictate and further customisation of the software as and when needed, and technically feasible, provides the necessary flexibility to ensure that changing requirements can be met.

The components that comprise a computing and information systems infrastructure for CAPM are the software applications and the supporting hardware. These are "configured to provide an information processing, storage and distribution capability which transcends immediate requirements" (Hughes 1988). However the emphasis is not solely on the physical components but also the information strategies necessary to utilise these technologies in the most effective way i.e. data management strategies (Bray 1988), open systems architectures (MacConaill 1990) and modular design principles (Hughes 1985).

This thesis discusses a new approach devised by the ACME team as a whole and applied by the author to the problem area of computing and information systems for CAPM. By identifying the likely parameters of
the CAFM operational performance envelope, the appropriate computing and information systems infrastructure and the components necessary to accommodate these may be selected to achieve a resilient solution.

A number of papers have been published by the ACME team explaining the programme of research and the development of theory. The reader is directed to appendices A, B, C, D, E, F for those involving the author and the work described in this thesis.

1.7 Significance of the Research

The significance of this research to UK's electronics manufacturing sector in overcoming fierce foreign competition cannot be overstated. Through dissemination of the methodology presented in this thesis, and its adoption by industry, the research will make a significant contribution to the development of more resilient CAFM systems. This capability will make a significant contribution to the overall level of company performance and competitiveness.

The process of dissemination has already begun through the publications by the author together with members of the ACME team. In addition a series of Department of Trade and Industry (DTI 1990) sponsored roadshows aimed at presenting the results of the work and the solutions developed to senior managers throughout the country has been undertaken. This has ensured that the conceptual basis of the approach has undergone rigorous testing by practitioners in the field of CAFM.
Current approaches to the development of CAPM systems are inadequate for the many reasons described and critically assessed in this thesis. As manufacturing grows even more competitive, possessing a capability to develop highly flexible and resilient computing and information processing systems will be paramount for the survival of the UK's manufacturing base, of which the importance of the UK's electronics sector to the national economy cannot be overstated and is widely supported (EITB 1988). The UK's manufacturing base has been so severely eroded throughout the 1970's and 1980's that the current account deficit in 1989 exceeded £20 billion - the highest ever in the history of the UK's economy. The advent of 1992, with the relaxation of European trade restrictions between EC member countries, does not bode well for the UK unless substantial improvements in performance can be achieved. The evidence indicates that any such recovery can only result from an increase in the performance of the electronics sector which in turn highlights the importance of the work by the ACME team, and of the author, which in itself represents a significant contribution.

1.8 Conclusion

This chapter has provided an introduction to the ACME CAPM research project carried out by the ACME team, of which the author was a part, and the specific work undertaken by the author on the subject of computing and information infrastructures for CAPM. The aims, objectives and scope of the authors research has been described together with the contribution to knowledge of the work. No such practical, cost effective methodology exists for the design and
implementation of resilient CARM systems that is based on such a sound and rigorously defined theoretical framework. The author's work, as an integral yet individually derived part of this methodology, represents itself a significant contribution.
CHAPTER 2

RESEARCH METHODOLOGY

2.1 Introduction
An important issue at the beginning of the programme of research concerned the selection of research methodology for undertaking the work and for achieving the aims as described in the previous chapter. This chapter explains how the issue was resolved and discusses the methodology which resulted. The methodology comprised both theoretical analysis and in-company data collection and analysis.

2.2 Theoretical Analysis
The theoretical analysis stage of the research sought, firstly, to identify the most up to-date and relevant concepts, principles and strategies for the analysis, design and implementation of computer based systems and secondly, to evaluate their usefulness for the CAPM methodology under development. Concepts such as user-led and the participative approach, which is perhaps most well known through the work of Mumford, Land and Hawgood (1978) and which is based on the premise that securing user ownership and commitment is a vital stage of systems design and development, were rigorously assessed. The systems approach in both its "hard" and "soft" forms (Checkland 1981; 1985; Wilson 1984) together with general systems theory and concepts (Bertalanffy 1981; Vickers 1981) were reviewed. The notion of infrastructures (Hill 1985; Meredith 1988; Hayes and Wheelwright 1984; Fine and Hax 1984) was researched together with the concept of
flexibility (Slack 1988; Dooner 1988). Design principles necessary for providing a flexible capability were re-examined (Hughes 1985 a; b; Mauill 1986; 1988) together with the most recent work covering data management strategies, communications and factory architectures (NBS; I-CAM; Kosanka 1990; Van Dyke Paranuk 1985; Rzevski 1987). The evaluation of these concepts, principles and strategies that was undertaken sought to establish their usefulness to the CAPM problem and for providing a coherent theoretical framework which could be presented for discussion with vendors, practitioners and users prior to the formulation of a workable CAPM methodology.

Of particular relevance to the author's specific research area, a number of contributions from the most prominent, worldwide, research projects that are concerned with examining a number of computing and information systems issues of importance to manufacturing were evaluated eg CIM-QSA (Kosannke 1990; Jorysz and Vernadat 1990; Klittich 1990). Company research and development programmes in the field of integrated systems were also assessed and examples of the use of relevant concepts and principles were identified for incorporation into both the author's and the ACME team's work, with the aim of providing an effective and usable methodology.

2.3 Data Collection and Company Visits

Concurrent with searching the literature and defining the field in theoretical terms, an important part of the research involved undertaking fieldwork visits to conduct interviews with selected personnel of a number of manufacturing companies. The purpose of
these visits included investigating the factors that were causing CAPM failure and to identify examples were such failure had been avoided through the implementation of best practice. The following companies were visited by the ACME team (Interim Report 1989):

Figure 2.1
Companies Visited

- BICC Citec;
- British Aerospace;
- Coutant Electronics;
- DuPont;
- Graphic Electronics;
- Hitachi;
- IBM (Greenock);
- ICL (Kidsgrove);
- Ivans
- J&S Marine;
- Mars Electronics;
- ML Engineering;
- Racal Marine Systems;
- Surface Electronics;
- Toshiba;
- Wandel & Goltermann.

In terms of product these companies encompass:

- automotive electronics manufacturers;
- computer manufacturers;
- connector manufacturers;
- defence systems manufacturers;
- instrument manufacturers;
- microwave oven manufacturers;
- PCB manufacturers;
- PCB assemblers;
- signal equipment manufacturers;
- television manufacturers;
- video manufacturers;
- weapons manufacturers;
- marine propeller manufacturers.

Through these visits the author and other members of the ACME team were able to observe CAPM systems in operation and gain an appreciation of the problems and issues associated with production management and the provision of information within this functional
area. These visits, additionally, provided an opportunity to interview the managers responsible for the various aspects of CAPM design, implementation, maintenance and operation.

Both 'focused' and free ranging interviews were conducted, the merits and problems associated with these data collection techniques have been previously reported (Maull 1986). Focused interviews provided an effective means of gathering the quantitative data on the information technology components (hardware, software etc) while more open ended discussions provided a means of capturing some of the richness of the situation and thereby allowing a wider understanding of the problems and issues to be gained. These sessions also facilitated the process of building good working relationships which resulted in confidential data being made available.

Major topics discussed included:

- the history associated with the development of the current CAPM system;
- the level of integration and the interfaces to wider manufacturing and business systems;
- the kind of computer support/information systems required for business planning and production management activities;
- important organisational and attitudinal issues;
the complexity and dynamic characteristics of the CAPM implementation environment and the wider system environment.

A summary of some of the CAPM systems of the company's visited are contained in Appendix G.

Data was also collected as a result of companies making available in-house documents including consultants' reports, policy documents and relevant memoranda. In chapter three the results of the survey of the electronics sector carried out by Coopers and Lybrand for ICL is discussed as an example of such a document.

Interviews and discussions were also held with members of the collaborating companies who supplied CAPM systems and consultancy services. These discussions were used by the ACME team to present the current research findings and thereby provided an opportunity to gain valuable feedback from senior managers, all of whom had considerable experience and expertise in the design, implementation, marketing and operation of CAPM systems. In addition, the suggestions and insights put forward by these people provided a valuable source of knowledge for progressing the conceptual development of the methodology.

Close co-operation through out the period of the research with other academic groups undertaking research on aspects of CAPM design and implementation, eg Bessant and Lamming (1989), Muhlemann, Price and Sharp (1989), Hollier and Barber (1989) further enriched the
findings. A number of visits and discussions with the Bradford CAFM team lead by Muhlemann, Price and Sharp (1989) were of particular relevance to the author's work. The team were involved in developing a highly flexible CAFM package (ELMS 1990), based on the fourth generation language Datafit, capable of being modified in response to the changing production management requirements of small to medium sized enterprises (SME's).

2.4 Continuous Validation
One of the principal strengths of the approach concerned the continuous evaluation of the ideas and hypotheses generated by the research team. This was achieved by presenting these ideas and hypotheses together with the findings from the in-company data collection and the potential solutions to the CAFM problem as they emerged to collaborators, users and other academics. This ensured that progression of the methodology was subject to regular academic review to ensure it remained theoretically sound. Regular reviews by industrialists ensured that these ideas were presented in a usable and practical way.

2.5 Analysis and synthesis
In-company fieldwork provided data on CAFM systems failure. Analysis of this data was subsequently undertaken to identify the causes of CAFM systems failure. The theoretical analysis stage sought to identify appropriate concepts, approaches and strategies for overcoming the difficulties and from this a theoretically sound base
was established from which the work of developing appropriate CAPM methodology, by both the author and the ACME team, proceeded.

This dual approach of theoretical analysis and in-company fieldwork was perceived to offer the most effective way of bridging the gap between theory and practice. For example, chapter three describes the distinguishing features of the electronics sector and explains how these characteristics set the general requirements for a process based CAPM methodology. The focus of concern was subsequently widened from the electronics sector in order that a generic framework could be provided, applicable to all manufacturing sectors. Chapter four provides detail on CAPM systems and in chapter five the causes of CAPM systems failure are highlighted. These causes of failure set the requirements for the ACME team and much of the author's work. The requirements are examined in detail in chapter six and the overall CAPM methodology derived to meet the requirements is presented in the following chapter. Chapter eight explains the requirements specific to the author's work on the computing and information aspects of CAPM systems. Chapter nine presents the solution to these requirements and discusses how the author's work integrates with the overall CAPM methodology.

2.6 Dissemination and Commercial Exploitation

The success, acknowledged contribution and commercial value of the work carried out by all the members of the ACME team, and principally Professor D R Hughes and his co-grant holders in leading the team, can be judged by the way it has been received both by the academic
community and industry. The results of the CAPM work, including the authors initial work on computing and information infrastructures for CAPM systems and the contribution throughout the last 3 years, have formed part of the methodology named Stratagem which has been sold commercially for use by IT Partners (Stratagem 1990).

2.7 Conclusion
This chapter has described and explained the research methodology devised and employed in the author's work as well as for the overall ACME project. In particular, the use of theoretical analysis for evaluating the relevance and appropriateness of concepts, principles and strategies for the analysis, design and implementation of computer based information systems such as CAPM has been explained. The data collection aspects of the research through company visits, and the subsequent analysis of this data, has been presented as one of the key areas of the research. Exposing the findings from the research to continuous validation from collaborators, the academic and user community and the suppliers of software and services has been described and its importance explained for progressing the CAPM methodology through all stages of its development.

Chapter three builds on this chapter by considering the electronics sector in detail and the characteristics of the sector that determined the type of CAPM methodology required for both the ACME team's work and for the author's specific work on the computing and information systems aspects of CAPM.
CHAPTER 3

THE ELECTRONICS SECTOR

3.1 Introduction

This chapter examines the electronics sector in order to identify its nature and distinguishing characteristics and thereby provide some understanding of one important environment within which CAPM systems are being designed, developed and operated. The electronics sector was perceived to represent the extreme edge of complexity and rapid change. By investigating the most difficult problem context for CAPM it was hoped that the insights gained would be equally applicable to the less complex and dynamic sectors, thereby permitting the development of a general, generic, methodology capable of coping with the range of conditions that cover all sectors of manufacturing.

The first part of this chapter deals with the problem of segmenting the electronics sector and discusses the results of the investigation into a number of classification schemes developed for this purpose - including one by Coopers and Lybrand for ICL.

The second part of the chapter discusses the nature of the environment which currently confronts and frustrates CAPM system designers and production managers who operate these systems. The implications and challenges this poses for the designers of CAPM systems and for the author and ACME team engaged in the development
of an effective methodology to overcome these difficulties are discussed.

3.2 Industrial Classification

In order to develop an effective methodology capable of application across all sectors an important requirement was to understand in detail the nature and composition of the most extreme example, the electronics sector. Of specific importance to both the research of the author and the ACME team was an understanding of the extent to which firms exhibit homogeneity, for this has a bearing on the type and nature of the methodology required. For example, if the characteristics of large numbers of companies, or groups of companies within the manufacturing sector exhibit significant similarities in the technologies and practices they employ then it may be possible to develop a methodology which has widespread applicability through examining, in depth, a limited number of companies and then extrapolating for the rest as a whole. A number of major, contingency based, studies in the 1960's and 1970's, notably Burns and Stalker (1961) and Lawrence and Lorsch (1967), sought to verify the existence of such a model. However, if the degree of homogeneity is small, a methodology developed by considering only a limited number of companies is unlikely to be appropriate to many other companies and therefore its general applicability and usefulness are limited. A radically different methodology is therefore called for.

This section summarises two studies that have attempted to segment the electronics sector. Both of these used the Standard Industrial
Classification scheme. The reader is directed to the 1989 CAPM Interim Report for a more comprehensive account of this aspect of the work.

The first study arose from the work carried out by the Engineering Industries Training Board, and was based entirely on the standard industrial classifications. The second study comprises a contract of work undertaken by Coopers and Lybrand for ICL in 1988. They extended the first study by introducing additional variables into the analysis. In addition, the author extended this aspect of the research by examining a number of additional studies in the field of micro-economics that also addressed the issue of homogeneity, and that ranged in scale from plant by plant to international comparisons. This was undertaken to determine if anything could be inferred concerning the nature of manufacturing generally and thereby widen the applicability of the author's work. The major studies by Baldwin (1990), Caves (1990), Green and Mayes (1990) were used for this purpose and the findings are reported in section 3.3.
3.2.1 Segmenting the Electronics Sector by Existing Schemes

The following groups of the Standard Industrial Classification were used by the Engineering Industries Training Board (EITB 1985) to segment the electronics sector:

AH 3301 Office machinery;
AH 3302 Electronic data processing equipment;
AH 3441 Telegraph and telephone apparatus equipment;
AH 3442 Electrical instruments and control systems;
AH 3443 Radio and electronic capital goods;
AH 3444 Components other than active components, mainly for electronic equipment;
AH 3453 Active components and electronic sub-assemblies;
AH 3454 Electronic consumer goods and other electronic equipment.

However, it was discovered that for the purpose of this research there were a number of problems with this classification scheme. The first concerned the composition of the scheme. Certain commonly accepted electronic goods such as electronic musical instruments and electronic toys are omitted from the above list. Typewriters, staplers and other non-electronic goods are, however, included. In addition the classification scheme does not take account of important manufacturing characteristics such as plant size, markets, product volumes and variety, manufacturing control philosophy or the technologies employed. These variables are extremely important and have a direct bearing on the development of any CAPM systems. Consequently, segmentation based purely on industrial classification would appear to be too broad to be of direct use for the purpose of...
this research and its aims and objectives. This problem has been encountered by other studies, notable Green and Mayes (1990).

A further investigation of the following major sources of data on the electronics sector, the Mackintosh Yearbook of Electronics data (1987), the Industrial Performance Analysis (1987) and Soete's Technological Trends (1985), although employing different classification schemes, never-the-less, displayed similar problems and were therefore of limited use only for this research.

3.2.2 ICL's Electronics Market Segmentation Project

In 1988 ICL, in conjunction with Coopers and Lybrand, undertook a major project to determine if the electronics sector could be segmented and if any inferences could be drawn about company size and the manufacturing applications required - including CAFM systems.

Their initial analysis used 22 areas of the Standard Industrial Classification scheme and small companies were eliminated from consideration because they were not regarded as potential customers. Of the remaining companies, the total in each of the 22 areas ranged from 0 to 30 with the average being approximately 12. Further differentiation of these areas on the basis of production mode - batch, repetitive, bulk, project, configured and FMCG (fast moving consumer goods) - and by the type of systems installed - production control, stock, CAD etc resulted in a very small number of companies in each group. Even when smaller companies were later included it did not significantly increase the numbers in each group. This provides some evidence and support for the notion that heterogeneity is a
significant characteristic of company's within the electronics sector.

Due to the inadequacies of the previously discussed classification schemes for the purposes of this research, the scale of analysis was reduced to the level of the firm. Firm by firm comparisons were carried out by visiting individual companies, conducting interviews and analysing the result of the data collected. Over twenty firms were visited by the research team and the author was involved in a number of these. The findings support the proposition that firms tend to exhibit heterogeneity and, specifically, that even companies operating in very similar markets apply different manufacturing control philosophies.

For example, one company organised their factory in a process layout and controlled it according to a traditional push (Browne, Harhen and Shivnan 1988) philosophy. Another company adopted a flow line layout and controlled this using materials requirements planning (MRP) with lead times and safety stock approaching zero. Their strategy incorporated many of the features of just-in-time manufacture (JIT) including continuous improvement, total quality management (TQM) etc (Interim Report 1989).

When products and processes were considered, companies in the electronics sector appeared to exhibit sufficient heterogeneity to make individuality a working assumption. This important factor was therefore given full attention and taken fully into account in the
development of the CAPM methodology by the ACME team (Hughes, Maull, Childe and Weston 1990). The implications of this are discussed more fully later in this chapter.

3.3 Supporting Studies

A number of other studies were examined to substantiate the assumption of heterogeneity in the electronics sector.

Much of the work in the discipline of micro-economics has recently focused on comparing the performance of individual companies, industrial sectors and at national and international levels. Green and Mayes (1990) undertook a major study which focused on the technical inefficiency of manufacturing in the UK. The results of this study were based on a statistical analysis of data for 19,023 establishments in 151 industries. The objective of the study was to estimate the technical inefficiency in each industry and explain the variance resulting from "the unobservable random factors". Similar studies have been undertaken in the US (Caves, 1988; Caves and Barton 1990), Australia (Harris 1989), Canada (Baldwin 1990), and Norway (Torstein and Forsund 1990).

The inability to estimate any measure of technical inefficiency for a large proportion of industries was partly attributed to the fact that many of these single industries were in fact a collection of heterogeneous sub-industries and firms.
Many studies have sought to identify the causes of variance in the performance of firms, sectors and national economies. The traditional, neo-classical, economic model assumes that perfect competition prevails (Lipsey 1978) and results in firms employing identical production functions ie the same mix and ratio of factor inputs (land, labour, capital) within any given industry. "Technical efficiency" refers to firms making the best use of its factor inputs and "allocative efficiency" is described as occurring when a firm employs its inputs in the correct proportions. "Most studies of industrial performance ignore the existence and diversity of productivity of firms within an industry" (Baldwin 1990). Baldwin attributes the cause of this to using the industry scale as the level of analysis. This tends to mask the underlying differences of firms which make up the industry and instead of acknowledging this, the notion of a representative or average firm is assumed. Reid (1987) points out that the concept of the representative firm has dominated the more complex notion of the diversity of firm performance.

The work of Liebenstein (1966; 1973) on X-inefficiency challenged the conventional neo-classical paradigm by arguing, from observation, for the existence of firm heterogeneity. X-inefficiency was the concept devised to explain the observed variance in performance from firm to firm. Liebenstein argued that this variance could be explained as resulting from the existence of a level of profit "slack" and the use of this "slack" by management in pursuit of their own goals. In essence, the achievement of profit maximisation by the firm was distorted by management goals which differed from this unitary,
profit maximisation, objective. In times of economic hardship the level of "slack" was reduced as firms imposed tighter control by reducing, or eliminating, financial incentives and bonuses. Similarly, in times of boom the level of "slack" was allowed to increase. The apparent differences in company productivity is therefore explained by Liebenstein as resulting from the differential use of this "slack".

The result of this on-going debate has been the development of an impressive body of literature and numerous studies. The results are as yet inconclusive and much controversy surrounds the phenomena, however, the statistical models used to investigate the existence of technical or allocative efficiency exhibit large residual values which are difficult to explain without the existence of heterogeneity. The results therefore, in part, support the notion and validity of heterogeneity as a valid assumption.

3.4 Implications for the Development of a Generic Methodology

It would appear from the studies discussed in the previous sections that segmenting the manufacturing sector, according to product, industrial classification, size or mode of production serves no useful purpose for the author's research. The aim of the research is to develop an original and theoretically sound methodology which has practical value for the design of computing and information infrastructures for CARM. Due to the apparent existence of heterogeneity, segmenting the manufacturing sector by any of the
above means does not result in a sufficiently large group of similar company types.

The assumption therefore is that companies are idiosyncratic to the extent that they have different CAFM requirements. Consequently, in developing a methodology for CAFM that is generic, this important factor must be given full consideration. The issue of idiosyncracy raised a number of important questions for the author and for the ACME team. What kind of methodology was needed to accommodate this requirement? Could a methodology be developed to cope with the diversity of requirements?

In answer to the first of these questions a useful approach perceived by the ACME team was to develop a methodology which was not dependent on the characteristics of a particular company or its environment, but on the process of CAFM design and implementation itself, thereby focusing on the element which transcends these variations. The development and composition of the process based CAFM methodology is discussed in detail in the following chapters and specifically chapters six and seven.

3.5 Environmental Characteristics

From a survey of the available literature a number of assertions would seem possible concerning the nature of the environment faced by manufacturers, the degree of national and international competition and the various ways in which companies are responding to this.
Worldwide it would appear that a new manufacturing paradigm is emerging in response to the complex, dynamic and highly competitive environment which many companies now face (Jones 1989; Browne, Harhem and Shivram 1988; Rooban and Abbing 1988; Bananson 1989; Thomson and Graefe 1989). Milgrom and Roberts (1990) state that "manufacturing is undergoing a revolution. The mass production model is being replaced by a vision of a flexible multiproduct firm that emphasises quality and speedy response to market conditions while utilising technologically advanced equipment and new forms of organization".

They continue by explaining that the transfer line approach and the specialised, single purpose equipment for mass production which influenced generations of industrialists and itself changed the face of manufacturing, is now being superseded by flexible machine tools and programmable, multi task equipment. Hounshell (1984) provides a documentary account of the origination of the transfer line approach by Henry Ford.

The evidence arising from this body of literature indicates that the volatility and unpredictability of consumer demand is one of the principal forces determining this change. In response to which, many manufacturers are attempting to dramatically reduce product development times in order to maintain competitiveness through being "first to market".

At the same time supply side forces brought about by the rapid reduction in the cost, and increases in the technical capabilities,
of many technologies (processes, materials, information etc) are providing major cost reduction, improved responsiveness and quality opportunities for companies willing and able to invest (Hughes, Weston and Maull 1988).

Valery (1987) points out that use of these technologies permit the efficient production of very small batches. Wright and Bourne (1988) report that in a recent survey of aerospace 8.25% of all batches were of size one and 38% were sixteen or less. Milgrom and Roberts (1990) reports that in an Allen-Bradley Company plant making electric controls, production amongst its 725 products and variations can be switched with an average changeover time for resetting equipment of six seconds, enabling it to schedule batches of size one with relative efficiency. Abegglen and Stalk (1985) and Valery (1987) comment that many manufacturers now plan production jointly with their suppliers and, through the use of on-line data communications, inventories of component orders and supplies can be replenished with "just-in-time" deliveries. Milgrom and Roberts (1990) point out the importance of information technology which, complementary with flexible production, is needed to realise the business benefits.

In taking advantage of the opportunities to be derived from the advances in technologies Milgrom and Roberts (1990) point out the need for change on a "trajectory" rather than incremental level. "Successful moves toward the factory of the future are not a matter of small adjustments made independently at each of several margins, but rather have involved substantial and closely coordinated changes
in a whole range of the firms activities" (Milgrom and Roberts 1990). Henkoff (1988) remarks "Don't just change selected parts of your factory like many manufacturers have done. To truly boost efficiency ... it's necessary to change the layout of the entire plant". In discussing the adoption of CIM, Valery (1987) states that "nothing short of a total overhaul of the company's strategy has first to be undertaken". Similarly, Kiechel (1988) notes: "To get these benefits (of more timely operations) you probably have to totally redesign the way you do business, changing everything from procurement to quality control".

The market trend appears to indicate that even higher levels of competition are likely and therefore it is postulated that possessing a capability to respond to these opportunities will be crucial for survival. Increasingly, manufacturing companies will need to shorten new product introduction times, reduce manufacturing cycle times and reduce sales and distribution times. The difficulties faced by the many UK companies currently striving to achieve this capability and modernise away from the old paradigm of economies of scale, large inventories and inflexible equipment and practices appears formidable. More and more companies will find they need to plan shorter production runs on a wider range of products and the implications of this for the computing and information systems for CAPM are extensive. Firstly, higher levels of coordination will be required to enable this new manufacturing capability to be realised. This will require more information integration between functions such as CAPM and other business functions and even external electronic
linkages to supplier firms - a move towards computer integrated manufacturing. In addition the business flexibility required will have to be matched by equivalent flexibility in the processing, storage and retrieval capability of the supporting computing and information systems.

3.6 Bringing About Change
The responsibility that jointly rests on British management, academic research institutions and Government to bring about a reversal of the recent decline in the UK's manufacturing base is enormous. The work being carried out through current research initiatives, eg ACME, have begun to unearth many of the root causes of the problem associated with CAFM and practical solutions are now beginning to emerge. An important finding has been that the indiscriminate installation and implementation of technology, without a well thought out strategy to harness the technology effectively and thereby raise competitive performance, is insufficient to bring about a major revitalisation of the many parts of the UK's manufacturing sector that are being out performed by international competition (Tranfield and Smith 1990). A number of world class manufacturing companies such as IBM and Hewlett Packard have recognised, and understood, the process of change, the extent of change required and the potential benefits that information technology has to offer if it is harnessed in a strategic and well thought out manner. However, for many UK companies, change on this scale will at best be painful and at worst impossible or only partially successful without the availability of practical and usable
methodologies which offer guidance as well as addressing the competitive needs of a changing environment.

3.7 The Need for New Methodologies

Change on a national scale requires the availability of generic methodologies which have been developed from a sound theoretical base, incorporate the very best in current practice and been designed for practical application. Methodologies must be capable of addressing the many technological, organisational and business factors that are necessary to develop solutions that not only solve single point problems but contribute towards raising company performance and competitiveness. Tools and techniques incorporated in such methodologies must be carefully selected to ensure that they are both appropriate for the task in hand and are presented in a usable way. Many system design methodologies, for example, embody normative assumptions which drive system designers towards exploiting technological possibilities rather than focusing on providing solutions in line with business requirements. This technologically deterministic approach has contributed significantly to the many system failures that have, and are, occurring today.

In addition, the methodologies must be capable of delivering solutions that provide an appropriate level of resilience to ensure survival long term and avoid the problem of premature failure, prevalent in today's dynamic and unpredictable environment. Infinite flexibility is, however, both inappropriate and exorbitantly
expensive. A resilient capability, therefore, must be sought that matches cost constraints.

3.8 Conclusion
This chapter has examined the electronics sector in order to identify its nature and distinguishing characteristics. The relevance of the findings for the development of a CAFM design methodology have been discussed. Specifically, the dynamic characteristic of the sector, the constantly changing consumer demand and the rapid developments in information, process and material technologies, all appear to raise issues concerning the ability of existing CAFM systems to survive. Although the incorporation of many of these technological developments allow the efficient manufacture and control of new products, themselves necessary to maintain and sustain a competitive advantage, the issues discussed give cause for concern and point to the difficulty for CAFM systems to survive in this turbulent environment. Are CAFM systems capable of being adapted as new requirements emerge? The findings from this chapter indicate a requirement for flexibility in order to provide the resilience necessary for survival long term. Chapter five therefore examines this issue further by investigating in detail the causes of CAFM systems failure.

This chapter has also highlighted the fact that companies within and across sectors appear to have idiosyncratic requirements as a result of the heterogeneous composition of manufacturing generally. What kind of methodology is therefore required to deal with the range of
likely CAPM problems? At this stage of the research the ACME team began investigating the notion of a process based methodology. This involved researching the common features of system design and implementation and the ways that these features could be applied to address the issues identified as significant and causal of CAPM systems failure. These common features were termed processual because of their focus on the way, or processes, involved in systems design and implementation which transcend company type and any particular technique. The CAPM methodology takes the user through a process which results in the identification and documentation of individual company CAPM requirements. The CAPM methodology is fully discussed in the proceeding chapters.

Chapter four builds on the work accomplished so far by investigating CAPM systems in detail in order to determine their capability to cope with the dynamic environment prevalent today. Chapter five then focuses on identifying the specific causes of CAPM systems failure. Company field work investigations were used for this purpose together with research into the approaches currently adopted for developing CAPM systems.
CHAPTER 4

CAPM SYSTEMS

4.1 Introduction

In the first part of this chapter a number of definitions of CAPM systems are discussed before examining some of the crucial issues surrounding their design and installation. These issues principally concern the problem of determining the functionality of the CAPM system that is required, deciding on those functions and activities that may benefit most from computerisation and selecting, amongst the many software options, a package which most closely matches the desired requirements.

The type and extent of computer support is discussed and this provides an introduction to the more detailed and extensive discussion contained in chapter eight on the components of the CAPM infrastructure and the techniques devised by the author to address issues such as those stated in the previous paragraph.

Integration and the interfacing of CAPM packages with other systems is discussed in this chapter together with the notion of "fit" and the role of manual policies, practices and procedures (PPP's). This serves to provide a context for chapter five in which the results of analysing the data collected from the fieldwork visits are discussed and by which it was possible to identify specific causes of CAPM systems failure.
4.2 CAPM Systems

Waterlow and Monniot (1986) define CAPM as "all the computer aids supplied to the production manager". They describe the three production management information processing activities as specification, planning and control and recording and reporting. Specification includes "ensuring the manufacturing task has been defined and instructions produced". Planning and control includes "planning the timetable, adjusting resources and priorities and controlling production activity". Recording and reporting covers "production status and performance for liaison with other departments, and future use in specification, planning and costing".

In one of the more recent publications to emerge from the ACME initiative, CAPM systems were defined as "the use of computer-based information systems to support management functions and to coordinate flows of orders, materials and finished goods" (ACME 1990).

There are a diverse and varied number of CAPM definitions and models all of which aim to place this system within a framework of the total manufacturing and organisational system. The view of the ACME Directorate (1990) is that in relation to the hierarchy of manufacturing systems CAPM falls below the manufacturing system and its attendant logistical structures (e.g. make or buy policy), and above short term scheduling at the cell level.

Browne, Harhem and Shivnam (1988) describe the production management system and related activities within a Computer Integrated
Manufacturing (CIM) framework. Within this framework the Production Management System (PMS) is defined as the decisions concerned with what to buy and make and the Production Activity Control (PAC) system as concerned with managing "the flow of material and the associated flow of data through the plant". The view here is that the PAC system "plays a particularly important role within the Computer Integrated Manufacturing (CIM) system...it is through the PAC that the PMS is linked to the factory floor".

This highlights some of the controversy surrounding the definition of CAPM systems, their composition and complexity. ACME (1990) report that emerging from the initiative is an understanding that "CAPM is a diverse bundle of elements consisting of:

- a model of relationships between functions with various forms of control embedded;
- a mapping of planning and control tasks onto organisational roles and strategic objectives;
- a collection of supporting policies, practices and procedures, sometimes called CAPM infrastructure;
- a software structure (whose functionality is often ill-defined;
- a database" (ACME 1990).

They continue by pointing out that the central task of CAPM systems is to coordinate order getting, supply getting and design and manufacturing functions. In doing this they argue that management decision making is crucial to realizing manufacturing strategy and
that given the differences in organisational culture, the style of this coordination will vary from company to company.

Browne, Harhem and Shivnam's (1988) model of CAFM systems discriminates between the decision making element and the information and material flows and they attempt to explain how the various elements integrate together. Jones, Barkmeyer and Davis (1989) similarly attempt to provide a model for CAFM which distinguishes between the various components as well as explaining their interconnections. They again define the production management system within a CIM framework and distinguish between the production management system, the data management system and the communications system. The production management system is defined as including "all functions related to the order, design, fabrication and inspection of parts". The data management system provides support to all the production management functions through the "timely access to all essential data" and the data communications system is concerned with ensuring the "reliable transmission of messages between computer programs".

This model provides a useful framework, particularly by highlighting the complexity and highly integrated nature of CAFM systems.

From the discussion so far an understanding can be gained of the complexity of CAFM systems and their highly integrated form, comprising of a technological component and a decision making component which are both focused on ensuring that the appropriate
production management tasks are carried out efficiently and
effectively, in line with strategic, competitive objectives within a
particular company culture.

In adopting a holistic and company wide CIM perspective Rzevski
(1987) distinguishes between the physical transformation system which
processes raw material into goods, the information processing system
which processes internal and external information and the managerial
decision making system. This work provides a valuable model to
demonstrate the integration between the material transformation,
information and decision making elements of the total system.

Doumeingts (1985) writes that the production management system is
"certainly the most complicated function of the firm". He goes on to
say that CAFM covers on the one hand technical, social and human
areas and on the other it forms a group of strongly interrelated
functions. "Thus the various components must be harmoniously
integrated, which appears very difficult as relations between the
components have a conflicting nature." (Doumeingts 1985).

CAFM systems originated "in the early 1960's when large manufacturers
and computer suppliers promoted concepts and developed software for
production planning and control" (ACME 1990). It is often
acknowledged (Short 1990) that UK industry lags behind the USA and
Japan in adopting these technologies but Tranfield (1990) points out
that the recent upsurge in investment in CAFM demonstrates that
adoption is not the problem but successfully exploiting and
implementing such an integrated system is. "The most frequently cited difficulty is that of integrating the system into business decision making and company organisation" (Tranfield, 1990).

This issue of complexity and the integrated nature of CAPM systems initially provided a hurdle which needed to be overcome for the research team and the author in developing effective CAPM methodology. The particular issue which proved problematical concerned determining the scope of the work, for there was a danger that proceeding to develop a CAPM methodology without considering the effect on the whole organisation, and the technical and human sub-systems, would only result in a sub-optimal solution. This issue of reductionism has been discussed at length by Checkland (1981) and Wilson (1984) and the body of knowledge known as systems theory developed to address this.

It was decided that the risk of creating a methodology which could only deliver a sub-optimal solution was unacceptable and therefore the scope of the work by the ACME team was widened. This is reflected in the CAPM methodology published to-date (CAPM Interim Report 1989; 1990; Maull, Hughes, Weston and Childe 1990; DTI Roadshows 1990; Stratagem 1990) which accommodates other functional areas and systems and addresses manufacturing strategy. The focus of concern of the ACME team's work is still CAPM but by adopting a systems perspective the danger of sub-optimisation has been avoided.
The findings of recent research (Milgrom and Roberts 1990) backs up this approach by noting that a holistic change model is imperative if major benefits are to be realised.

This same issue arose for the author for clearly the computing and information systems aspects of CAPM are intimately woven into the wider computing and manufacturing systems generally. This aspect is more fully addressed in chapters eight and nine but, briefly, the author's work on developing a computing and information infrastructure for CAPM necessitated research into the hardware and software requirements and technological issues of compatibility, standards, architectures and information strategies. This was required in order that the technological integration aspects could be fully addressed, as well as devising means to integrate these with the manual production management tasks. This would help to integrate the CAPM system overall into the organisational design requirements by considering the production management processes and tasks and the software as interdependent elements. In addition, by relating the CAPM system to the business and manufacturing strategy, this would enable the system potential to be fully exploited and ensure the development of a highly resilient CAPM capability.

4.2.1 The Nature and Extent of Computer Support for CAPM systems

The potential areas that CAPM systems may help production managers with their information processing requirements were described by Waterlow and Monniot as transaction processing, management information and automated decision making. Transaction processing
involves "maintaining, updating and making available specifications, instructions and production records" (Waterlow and Monniot 1986). Management information provides the "information for exercising judgments about the use of resources and customer priorities" (Waterlow and Monniot 1986). Automated decision making concerns "deriving production decisions using algorithms" (Waterlow and Monniot 1986).

These information processing activities support a number of broad production management functions including the following which were derived from discussions with CAPM users, consultants and suppliers of systems and software (CAPM Interim Report 1989).

**Figure 4.1**
Production Management Functions

Master Production Scheduling
Stock recording (bought out parts)
Stock recording (finished parts)
Capacity Planning
Detailed Scheduling
Process Planning
Materials Requirement Planning
Order Control
Bill of Materials processing
Monitoring Work in Progress
Costing
Forecasting
Performance Analysis
Purchase Order File
Sales Order Processing

This aspect of the research highlighted the point that perceptions differ over the precise functional composition of CAPM systems. The problem concerned both semantics, i.e different names used to describe the same function, as well as that of establishing the CAPM
boundary to demarcate this from the other CIM sub-systems. Overcoming these problems has been helped by the ACME Directorate coordinating a programme of dissemination of the CAEM initiative findings amongst the academic, supplier and user communities (ACME 1990).

The set of activities shown above were, nevertheless, useful for providing a framework from which the author could investigate a number of CAEM packages to see if any general conclusions could be drawn regarding their functionality, flexibility and features.

4.3 CAEM Packages

During the past few years UK manufacturers have "invested at an increasing rate in software that helps them to manufacture goods faster, at a lower cost, more reliably and more accurately.... manufacturing management is the fastest growing sector, outselling the next most popular category (mechanical design) by more than 50 percent" (Benwell 1988). This is further supported by Kearney (1989).

Despite the level of investment in this technology widespread failures have been reported (Tranfield and Smith 1990). Of particular interest to this research is the problem of selection - ie the matching of CAEM software against requirements. This is considered by a number of authors to be a particularly important, but as yet, inadequately addressed area. (Waterlow and Monniot 1986; Doumeingts 1985).
The author examined the features of a large number of the most widely used and available CAM packages to assess what degree of commonality existed eg in terms of their functionality, flexibility and compatibility with other systems. The degree to which the various manufacturing control philosophies could be supported, either singularly or simultaneously, was also investigated because of the interest in the comparatively recent emergence of other production control techniques such as just in time (JIT).

In line with the general, process based and user led ethos of the ACME team's work, packages were assessed by the author at the module level and in terms of hardware requirements, flexibility potential etc. The results of this investigation are summarised in appendix H which provides details of a number of the more popular of the packages to illustrate their various features and to provide an understanding of the rationale behind the author's approach.

An approach at the more detailed level of data structures or processing logic would both be incompatible with the aims of this research to provide a user-led methodology, ie one that places the onus on the user to make conscious decisions about the configuration of the system, and unrealistic as this information is restricted by the vendors. What is required is a framework of general principles from which the user can make an informed decision of the most appropriate package and the enhancements and modifications needed to provide a good fit both now and in the future.
Given the variety of company contexts and their resulting idiosyncratic requirements, as previously reported, the process orientation demanded that a general framework be developed consisting of tools and techniques for assessing candidate packages and for selecting the most appropriate one. The CAFM software market is highly competitive, comprising of rapidly evolving products. The number of CAFM software packages currently available exceeds 150 (Industrial Computing 1990). Any direct comparison of the set of products would only provide a static, limited and inappropriate framework. The complexity of the products in terms of the number of production management functions and activities supported, the complex algorithms embedded in the functions and the technological features of the packages negates the easy construction of any but the most broad of classification scheme. Such broad classifications and inter-package comparisons are widely available (Industrial Computing 1987; 1990 a; b; Benwell; 1988). The author therefore concentrated on distilling the essential features and identifying the essential criteria by which users could identifying candidate packages and then, on the basis of a more detailed analysis, determine the most suitable package in line with their particular requirements.

The author's work therefore focuses on the process of defining the CAFM requirements, deriving a functional specification to meet the requirements, selecting appropriate packages, customisation and determining the overall composition consisting of the manual and computerised components.
4.4 Technological Factors

From investigating the packages and through discussion and interviews with the users, consultants and the suppliers of software and systems, the author began to develop a short list of suitable technological factors that could be used as a basis for defining the hardware and software specification of the CAPM computing and information systems infrastructure. These are summarised as follows and provide one important aspect of the total infrastructure approach detailed in chapter nine.

- **Compatibility and portability**, i.e. the hardware that the CAPM software will operate on, IBM, DEC, HP, ICL etc. The importance here is for compatibility to ensure that the chosen platform is compatible with those already in existence in the company for future integration purposes. The programming language used is also of importance for reasons of compatibility and flexibility. Fourth Generation Languages (4GL's) provide a flexible capability because they are more easily modified and therefore this type of software offers the greatest potential for enhancing the flexibility of the CAPM system. A growing number of packages are now being developed from 4GL's;

- **The potential for expanding** the system is also of importance for reasons of flexibility. Some CAPM systems may be configured as a start up system with a single micro and then be subsequently expanded to a multi-user mini system;
. Package enhancement and forward and upwards compatibility are also important for flexibility reasons. Upwards compatibility allows the original software to be run on a larger machine and forwards compatibility refers to the original software being supported by new hardware models.

. Packages vary in design and suitability for different modes of production i.e discrete parts manufacture, make-to-stock, make-to-order, flow line/repetitive manufacture, batch production;

. Packages also differ in the manufacturing control philosophy, or combination of control philosophies they support. i.e MRP, JIT/Kanban, MRP/JIT, Optimised Production Technology (OPT);

. Although there appears to be some commonality in the modules or tasks supported by the packages at a broad level of analysis, there is no standardisation. The issue concerns the way the tasks are arranged into modules and the way they are processed. In addition there are differences in the degree to which these modules are integrated and the extent to which the package can be extended into a complete CIM system at a later date;

. Technical precedence, or the order in which the modules have to be implemented is an important factor (Hollier and Barber, 1989).
4.5 Computerised or Manual Production Management Systems?

One of the principal issues identified from both the literature, and as a result of the data collected from company visits, concerns determining the most appropriate combination of computerised and manual policies, practices and procedures (PPP's) which make up the total CAPM system. An additional issue of importance concerns implementing policies to ensure that the task of housekeeping and maintenance of the CAPM system is carried out efficiently and effectively (ACME Conference 1990; CAPM Internal Report 1990).

These issues will now be discussed, beginning with determining the composition of the CAPM system.

Determining how the CAPM requirements can be best met, by computerised or manual means, is an important aspect of designing a CAPM system and requires consideration of all the various technical, economic, business and social costs and benefits. It may be technically feasible to automate all the required functions of a CAPM system but the cost may be prohibitive. In addition the benefits to the business in terms of effectively providing information for planning and controlling the production management function may well be equally met with a partly manualised system. For example a partly manualised system may be able to provide reliable and accurate information in the time frame required and fully computerising this would only lead to an improvement in the speed of information provision.
It may also be more beneficial, for socio-technical design reasons, to include manual processes in the overall CAPM system design and thereby ensure that both the technical and the organisational requirements are fully integrated.

Any decision taken concerning the level of computerisation should only be made on the basis of sound principles. However this is not a straightforward issue for the degree to which CAPM functions are individually or collectively automated varies. Jones, Barkmeyer and Davis (1989) view is that executing these functions in a CIM environment means automating each function to the extent possible. However, they acknowledge the difficulty of achieving this.

A requirement for the author's work is therefore guidance on the issue of selecting between the manual and the computerised elements of the computing and information system for CAPM.

Waterlow and Moniott (1986) report that the majority of companies in their study were found to be using CAPM systems for "transaction processing and recording, and simple data aggregation to provide management information". Of these companies, the control algorithms in the software were not relied upon or any attempt made to install systems containing automated decision rules, eg for "finite capacity planning or batch sizing".

This provides some indication of the degree to which CAPM systems are computerised, the degree to which manual procedures are still relied
upon and identifies some of the activities which are not computerised or amenable to computer support. The work emanating from the CIM-OSA programme (MacConaill 1990) provides a clue to the current status of computerisation within CIM systems. Here a distinction is drawn between problems which can be solved deterministically and those which the solution can only be inferred. It is clear from this work that not only the task, but the nature of the task and the decisions surrounding the execution of the tasks are important. If a clear distinction can be made between decisions that are by nature predictable and those that are inferential, then this provides one means of selecting the automated elements of the solution. Of course, and in line with the general ethos of this work, other factors such as the desirability or acceptability of automation may override this rule. In the absence of such, predictable decisions are more amenable to conventional algorithmic solutions, require the processing of data and are therefore more easily automated. On the other hand there are a whole class of manufacturing problems which cannot be solved in this manner and where the required solution must be inferred from the available information e.g. short term scheduling and shop floor control and the execution of many of the day to day decisions within the various tasks of the enterprise (CEN/CENELEC 1989). The system required to solve these kind of problems requires the processing of information rather than data.

Much of the discussion in the BSI standards literature (CEN/CENELEC 1989; 1990) supports this argument, and the solution called for is
the creation of Knowledge Based Systems for the non-deterministic tasks.

For the purpose of this research, however, an assumption was made that the total CAPM system would comprise of some combination of computerised and manual processes. The rational for this is discussed further in section 4.6 but, briefly concerns the need to provide a sufficient level of flexibility so that the CAPM system can be adapted to changed requirements. The view of CAPM systems as comprising of both manual and computerised elements was adopted early in the research study by the ACME team (Interim Report 1989), although the detailed content of the manual functions of the CAPM systems is outside the bounds of this study. Much of the early work on this component can be found in the study by Vowles (1990) and is reported in the later work by Childe (1991). In summary this work provides a model of the CAPM functions, some of which were found to make up the CAPM system in Ivans, a local Plymouth company. This resulted in the development of a task model for use in the requirements definition phase of the overall CAPM methodology. The purpose of the model in the CAPM methodology is for deriving a template of CAPM task requirements, and, therefore a description of the functional requirements of the CAPM system. The task model is, in essence, a generic functional CAPM model which provides a set of related core and dependent tasks that any manufacturing company must perform and related optional tasks that are determined by specific operating conditions.
The task model is at a logical level of detail and the distinction between this, and a physical model, is important. A physical model represents the processes, how the processes are undertaken (by computer or manually) and by whom. A logical model does not describe any aspect of the physical system such as storage medium, indexing, program flows or hardware. Its use is solely as a conceptual model in the initial stages of systems analysis and design. As such it is possible to use the model as a conceptual design tool for evaluating the difficulties and consequences of computerising different configurations of tasks. A number of different CAFM system options can therefore be assessed without constraining the design at this early stage through physical, hardware and software, considerations.

In parallel to the task model, the ACME team developed the concept of production management policies, practices and procedures. These can be conceptualised at a number of levels. Firstly they represent how each function or process is carried out. This may be through manual means or by the use of a computer. Secondly they comprise a set of rules for controlling the housekeeping aspects of CAFM systems eg to enforce the need to maintain data integrity of materials resources planning (MRP II) systems. The PPP's at this level relate to both the technical and organisational systems eg. PPP's may include regular training to ensure that operators understand the need to maintain a high level of data integrity. Thirdly, and at a higher level of abstraction, they can be thought of as providing guidance on the selection of the production management processes themselves, such as
the need to forecast if the production lead time exceeds the delivery time.

The concept of PPP's is worthy of further consideration. The second and third of the above levels, which are of particular relevance to the author's individual work, are now discussed in more detail.

The second level of PPP's associated with the controlling and housekeeping aspects of CAPM system were highlighted at an ACME CAPM research seminar held at Bristol in 1988 (Waterlow and Clouder-Richards 1988).

A number of specific PPP's relating to MRP II systems were discussed and included the following. Firstly the need to ensure that basic and accurate data is available and the disciplines for maintaining data integrity can be enforced. Secondly that the expertise and experience necessary to use such a complex planning and control systems such as MRP II exists. Thirdly that accurate transaction data within each area is input to the CAPM system swiftly and that the necessary links to engineering and inventory status are maintained for the purpose of controlling the bill-of-materials function.

It was also noted at the seminar (Waterlow and Clouder-Richards 1988) that an organisational requirement existed in the form of strong, top down management support and, additionally, that CAPM system functions should be matched to departmental responsibilities. This requirement
highlights the socio-technical design approach needed to develop workable CAPM systems.

An effective project management approach, a modular implementation strategy and clearly identifying individual responsibilities was outlined as crucial for success together with the need for a high level of training and education for all staff involved with the system. Education, it was recommended, should cover details of the complete system, systems facilities, any assumptions made and disciplines involved.

In order to realise the benefits of MRP II Waterlow and Clouder-Richards (1988) recommended that top management commitment to achieving and maintaining a formal planning and control process is of prime importance together with accurate and up-to-date data particularly in the areas of the master production scheduling, bill of materials, inventory status, capacity availability and product routings. In addition they pointed to the requirement for software with a full range of modules, flexible interfaces and a capability to permit modification and ad hoc reporting. They suggest that this capability is unlikely to be developed in house.

Similarly to that of MRP II, FPP's which govern the control and housekeeping aspects of CAPM systems based on different manufacturing control philosophies eg just-in-time (JIT) or optimised production technology (OPT) can be identified.
Just-in-time manufacturing is a control philosophy covering all aspects of manufacturing operations with the overriding aim of producing only as required and with perfect quality and no waste (Waterlow and Clouder-Richards 1988). It is based on a number of concepts including continual improvement, quality and excellence in all phases of manufacturing, removal of waste, system redesign and simplification etc and its successful implementation relies heavily on thoughtful and disciplined shop floor practice. JIT facilitates the implementation of a pull type of control system where priorities are set in response to the actual demand.

In terms of the computing and information aspects, JIT is not a data processing intensive system and shop floor disciplines are far more important. Data is required for the analysis of products and the physical processes and highly complex environments may require electronic monitoring. Software is not an absolute prerequisite for JIT but is required for material procurement. Electronic data exchange (EDI) communications linkages may also be required for placing the purchasing requirements with suppliers.

The shop floor control system for JIT involves the use of Kanban cards. "The Kanban technique controls the initiation of production and the flow of materials with the aim of getting exactly the right quantity of items at the right place at precisely the right time" (Browne, Harhen and Shivnan 1988). All material is pulled into the final assembly lines and all operations are linked to the final assembly lines using a card system. From the assembly lines and from
each work centre, workers go to the feeding work centres to draw standard containers full of parts. In this way work centres are linked together in a chain and the final assembly therefore coordinates the rate at which parts are manufactured throughout the system, extending back to the material supplier.

Kanban uses withdrawal cards and production cards. The withdrawal card is used only for a specific part number and defines "the quantity that the subsequent process should withdraw from the preceding work centre" (Browne, Harhen and Shivnan 1988). The card therefore only circulates between centres - the preceding work centre and the using work centre. The production card is used only at the work centre producing the part and defines the quantity of the specific part that should be manufactured to replace those which have been removed.

Optimised production technology was "initially developed by Eli Goldratt in Israel during the 1970s" (Industrial Computing 1990). It is an approach based on the assumption that the only goal for a manufacturing company is to make money and that all activities in the business are but means to achieve this goal (Browne, Harhen and Shivnan 1988). Net profit, return on investment and cash flow are the "bottom-line" financial measurements used to indicate progress towards this goal. At the operational level, throughput, inventory and operating expenses are the three criteria used to assess the performance of the manufacturing system. Changes in any of these result in changes to the financial measurements mentioned earlier.
The goal of manufacturing, therefore, is to increase throughput while at the same time decreasing inventory and operating expenses.

Ten rules underpin the OPT philosophy (Goldratt and Cox 1984) and "probably the most critical of all these rules relate to manufacturing bottlenecks" (Industrial Computing 1990). The resources used in a manufacturing environment are classified as bottlenecks or non-bottlenecks. Bottlenecks constrain the amount of product that a factory can produce and therefore one of the key rules of OPT is to keep the bottleneck busy. Saving an hour on a bottleneck set-up may save an hour's complete production for the entire system. Therefore OPT aims to maximise the bottleneck's utilisation eg by placing maintenance crews on standby, and by placing quality control in front of the bottleneck.

While bottlenecks need to be tightly scheduled, non-bottlenecks need to feed the bottlenecks just-in-time. OPT based software simultaneously schedules the bottleneck for continuous production whilst switching non-bottlenecks on/off to keep the bottleneck working.

OPT takes a different view, to MRP, on batch size. For a bottleneck, larger batch sizes mean fewer set-ups and more throughput. For non-bottlenecks larger batch sizes mean fewer set-ups but an increase in inventory. For non-bottlenecks, therefore, batch sizes should be kept as small as possible to control inventory and operating expenses.
OPT is a philosophy supported by a software package and the secret algorithms means that there has to be a readiness to follow the dictates of the consultants, hence this is an expensive part of the overall system implementation costs. The functionality of OPT includes a simple bill-of-materials explosion as part of the modelling process, finite capacity scheduling and loading of the bottleneck resources. There is also a pull scheduler for non-bottleneck resources with a bottleneck schedule as a master scheduler and a 'what if' simulation capacity with the modeler separate from the scheduler.

"Data requirements are accuracy of dynamic data, both in terms of numbers and timeliness, and accuracy of bottleneck and near-bottleneck data. Some level of inaccuracy can be tolerated for static data. The majority of OPT implementations have been in conjunction with MRP and electronic data exchange between the packages" (Waterlow and Clouder-Richards 1988). The OPT software distinguishes modelling from scheduling and derives lead times from batch sizes and capacity. Delivery dates are derived from capacity consideration, whilst due dates indicate priority. The software also embodies some JIT ideas, and is the latest in a long line of capacity schedulers.

Implementation of OPT requires a significant capital investment with a typical initial cost of £150,000 with the software rented. Technically OPT has unfriendly software and requires high level of analytical skills to build up and maintain the model. The source code
is unavailable and there is a need to ensure that the OPT model is integrated with the MRP database.

4.5.1 High Level PPP’s

The highest level of PPP’s concern the rules for selecting the functions or processes of the CAFM system themselves. For example, Waterlow and Clouder-Richards (1988) report that although MRP II is conceptually applicable to a wide range of manufacturing environments, eg job shop, batch, flow, cellular. it is most useful in a business context of "multilevel batch manufacture and least useful in continuous high volume flow manufacture" (Waterlow and Clouder-Richards 1988).

Parnaby (1988) has provided valuable insights into the problem of matching manufacturing control philosophy to production mode. He has devised a framework which matches the production characteristics with the appropriate production philosophy. This is based on a Pareto analysis of products made by the factory and by each cell which are then classified according to regular runners, irregular runners and strangers.

Central to Parnaby's message is the creation of a logical simple cellular structure. Product group modules consist of machines, skills or processes grouped in cells according to the routing of a family of parts. A cell is therefore responsible for completing a family of components, a sub-assembly, or the completion of a certain logical stage of manufacturing.
In an environment predominantly based on regular or irregular runner modules, Parnaby proposes the adoption of JIT-MRPI. In a stranger (jobbing type manufacture) Parnaby suggests an MRPII form which explains exactly what has to be done by operators at every stage. Cells are designed on runners with provision for strangers, there is not necessarily a strangers cell.

Another outstanding contribution to the understanding of the applicability of these techniques has been made by De Toni, Caputo and Vinelli (1988). They consider production management systems as consisting of three sub-systems; inventory management, manufacturing priority assignment and material picking and moving, and production planning.

For each of these sub-systems a number of important rules have been derived to ensure that the appropriate technique is selected given the production characteristics. For inventory management they make the distinction between reorder point (ROP) and materials requirements planning (MRP). For ROP, an order for material is placed when the reorder point is reached and this is based on previous consumption or look back logic. In contrast the order for material in a MRP system is determined from forecasts of future needs based on look ahead logic.

De Toni, Caputo and Vinelli raise and explain a number of points based on the value of use, lead time and planning time, frequency of
should be used. If manufacturing is repetitive Kanban should be used and if manufacturing is semi-repetitive Syncro-MRP should be used.

The production planning sub-system can also be classified according to push-pull logic. De Toni, Caputo and Vinelli define push/pull in the classic sense i.e. push means to take action in anticipation of a need and pull means to take action upon a request.

A master production schedule (MPS) which employs some form of forecasting is based on a push logic. Frequently, master production schedules operate on product families in order to delay finalising the final assembly schedule (FAS) as much as possible. When both the MPS and FAS are executed by order of customers they can be associated with pull logic. A MPS carried out by forecasting and a FAS by order are planning systems based on mixed push-pull logic.

De Toni, Caputo and Vinelli (1988) suggest that when customer lead time is zero (make to stock firms), MPS and FAS should be determined by forecasting (push). When customer lead time equals manufacturing and assembly lead time (make to order firms), MPS and FAS should be determined by orders (pull) and when customer lead time equals assembly lead time (assemble to order firms), MPS should be determined by forecasting (push) and FAS by order (pull).

De Toni, Caputo and Vinelli provide a clear and comprehensive analysis of the appropriateness of production management techniques together with a view which ignores traditional MRP/JIT/OPT.
should be used. If manufacturing is repetitive Kanban should be used and if manufacturing is semi-repetitive Syncro-MRP should be used.

The production planning sub-system can also be classified according to push-pull logic. De Toni, Caputo and Vinelli define push/pull in the classic sense i.e. push means to take action in anticipation of a need and pull means to take action upon a request.

A master production schedule (MPS) which employs some form of forecasting is based on a push logic. Frequently, master production schedules operate on product families in order to delay finalising the final assembly schedule (FAS) as much as possible. When both the MPS and FAS are executed by order of customers they can be associated with pull logic. A MPS carried out by forecasting and a FAS by order are planning systems based on mixed push-pull logic.

De Toni, Caputo and Vinelli (1988) suggest that when customer lead time is zero (make to stock firms), MPS and FAS should be determined by forecasting (push). When customer lead time equals manufacturing and assembly lead time (make to order firms), MPS and FAS should be determined by orders (pull) and when customer lead time equals assembly lead time (assemble to order firms), MPS should be determined by forecasting (push) and FAS by order (pull).

De Toni, Caputo and Vinelli provide a clear and comprehensive analysis of the appropriateness of production management techniques together with a view which ignores traditional MRP/JIT/OPT
classifications and concentrates on the building blocks of production management ie inventory management, manufacturing priority assignment and picking and moving, and production planning.

4.6 Flexibility and "fit"
Waterlow and Monniot (1986) found that CAPM software packages, using recent advances in data base technology and man-machine interfaces, offered the potential of greater flexibility than earlier packages. The degree of 'fit', which can be regarded as the degree to which the functionality of the software matched the functionality required by the business, without software modification and customisation was, however, low. Even after customisation the main use of CAPM systems were for transaction processing and "managers did not generally rely on the use of complex control algorithms to assist decision making. Too many of the variables were indeterminate - process times, machine reliability and priorities - for realistic use of scheduling or batch sizing rules" (Waterlow and Monniot 1986).

Discussion carried out with the research collaborators confirmed the importance and relevance of the concept of "fit" and, that matching the CAPM package with a company's requirements, was a process involving both customisation of the software and changing the way production management was carried out. A degree of 'fit' was possible from installing the software alone, a higher level of 'fit from customising the software but the highest level of fit was only obtainable through a combination of software customisation and changes in the operating policies, practices and procedures.
This aspect of the research, therefore, identified an important requirement for the methodology under development by the ACME team and for the author's own work. It also confirmed the findings by Waterlow and Monniot (1986) i.e. the need to ensure that a close match between the software package and the requirements of the production management function is achieved at the outset. The techniques developed for this purpose are the focus of chapters eight and nine.

4.7 Enhancements to Accommodate Changing Requirements

In a dynamic environment, such as electronics manufacturing, where change is widespread, the ability to re-configure and enhance the CAPM system is of paramount importance (Monniot and Waterlow 1986). Gattorna (1990) describes the likely result of reactive firms that "make the mistake of not planning for change, not realising that the nature of today's environment is change itself ... are an endangered species. The difference between these reactive organisations and proactive organisations is the difference between tactics and strategy". The ability to adopt new PPP's enhances the flexibility of the CAPM system. However, experience from many implementations and discussions with a number of practitioners, validated with the users themselves, show that customising the software is relatively more easy than radically changing the way production management is carried out. Hence this study concentrates on the computing and information aspects of CAPM. This is further borne out by recent developments in
4GL technology and the incorporation of this in many of the more recent packages such as MCC (Davy Computing 1990).

4.8 Conclusions
This chapter has covered some of the principal issues concerned with the design and operation of CAFM systems. The nature and extent of CAFM computerisation has been discussed together with the notion of "fit" and the role of practices, procedures and policies.

The next chapter focuses on the data collection stage of the ACME team's research and the subsequent analysis undertaken to determine the causes of CAFM systems failure. The implications for the author's work are discussed.
CHAPTER FIVE

THE RESULTS OF THE IN-COMPANY FIELD WORK ANALYSIS

5.1 Introduction
The companies visited by the research team have previously been detailed (Figure 1.1). In addition a large number of presentations were made at each stage of the development of the methodology. This provided an important and useful method of validating the findings and for progressing the methodology. This chapter focuses on the results of the extensive fieldwork carried out and the subsequent analysis undertaken to identify the principal causes of CAPM failure. The final part of this chapter provides a critical assessment of the most widely adopted approaches to CAPM design and development in the light of the research findings. This critique serves to set the requirements for much of the author's work explained in the proceeding chapters.

5.2 Data Collection
The following section describes the in-company fieldwork carried out by the ACME team and the subsequent analysis of this to determine the causes of CAPM system failure.

In addition to the companies visited a large number of discussions and workshops were held with CAPM practitioners and consultants (Coopers and Lybrand, IT Partners, Mannorgrant), vendors of hardware and software (IBM, Davy Computing, PA Pactel, ICL), production
managers operating CAPM systems in the electronics manufacturing sector, and other research groups. Presentations of the findings at each stage of the research were made at conferences, at ACME workshops (ACME 1988; 1989; 1990) and at Department of Trade and Industry (DTI) sponsored roadshows (1990).

The aim of these presentations was to expose the research findings and solutions as they developed to the widest possible audience and to ensure that they were rigorously scrutinised. CAPM users, vendors, consultants and academics were included in order to validate the ideas and to provide feedback at each stage of the research. This provided a valuable mechanism for checking the ideas against the knowledge and expertise of an audience that represented, and experienced, all sides of the CAPM problem. In addition, it also allowed further data to be collected and areas of concern, from the user community, to be raised with vendors and practitioners in order to substantiate the validity of these concerns.

From an analysis of the results of the data collected a clear set of factors responsible for the failure of CAPM systems emerged. These were validated through discussion with consultants, vendors and users as described above. Four factors were identified as causal in the immediate or eventual failure of CAPM systems. These were as follows:
Figure 5.1
Causes of CAPM Systems Failure

. Requirements were defined incorrectly.
. Requirements were defined correctly, but the wrong system was implemented.
. Requirements were defined correctly, the right system was implemented, however requirements changed over time and the system failed.
. The correct system was defined and implemented, however implementation was badly managed resulting in failure.

For brevity, the reader is directed to the papers by Weston, Maull and Childe (1988), Hughes (1988), Maull (1988) and internal reports (CAPM Interim Report 1988; 1989; 1990) for a fuller account of these failure modes and for more extensive details of the company failures summarised in this section.

If these four principal causes of failure are examined for relative importance, the third, involving changed requirements, can be seen to be of considerable importance. This is because the process of defining the requirements, of specifying an appropriate solution and of implementing this solution can be carried out correctly, however the system can still fail due to subsequent change in the requirements which render the system obsolete.

Thus "even systems which are currently performing well, but which lack the flexibility to respond to new requirements, are potential failures" (CAPM Internal Report 1989).
From analysing the data collected from the fieldwork visits, combined with a critical review of the literature, a number of valuable insights into the nature of the problem facing CAPM users and designers emerged. The results of this work pointed to an ontological discontinuity between the nature of the problem and the solutions currently being offered. In brief, a relatively static solution, the implementation of a software package, was being applied to an inherently dynamic problem. This problem is enlarged upon in the next section.

Extending the analysis of the causes of failure resulting from changed requirements, three types of failure were identified.

**Figure 5.2**

**Types of Failure due to Changing Requirements**

- Change in the volume of data to be stored and processed;
- Change in the technical integration requirements;
- Change in the manufacturing control philosophy support requirements.

All of these are of considerable importance for the development of computing and information infrastructures for CAPM. For example, large scale changes in the volume of data to be processed and stored is of direct relevance. This may arise due to changes in the volume of demand for orders. Changed technical integration requirements, without compatible data formats, the availability of physical connections and a well thought out integration strategy could render
the CAFM obsolete if access and transmission of data is not feasible. The move towards more highly coordinated manufacturing has increasing placed new demands on the computing and information systems of firms as the volume and frequency of reports required for planning and control purposes has increased. Additionally, the focus and content of the management information reports have themselves undergone a transition for now they need to contain data from many different areas of the business in order to achieve the desired level of coordinated control.

The third type of failure due to change in the manufacturing control philosophy support requirements can also lead to failure if the existing CAFM system is incapable of accommodating this. Changes to the range and type of products manufactured may necessitate a variety of control strategies to be implemented over a relatively short time frame. These may range from the more traditional MRP based systems to pull based JIT control.

The failures were categorised into the following three modes. Systems which failed to meet the requirements and which needed immediate replacement were defined as outright failures. Systems which only partially fulfilled their requirements were defined as partial failures and systems which were able to fulfil current requirements, but which lacked the flexibility to respond to new demands were defined as potential failures.
Figure 5.3

Failure Modes

Outright - System does not meet requirements
Partial - System does not meet all requirements
Potential - System cannot meet new requirements

It is apparent from these failure modes that traditional approaches to CAFM implementation which concentrate solely on the current hardware and software requirements, without considering how these requirements might change over time, can at best provide a solution which is a potential failure.

The traditional approach consists of identifying the technical hardware requirements followed by a cursory definition of the CAFM modules. The scale of the package is then determined by sizing the data and the functional "fit" is substantiated by visiting existing software installations of companies with similar production management characteristics.

At best, if the current requirements are fully captured, the outcome of this approach is a system capable of functioning for a time before decaying into partial failure and subsequent outright failure as the requirements change.

In highly stable manufacturing situations this process may take some time, however in other situations the mismatch between the system
implemented and requirements may develop so rapidly that almost immediate replacement is required. The lack of flexibility in many CAPM systems currently considered as potential failures is likely to eventually result in outright failure.

5.3 Current Approaches

The problem of defining requirements correctly and addressing future, as well as current requirements, raises the issue of the adequacy of current approaches to the development and implementation of CAPM systems. Waterlow and Monniot (1986) note that the consultants tended to lack the ability to define requirements correctly. The research added another dimension to this issue revealed, not surprisingly, that traditional vendor led solutions tended to focus on hardware and software installation. In contrast, successful implementations were characterised by an additional supply of CAPM services (DTI Roadshow 1990). The results of the Waterlow and Monniot study (1986) showed that 80% of CAPM system users were dissatisfied with the performance of the system after implementation. Vendors overselling their wares together with ineffective implementations, poor project management and incorrect requirements definitions were identified as being responsible for this.

Vendor led approaches are characterised by a methodology comprising the following five stages:
Figure 5.4

Vendor Led Approaches

- "Identify technical requirements
- Complete a cursory definition of modules
- Specify financial systems requirements
- Determine the scale of the package
- Visit an existing software location" (Weston and Maull 1990)

The problem of dealing with changing CAPM requirements is compounded in a situation, such as the electronics sector, where the rate of change in product demand and developments in information systems technology, product and process technologies is difficult to predict. Current design approaches which focus on the creation of single point solutions are clearly inadequate in this context. Single point solutions focus on a particular and current problem and are inherent in the traditional vendor driven approach described above.

Clearly, none of these stages are designed to cope with a fast changing demand and technological environment. This raises a serious dilemma for the designer and user of new information systems, such as CAPM.

Clearly, a new approach is required which directs attention towards the creation of a computing and information processing infrastructure with the capability of coping with change and the variety of potential demands. (Weston and Hughes 1989; Weston and Maull 1990). Ashby's well known Law of Requisite Variety states that effective
control in a changing environment requires a controller with a variety of responses which can match the variety of the environmental information and be capable of being changed at least at the rate of change. (Ashby 1956)

The requirement for variety matching is discussed along with the concepts of operational performance envelopes and computing and information systems infrastructures in chapter eight.

The principle cause of failure, changed requirements, is a result of the increasingly complex and uncertain manufacturing environments discussed previously in chapter three and the inadequacy of single point solutions to adequately address this issue. Traditional approaches provide single point solutions to an inherently dynamic problem. They attempt to meet current needs rather than provide a solution with the resilience to withstand changing priorities and requirements.

Developing a capability to respond to a range of likely conditions requires a fundamentally different approach. This aspect of the research, therefore, provided an important requirement for the authors work, that of creating a way of building into the design sufficient flexible to provided a resilient solution. This requires the design of computing and information systems that are sufficiently flexible so that they can be re-configured as new and unplanned requirements emerge. Only though this new and original approach can systems be designed with the flexibility, and therefore the
capability, to survive in highly competitive world markets. The author's research has demonstrated that traditional approaches are likely to result in highly inflexible and unreliable systems "inappropriate in situations where requirements cannot be predicted and/or where requirements are subject to rapid change, like manufacturing" (Hughes, 1988).

5.4 Examples of Failures
This section illustrates the causes of CAPM failure by discussing examples uncovered through the company visits. The implications for the development of the overall CAPM methodology by the ACME team and for the author's individual work are highlighted.

In addition to the ACME CAPM work the author also carried out research for IBM (IBM Study Grant; 1988) into the computer linkages between the office automation system and other manufacturing systems, including CAPM systems. The work carried out by the author in British Aerospace, previously described, also provided many insights into the problems and issues surrounding the incremental development of a CAPM system and, particularly, the difficulty of integrating 'islands of automation' without a well thought out information strategy. In addition this provided valuable insights into the processual issues associated with carrying out the analysis and design of CAPM systems.

Together, these pieces of work and the work carried out by Hughes and Maull into engineering change management systems (Maull 1988), provided additional material and examples. A comprehensive
description of the linkages between the CAPM and the sales order processing, design, purchasing and procurement, engineering change control and the costing and finance systems can be found in the CAPM Internal Report (1989).

5.4.1 Examples

Company A who recently implemented a new CAPM systems failed to identify their purchasing requirements correctly. They produced multi-layer printed circuit boards and therefore required a bill-of-materials (BoM) facility given the large number of purchased components. The consequence of this was that the CAPM system only partially met the total requirements and was unable to function in support of the business processes. This necessitated manually calculating component quantities and manually processing the purchase orders.

Another company had a history of failed CAPM implementations. One of these involved installing trial kitting software in an incremental attempt to exert greater control over production. Trial kitting meetings were held weekly and the team members were provided with a weekly schedule from the higher level, OMAC, schedule which they then attempted to match against available components and boards. Inevitably, not all orders could be made and therefore team members sub-optimised by making part orders or back scheduling orders. The result was a schedule which met only a sub set of requirements. As a result of this situation the company embarked on a process of reviewing their entire CAPM system.
A detailed and holistic approach to the problem was required which highlights an important requirement for the methodology discussed here.

An example which illustrates failure due to implementing the wrong system occurred in company B who, despite commissioning a detailed requirements definition, implemented MARPACS. This failed to meet their requirements despite lengthy and expensive modifications and enhancements. They later discovered that another package would have provided a much higher level of "fit". This again illustrates the need for methodologies to be able to identify both requirements correctly and provide the tools and techniques for selecting the most appropriate package.

Company C provided an example of CAPM failure as a result of a large scale change in the volume of data that required processing and storing. The change occurred over a four year time period and resulted from an increase in the volume of products manufactured over this time. The consequence for the CAPM system was that it became overloaded. The system ran sufficiently well until batches were raised at a rate of 15 per month, and was claimed to be out of control once the rate rose to 35 per month (the current rate is 50 per month). This was worsened by the fact that the system could not bulk together purchase orders to suppliers. The system was processing sales orders, purchase orders, manufacturing orders and costing, etc. whilst the Materials Requirements Planning was performed in Japan.
(where the engineering data resided) with a job by job set of orders being returned by mail on magnetic disk.

The system has since been replaced but again is in danger of being overloaded as manufacturing volumes have now increased six fold from the original level.

This demonstrates a company reacting to current requirements rather than, proactively, thinking through the likely implications of change in the volume of data to be processed and stored. Techniques for providing a strategic 'look forward' are therefore called for in this case.

A number of examples of failure as a result of change in manufacturing control strategy requirements were identified. One company invested in developing and implementing a costly automatic material handling warehousing system. This system was designed to integrate with the closed loop MRP system. However, the company had recently implemented a form of JIT to minimise inventory. At the same time the company introduced a supplier total quality management (TQM) program which reduced the need to check quality and the number of units delivered. These developments have rendered the warehousing system almost obsolete within one or two years of the investment. As CAPM is now associated with supplier relationships, continuous improvement and simplification programmes, a long term strategic approach is needed to prevent obsolescence such as this.
Another company originally installed a push type MRP system. Recent changes in manufacturing strategy have led to the development of flow lines throughout the plant and, as a consequence, a reduction of incoming stock and work in progress. This has forced the implementation of a new CAPM system with the ability to order material for assembly just as it is required. However, by encouraging a continuous improvement environment, the company has found that their problems have moved from the factory floor to the CAPM system.

Numerous design changes (in the order of 10 per day) have meant that the Bill of Materials and parts registration systems need far more resources than originally envisaged to manage the continual updating.

Many of the companies visited during the period of the research had ongoing development programmes aimed at integrating their internal systems and, in some cases, extending this to include integration with their suppliers. One of the collaborating company's have a company wide integration strategy which utilises the manufacturing automation protocol (MAP) and technical office protocol (TOP) communications standards. Each new software module developed must conform to these standards. This provides a good example of a progressive company attempting to come to terms with change by building in a provision to cope with this.

However, the ACME team's research has also uncovered examples of companies who have failed to define their integration requirements and installed systems which cannot, for example, process existing BoM files or be integrated to their existing order processing or
financial systems. It is therefore important in developing a CAPM methodology to address the integration aspects of linking the CAPM system to the wider business systems.

This aspect of the research was covered fully by the author through an investigation of factory reference models, architectures and integration standards. The results of this form the basis of chapter eight.

5.5 Conclusion

The analysis of the in-company field work data revealed four causes of CAPM systems failure. These causes of failure have been identified and discussed by referring to specific examples that illustrate the types and causes of failure. The implications regarding the design of new CAPM systems have been discussed.

The results of the field-work indicated areas of work worthy of further investigation for the author as part of the ACME team and for the specific focus of this thesis. Some of these have already been discussed in the text of this chapter.

In terms of the author's specific area of interest, failure due to changed requirements was regarded as the most significant. This supported the findings of chapter three regarding the likely implications of the dynamic nature of the electronics sector for CAPM systems and was significant because even systems which meet current requirements will eventually fail due to this reason.
Examination of the current approaches to developing CAFM systems provided insights into the root cause of the problem. Current approaches to systems design and development tend to be driven by the vendors and focused primarily on the technical aspect of installation. The system provided often comprised of hardware and software alone and was invariably focused on a single point solution. Single point solutions address a specific problem arising at a particular time. A requirement for the author was therefore to investigate the potential for developing a flexible computing and information systems capability for CAFM in order that the system may respond to a range of conditions.

This requires a new and original approach which differs from the creation of single point solutions.
CHAPTER 6

REQUIREMENTS FOR A CAFM METHODOLOGY

6.1 Introduction
In the previous chapter the results of the data collection stage of the research and the subsequent analysis undertaken to determine the causes of CAFM systems failure have been fully explained. The causes have been defined and the implications for both the author and the ACME team in their quest to develop an appropriate CAFM methodology has been discussed in outline.

This chapter now focuses in detail on addressing the requirement for a fundamentally new approach that is capable of ensuring that:

. the CAFM requirements are defined correctly
. the system selection process addresses both current and future requirements to provide a resilient solution
. commitment to the solution is achieved
. the project is managed effectively.

These requirements are discussed together with the concepts and theoretical frameworks which contributed to the development of the CAFM methodology and the techniques it contains.

Chapter seven then takes the reader through the structure and stages of the resulting CAFM methodology. These two chapters serve to set
the scene and provide a context for chapters eight and nine in which the author's original contribution on computing and information systems infrastructures for CAPM culminates.

6.2 Issues, Concerns and Requirements

The specific issues of importance at this stage concerned specifying the type and scope of the CAPM methodology required to improve on current practice and assist in eliminating the high failure rate of CAPM system implementations. A number of issues and concerns were identified, for example what constituted an appropriate structure for the methodology? What content - tools, techniques and theoretical frameworks - were appropriate for inclusion? If appropriate tools and techniques could be identified or devised was it possible to integrate these into a coherent, consistent and theoretically sound approach? Could the requirement for a quick, cost effective and usable approach also be met? Could the causes of CAPM system failure be addressed by use of the methodology? What were the constraints on CAPM flexibility and how could the current technology be applied more effectively to meet the requirement for flexibility.

The problem of incorrectly defining requirements is an issue many of the more recent structured systems methodologies for example SSADM seek to address. Incorporated in these methodologies are techniques, such as data flow diagramming and data analysis for modelling the functional and data characteristics within the current physical system. Problems with the current system are recorded in the form of a requirements statement list and logical models are then developed.
These are then used to describe the various options available and for comparing the anticipated performance of each option for overcoming the shortcomings of the current system. A particular option is then chosen and this provides the focus for the requirements definition report, which forms the basis and starting point for the next, design stage, of the development process. SSADM, for example, is a standard approach to the analysis and design of computer-based information systems and comprises a set of structural, procedural and documentation standards.

The structural standards define the stages of the methodology and the tasks which are required to be undertaken at each stage. The interfaces between the stages are clearly defined and each represent a tangible product such as a requirements definition report.

In terms of the systems development cycle, which provides a model of the stages of system development from conception to replacement, SSADM addresses analysis and design and begins with a "statement of requirements" (SSADM 1986) and ends with "programm specifications and file/database designs for the target hardware/software environment; manual procedures; operating instructions: implementation plan" (NCC 1984).

The procedural standards provide the development staff with a "set of proven, usable techniques and tools, and detailed rules and guidelines on when and how to use them" (SSADM 1986). The
documentation standards provide the means of documenting in detail the results of using the techniques and tools.

One potential problem with this approach, and indeed all structured systems methodologies, concerns their reductionist underpinnings. Wood-Harper and Fitzgerald's (1982) taxonomy of current approaches and techniques of systems analysis classifies traditional systems analysis approaches, eg data flow diagramming and data analysis, as belonging to the science paradigm. In Cookson's (1983) critique of this taxonomy the choice of 'science' as one of the paradigms in the scheme is questioned, but never the less the revised taxonomy clearly defines both the aforementioned approaches to systems analysis as reductionist. Structured methodologies are critically assessed in more detail in chapter eight but the notion of reductionism has relevance here for it represents the antithesis of the systems approach, identified by Waterlow and Monniot (1986) as a requirement for any CAPM methodology.

The systems paradigm focuses on solving problems in terms of 'wholes', and is best explained in the work of Checkland (1981). Checkland's 'soft' systems approach to problem solving provides a way of thinking about an issue of concern, such as CAPM systems. Embodied in the approach is the concept of the human activity system which is described as a complex set of interdependent human and physical elements that interact with each other and with their environment. A reductionist approach to CAPM systems design would involve drawing a boundary around the CAPM system and then using various techniques to
define the requirements of the system. In contrast a 'soft' systems approach would incorporate consideration of both the human and physical elements and examine the CAFM system and its controlling environment to identify all relevant inputs to the system which affect its functioning.

Therefore one of the principle general requirements for the CAFM methodology is an holistic approach by which the elements and inputs to the CAFM system are defined, in addition to the elements contained within the CAFM system itself.

System theory provides an appropriate theoretical framework from which to develop an holistic approach and has been covered extensively in general terms (Bertalanffy 1981; Vickers 1981) and in the specific area of information systems (Wilson 1984; Checkland 1981; Jenkins 1981).

An other important issue which remained to be addressed by the research concerned how to ensure commitment to the solution generated and therefore avoid problems associated with the implementation not being accepted by the users. A number of authors on the subject of user involvement and participation were reviewed (Olsen and Ives 1983; King and Rodriguez 1978; Swanson 1974; Robey, 1978; Lucas 1978; Mumford 1983). These all indicated that the likely chance of a successful implementation was increased with a high degree of user involvement.
The following framework devised by Tranfield and Smith (1988) was found to provide a useful checklist for evaluating the success of implementations according to technological, user, organisational and business criteria.

Figure 6.1

Validation Criteria

1. Technological Validity - Was the hardware and software installed running and delivered according to specification.

2. User Validity - Did those who operated the system use it, have the skills to use it, and feel comfortable using it.

3. Business Validity - Has the system contributed to the business related improvement criteria (lead times, cost, quality, responsiveness, robustness) for which it was purchased.

4. Organisational - Was the organisation designed or redesigned in both structural and cultural terms to deliver the benefits.

It is clear from the literature that no single methodology exists which addresses all four of the above criteria. Research was undertaken to clarify the requirements of such a methodology.
In terms of the approaches to user involvement and the way they are utilised in the stages of systems analysis and design, two different methods can be identified from the literature (Boland 1981). The first of these, as exemplified by Argyris (1978; 1984) focuses on the individual as the level of concern. The second approach focuses on the organisation and its socio-economic structure.

"In other words, Argyris starts from the micro aspects of social performance and works outward (basically a psychological view) whilst Churchman begins with the largest relevant system in the design situation and focuses inward (basically a sociological view). For Argyris, users constitute the individuals or groups directly impacted by systems change, for Churchman the total system or organisation provides the point of departure. The strength of the former is that user-led developments from this perspective tend to have the support for quality and implementation mentioned earlier, but in systems terms usually involve marginal changes in an incremental mode. The latter offers the possibility of total system redesign and radical change, but thereafter remains the problem of user support for implementation. Clearly an adequate methodology for CAPM systems needs to take account of the strengths and weaknesses of both of these" (Tranfield and Smith 1988).

This began to clarify a framework for the work from which the second and fourth of the validation criteria shown previously could be met as well as providing insights into the structure, stages and content of the methodology required. Processual elements within the
methodology, workshops, technical briefings etc would be needed to enlist the participation of all the users and a top down structure focusing on the structural and infrastructural components of the system and the physical resources would be required to address the total systems aspects.

Tranfield and Smith (1988) comment on the usefulness of Parnaby's (1988) insights into the need for fundamental redesign of the manufacturing system due to their age and outdatedness, resulting from the employment of incremental development strategies. Relating this to CAFM systems, Tranfield and Smith remark that "Much the same argument could be made concerning the supporting CAFM systems needed to service such manufacturing systems...this argument for fundamental reappraisal and morphogenic change in manufacturing is generally accepted by researchers (Tranfield and Smith 1987; 1988 a; b), consultants (Ingersoll Engineers 1987) and managers in the area of manufacturing technology and in CAFM systems".

The conclusion to be drawn from this aspect of the work is that while an overall system redesign such as proposed by Churchman appears to be a definitive requirement for the development of a methodology it could result in the alienation of those implementing and operating the new system. "This lack of attention to individual operational users is often related as one of the prime causes of failure of MRP II systems...is the answer total user education on the functioning of the whole system, or detailed exploration and involvement of the individual on redesign at the micro level? To obtain both strategic
and localised benefit then the answer must be both. Clearly a user-led implementation methodology must possess a strategic redesign element and a user education programme to disseminate this, as well as retaining sufficient flexibility to permit response to local needs and conditions" (Tranfield and Smith 1988).

6.3 Summary of Requirements

The requirements at this stage of the methodology therefore called for a top down, business driven, systems approach which enlisted the participation of the users in the re-design of the total system. CAPM as one of the principal subsystems of the total system was still the main focus of concern for the ACME team and particularly for the author's work. In specific terms the methodology had to address the aspects concerned with re-designing the CAPM system in a way which provided a resilient solution capable of coping with the variety of potential demands that were likely to be experienced by a particular company.

The work so far had provided an overall framework for the rest of the research programme and the requirements for the methodology, identified above, were met through the dual approach of theoretical analysis and creative discussion held between the ACME team members, user groups and collaborators.

The two specific general requirement areas were the processual framework and the structure, content and detail of the top-down business driven approach.

102
The processual requirements included mechanism for applying the methodology in such a way as to enlist the support of all those concerned. For collecting company data and for establishing the validity of that data so that some accommodation could be reached on the company actions and scale of change required.

The top-down, business driven requirement highlighted the need to develop tools and techniques for defining the company environmental characteristics and for auditing the internal capability of the firm to meet its competitive requirements.

The requirements of the author's approach was similarly for a top-down framework by which the characteristics of the company's information technology environment could be defined and internal computing resources and capability audited in order to establish an IT strategy and framework for future systems development. In addition techniques were required for selecting candidate packages, choosing the best "fit" package, the software customisation requirements and the manual policies practices and procedures to enhance the overall "fit".

In summary it was perceived at this stage of the research that the CAPM methodology must provide means of achieving the following as shown in figure 6.2.
Figure 6.2

Summary of Requirements for the CAMP Methodology

- an articulation of the company's business strategy with respect to the CAMP system;
- an identification of the types and extent of the CAMP flexibility required;
- the development of flexibility of each element in an integrated strategy;
- implementation is carried out according to best (CAMP Interim Report 1989).

The author's approach must provide the means of achieving the following as shown in figure 6.3.

Figure 6.3

Summary of Requirements for the Author's Approach

- an articulation of the company's IT strategy with respect to the CAMP system;
- a definition of the CAMP flexibility requirements in the volume of data to be processed, integration and manufacturing control philosophy requirements;
- selection of candidate CAMP packages, best "fit" package, degree of customisation and PPP's.
6.4 Conclusion

This chapter has describe and explained the set of requirements which resulted form the work carried out to determine the causes of CAPM systems failure. The next chapter provides a detailed description of the CAPM methodology which resulted.
CHAPTER 7

THE CAPM METHODOLOGY

7.1 Introduction
This chapter provides details of the results of the work carried out by all the members of the CAPM team under the guidance of Professors Hughes, Tranfield and Smith. Figure 7.1 depicts the relationship between Stratagem (1990), the relevance of which was explained in section 2.6 of chapter two, the CAPM methodology and the individual work undertaken by the author. The reader is directed to figure 9.1 for a more detailed representation of how the author's work relates, stage by stage, to the CAPM methodology.

The following sections of this chapter describe the overall structure of Stratagem and the content of the first two stages of the CAPM methodology together with the user-led ethos, the relevance of which was explained in the previous chapter and which governs the work of the team as a whole.

Sections 7.3.1, and 7.3.2, describe the strategic analysis and manufacturing analysis stages of the CAPM methodology. Included are the tools and techniques used to put these stages into practice and the computing and information related outputs from these stages which provide inputs into the author's approach - fully covered in chapters eight and nine. The final two stages of the CAPM methodology, the
CAPM requirements and CAPM solution stages are discussed in chapter nine as these form an integral part of the author's work.

The reader is directed to the Stratagem Workbook (1990) and to CAPM Interim Reports and Final Report (1990 a; b) for a complete description of Stratagem and the CAPM methodology respectively.
Figure 7.1

Stages in the STRATAGEM process

STAGE 1  Commitment
STAGE 2  Contracting
STAGE 3  Launch
STAGE 4  Application
STAGE 5  Close

The CAPM Methodology

Computing and Information Systems Infrastructure

- Strategic Analysis
- Manufacturing Analysis
- CAPM Requirements
- CAPM Packages
- CAPM Solution
- PPP's

108
7.2 Overall Framework

The Stratagem (strategic manufacturing) methodology provides an overall framework within which the CAPM methodology and the author's work formed a part. The relationship between the various elements of the completed work are as shown in figure 7.1 on the preceding page. The Stratagem methodology provides an approach for raising company competitive performance and achieving manufacturing excellence through the application of "the best manufacturing standards and practices that are currently in place worldwide." (Stratagem, 1990). The Stratagem methodology provides a structure for "companies to control their evolution to World Class performance" (Stratagem 1990), and the workbook fully explains the role of the facilitator to guide companies through the process. It is vitally important for companies which lack the experience or skills to use such a methodology to be provided with the assistance necessary. The role of the facilitator is described below.

"The Stratagem process consists of five stages.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>Commitment</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Contracting</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Launch</td>
</tr>
<tr>
<td>Stage 4</td>
<td>Application</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Close&quot; (Stratagem Workbook, 1990)</td>
</tr>
</tbody>
</table>

The first stage, commitment, aims to ensure that the support of the 'top management' team is secured at the outset. "Leadership from the top is critical to the success of the improvement process... it is critical to the successful application of Stratagem within the client company that top management is seen to give full backing to the
improvement process." (Stratagem 1990).

"The objective of the contracting, phase is to agree the start date for the Stratagem process and to identify the individuals involved from both the client management and facilitation teams." (Stratagem 1990).

The launch phase provides a way of introducing to all relevant company personnel that Stratagem has been adopted, serves to enlist the support of everyone and provides an unambiguous statement of the terms of reference for the work and the roles and responsibilities of all those involved. It is important that as little uncertainty as possible is generated within the company so as not to raise anxiety levels and thereby jeopardise the project from the start.

The application phase involves carrying out the work as agreed, following the structure and stages of the CAPM methodology, in the case of the CAPM application, and using the tools and techniques through the processes provided. The CAPM methodology provides an example of the application of the Stratagem principle, contains the tools and techniques for undertaking a strategic and manufacturing analysis; determining the manufacturing strategy, defining the CAPM requirements and generating an appropriate and acceptable solution. These stages are put into practice through a process involving the use of facilitators, workshops, pre-work and pro-formas, technical briefings, information sheets and toolkits.
The workshops, pre-work, pro-formas and technical briefings are managed and orchestrated by the facilitator who guides and coordinates the entire process. Pro-formas provide the necessary structure for the users to carry out the tasks required and, through the skilful construction of these, the questions asked of the users and the data requested for collection, provide the necessary guidance to ensure that this part of the process is carried out efficiently and effectively. The questions contained in the pro-formas can be thought of as the knowledge base of the methodology. The pre-work activities ensure that the data required for use in subsequent workshops is collected on time and the technical briefings provide a way of updating company personnel who may not have the experience to carry out the tasks without such aids. Workshops provide the mechanism whereby the data that has been previously collected and the results of the pre-work activities are brought together for collective decision making about some crucial aspect, eg deciding on an appropriate manufacturing strategy or the selection of the most appropriate CARP-I package. At each stage of the process the appropriate pro-formas, information sheets etc are available and provided as a collective toolkit for that specific stage.

The ethos behind the approach follows the user-led concept explained in the previous chapter. It is implicitly recognised and understood that both a top down, organisational and environmental focus is required to determine the structural and technological change required to meet the needs of a changing environment and also that this change must be managed through cooperation with the users. The
solution aimed for is one that provides optimality between strategy, technology and people. "If companies adopt inappropriate and ineffective strategies no matter how good their technology, nor how well trained and motivated their work force they are bound to fail" (Stratagem 1990). The approach, therefore, places emphasis and provides the tools, techniques and mechanisms to bring about appropriate and simultaneous change in company strategy, technology and people.

7.3 Content, Structure and Stages of the CAPM Methodology

Figure 7.1 clearly shows the relationship between Stratagem, the CAPM methodology and the specific area of interest of the author's work, which is highlighted by the broken lines. The remaining sections of this chapter describe in detail the first two stages of the CAPM methodology. This provides an introduction to the computing and information systems infrastructure work of the author contained in the chapters eight and nine.

The CAPM methodology can best be conceptualised as providing a framework and the necessary tools and techniques through which the flexibility requirements of the CAPM system can be defined and the appropriate infrastructural components and software specified. The top down orientation of the methodology ensures that the CAPM system supports the strategic and contextual requirements of each company.

It is intended that the methodology be of practical use to managers, incorporating the best project management practices and, is in
accordance with the guidelines for a CAFM methodology devised by Waterlow and Monniot (1986).

7.3.1 Strategic Analysis

This stage, together with the manufacturing analysis stage, provides a strategic context for the definition of the CAFM requirements. Gattorna (1990) describes the process of strategy formulation as ensuring the long-term profitability of the organisation and "forces management to reconcile two almost contradictory tasks: long term (visionary) planning with short-term responsiveness to customers" (Gattorna 1990). Gattorna further describes this process as covering vision statements (what the company stands for), aims (directions in which the company wants to go) and objectives (specific quantified targets). It is in this way that companies maintain their market relationship. "The chief executive is in the best position to understand the expectations of 'stakeholders' and the organisations long-term goals. Accordingly, he (or she) must be the one to articulate the vision statement" (Gattorna 1990).

The process of undertaking the Strategic Analysis stage of the CAFM methodology starts with a corporate mission workshop in which the company's purpose and the broad scope of its business activities are
defined (Stratagem 1990). This provides an initial focus for the subsequent analysis.

7.3.1.1 Strategic Audit

The corporate mission workshop is followed by the strategic audit workshop which involves the company's top team working closely with the facilitator to develop an understanding of the company's key stakeholders associated with each, previously agreed, product family. Gattorna (1990) stresses that understanding the environment is vital and that all organisations are directly affected by six environments: "the market; government; suppliers of materials and services; the labour market; and the finance market. Four other environments either directly or indirectly affect the organisation; the economy; the community; the nation's resource base; and the world environment" (Gattorna 1990).

The strategic audit is undertaken with the aid of Mendelow's (1981) framework for analysing the potential opportunities and threats posed by the various stakeholders. For the purpose of the CARM methodology developed by the ACME team the stakeholders were defined as the competitors, customers and suppliers. The relative power and influence of each of the stakeholders is assessed and expressed
according to the measure of uncertainty. In addition the techniques developed by Duncan (1972) to measure uncertainty are used to provide a means of assessing environmental uncertainty and are used in combination with Mendelow's modified stakeholder analysis. Through this process both the power and uncertainty associated with each of the stakeholders can be determined and the company's existing product families can be strategically assessed - to identify opportunities and threats. This enables a company to rationalise its product portfolio and identify opportunities for new products.

Figure 7.2 is used to assist in this purpose.

**Figure 7.2**
*Amended Mendelow Stakeholder Analysis*

* POWER - ranging from high to low
* UNCERTAINTY - ranging from static to dynamic.

![Power and Uncertainty Diagram](image)

*Power* | *Uncertainty*
---|---
High | Dynamic
Low | Static

115
In addition to the above figure, detailed pro-formas on competitors, customers and suppliers, in order to identify the degree of power and the level of uncertainty associated with each, are used to complete the strategic audit together with information sheets explaining how the techniques may be used. Examples of these pro-formas are provided in appendix I.

7.3.1.2 Financial Evaluation

The next stage of strategic analysis involves undertaking a financial contribution analysis of each of the sales product families. This is carried out using the Boston Consultancy Group 1 (BCG 1) method (Henderson 1970) shown in figure 7.3.

Figure 7.3
Boston Consultancy Group 1 Financial Evaluation

<table>
<thead>
<tr>
<th>Market Share</th>
<th>Cash Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>
"Taking each sales family in term participants identify the family as a star, cash cow, dog or a question mark" (Stratagem 1990). This process enables companies to appreciate more fully the cash contribution profile of each of their sales products.

7.3.1.3 Product Portfolio Development

The BCG 1 technique has limitations, however, and does not really provide any guidance on how to formulate an appropriate competitive strategy for each product family. In order to overcome these limitations the Boston Consultancy Group 2 (BCG 2) method, shown in figure 7.4, is used to develop the product portfolio.

**Figure 7.4**
Boston Consultancy Group 2 Portfolio Development

<table>
<thead>
<tr>
<th>Number of Approaches to Differentiation</th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many</td>
<td>Fragmented</td>
<td>Specialised</td>
</tr>
<tr>
<td>Few</td>
<td>Stalemate</td>
<td>Volume</td>
</tr>
</tbody>
</table>

Where products fall within the volume quadrant a strategy of improved market share and cost reduction should be pursued. Firms with
products within this quadrant should aim to dominate the industry sector on the basis of cost while at the same time achieving parity with close competitors on the basis of product differentiation.

Products which lie within the fragmented quadrant depend on some product attribute to achieve competitive advantage. Each firm may therefore seek to achieve competitiveness in a different way. Where a company pursues a differentiation strategy, it seeks to be unique in the industry along a dimension that is highly valued by a potential customer. The firm selects one or more attributes that a customer sees as important and uniquely positions itself in its chosen market.

The basis of differentiation depends on the individual industry. However, in the sense that a firm achieving and sustaining differentiation will continue to be an above average performer only if its price premium exceeds the extra costs incurred by being unique, a differentiator must aim at cost parity or proximity in relation to its competitors.

The specialisation quadrant favours those companies able to distinguish themselves from their competitors through the pursuit of a focused strategy. This strategy differs from either of the above strategies in that it rests on the choice of a narrow competitive scope within an industry.

The focus strategy has two variants: cost focus and differentiation focus. Cost focus exploits differences in cost behaviour in some
segments while differentiation focus exploits the special needs of buyers in a market segment. Such differences imply that segments are poorly served by broadly-targeted competitors.

Businesses manufacturing products which fall within the stalemate category all experience low profitability and few opportunities for gaining a competitive advantage. The horizontal axis of the BCG II matrix relates to barriers to entry. Only by erecting high entry barriers can a firm sustain a long-term defensible advantage.

The vertical axis of the matrix, on the other hand, is strongly linked to differentiation and encompasses the two extremes of commodities and special products.

7.3.1.4 Competitive Audit
The next stage of strategic analysis involves undertaking a competitive audit to identify the order winning criteria for each product family. This follows the current practice of Hill (1985), for example, in identifying the competitive dimensions for product families. However Hill's approach was developed further by the ACME team into the technique known as the price of non-competitiveness (PONC11). This technique builds on the work of Crosby (1979) and specifically that concerning the price of non-conformance. The PONC II technique is used to identify "the value, in precise financial terms, of securing improvements in key competitive criteria" (Stratagem 1990). By using this technique it is therefore possible to estimate the financial benefit of improving the performance of a key
competitive criteria eg cost, quality, functionality etc. From this the benefits to the business of improving the competitive profile of each product family can be established in precise financial terms.

The output from the strategic analysis stage is an agreed product portfolio together with the required improvements in the competitive profiles for each product family and a financial measure of the benefits to the business if these are achieved.

Of relevance and importance to the authors work on the computing and information systems aspects is the data on the current and future product volumes, customers and suppliers etc as they impact on the production management processing and information systems requirements. This is explained further in chapter nine.

7.3.2 Manufacturing analysis

7.3.2.1 Manufacturing Audit

The manufacturing analysis stage starts with a manufacturing audit. The objective of this is to identify the resources (machines, labour) and control systems that have a direct bearing upon production.
7.3.2.2 Resource Impact Analysis

The resources and control systems are matched against each product family in order to assess their role and use in achieving the required competitive profiles, identified in the previous strategic analysis stage. This enables those resources and control systems which need to be changed in order to support the requirements of the product family profiles to be identified. In this way the resources and control systems are integrated with the strategic requirements.

The following figure, 7.5, may be used for the purpose of matching. The vertical axis represents the resources and control systems. On the horizontal axis the competitive dimensions are displayed.

**Figure 7.5**
Resource Impact Matrix

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Delivery</th>
<th>Quality</th>
<th>Functionality and Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales Order processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchasing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personnel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An important and relevant output of this stage of the CAPM methodology for the author's work is a statement of the most
appropriate control configuration for each product family. The individual control requirements are then gathered together later in the methodology and, using quick rules of thumb developed by Parnaby (1988) on runners, repeaters and strangers and by De Toni (1988) on look back, look ahead logic, these are used in conjunction with the task model (Childe 1991) to highlight the tasks to be done. This provides an input to the author's work on computing and information systems infrastructures and particularly the stage of the approach which concerns the selection of an appropriate CAFM package. This is fully explained in chapter nine.

The manufacturing analysis stage of the methodology, and particularly the relevant computing and information systems aspects mentioned above, are carried out with an explicit understanding that change is inevitable. The concept of operational performance envelopes, explained in section 1.6 of chapter one, is used for this purpose. By using this concept every effort is made to elicit information on the current and future resources and control requirements. In this way the approach addresses failure due to changed requirements.

7.4 Conclusion
This chapter has provided details of the work completed by the ACME team and specifically the Stratagem methodology and the CAFM methodology. The first two stages of the CAFM methodology have been examined in detail and the relevance of these stages to the author's individual work has been described.
The next chapter provides comprehensive details of the requirements for a fundamentally new computing and information systems infrastructure approach and therefore builds on the previous chapters. In particular, the means of addressing the requirements of the author's approach are discussed before bringing together all the work of the author in chapter nine.
CHAPTER 8

REQUIREMENTS FOR A COMPUTING AND INFORMATION SYSTEMS INFRASTRUCTURE APPROACH TO CAPM

8.1 Introduction
The previous two chapters have focused on the requirements for the overall CAPM methodology and the first two, strategic analysis and manufacturing analysis, stages of the resulting CAPM methodology have been explained in detail, together with the overall structure of the methodology and the process developed for applying this in-company.

This chapter now focuses in detail on addressing the CAPM requirements and solution stages, specifically concerning those aspects relating to the computing and information systems infrastructure. The rationale behind the development of the author's approach is explained together with a discussion of relevant concepts, principles and theoretical frameworks.

Chapter nine which follows is then used to demonstrate how the author's work integrates with the overall CAPM methodology and how the components discussed in this chapter are employed to provide an approach capable of being used to specify a resilient CAPM system.

Integration and networking strategies, reference models, architectures and other technological frameworks and conceptual models are examined and their usefulness for the development of a
computing and information infrastructure approach are assessed. The concept of contextually bound infrastructures and operational performance envelopes are explained together with the novel way devised by the author for selecting the appropriate software and hardware configuration.

This chapter, therefore, examines some of the individual computing and information systems components which form the building blocks of the computing and information systems infrastructure approach to CAPM as well as discussing some of the major issues concerned with the design of such systems.

The chapter begins by discussing a number of computing and information systems requirements that emerged from the research and that needed to be addressed by the author's approach.

8.2 Issues, Concerns and Requirements

The outstanding issues and requirements for the author's work on the computing and information systems infrastructures aspects of CAPM are summarised as follows:

- an holistic approach to CAPM is needed which is capable of addressing the internal and external environmental elements which affect the performance and resilience of the CAPM system;

- failure due to changed requirements requires an approach to systems development which does not focus on single point
solutions but on the development of flexible, and therefore resilient, systems. From the research findings, flexibility is required in the areas of data storage and processing, integration and interfacing between the CAPM and other systems and in the manufacturing control philosophies supported.

. new and appropriate techniques are needed to define the CAPM requirements correctly;

. new and appropriate techniques are required to convert the CAPM requirements into physical requirements;

. to overcome failure resulting from implementing the wrong system techniques are required for identifying and selecting appropriate candidate packages;

. techniques are required for selecting the best "fit" package;

. customisation of the software and selection of the manual PPP's must be addressed to improve the "fit" and integrate the software with the organisational design;

. installation and implementation must be carried out effectively.
8.3 Addressing the Issues

The causes of failure have been previously stated in chapter five of this thesis (see figure 5.1). The authors' work is specifically designed to address the first three of these failure types and particularly that involving changed CARM requirements.

The first of these causes of failure, involving the incorrect definition of requirements, was highlighted as problematical by Waterlow and Monniot (1986) and the inadequacy of current, vendor led, approaches has already been described in section 5.3 of chapter five. Doumeingts (1985), additionally points out that despite the attention which has been focused on computerising production management systems over the last twenty five years, and the advances in information technology made in this time, these "have not lead to convincing results". He further states that the main problem areas are in selecting a software package, the time taken for implementation, adoption problems by users and, finally, insufficient account is taken of the dynamic aspects.

Addressing these issues raises a number of serious difficulties, particularly concerning the way design has traditionally been undertaken in the past. Traditional approaches and techniques such as modelling and adopting a "means" "ends" schema are clearly inadequate. Checkland (1981) is perhaps the most articulate critic of these approaches and their usefulness for problem solving in human activity systems - where business and human requirements, as opposed to technical requirements, need to be considered. The "means" "ends"
schema refers to an approach which takes the problem as given and merely concentrates on providing a solution to meet this. In contrast, and as Checkland (1981) points out, in many instances the problem itself is ill defined and requires clarification before any consideration is given to the means of providing an appropriate solution.

McAleer (1982) points out that reductionist techniques such as structured systems analysis may provide useful tools for revealing the structure of systems but to understand how a system works an expansionist, or systems approach is necessary.

In a similar way Hughes (1985) has critically evaluated traditional approaches to the development of CIM systems. Four main approaches are identified and the relative merits and drawbacks associated with each explained. The four approaches are discrete applications, blueprint, turnkey, and planned evolution.

8.3.1 Discrete Applications

Many companies developing CIM systems are doing so by implementing discrete applications which are unable to talk to one another. The result is a series of 'Islands of Automation' each with it's own database and unable to transfer data to any other application. Many failures have been documented and Maull (1986) attributes one of the major causes of this problem to result from a lack of detailed investigation of future requirements.
8.3.2 Turnkey

The turnkey approach is used to describe the purchase of a "total" CIM system from a single vendor. Often this places unacceptable limitations on further development of the CIM system due to the shortcomings of their chosen vendor's equipment. The assumption behind the approach is that the requirements of many companies can be met through the same CIM system. In contrast, chapter three has demonstrated that firms tend to have idiosyncratic requirements.

8.3.3. Blueprint

The blueprint approach is a linear attempt to develop CIM systems and is only appropriate if all the requirements of the system can be defined in advance and remain unchanged while the system building process proceeds. Often companies who adopt such an approach find that by the time the system has been developed and implemented the requirements have changed to such a degree as to render the system inoperable.

8.3.4 Planned Evolution

Previous research (Rzevski 1983; 1984; Hughes and Maull 1985) has demonstrated that planned evolution is an effective approach to the development of computer-based information systems for most environments and certainly manufacturing. Although evolution implies an incremental strategy to implementation considerable effort must be spent in the initial stages to ensure that the systems designed are "well structured, modifiable, maintainable and extendable" (Rzevski and Hughes 1986). In this respect Hughes and Maull (1985) have
established the relevance of techniques for the development of CIM systems; the importance of modelling the existing systems; the importance of using diagrammatic means to help users articulate their understanding and as an aid in communicating this understanding.

However the focus of planned evolution is still on the evolutionary development of a specific system and not on developing a capability to accommodate a range of systems with changing priorities and requirements.

Modelling techniques will now be described and critically evaluated.

8.4 Modelling Techniques

Techniques and methodologies such as SADT (Ross 1977) and IDEF have been developed and many examples of the use of these can be found in the literature (Hughes 1985; Maull 1986; 1988). In the general area of the analysis and design of computerised information systems, recent years has witnessed the development of many techniques (Martin and McClure 1985; Jackson 1983; Grindley 1975; De marco 1978; Gane and Sarson 1979; Olle, Sol and Verrin-Stuart 1982; Yourdon and Constantine 1975), each with claims and counter claims for solving systems problems. More recently, these techniques have been automated to overcome many of the difficulties associated with their manual use (Jones 1986; MACCADD; MUST). It is important that those adopting these techniques are aware of what can and cannot be achieved and under what environmental conditions. There is as yet little knowledge relating methodologies, tools and techniques for the analysis and
design of CIM systems to the problem contexts in which they are currently being used.

Doumeingts (1985) distinguishes between informational (Idef 1; SSADM), decisional (GRAI) and physical methods (PETRI NETS) - advocating the use of the decision model on the basis that decisions, and the decentralisation of decision making, are often overlooked. The authors work from 1985 to 1987 was concerned with investigating the use of systems analysis and design techniques for modelling computer integrated manufacturing (CIM) systems. Working in-company, with members of a systems department of a large aerospace manufacturer, the author developed a formal data flow model of the companies current CAPM system using the structured systems analysis and design methodology called Project Development Method (PDM), a derivative of SSADM. The data flow figure included the processes and information flows for identifying the work to be manufactured, issued to the machine shop, and downloaded to the N.C. machines. Subsequent analysis was undertaken to study the way the machine shop receive and action the work together with the role played by support areas i.e. N.C Programming, Tool Progress, Cutter management and Stores etc.

From this work a number of drawbacks with the data modelling approach were identified. The first concerns the issue of problem solving versus modelling. With the traditional modelling based approach problem solving is not addressed but rather it is assumed that successful data analysis leads to successful design. Wood-Harper and Fitzgerald (1982) provide a classification of systems analysis
methodologies and approaches. Their classification is based upon a number of criteria including the conceptual base and objectives of the respective methodologies. It is worth examining two of the approaches in more detail - that of structured systems analysis and data analysis.

Wood-Harper and Fitzgerald classify both of these approaches as sharing the science paradigm, characterised by reductionism, repeatability and refutation (Checkland 1981); having the same objective, namely analysis, but differing in both approach and conceptual models. In the data analysis approach, the conceptual model can be thought of as one of data entities, attributes and relationships. Whereas in the structure systems approach, the emphasis is more on the functions rather than on the data, although the functions are observed from the viewpoint of the data rather than of any person or organization.

The structured systems analysis approach, exemplified by de Marco (1978) and Gane and Sarson (1979), provides tools and techniques for analysis and documentation such as data flow diagrams, the concept of data dictionaries and structured english. The method of data analysis is based on the concept that the underlying building blocks of a system are data and that if the set of data elements (entities and attributes) that exist within a particular situation can be identified and modelled, then a true representation of that system can be obtained. It is assumed that the processes which use the data can change and be changed, but that the underlying nature of the
system remains unchanged because the data is taken as static; much less likely to change than the functions or processes applied to it.

In essence the implications for defining the requirements of a system, such as CARM, is that the system can be defined without defining the individual applications that need to use it. In addition, through defining the relationships between the data, the model can be validated before implementation and as such data analysis can be seen as providing a neutral method of agreeing the requirements.

The data analysis methods can be thought of as developed from the concept of a data base and, as Shave (1981), describes, seeks to model the system as it exists and then solve later problems through functional applications on a data base. These methods are not orientated to problem solving in itself, rather what is attempted is a definition of the system in which the problem exists - defined in terms of the underlying data and the relationships between data.

8.4.1 Critique of Modelling Approaches
The major issue of concern arising for the analyst with this approach is that problem solving is not addressed, rather it is assumed that successful data analysis leads to successful design. Indeed, as Jayaratne (1985) points out data analysis may not solve the underlying problems an organisation might have and may indeed capture existing problems within the data model.
In contrast, the author's work and the CAPM methodology has been designed to address the root cause of information systems and other problems affecting manufacturing companies. The solution put forward provides a means of addressing business strategy, information technology and human requirements in a simple, cost effective, and highly practical manner.

Another important issue concerning the use of modelling approaches is the time required to model the system under consideration and the lack of focus on flexibility requirements. The underlying assumptions of structured systems analysis and design methodologies do not necessarily encompass flexibility requirements - rather they are focused on the provision of solutions to meet current requirements. In addition they are often employed in a technologically deterministic way. This refers to the normative stance often adopted by the analyst/designer community who perceive that technology, and a technological solution, should be applied wherever the technical benefits can be exploited. This neglects the benefits to the user community of providing a more flexible solution through the incorporation of manual policies, practices and procedures to enhance the overall solution and attain a higher level of "fit" of requirements.

The length of time required to use these techniques means that the system may be outdated by the time it is installed and implemented. The work by Rzevski (1983; 1984) on the Evolutionary Design Methodology (EDM), which incorporates techniques such as prototyping
and advocates the use of advanced software tools and application generators, aims to overcome some of these problems. Prototyping involves rapidly constructing a system to meet only the very basic requirements but which is then used to identify new and more comprehensive requirements which can then be incorporated into the overall system specification. The system therefore evolves in an evolutionary manner (Rzevski and Hughes 1986).

However, this approach, although having merit and sharing some of the principles expressed in the work by the ACME team, nevertheless lacks the contextual orientation and the detailed human and processual mechanisms for putting this into practice in a way which guarantees ownership and commitment to the solution generated.

The author's work and contribution addresses the root problems of CAPM failure by, firstly, identifying the dimensions of change and secondly by providing the tools and techniques to specify a resilient solution.

8.5 Conceptual and Reference Models

A number of conceptual and reference models were examined as a way of overcoming the inadequacies of the modelling approach. Doumeingts (1985) points out the need for a conceptual model as a reference when drawing up specifications. "The conceptual model helps man in figuring the whole system and in designing" (Doumeingts 1895) He further quotes from Simon (1969) in that it is difficult for a man to conceive artificial systems. "The conceptual model aims to figure
through abstract terms the real production management system, its
tentities and links between then " (Doumeingts 1895).

There are a wide and varied number of models which provide
comprehensive task and information details for the general area of
manufacturing and for specific functional areas such as production
management. For example, the ICAM conceptual model (ICAM; Mayer 1985)
provides a top down model of the main functions of a manufacturing
company. The CAM-I (Liu 1985) model provides both general and
specific models eg for data collection and reporting at the shop
door level. Jones, Barkmeyer and Davis's (1989) detailed model of
CAPM tasks covers all those related to the order, design, fabrication
and inspection of parts. More recently the CIM-OSA architecture
'cube' (MacConaill 1990; Jorysz and Vernadat 1990) provides a
reference model encompassing enterprise wide functions, information
and infrastructure requirements. This is described in more detail
later in this chapter.

Kochar (1990) has developed a reference model for CAPM which matches
control system requirements to eight different manufacturing control
philosophies that he identifies. His reference model is "designed to
help users determine the need for and suitability for the
implementation of particular types of control systems, namely
Material Requirements Planning (MRPI), Inventory
Control/Purchasing/Capacity Planning and Scheduling/Shop Floor
Modules of an overall MRPII system, Reorder point control, Pull or
Kanban type of control, and OPT" (Kochar, 1990). As Kochar
recognises, one of the fundamental problems concerns understanding the environmental conditions which are "critical to successful implementation of particular control philosophies; and how to combine philosophies" (Kochar 1990).

The conclusions from his work are relevant for both the author's work and the combined work of the ACME team. The basic conclusions he draws are "that philosophies are complementary and not competing as the literature sometimes implies" (Kochar 1990). This augurs well for the development of software with multi-philosophy support capabilities. He further remarks that "the most general prerequisites apply to all CAPM implementations, and are not specific to particular philosophies" (Kochar 1990). The computing and information systems prerequisites which emerged at the CAPM workshop (Waterlow and Clouder-Richards 1988) have previously been described in section 4.5.

Kochar's (1990) reference model aims to provide guidance for users on matching manufacturing characteristics with control system philosophies. He acknowledges that this is a complex process and "requires a large number of factors to be considered" (Kochar 1990). His model weighs each of the 8 selected control system philosophies on 39 parameters. Seventeen of these are concerned with complexity issues, 10 of the characteristics deal with uncertainty and the remaining 12 are associated with flexibility. The findings of this work are discussed in "a reference model for the selection of manufacturing control systems suitable for a given environment" (McCarrie and Kochar 1990). Much of this work is outside the scope of
the author's area of interest but is relevant to the activity of defining CAPM task requirements, explained previously, and, more importantly, provides guidance on when and how these control tasks should be undertaken.

The need in this case, as previously stated, is for a fast and cost effective method which users can apply themselves. In order to provide a simple, yet effective solution to this problem the ACME team investigated the notion of core and optional tasks (CAPM Interim Report 1990).

Core tasks are essential to every manufacturing situation, for example sales order processing, and optional tasks are only required in certain situations, for example, forecasting. Core and optional tasks are discussed in more detail in section 9.6.

In effect the core and optional tasks represent a generic template, or CAPM production management architecture and an alternative approach to the more traditional, modelling based approaches. This provides a useful starting point for identifying and selecting an appropriate computing and information infrastructure.

8.6 Dealing With Changing Requirements
The need to develop a methodology with a capability of addressing the problem of changing requirements has been explained in chapter four. The issue for the author at this stage of the research concerned how to meet this requirement. Techniques were required for communicating
to users the notion that an appropriate solution must be sought, capable of coping with the range of potential demands arising from change. This is required in order to overcome any predilection that may exist for single point solutions. In addition, techniques were required for communicating the concept of infrastructures and for providing a means of assessing the degree of flexibility that was required.

The following two sections explain how the concepts of operational performance envelopes (OPE's) and contextually bound computing and information systems infrastructures were devised for this purpose.

8.6.1 The Infrastructure Approach

Dictionary definitions of infrastructure and much of the recent work concerning infrastructures in a manufacturing context are not really appropriate to this work, which uses the term in a specific sense. Hill's (1885) definition is relevant, however, for indicating components of an infrastructure as the "controls, procedures, systems and communications combined with the attitudes, experience and skill of the people involved" (Hill 1985). Skinner's definition supports this to the extent that manufacturing infrastructures are defined as the "policies, procedures and organisation by which manufacturing accomplishes its work, specifically production and inventory control systems, cost and quality control systems, work force management policies and organisational structure" (Skinner, 1985). The work by Meredith (1988) and Fine and Hax (1984) concentrate on distinguishing between structure and infrastructure with the latter defining the
organisational infrastructure as planning and control systems, operating policies, and lines of authority and responsibility in addition to a corporate culture that reinforces manufacturing strategy.

The infrastructure concept, for the purposes of the work carried by the ACME team, has a specific meaning which is "the combination of computer hardware, software and the policies, procedures and practices infrastructure which supports the production management activities of the company" (Stratagem 1990). Of particular relevance to the author's work, Hughes (1988) states that "a contextually bounded information processing infrastructure (IPI) is an infrastructure able to provide an information processing capability able to support a range of potential manufacturing conditions". This conveys much of the essence of the approach offered and presented in the papers by the author and other members of the ACME team (Appendix A, B, C, D, E, F).

8.6.2 Operational Performance Envelopes (OPE's) and Computing and Information Systems Infrastructures.

In order to communicate to users that a variety of potential and unpredictable demands may be placed on the computing and information systems, the concept of operational performance envelopes was devised. OPE's represent the range of conditions likely to be experienced by a company and the boundary of the envelope indicates the likely extreme conditions that may arise. Three such envelopes may be thought of as existing, each describing the potential demands
at different environmental levels. The strategic performance envelope represents the company's markets, products and competitors and sets the requirements for the manufacturing performance envelope that the manufacturing system must fulfil, which in turn sets the requirements for the CAPM performance envelope and the requirements of the system at this level. This sets the requirements for the computing and information infrastructure, as described in Weston and Maull (1990).

The relationship between the three operating performance envelopes are shown in figure 8.1 together with the various stages of Stratagem, the CAPM methodology and the author's computing and information systems infrastructure approach. The way the various stages are used to define a resilient CAPM system is described and fully explained in chapter nine.

The CAPM operating performance envelope is of particular importance for it sets the parameters that the computing and information systems infrastructure must be capable of supporting.
Figure 8.1
Operating Performance Envelopes

- **Strategic Analysis**
  - Stakeholder Analysis
  - Financial Evaluation
  - Product Portfolio Development
  - Competitive Audit

- **Manufacturing Analysis**
  - Manufacturing Audit
  - Resources Impact Analysis
  - Manufacturing Solutions

**CAPM Methodology**

- Strategic OPE
  - Current and Anticipated Customers, Suppliers
  - Product Portfolio, Product Mix and Volumes
  - Desired Competitive Profiles

- Manufacturing OPE
  - Resources and Control Systems, Current Applications, Product and Process Technology
  - Rough Out Control Strategies

- CAPM Task Models
  - (Sets the Scope of the Computing and Information Systems Infrastructure to support the CAPM OPE)

**CAPM Computing and Information Systems Infrastructure Approach**

- CAPM Packages, Enhancement Possibilities
- CAPM Integration Data Processing, Data Storage, Network Requirements
- (Sets the Size of the Computing and Information Systems Infrastructure to support the CAPM OPE)

**Company Computing and Information Systems Infrastructure Approach**

- Hardware and Software, Data Communications Enhancement Possibilities, Standards, Reference Models
- Company IT Constraints, Preferred Supplier, DF Skills etc
The concept of "contextually bounded" infrastructures complements the operational performance envelope concept by expressing that there are a (any) number of possible solutions and combinations of components and alternative strategies that could be employed to meet the range of potential demands. Contextually bound acts as a conditional statement for limiting the possible solutions to a range that is required, by the specific context, and which is acceptable given the cost constraints. The final form of the solution comprises strategies, hardware and software components and policies, procedures and practices.

In terms of the findings from this work and the causes of CAPM systems failure that have been identified, the three parameters of the CAPM operational performance envelope comprise the data volumes, the integration and the manufacturing philosophy requirements as
shown in figure 8.2.

The exact specification of the computing and information systems infrastructure will depend on the degree of flexibility required after considering the data volume, integration and manufacturing philosophy requirements. This is aided by use of the following figure (figure 8.3). The degree of change, the dynamic component, may vary over some time period from relatively static to dynamic and differentially across all three dimensions. The infrastructure to support the requirements must possess an equivalent degree of flexibility.
Where large changes in the volume of data to be processed are anticipated then a system which can be expanded in line with the changing requirements would be most suitable. Change in manufacturing philosophy requirements may be best accommodated through a package which has the capability to support the range required. Monniet and Waterlow (1986) provide an additional model which has utility in determining how the integration requirements may be met. Their model shown in figure 8.4 provides a classification of the levels of integration. Companies in level 0 may well be supported with an infrastructure consisting of a modular based package. Progression through levels 1 to 4 requires the development of an increasingly sophisticated integration infrastructure through the implementation and adoption of standards and company wide reference models. These elements are described next.
Figure 8.4
Levels of CAPM Integration

<table>
<thead>
<tr>
<th>Level</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 No CAPM</td>
<td>No CAPM or installing now</td>
</tr>
<tr>
<td>1 No integration</td>
<td>Several functions computerised but without regard to integration</td>
</tr>
<tr>
<td>2 Partial integration</td>
<td>Several functions linked via common files and coordinated controls</td>
</tr>
<tr>
<td>3 Full integration</td>
<td>All CAPM functions using common data bases</td>
</tr>
<tr>
<td>4 Integration of manufacturing systems</td>
<td>CAPM systems designed in conjunction with material conversion, handling and quality systems against manufacturing strategy objectives.</td>
</tr>
</tbody>
</table>

8.7 Computing and Information Systems Infrastructure Components

The technological components which form the computing and information systems infrastructure to match the flexibility requirements are the hardware and software elements and integration strategies. In-line with the ethos expressed in Stratagem (1990) that strategies for success, appropriate and effective technology and well-motivated people are the fundamental enablers of achieving and maintaining manufacturing competitiveness, the author's research addresses information technology (IT) strategy, computer technology and users, their skills, needs and requirements.
As explained in section 1.6 of chapter one, these areas are addressed by undertaking an appraisal of a company’s IT environment followed by an internal audit of its computing resources etc. The following chapter demonstrates how the approach may be used together with specific detail of each stage (see figure 9.1).

In the concluding sections of this chapter the components of the IT environment are described and critically evaluated. These components consist of the standards, reference models and architectures which it may be necessary to consider in order to establish an IT strategy. The CARM technology and the user and data processing skill base which both must be audited and documented are discussed together with decisions surrounding the level of computerisation required.

The infrastructure components will now be considered in detail with reference to the degree of flexibility they provide. The technological factors of speed, access, compatibility etc which serve to constrain the solution have been discussed previously in section 4.4 of chapter four and are further discussed in the next chapter.

8.7.1 Strategy

The problem of ensuring the availability of information across the enterprise in an heterogeneous equipment environment has been discussed at length over the past decade and researched on a scale unprecedented in the field of information technology development. The total ESPRIT I budget for 1984-1988 was 1.5 billion Ecus. 3.2 Billion Ecus has been earmarked for ESPRIT II (MacConail 1990). The movement
towards a new manufacturing paradigm of industrial automation and the
application of information technologies, machines and equipment, and
telecommunications to the manufacturing process has been gaining
rapidity worldwide over the last decade (Lui 1985; Ranky 1986).
Standards have been developed during this time to support the ever
growing level of automation but, as Lui (1985) observes the major
problem arises from the comparatively recent trend towards the
integration of these technologies and equipments.

A number of integration strategies have emerged in response to this
issue and attempts have made to provide a "standard internationally
accepted model (or models) of the various aspects of industrial
(factory) automation" (Lui 1985). Of recent interest has been the
concept of architecture. Hughes (1987) describes factory
architectures as encompassing "systems configuration; ie the set of
system components, hardware, software, machines and equipment and
their interconnections, the mode of operation (batch or real-time),
the mode of processing (time-sharing or dedicated) and the mode of
control (centralised or decentralised) established to achieve the
desired system management and control functions" (Hughes 1987). The
work by Hughes provides a comprehensive, and critical review, of some
of the USA, European and UK architecture approaches including the
following shown in figure 8.5.
Hughes (1987) concludes that "evident in the approaches outlined above is the increasing functionality of controllers, at all levels, a greater emphasis on integration between levels and integration with other business systems. This process seems certain to continue as the technology develops and as vendors and users seek to integrate existing islands of automation. It will be further re-enforced as companies increasingly recognise that the true benefits of CIM cannot be obtained without integrating manufacturing with the rest of the business systems in order to secure and maintain a competitive advantage" (Hughes, 1987).

Hughes (1987) provides a number of additional insights relating to the convergence of factory management and control software and hardware and in factory architectures towards industry standards. Hughes postulates that as a result of the expanding number of
software and hardware vendors, and the choice of factory management and control hardware and software currently available to users, "considerable pressure will be placed on vendors by their customers to provide portable and extendable solutions" (Hughes 1987).

Concerning factory architectures, Hughes (1987) view is that the distributed factory management/control architecture based on the principle of hierarchical control will emerge as the dominant standard. Of particular importance Hughes (1987) cites the work undertaken at CAMI and subsequently NBS as influencing this "to the extent that a reference model on factory management/control architecture has been proposed to the International Standards Organisation (ISO).

A de-facto standard has already emerged which partitions the factory into five hierarchical levels: Facility (Plant), Shop (Area), Cell, Work station and Equipment. By petitioning the various standards bodies, Esprit and the NBS, who support this approach, are likely to see it accepted in the reference model.

Current ideas on factory management and control architecture are fully compatible with wider CIM concepts relating to the distribution of activities and intelligence and, in particular, the need for a hierarchy of planning and control systems (for example, local scheduling). The current consensus amongst vendors and users that decisions should be made at the lowest possible level underlines this
view and is likely to lead to demands for increased functionality in control equipment" (Hughes 1987).

In line with a need to incorporate the expectations of computer integrated manufacturing (CIM), which Rzevski (1987) describes as to add value to the business by employing information technology, the work on the ESPRIT CIM-Open Systems Architecture project (MacConaill 1990) provides the most up-to-date body of knowledge on the subject of reference models, standards, architectures and integrating infrastructures. Of relevance here is the "CIM-OSA architecture for the manufacturing enterprise at large and for its operation in enterprise wide heterogeneous environments" (Kosanke 1990). This work provides modelling techniques at an enterprise function and information level and an "integrating infrastructure for vendor-independent information processing" (Kosanke 1990). The work currently underway in the second phase of the project "will consolidate the results of ESPRIT 1 with a strong leaning toward strategies, tools, methods and components for building multi-vendor systems based on open systems concepts. Moving centre-stage are low cost, reliable and customizable CIM systems also suitable for use in small, medium-sized enterprise (SME) environments" (MacConaill 1990).

Underpinning this work is a statement of the objective of CIM, which is "the appropriate integration of enterprise operations by means of efficient information exchange within the enterprise with the help of information technology. Integration includes the physical and logical connection of processes by means of data communications technology"
operating to specified standards, but also the integration of enterprise functions as well as enterprise information." (MacConaill 1990). The generalised models and the open systems architecture presented in the CIM-OSA work aims to reduce the "system complexity to a manageable level" (MacConaill 1990). The open systems architecture allows the functionality and behaviour of CIM systems to be represented at three different levels (requirements definition, design specification and implementation description. (MacConaill 1990).

CIM-OSA incorporates many of the accepted ideas and principles of previous work such as functional decomposition in SADT (Ross 1977) and IDEF (Yadav 1985); entity relationship modelling (Chen 1986; SSADM,); OSI, MAP and TOP developments in data communications and computer networks and the work on architectures previously mentioned at NBS (Simson et al 1982), IBM and CAM-I (CAM-I 1988). MacConaill (1990), however, argues that CIM-OSA goes far beyond previous modelling tools and CIM system methodologies, particularly as a result of the following:

. CIM-OSA covers the complete CIM system development life cycle for discrete manufacturing enterprises including the analysis, design and implementation stages. Software tools are used to support the design and implementation stages;

. the CIM-OSA model enforces the design principle of modularity;
the use of well accepted standards are enforced; enterprise information, functionality and behaviour are clearly separated; business processes rather than organisational functions or departments are the main focus for analysis and design. A logical approach is therefore adopted which greatly reduces the chance of automating existing organisational structures and the resulting problem of the so called 'Islands of automation'; a processable model of the CIM system is produced by the CIM-QSA approach "as opposed to SADT-based methods or to IDEF which only produce a static, incomplete, descriptive model of system requirements (lacking dynamics modelling, precise information modelling and technical implementation." (MacConaill 1990).

Many of these precepts are embodied in the work by the ACME team and that of the author, although at a different scale of analysis (CAPM) and underpinned by an objective to provide a simple and cost effective method which users can apply themselves.

An overview of the CIM-QSA architectural framework is provided by MacConaill (1990) and of particular note is the separation of enterprise functionality and information. This provides two different perspectives from which to view systems development and serves to
remind practitioners that the role of information and information systems is to support the functionality that is required.

This principle is also adhered to in the CARM methodology by separating the task model and template from the computing and information systems infrastructure and the policies, procedures and practices. In this way a higher degree of stability and flexibility is created for changes in one of these will only have a limited effect on the other two. ie new requirements can be defined through iterative use of the task model and accommodated through either software enhancements or changes in the PPP's. Also of similarity is the process of stepwise instantiation and stepwise derivation where particular requirements are determined from general models. The task model and the computing and information systems infrastructure are two of the generic building blocks or basic constructs on which the CARM methodology is based and from which the requirements and solutions of a particular company can be specified.

In concluding this section, the greater the requirement for integration as firms make the transition to level four of the Waterlow and Monniot framework as shown in figure 8.4 then it is more important that standards are adopted and a company wide architectural framework for integration is developed. The work on the ESPRIT CIM-OSA programme is vitally important for promoting the development of standards to overcome the problems inherent in heterogeneous environments and for providing a coherent, but as yet incomplete, set of techniques to achieve integration at an enterprise level. The body
of knowledge provided by CIM-OSA, and the principles, techniques and strategies provide an important and vital component of the computing and information systems infrastructure discussed here.

8.7.2 Technology

In chapter four CAPM packages were discussed. Figure 8.6 outlines CAPM package flexibility parameters.

**Figure 8.6**

*CAMP Package Flexibility Parameters*

- the portability of the software to run on different hardware platforms;
- the interfacing capability to other packages such as computer aided design (CAD) systems, quality, accounting etc;
- the modularity and the degree to which individual modules can be implemented, individually, bearing in mind the issue of technical precedence (the need for one or more modules to be in place prior to the implementation of another module (Hollier and Barber 1989);
- expeendability of the system;
- the degree to which different manufacturing philosophies can be supported.

On of the most recent advances in software flexibility for CAPM systems has been through the development of fourth generation languages (4GL's). Their low cost and availability offers users with
the data processing and programming skills an opportunity to create applications that can be easily modified and enhanced as changing requirements dictate (Grindley Report 1985). The work by Muhlemann, Price and Sharp (1989) have demonstrated their particular usefulness for small, medium-sized enterprises (SME's). Through the adoption of modular design principles, templates and data structures designed as interconnectable control models, "changes in management policies, which require different control principles, can be implemented by restructuring the modules, through rearranging the interfaces and frequency of communication between the modules" (Muhlemann, Price and Sharp 1989).

Even if companies do not possess the in-house skills to develop their own CAPM systems, proprietary packages based on 4GL's provide the flexibility for rapid enhancements to be made. The falling cost of information technology over the last decade, the advancements in hardware performance and the increased flexibility and modularity of software packages has presented new opportunities of using computer systems for production management, which renders much of the early work on the application of computer systems, notably Schofield and Bonney (1980) obsolete. The importance of the "environment affecting systems" (Schofield and Bonney 1980) are not challenged but rather that since the study was undertaken, (and based on 1960's and 1970's technological capabilities), the developments in information and communications technologies (and simplification techniques) has widened the scope of possibilities to such an extent that their recommendations now appear naive. Even the use of micro-based
spreadsheets for production management (Bentley 1987), a taken for
granted technology nowadays, would have been revolutionary in the
late 1970's.

To conclude this section, the degree of flexibility offered by CAPM
software varies from modular packages such as Copics and Mapics (IBM
1990) based on traditional procedural languages through 4GL's which
provide a flexible development environment. The expansion capability
of CAPM systems currently offer the opportunity to purchase a
'starter system', (perhaps micro-computer based), and develop this
into a mini system supporting a number of terminals. It is claimed by
the vendors that some of these packages can support a number of
control philosophies (MRP and JIT) simultaneously. The range of
software options would seem to provide the necessary support and
flexibility to accommodate a large proportion of the integration,
data volume and manufacturing philosophy requirements. What is
lacking, and is addressed in this thesis, are techniques for defining
the flexibility requirements and selecting appropriate packages.

The ACME team's approach of software and policies, procedures and
practices offers the possibility of a high level of "fit", tuned to
the requirements of the business and the users.

8.7.3 People

A number of technological factors constraint the choice of package.
These have been introduced and discussed in chapter four as,
usability, compatibility, reliability, cost, security etc. Of
particular importance to this piece of work and its user-led orientation are the requirements of the users and their acceptability preferences. The most technically appropriate solution eg in terms of functionality or the most desirable level of task automation, may be rejected on the grounds of user or organisational factors. It may be required for reasons of organisational harmony, cooperation or to ensure motivation that tasks are carried out manually. In this way a solution is provided which provides the highest level of "fit" to the business and organisational requirements. The requirements of the users themselves are therefore taken into consideration in the overall CAFM computing and information systems infrastructure design; their skills in operating or enhancing the system and their wider social and organisational needs.

8.7.4 Manual or Computerised Tasks

Research into the problem of choosing how the CAFM tasks should be carried out - manually or by computer was a requirement for the author's work. Useful rules to address this problem were sought. Clearly, given the complexity and volume of data to be processed in a modern, high volume process or discrete manufacturing company, would appear to necessitate the use of computers. This is supported by the systems already in existence, or being installed, in all the companies visited by the research team and the overwhelming examples of CAFM installations reported in the literature. The question is not therefore so much concerned with the choice between a manual or a computerised CAFM systems, it is the mix or composition of the final solution which is all important.
The technological deterministic view, as espoused by Jones, Barkmeyer and Davis (1989) advocates the widespread automation of all tasks to the extent possible. The opposing view is one that advocates the minimalist use of information technology and only where the task cannot be carried out manually. Clearly both of these views are inadequate and some simple rules of thumb and guidance are necessary. The position outlined in Stratagem (1990) is for a process of simplification prior to computerisation. Current manufacturing philosophies, notably JIT, through the simplification of procedures, rely less on complex and sophisticated information processing technologies. The work undertaken on the IBM Study Grant (1990) into advanced office automation systems provided insights and instances where companies had removed non-value added activities from their office automation systems. The traditional invoice processing systems had largely been dispensed with in a number of cases in favour of simpler, and less costly systems where data was collected on the number of completed products in a time period, the number of components used were calculated and payment despatched for the appropriate amount to the component supplier.

The nature of the tasks, and the decisions associated with the tasks, have an important bearing on the feasibility and desirability of computerisation and automation. The work by CIM-OSA highlights the distinction between inferential and non-inferential decisions and notes that only in the latter category has computerisation really been exploited. Doumeingts' work (1985) is important for providing
the tools and techniques for modelling the decision making component of CAFM systems. The author argues that these, together with the simple rules associated with the volume, frequency and repetition of tasks are also useful. In the mid seventies much of the management information literature (MIS) concentrated on distinguishing between the information requirements at different levels within an organisation (Gorry and Morton 1971). Information processing at lower levels was characterised by a requirement for frequent, repetitive and largely internal information. In contrast, at strategic levels in the hierarchy information was required mainly from external, environmental sources on an infrequent basis with little repetition. The time horizon for decision making based on this information was long and as such not amenable to conventional data processing support. The distinction was therefore made between data processing support at the lower levels and for programmable decision making and environmental scanning and decision support systems for the non-programmable strategic levels. This provides a framework within which the decision to automate or not can be made. Non-deterministic decisions, and software algorithms associated with these types of tasks, appear to be received less favorably by users, as Waterlow and Monniot (1986) discovered. Deterministic, repetitive and simple tasks that require the processing of data and which are carried out frequently appear to be well suited to computer support.

This framework of rules should not be adhered to too rigorously. Clearly, there are situations where an application may be implemented which does not justify computerisation by itself due to low data
storage and processing requirements, however, this may interface with other applications with high data volumes.

The way this framework was used by the author in developing the methodology is covered in the next chapter.

A requirement for identifying the production management tasks that the CAfM system should support was that this should be undertaken without any consideration of how the tasks should be physically (computer or manually) accomplished. It is important to delay any consideration of how the requirements are to be met and the CAfM system built until the requirements have been firmly established. This avoids any possibility of conditioning the requirements due to the constraints inherent in a potential solution. The physical design specification concerns choosing the hardware and software, deciding on the level of desired automation, customising the software and selecting the appropriate policies, procedures and practices to create a resilient CAfM solution.

8.8 Conclusion
This chapter has covered the requirements for the author's work in developing an infrastructure approach to the computing and information systems aspects of CAfM. These requirements also apply to the overall CAfM methodology and are specifically relevant for completing the final two stages of the approach. The tools and techniques devised for this purpose have been discussed together with
the strategy, technology and people components of the infrastructure on which the approach has been based.

The basis for the selection of components has been described and explained as a flexibility requirement to accommodate change in the volume of data, integration and manufacturing philosophy requirements. Both analytical tools, in the form of the operational performance envelope and its three axis framework, and communication tools in the form of contextually bound computing and information systems infrastructures has been presented. The next chapter concludes the work by describing the arrangement of these tools and techniques into a workable approach.
CHAPTER 9

DEVELOPING A COMPUTING AND INFORMATION SYSTEMS INFRASTRUCTURE FOR CAPM

9.1 Introduction
The objectives of this chapter are twofold. Firstly to demonstrate how the concept of a computing and information systems infrastructure and the approach devised by the author may be applied to develop a resilient CAPM system. In this way the chapter draws together all previous work reported in the thesis, in particular, the work reported in chapter eight on the theoretical aspects of computing and information systems infrastructures. Secondly to explain how this work integrates with the overall CAPM methodology.

These objectives are achieved by working through the approach, stage by stage, to demonstrate how it may be used to define the CAPM requirements and to specify an appropriate and resilient CAPM system.

For brevity, and because the focus of the author's work is on CAPM systems, this chapter concentrates on using the approach in respect of CAPM. In practice, the approach would encompass all company applications and address the development of a company wide information technology (IT) infrastructure.
9.2 Structure and Stages of the Computing and Information Systems Infrastructure Approach

To reiterate, the CAPM methodology consists of four stages, strategic analysis, manufacturing analysis, CAPM requirements and CAPM solution as illustrated previously in figure 1.1 of chapter one. The authors approach integrates with this framework, as shown in the previous figure, 7.1, and in figure 9.1 which shows the individual stages that make up the computing and information systems infrastructure approach.
Figure 9.1

The CAPM Methodology and the Computing and Information Systems

Infrastructure Sub-stages

CAPM METHODOLOGY

STAGES

Computing and Information Systems Infrastructure Sub-Stages

1. STRATEGIC ANALYSIS
   - IT APPRAISAL
     - 1.1

2. MANUFACTURING ANALYSIS
   - IT INTERNAL AUDIT
     - 2.1

3. CAPM REQUIREMENTS
   - INFRASTRUCTURE REQUIREMENTS
     - 3.1

4. CAPM SOLUTION
   - CAPM packages
     - 4.1
   - INFRASTRUCTURE SOLUTION
     - 4.1.1
The computing and information systems infrastructure stages shown in figure 9.1 may be regarded as sub-stages of the overall CAPM methodology and consist of a series of activities which utilise outputs from the CAPM methodology as well as contributing inputs to it. It must be emphasised that the structure and stages of the approach are used iteratively and not linearly.

Figure 9.2 shows the data, source of data and the specific use to which the data is put. This data provides the foundation from which decisions can be subsequently made to determine the CAPM requirements and for specifying how the system will be built.
### Figure 9.2
Data, Sources of Data and Use of Data

<table>
<thead>
<tr>
<th>DATA</th>
<th>SOURCE OF DATA</th>
<th>USE OF DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current and anticipated customers, suppliers</td>
<td>1. STRATEGIC ANALYSIS</td>
<td>To identify the computing and information systems requirements, size, functionality eg. quality control etc</td>
</tr>
<tr>
<td>Defined portfolio of existing and anticipated products, mixes,</td>
<td>. Stakeholder Analysis</td>
<td></td>
</tr>
<tr>
<td>volumes</td>
<td>. Financial Evaluation</td>
<td></td>
</tr>
<tr>
<td>Competitive dimension for each product family</td>
<td>. Product Portfolio Development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>. Competitive Audit</td>
<td></td>
</tr>
<tr>
<td>Resources and control systems, current applications, process technology</td>
<td>2. MANUFACTURING ANALYSIS</td>
<td>To identify the manufacturing philosophy requirements (MRP, JIT, OPT) and initial integration requirements</td>
</tr>
<tr>
<td>Rough cut control strategies</td>
<td>. Manufacturing Audit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>. Resources Impact Analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>. Manufacturing Solutions</td>
<td></td>
</tr>
<tr>
<td>Hardware and software, data communications enhancement possibilities, standards, reference models</td>
<td>1.1 IT APPRAISAL</td>
<td>To identify new IT products, CAFM package enhancements, standards, reference models</td>
</tr>
<tr>
<td>Technological constraints, CAFM integration, data processing,</td>
<td>2.1 IT INTERNAL AUDIT</td>
<td>To identify in detail the technological constraints which must be taken fully into account in selecting the CAFM</td>
</tr>
<tr>
<td>storage and network requirements, preferred supplier, DP skills</td>
<td>. Manufacturing Audit</td>
<td>system</td>
</tr>
<tr>
<td>CAFM task models</td>
<td>2. MANUFACTURING ANALYSIS</td>
<td>To identify the overall manufacturing control philosophy requirements and scope of the CAFM system</td>
</tr>
<tr>
<td></td>
<td>3. CAFM REQUIREMENTS</td>
<td></td>
</tr>
<tr>
<td>CAFM Infrastructure requirements</td>
<td>3.1 INFRASTRUCTURE REQUIREMENTS</td>
<td>To provide a detailed, documented, specification of the size and scope of the CAFM system required</td>
</tr>
<tr>
<td>CAFM packages</td>
<td>4.1.1 INFRASTRUCTURE SOLUTION</td>
<td>To enable the candidate CAFM packages to be identified that meet the requirements as specified</td>
</tr>
<tr>
<td>Best &quot;fit&quot; package, PPP's, installation and implementation framework</td>
<td>4. CAFM SOLUTION</td>
<td>To identify the best fit package, combination of PPP's, installation and implementation requirements</td>
</tr>
<tr>
<td></td>
<td>4.1.1 INFRASTRUCTURE SOLUTION</td>
<td></td>
</tr>
</tbody>
</table>
The series of tasks of the computing and information systems infrastructure sub-stages and how these interrelate with the overall CAFM methodology will now be explained.

9.3 Strategic Analysis
An output of the strategic analysis stage of the CAFM methodology (denoted by the numeric identifier 1. in figure 9.1) is a defined portfolio of current and anticipated products and the competitive dimensions for each product family. The product portfolio is derived after analysing all the relevant environmental factors and influences (ie stakeholders, products and marketing position) and consists of the current and anticipated future product requirements.

This provides an essential input to the computing and information infrastructure sub-stage of the methodology by indicating the current and likely future product volumes, variety and mix, anticipated number of customers, orders and suppliers etc. This in turn provides valuable information to assist in specifying the size of the CAFM system required and to indicate the likely volume of data to be processed and stored both now and in the future. In addition, the competitive dimensions identified for each product family also serve to set the requirements for the CAFM system. For example, certain product families may compete on volume and cost and, together with other considerations, a flow line approach may be the most appropriate method of manufacture. Others may occupy a niche market and compete on dimensions which can best be achieved through batch
The implication for the CAPM system is that it must be able to accommodate both the manufacturing philosophies of JIT and MRP. In such a situation this capability may be achieved through the implementation of a CAPM system such as OMAC JIT (OMAC 1990) which, it is claimed, supports both philosophies. Alternatively it may be decided that the requirements are best met by implementing two individual, but integrated, CAPM packages that again provide the total control functionality required.

If quality is identified as an important competitive dimension then, again, the CAPM system must contain the necessary functionality for this dimension to be monitored and controlled. Protos sold by Powell Duffryn Systems incorporates quality management techniques for statistical control and, by linking this module to a report generator, allows statistical data to be extracted from the data base and manipulated to provide customised reports (Benwell 1988).

9.4 Manufacturing Analysis
The manufacturing analysis stage (denoted 2. in figure 9.1) provides a list of the necessary manufacturing control philosophy requirements for each product family, and, in-line with the requirement for resilience, again takes into account both the current and the potential future control requirements for the defined product portfolio. The output of this stage is a rough-cut manufacturing control strategy which sets a direct requirement for the CAPM system.
The runners, repeaters and strangers framework by Parnaby (1988) and the De Toni (1988) look back, look ahead logic assists in the selection of CAFM tasks. This in turn is used to define the scope of the CAFM systems and the supporting computing and information systems infrastructure.

9.5 IT Appraisal and IT Internal Audit

In parallel with the strategic analysis and manufacturing analysis stages, the information technology (IT) appraisal (1.1) and IT audit (2.1) sub-stages are undertaken.

The IT appraisal stage consists of Investigating the company’s IT environment comprising that part of the IT supply industry which directly impacts on the company together with the company's existing hardware, software, data communications and service suppliers. Major research and development initiatives such as CIM-OSA and their relevant contributions may also be appraised.

The objective is firstly to identify new IT products, package enhancements and forefront technologies and suppliers. Secondly to identify the emergence of standards and reference models. The extent of the investigation will depend on the size of each individual company and its level of CAFM integration as shown in figure 8.4.

In terms of package enhancement it is important to be aware of the upward and forward compatibility potential. Upwards compatibility is the term which covers the ability to move to a larger machine and
still use the original operating and applications software. Forwards compatibility means that when a new hardware model is introduced the original software may continue to be used. Such concepts, together with the importance of emerging standards and reference models were discussed in chapters four and eight.

It is equally important if the company computing and information system infrastructure is to be upgraded, developed and extended as new requirements emerge that the technological constraints do not render this infeasible. The IT internal audit stage, 2.1, of the approach, therefore, consists of documenting the existing hardware and software resources together with the technological constraints, user and data processing skill base and if a preferred supplier is in existence.

Figure 9.3 provides a list of some of the possible technological constraints which require documenting. This list is not meant to be exhaustive but to provide a framework so that the author's approach can be understood. Clifton (1986) provides technical details on each of the constraints listed.
### Technological Constraints

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Computer Processing Capacity</td>
</tr>
<tr>
<td></td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>Mini</td>
</tr>
<tr>
<td></td>
<td>Mainframe</td>
</tr>
<tr>
<td>2</td>
<td>Computer Storage Capacity</td>
</tr>
<tr>
<td></td>
<td>Magnetic Tape, Disk</td>
</tr>
<tr>
<td></td>
<td>Optical Disk</td>
</tr>
<tr>
<td>3</td>
<td>Computer Input/Output Devices</td>
</tr>
<tr>
<td></td>
<td>Terminals, Keyboards, Visual Display Units, Printers</td>
</tr>
<tr>
<td>4</td>
<td>Software</td>
</tr>
<tr>
<td></td>
<td>Operating Systems</td>
</tr>
<tr>
<td></td>
<td>Applications Software</td>
</tr>
<tr>
<td></td>
<td>Data Communications Software and Protocols (MAP, TOP)</td>
</tr>
<tr>
<td></td>
<td>Applications Development Tools</td>
</tr>
<tr>
<td>5</td>
<td>Data Communications</td>
</tr>
<tr>
<td></td>
<td>Data Communications Architecture</td>
</tr>
<tr>
<td></td>
<td>Distributed</td>
</tr>
<tr>
<td></td>
<td>Hierarchical</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
</tr>
<tr>
<td></td>
<td>Data Transmission Media</td>
</tr>
<tr>
<td></td>
<td>Telephone, Coaxial Cable, Fibre Optics</td>
</tr>
<tr>
<td></td>
<td>Networks and Network Topology</td>
</tr>
<tr>
<td></td>
<td>Local Area Networks (LANS),</td>
</tr>
<tr>
<td></td>
<td>Wide Area Networks (WANS),</td>
</tr>
<tr>
<td></td>
<td>Tree, Star, Bus, Ring</td>
</tr>
<tr>
<td>6</td>
<td>User and Data Processing Skill Base</td>
</tr>
<tr>
<td>7</td>
<td>Preferred Supplier</td>
</tr>
<tr>
<td>8</td>
<td>Reliability</td>
</tr>
<tr>
<td>9</td>
<td>Cost</td>
</tr>
<tr>
<td>10</td>
<td>Security</td>
</tr>
</tbody>
</table>
The technological constraints list shown in figure 9.3 provides a framework for carrying out the IT internal audit sub-stage 2.1. One of the first tasks is to document all the current applications and the supporting hardware and data linkages between applications. As the research findings have shown in chapter four, determining the current, and anticipated, linkages between this application and any other is of paramount importance to the development of a resilient CAFM capability, particularly in ensuring that the integration requirements can be fully met.

Auditing the current computer hardware environment also assists in determining the size of the computer required for CAFM ie mainframe, mini or micro. It is unlikely that a micro computer would be suitable in a company where the computing environment is dominated by mainframe systems. The output from the strategic analysis stage additionally aids in this process as previously discussed in section 9.2.

9.5.1 First Cut Physical Design

All the technological constraints which may potentially affect the functioning of the CAFM system once it is implemented must be fully assessed and taken into account in the design stage of the development process. The constraints place limitations on the choice of the available CAFM hardware and software and therefore consideration of these constraints first greatly assists the selection process.

The first consideration should naturally concern the operating systems, applications systems and communications software for, as Hughes (1985)
points out, developments in the area of computer integrated manufacturing should be software led. The incompatibility of heterogeneous equipment and software from different vendors continues to cause integration problems.

This should be followed by consideration of the required hardware platform. The existence of a preferred supplier policy should be ascertained and recorded at this time i.e. a company may only purchase from one, or a limited number of suppliers. Consideration of hardware and packages from alternative suppliers at a later date would be unacceptable and therefore ascertaining this information at this stage greatly assists in simplifying the selection process.

Once in operation, however, the constraints also serve to limit the functioning of the CAPM system and it is therefore equally essential that all such limitations are fully understood. These may include speed, capacity, reliability, testing, cost, and compatibility etc. Speed refers to the time required to access stored information, transmit and process information. Connor (1985) points out that insufficient processing capacity can cause totally unacceptable response times in interactive, on-line systems. The storage capacity describes the amount of data that can be stored and processed. Again, insufficient disk storage space could limit the efficiency or effectiveness of the system once installed.

Reliability can be thought of as the mean time between failures and can be enhanced through the aid of fault tolerant computers and operator
education and training. Rzevski (1982) provides a detailed account of some of the factors which can lead to software failure. The automatic testing of hardware and software by diagnostic tools are widely available and used in even the simplest micro-computer today.

The availability of software development tools such as data dictionaries which allow design information to be stored and from which new applications can be automatically generated was discussed in chapter eight. Such tools together with flexible fourth generation languages greatly assist the modification of existing applications and the creation of new ones.

An often overlooked aspect of systems design and development is the computing skill base of the users and that of the data processing staff. Any computing deficiency or lack of confidence amongst the users may be overcome by the use of appropriate man-machine interfaces, user friendly devices and training. Documenting this constraint is therefore essential for both the design and implementation stages of systems development. Technical deficiencies amongst the data processing staff may require support from the facilitator in the form of technical briefings and through the aid of information sheets.

Data is collected in the IT internal audit sub-stage of the methodology on each of the technological constraints described previously. This data is then used in the later infrastructure requirements and infrastructure solution sub-stages (sub-stages 3.1 and 4.1.1 of figure 175.
9.1) which concern specifying and designing an appropriate computing and information systems infrastructure. These are discussed next.

9.6 Infrastructure Requirements

The infrastructure requirements sub-stage of the approach (stage 3.1 in figure 9.1) provides a first step towards identifying a set of appropriate CAPM packages. The output from the previous stages have provided a strategic context for the definition of CAPM requirements and the technological constraints have been also been documented. The approach devised by the ACME team for defining the CAPM requirements, as discussed in the DTI Guide (1990), the CAPM Interim and Final Reports (1990; 1991) and the Stratagem Workbook (1990) involves the use of a task model. This is used in the CAPM requirements stage and the results provide an input to the infrastructure requirements sub-stage (3.1).

The model, provides a set of related core, optional and dependent CAPM tasks. The core tasks represent tasks that are essential to every manufacturing situation "and are, therefore, done by every manufacturing company. For example, sales order processing, purchasing, release of material to the shop floor, invoicing etc" (CAPM Interim Report, 1990). The choice of a particular task necessarily involves carrying out subsidiary, dependent tasks. Optional tasks are those which are required only in certain situations, "for example, forecasting. Forecasting is indicated in situations where the manufacturing lead time for the product is greater than the maximum accepted lead time to market" (CAPM Interim Report 1990).
The CAPM requirements stage of the CAPM methodology therefore involves using the task model to define the detailed scope of the CAPM system.

The activity of defining the required CAPM tasks is a complex process and as such demands a considerable amount of time for thought and debate by all the users concerned. A workshop is used for the purpose of bringing together all the necessary users "to agree the set of CAPM tasks to be performed by the CAPM solution" (Stratagem 1990). Included are representatives from the manufacturing team, data processing and information systems staff and other staff concerned with the development of manufacturing systems.

Presentations of the findings from the previous stages of the work, eg the rough-cut control philosophy requirements are made and with the aid of the task model agreement is reached on the CAPM tasks required. The relevant core, optional and dependent tasks shown on the task model are highlighted and this serves to provide a template of the functions that must be supported by the CAPM hardware, software and the policies procedures and practices within which the hardware and software operates.

More detail of the task model can be found in the work by Childe (1991).

Given the task template, the infrastructure requirements sub-stage (3.1) of the methodology involves analysing the implications of the
CAPM task template for developing the computing and information systems infrastructure. With the data from the previous stages of the methodology on the computer processing and storage capacity requirements, integration requirements, manufacturing control philosophy requirements and technological constraints a physical design specification is derived.

The requirements definition of the CAPM system provides a detailed definition of what the system must do, in the physical definition the requirements are converted into a physical specification of how the system will be built. Unlike traditional structured approaches to this phase of systems development the focus of the physical design is not only on meeting the current requirements of the system but also the anticipated future requirements as identified through the strategic orientation of the methodology. A single point solution, therefore, is not sought but rather a computing and information systems infrastructure in which the CAPM system can continue to function as requirements change.

The facilitator may be required to provide an input to the process at this stage by way of presenting and explaining the concepts of operational performance envelopes and contextually bounded computing and information systems infrastructures. This is required to ensure that the problem of change, and specifically in data volumes, integration and manufacturing philosophies, is not overlooked. The contents of the previous chapter, and with the aid of figures such as 8.1 and 8.2, assist in this process.
9.7 Infrastructure Solution

This stage involves using the physical design specification to identify and select a set of candidate packages. Appendix H provides details of the functionality and features of some of the CAPM packages and could be used as an information sheet to assist in the process of package identification. Experience has shown that the data processing manager would possess sufficient knowledge to undertake this activity, which is essentially a research task, and identify a set of appropriate candidate packages that meet the requirements of the physical design specification.

Again the facilitator may be required to intervene to reinforce the concepts of operational performance envelopes and contextually bound computing and information systems infrastructures as this stage of the process has resulted in the many past failures, discussed previously in chapter four.

9.8 Choosing the Most Appropriate CAPM Package.

The next stage of the work is to choose the most appropriate CAPM package from the set of candidate packages, the amount of software customisation required and the policies, practices and procedures to provide the best "fit" and a resilient solution.

This is a complex process and as such requires ample time for deliberation and discussion by all the users concerned. Often insufficient time is given to this task and results in package
selection based on popularity or best sales performance without considering the company's real needs.

A workshop is used for the purpose of debating the relative merits of alternative packages and for generating a CAFM solution which best satisfies the CAFM requirements and constraints. The workshop, comprising members from the manufacturing, data processing and systems functions etc, agree the best choice of package. "Where the packages do not fully meet the requirements or when packages need to be supported by particular policies, procedures and practices this needs to be taken into consideration" (Stratagem 1990).

In deciding on the scope of computerisation the rules of thumb, discussed in sections 4.5 and 8.7.4, for selecting between tasks that are to be carried out manually and those that are suitable for computer processing are used. As indicated, this process is complex and involves a number of variables including the nature of the tasks, the decisions associated with the tasks, transaction processing volumes, frequencies and repetitiveness and organisational factors specific only to a particular company context. The role of the facilitator at this stage is to help the users understand the trade offs involved and to reach an acceptable and workable solution.
9.8.1 Customisation
Further enhancements of the software may be possible through
customisation to improve the level of fit. The level of customisation
includes changing field sizes and names, screen layouts etc.

9.8.2 Policies, Practices and Procedures
In addition manual policies, procedures and practices may be used to
further improve the hardware and software fit. "Required functionality
and flexibility which cannot be provided by the hardware and software
might be achieved by adjusting the production management policies,
procedures and practices. Thus, a combination of hardware, software,
policies procedures and practices can be identified which are able to
support CAPM requirements" (CAPM Interim Report 1990).

9.8.3 Installation
The final stage concerns establishing an implementation plan for "once
a suitable CAPM configuration has been identified the implementation
sequence must be specified. For example it is clear that many recent
CAPM packages require an inventory module to be in place before
subsequent activities can take place (Hollier and Barber 1989). The BOM
file is also an essential pre-requisite to many activities, for example
MRP. In addition activities such as MPS are essential if MRP is to be
effective. Consequently, technical precedence must be considered" (CAPM

The output from this workshop is a detailed CAPM specification of the
total CAPM infrastructure comprising the computing and information
systems components and the policies, procedures and practices that need to be in place to run the system.

9.9 Decisions Involved in the Development of a Resilient Computing and Information Systems Infrastructure for CAPM

In order to complete the process of selecting the computing and information systems infrastructure for CAPM a number of important decision must be taken. The series of decisions are as shown in figure 9.4.
### Figure 9.4

**Decisions Required to Develop a CAEM Computing and Information Systems: Infrastructure**

<table>
<thead>
<tr>
<th>Decision</th>
<th>Source of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of System</td>
<td>1. Strategic Analysis</td>
</tr>
<tr>
<td></td>
<td>. Stakeholder Analysis</td>
</tr>
<tr>
<td></td>
<td>. Financial Evaluation</td>
</tr>
<tr>
<td></td>
<td>. Product Portfolio Development</td>
</tr>
<tr>
<td></td>
<td>2. Manufacturing Analysis</td>
</tr>
<tr>
<td></td>
<td>. Manufacturing Audit</td>
</tr>
<tr>
<td></td>
<td>2.1 IT Internal Audit</td>
</tr>
<tr>
<td>CAEM, functionality required and scope</td>
<td>3. CAEM Requirements,</td>
</tr>
<tr>
<td></td>
<td>. CAEM task model</td>
</tr>
<tr>
<td>Overall control requirements</td>
<td>2. Manufacturing Analysis</td>
</tr>
<tr>
<td></td>
<td>. Manufacturing Solutions</td>
</tr>
<tr>
<td></td>
<td>3. CAEM Requirements,</td>
</tr>
<tr>
<td></td>
<td>. CAEM task model</td>
</tr>
<tr>
<td>Integration requirements</td>
<td>2. Manufacturing Analysis</td>
</tr>
<tr>
<td></td>
<td>2.1 IT Internal Audit</td>
</tr>
<tr>
<td>Hardware, software platform</td>
<td>1.1 IT Appraisal</td>
</tr>
<tr>
<td></td>
<td>2.1 IT Internal Audit</td>
</tr>
<tr>
<td></td>
<td>. Manufacturing Audit</td>
</tr>
<tr>
<td>Constraints, preferred supplier</td>
<td>2.1 IT Internal Audit</td>
</tr>
<tr>
<td>Candidate Packages</td>
<td>4.1.1 Infrastructure Solution</td>
</tr>
<tr>
<td>Most suitable package, customisation</td>
<td>CAEM Workshop, CAEM Solution</td>
</tr>
<tr>
<td>requirements, PPP's</td>
<td>Stage 4. of Methodology</td>
</tr>
<tr>
<td>Installation and implementation requirements</td>
<td>CAEM Solutions Workshop, CAEM Solution Stage 4.</td>
</tr>
</tbody>
</table>
9.10 Conclusions

This chapter has demonstrated the use of the techniques, principles and concepts developed in this thesis for defining a CAPM computing and information systems infrastructure. The application of these concepts through the process based framework and mechanisms eg workshops has been described and explained. The causes of CAPM system failure, as previously identified, have been fully addressed to ensure that the specification of the CAPM infrastructure is capable of meeting the contextual demands of change.

All the stages necessary to define a resilient CAPM system have been outlined. Specifically, the size of the CAPM system has been addressed with reference to data derived from phases of the overall methodology and the author's approach. Similarly the integration and overall manufacturing control philosophy requirements have been addressed. These requirements have been defined through adopting a wider, strategic approach, to avoid the problem of developing a single point solution - the likely outcome from traditional approaches.

The final stages of the approach have been described which concern specifying the overall solution of hardware and software, the customisation requirements and the PPP's necessary to provide a high level of "fit" and a resilient capability.
CHAPTER 10

SUMMARY AND CONCLUSIONS

10.1 Summary
Throughout this thesis the emergence of a new paradigm and era for manufacturing has been described and the specific CAFM design and implementation problems following in its wake have been explained. The extensive fieldwork undertaken by the ACME team uncovered a number of key environmental factors which, when related to the production management function and the CAFM system, were responsible for the high level of reported failure. The dynamic nature of the environment within which manufacturers must currently compete places demands on the supporting infrastructure that can only be met by building in the requisite degree of flexibility. In addition a legacy of less turbulent times is the predilection for single point solutions. These have been shown to be inadequate in the current climate of change.

Specific causes of CAFM systems failure have been identified as changing data volumes, changing integration requirements and changing manufacturing control philosophy requirements. However, it was recognised early in the work by the ACME team that in order to provide a methodology capable of preventing these types of failure, a far wider approach was called for than was currently available. The CAFM system is one of the most complex, interrelated and vital functions in a modern manufacturing enterprise and is inextricable linked with
business and manufacturing strategy, policies, procedures and practices, and technological and human resources.

The methodology required to address this factor has been presented as the CAPM methodology and its commercial counterpart, Stratagem (1990). Environmental, business, strategy, people and technological issues are addressed in the five phase process of Stratagem and the four stage process of the CAPM methodology, which represents an example of a particular application (see figure 5.1) of Stratagem.

Within this overall work the author undertook a specific piece of research to develop suitable concepts and techniques for the design and selection of the computing and information systems components for CAPM. The concepts of operational performance envelopes (OPE's) and contextually bounded computing and information infrastructures were devised together with techniques for their practical application. The rationale behind the concepts, and the concepts themselves, have been fully explained in the context of the wider CAPM methodology. The components from which the infrastructure would be selected have been discussed in relation to the varying degrees of flexibility which might be required.

10.2 Conclusions

In conclusion, the validity and contribution of the work by the ACME team as a whole, and the specific work by the author, can only be judged by the implementation of more effective and resilient CAPM systems. In this respect the methodology developed is currently being
used by a large consultancy group in a number of their clients. Its contribution to scholarly research can be judged by the written contributions in learned journals and conference presentations to academic colleagues and industrialists where the presentations have been well received. However, in the dynamic 1990's where the importance of continual evolution has been demonstrated for CAPM systems, development of methodology is necessary to both increase its scope and functionality.

10.3 Further Work
Further work is therefore required in the form of testing and validation of the methodology. Specifically, in terms of the author's work, to complement and extend the concepts and techniques devised, work is required on the process of selecting appropriate infrastructure components ie the hardware, software and integration strategies. Additional rules are needed to enable the contextual characteristics to be specified more precisely and for selecting an appropriate infrastructure configuration to match these.
REFERENCES

ACME (Application of Computers to Manufacturing Engineering)


COPICS. Available from IBM UK Ltd.


DECNET. Available from Digital Equipment Corporation.


Henkoff, R. This Cat is Acting Like a Tiger. Fortune, December 19, 1988, 69-76.


196


I-CAM PUBLICATION. I-CAM Program Library. AFVAL/MUTC. Wright-Patterson AFB. OH 45433.


Kochar, A.K. The Effects of Planning Parameters Setting on the


MaPICS. Available from IBM UK Ltd.


MOC, Available from Davy Computing, Sheffield.


MACCADD. Available from Logica UK Ltd.


MUST. Available from CCTA. HM Treasury.


National Bureau of Standards (NBS) centre for Manufacturing Engineering. Gaithersburg, Maryland. USA.


OMAC JIT. International Computers Limited.


Rzevski; G. Software Failures 1982 xxx


Second Interim Report on SERC ACME Grant GR/E56577, March 1989


STRATAGEM. Stratagem Workbook. Entrepreneurial Technologies. 1990


The Economic Monitor. No 27 March 1988. Published by the Engineering Industry Training Board.

Third Interim Report on SERC ACME Grant GR/E56577, January 1990


VMS. Available from Digital Equipment Corporation.


APPENDIX A

Paper presented to the 10th International Conference on Production Research, The University of Nottingham, August 1989.
THE DESIGN OF AN IMPLEMENTATION METHODOLOGY
FOR COMPUTER INTEGRATED MANUFACTURING SYSTEMS
IN THE ELECTRONICS SECTOR

N Weston, D R Hughes CIM Institute, Plymouth Polytechnic

1. INTRODUCTION
The environment facing many manufacturing companies today is dynamic, complex and often highly uncertain. Changing consumer demand, often difficult to predict, has forced dramatic reductions in product development times as companies strive to maintain competitiveness by being "first to market". At the same time process and material technologies and production techniques are rapidly changing providing significant opportunities for cost reduction, improved responsiveness and quality for companies willing, and able to adopt them.

As manufacturing grows even more competitive, responding to these opportunities will be crucial for survival. This paper argues that the major bottleneck inhibiting the full exploitation of advanced manufacturing and information technologies is no longer the availability of the technology itself but the lack of a rigorous, practical methodology for applying them. Such a methodology would enable companies to select the most appropriate technologies, secure user ownership and commitment to more effective, and resilient solutions capable of delivering the full business benefits.

As a first step in overcoming this deficiency a Process Methodology is presented and discussed for implementing flexible computing and information systems within electronics manufacturing companies. Computer aided production management (CAPM) systems have been chosen as a relevant application area to illustrate the advantages of the approach.

2. TRADITIONAL APPROACHES
Increasingly complex and uncertain manufacturing environments require the development of computing and information systems able to provide the flexibility and resilience needed to survive in highly competitive world markets. Experience has shown that traditional systems development approaches tend to create highly inflexible and unreliable systems inappropriate in situations where requirements cannot be predicted and/or where requirements are subject to rapid change, like manufacturing.

Traditional approaches provide single point solutions to an inherently dynamic problem. They attempt to meet current needs rather than provide a solution with the resilience to withstand unforeseeable and unplanned events. A resilient solution requires the development and implementation of a flexible computing and information systems infrastructure in which systems can be re-configured as new and unplanned requirements emerge.

However, unlimited flexibility is impractical and would be prohibitively expensive. Flexibility therefore needs to be restricted and it is for this reason that the concept of 'contextually bound'
infrastructures (Weston et al, 1988) has been devised. This explicitly recognises that in any manufacturing situation there are a number of alternative strategies that could be adopted and a variety of means by which the strategies could be implemented. Given that unlimited flexibility is prohibitively expensive there is a need to restrict the number of possibilities that could realistically be addressed by a particular company.

The notion of "context" relates both to the external constraints of the environment (market, trading conditions etc) and internally by the existing technical core (machines, skills, financial resources etc). In some situations it may be feasible and desirable to relax certain constraints but in practice many constraints would prove impossible to remove. For example, it would be unrealistic to expect that a manufacturer of milk bottles could become a manufacturer of printed circuit boards. However, it might well be possible for a manufacturer of computers to manufacture PABX's and vice versa.

The 'contextually bound' computing and information systems infrastructure is defined as an infrastructure able to provide an information processing capability able to support a range of potential manufacturing conditions.

This concept clearly challenges conventional notions concerning the design and implementation of information systems. The emphasis is not on understanding the existing system, and on forecasting future requirements. It is concerned with identifying the functionality, the extent, location and nature of the required flexibility to respond to a range of potential demands.

Traditional approaches are also deficient because they failed to adequately address human factor considerations. The Process Methodology recognises the importance of these factors and has been designed to ensure user ownership and commitment to the solution generated. Through this the methodology dramatically improves the prospects for successful implementation and in addition provides a catalyst for change by assisting in the educational process of understanding the nature and extent of the system requirements.

3. THE PROCESS METHODOLOGY

The Process Methodology has been specifically developed to overcome the deficiencies of traditional approaches and to provide an effective method of coping with unpredictable situations and situations where company characteristics tend towards idiosyncracy. For example, an ongoing research project (Hughes et al, 1989) has demonstrated that segmenting the electronics sector, according to product, industrial classification, size or production mode serves no useful purpose in developing an implementation methodology since it leads to no large homogeneous groups.

Consequently, an implementation methodology for the electronics sector must be capable of addressing all these idiosyncratic requirements if it is to be effective for all electronics manufacturing companies. This can only be done by developing a methodology which is not dependent on
the characteristics of the company, or the unique characteristics of its environment, but on the process of implementation itself.

The following sections describe and explain the factors causing the failure of arguable one of the least understood yet most important CIM application areas, namely, CAPM systems. Infrastructure and flexibility concepts are further explained and their importance for preventing premature failure discussed together with a detailed outline of the methodology itself.

3.1 Factors Leading to Capm Failure
The authors have interviewed CAPM practitioners and visited over 20 UK electronics manufacturing companies to collect data on CAPM implementation. A number of factors which have lead to immediate or eventual failure of CAPM systems have been identified.

- Requirements were defined incorrectly;
- Requirements were defined correctly, but the wrong system was implemented;
- Requirements were defined correctly, the right system was implemented, however requirements changed over time and the system failed;
- The correct system was defined and implemented, however implementation was badly managed resulting in failure.

Of these four principal causes of failure the third, involving changed requirements, is of considerable importance. It is important because even when requirements are defined correctly and the correct system is specified and implemented successfully, subsequent changes in requirements can lead to failure. Thus even systems which are currently performing well, but which lack the flexibility to respond to new requirements, are potential failures.

Three primary reasons for changes in requirements have been identified:

- Large scale changes in manufacturing volumes;
- Changes in integration requirements;
- Changes in manufacturing strategy.

The authors regard systems which do not meet the requirements and which need to be replaced as outright failures. Systems which only partially fulfill their requirements are regarded as partial failures and systems which are able to fulfill current requirements, but which lack the flexibility to respond to new demands as potential failures.

It is apparent from these failure modes that traditional approaches to CAPM implementation are unlikely to succeed. At best the outcome will be a system capable of meeting current requirements before decaying into partial failure and subsequent outright failure.

In highly stable manufacturing situations this process may take some time, however in other situations the mismatch between the system implemented and current requirements may develop so rapidly that almost immediate replacement is necessitated. The lack of flexibility in many CAPM systems currently considered as potential failures is likely to
eventually result in outright failure.

3.2 Flexible Infrastructures

CAPM flexibility concerns both the software packages themselves and the additional supporting infrastructure components - the policies, procedures and controls associated with the production management activity.

CAPM systems can be thought of as encompassing all computer aids supplied to the production manager (Waterlow and Monniot, 1986). This includes 3 main information processing activities.

SPECIFICATION ensuring the manufacturing task has been defined and instructions produced;
PLANNING AND CONTROL planning the timetable, adjusting resources and priorities and controlling production activity;
RECORDING AND REPORTING recording and reporting production status and performance for liaison with other departments and future use in specification, planning and costing.

These activities support a number of modules including:-

Master Production Scheduling
Stock Recording (bought out parts)
Stock Recording (finished parts)
Capacity Planning
Detailed Scheduling
Process Planning
Materials Requirement Planning
Order Control
Bill of Materials Processing
Monitoring Work in Progress
Costing
Forecasting
Performance Analysis
Purchase Order File

Many current CAPM packages are modular based, enabling users some degree of freedom to implement the most appropriate set of modules to meet their immediate requirements, as well as offering the potential to develop their CAPM systems as new requirements emerge. The customisation of the modules provides for additional flexibility and allows a better 'fit' to be achieved. However, not all CAPM packages necessarily contain the complete set of modules required to meet the idiosyncratic requirements of an individual company, and, even less so, the diverse range of companies which comprise the electronics sector.

It is important, therefore, that companies have the facility to 'pick and mix' modules from different software vendors if they are to develop an effective infrastructure with the requisite amount of flexibility.

Another equally problematical area which has still to be addressed concerns the ability of CAPM packages to concurrently support a number of production philosophies such as MRP and JIT. For many users the
excitement of recent developments in production philosophy, and what these promise in terms of business benefits, has been tempered both by a lack of suitable software - which has often resulted in users augmenting their CAPM system with micro-based spreadsheets - and a lack of understanding of the likely impact of adopting these philosophies for their existing CAPM system. As previously described, the implementation of a different production philosophy generally results in failure of the existing CAPM system.

Although a number of software vendors are currently developing CAPM software which, it is claimed, support more than one production philosophy, this is an important infrastructure requirement which has yet to be fully addressed.

3.2 Requirement for Integration
The requirement for companies to respond quickly to new demands in the electronics market requires all systems within the company which are connected with production - and therefore with CAPM - to respond in a coordinated fashion to changing requirements.

Visits to collaborating companies have revealed a number of moves towards the development of integrated solutions. One, company A, have established Electronic Data Interchange (EDI) with key suppliers and are now able to access existing supplier databases and place component orders. Company B have an integration policy based on MAP/TOP connections. Each new software module has to be capable of integrating with MAP/TOP protocols and existing software structures.

However, the research has found examples of companies who have installed CAPM systems which cannot process existing BoM files, integrate with existing order processing, access process planning data or link to the financial data necessary for accurate costing. It is therefore important in the context of CAPM implementation to consider the linkages which integrate CAPM with the wider business.

Company visits, discussions with practitioners and CAPM consultants and a survey of the literature has led to the identification of existing or potential links between CAPM, other manufacturing and wider business systems. Some of these linkages have been modelled using the ICAM Definition method IDEFO. This area of work is still being undertaken with the aim of developing the methodology for company wide computer integrated manufacturing (CIM) implementations.

4. THE PROCESS METHODOLOGY IN DETAIL
The process methodology incorporates a number of important concepts which are brought together in a highly practical framework. The methodology provides a mechanism for guiding users through a series of questions relating to the principal issues that need to be considered in order to identify the nature and extent of potential manufacturing requirements and ultimately CAPM requirements.

In this way the methodology provides users with a means of thinking through their market and trading conditions and the resulting
repercussions of change for manufacturing. Carrying out this process will enable resilient CAPM solutions to be specified, able to support a range of likely/potential manufacturing conditions. Resilience would be achieved through the implementation of infrastructures with the necessary degree of flexibility.

A resilient solution is provided by defining a hierarchy of operating performance envelopes. Each envelope represents a range of states within which the system may be required to operate. Thus, through the identification of appropriate envelopes, systems with the appropriate type and extent of flexibility to support the range of conditions bounded by the envelope can be specified.

The process begins by defining the strategic performance envelope. This envelope is established through consideration of the company's markets, products and competitors and is constrained by the technical and economic factors which reduce or limit the range of possibilities.

This envelope sets the requirements for the manufacturing performance envelope that the manufacturing system must fulfil. Further consideration of these requirements, through analysis of the principal manufacturing resources, enables the requirements and constraints of an appropriate CAPM solution to be defined.

This, in turn, sets the condition for the CAPM performance envelope and the requirements of the system at this level.

Finally, the CAPM performance envelope sets the requirements for the information systems and supporting infrastructure. Using this approach a logical specification may be derived. This can then be compared with the current company conditions to determine the implementation space and the appropriate implementation strategy to bring about the change required.

Research by the authors has revealed that once an appropriate CAPM software solution has been specified using the Process Methodology, the degree to which this ultimately meets the business requirements varies according to the implementation strategy adopted. The implementation of a generic CAPM package provides the least best 'fit'; customisation of the package provides a better 'fit' while the addition of services provides the best 'fit'. The services component involves analysing the existing company policies, practices and procedures to assess the degree to which these need to be changed to complement the customisation capability of the software.

5. CONCLUSION
In this paper the authors have presented a new methodology that challenges many of the traditional assumptions underlying current thinking. The top down, business oriented, structure of the methodology has been described and the stages necessary to implement flexible, resilient CAPM systems discussed. Although the paper has specifically focused on the detailed CAPM implementation requirements and the means by which an informed choice of CAPM software and services can be made, the authors believe that this approach is equally applicable for
company wide CIM implementations.

Many of the deficiencies of the traditional approaches have been identified and the implications of employing these methods for the long term survival of CAPM systems fully explained.

The context within which both CAPM and other manufacturing and business applications exist has been outlined for the electronics sector and the importance of developing flexible infrastructures stressed.

The methodology brings together a number of important concepts, in a practical way, and provides a means of ensuring that resilient solutions are created which are capable of delivering the full business benefits.

REFERENCES


APPENDIX B

THE DEVELOPMENT OF COMPUTING AND INFORMATION INFRASTRUCTURES FOR CIM SYSTEMS

David R. Hughes, Neil Weston, Roger S. Maull,

The CIM Institute, Department of Computing, Plymouth Polytechnic,

ABSTRACT

The paper discusses the development of an approach for the design of Computer Integrated Manufacturing (CIM) systems - focusing upon those companies developing Computer Aided Production Management (CAPM) systems within the Electronics sector.

The turbulent environment facing designers of CIM systems within Electronics is described and the implications examined. A new process orientated approach is proposed which focuses upon the development of contextually bounded computing and information infrastructures.

INTRODUCTION

In recent years much emphasis has been placed on the importance of introducing advanced manufacturing and information technologies into British industries. These technologies result in an approach to manufacturing which differs from traditional approaches in the extent to which the computer is used in the design of products, in the design of the production process, in manufacturing and test and in the management and control of the manufacturing system. Undoubtedly, for those companies able to harness and utilise these technologies effectively the rewards derived from improvements in manufacturing competitiveness are substantial.

Unfortunately, the results of introducing Advanced Manufacturing Technology and Information Technology in many companies have been unsatisfactory when evaluated against technical, user, business or organisational criteria and it is not unusual for the performance of the implemented system to differ markedly from that which was originally conceived. One of the reasons for this stems from the fact that the benefits from large scale investment in such technologies often cannot be fully exploited without also undertaking a major reorganisation of the company, involving a redistribution of activities and intelligence and a fundamental rethink of manufacturing strategy and systems. The problem of achieving these benefits is further compounded in an environment where it is difficult to define current requirements and near impossible to predict future ones.

THE ELECTRONICS SECTOR

Recent evidence [1] suggests that the UK Electronics sector is one of the fastest growing industrial sectors in Europe. The growth in Electronics output in the period 1979-1981 was consistently more than twice total manufacturing output growth. The 1983 figure was even more significant with electronics output growing by 21% compared to 1.9% for manufacturing as a whole. Evidence such as this supports the view that whatever 'recovery' took place in the UK during 1983 it was by and large electronics led. However, these figures mask an underlying malaise. In terms of international competitiveness, the UK had a trade
deficit on electronics of £2,000M in 1983.

Research undertaken by the authors has indicated that the ability to respond quickly to changing market requirements is of paramount importance and one of the principal areas in which companies are facing increasing competition. However, as Bentley [2] has pointed out, predicting market requirements in Electronics is problematical. This can lead to disastrous consequences if companies "back a loser" having committed investment to the development of a CAPM system which when implemented does not enable the company to meet the requirements of a changed marketplace.

In such an environment a major problem for companies is coping with uncertainties in supply and demand on one hand and the need to utilise manufacturing facilities efficiently on the other. This problem is compounded by an increasingly competitive market in which stock and WIP need to be minimised to reduce costs; where shrinking product life cycles reduce the time available to design and manufacture; where frequent design changes create large volumes of rework; where the quality of components received from suppliers needs to be carefully monitored and in situations where the supply time of critical components frequently exceeds the period covered by the assembly schedule.

An essential requirement therefore is to reduce these uncertainties through the provision of timely information to a work area about its own situation and that of other, possibly remote, areas. Most of the current computer support and information systems provision in electronics manufacturing is focused on material supply and production planning. In developing an integrated system further information on cost, quality, machine status etc is required. In a fully integrated system part programs, test programs and routing information would also be required.

Solutions to the business planning and production management problem such as MRP, OPT or JTT based on standard or customised packages offer some help in integrating planning and control activities [3] and quality [4]. However, as was recognised in a CAPM State-of-the-Art Report [5], the key to full exploitation of CAPM does not lie in the implementation of a particular system to address a specific need but in the development of an infrastructure within which organisations can continue to adapt and grow, that is learn. Modular system design strategies [6,7] and modular CAPM packages [8] facilitate this kind of evolutionary development.

COMPUTING AND INFORMATION INFRASTRUCTURES

When the environment is highly dynamic and markets turbulent single point solutions are inappropriate and ineffective. In such a situation the authors propose that the way forward lies in the development of infrastructures to provide adaptability, flexibility and to facilitate the continual evolution of the organisational system. Evidence from research so far undertaken suggests that these infrastructures need to address computing and informational, technical and organisational factors in an integrated manner in order to achieve the necessary level of responsiveness to changing and often unpredictable demands.

The implications for the design of CIM systems are staggering. Traditional methods involving the specification of a design are no
longer valid because of the difficulty, or impossibility, of defining the 'ends' required - when the 'ends' are subject to continual change. The focus of attention must therefore be directed at ensuring that the 'means' are available to cope with the variety of potential demands on manufacturing. This can only be achieved through the development of an appropriate set of infrastructures.

The authors recognise that there is a trade off between flexibility and cost and attempting to develop infinitely flexible systems able to respond to all potential changes in the environment - even if this were technically feasible - would be prohibitively costly. It is therefore proposed that contextually bounded infrastructures are developed which are circumscribed by the core business activities.

The challenge to those concerned with the creation of computing and information systems infrastructures involves firstly identifying and removing the barriers inhibiting the development of well structured, flexible, modifiable and maintainable systems and secondly, promoting the establishment of systems with performance parameters consonant with the requirements of the wider system. Modular design strategies, modular CAPM packages, 4GL's, fault tolerant computers etc are examples of current technologies which facilitate this desired system state.

The premises under investigation within this, and the overall research project [9], have implications that challenge conventional notions concerning the design and implementation of integrated manufacturing systems. It is proposed that the focus of attention should no longer be placed on gaining a good understanding of the existing system state, and on forecasting future requirements, but rather on the process of creating appropriate infrastructures.

An approach to the design of infrastructures

An approach to the design and implementation of infrastructures is currently being developed whose theoretical foundation is based upon contingency theory [10]. The objective is to provide users and practitioners with a structured set of guidelines for the implementation of infrastructures contingent on the organisational environment. A relevant infrastructure set can be thought as comprising of both social and technical elements; attendant system components and their configuration. The attributes of the infrastructures relate to the degree of flexibility and the reconfigurability of the system to meet new requirements. For example the level of flexibility of the informational infrastructure is dependent upon the compatibility of the system components and the level of data and informational integration [5].

The initial stage of the approach concerns carrying out an external appraisal and internal analysis of the company with users. The output of this stage is a 'fingerprint' of the company and its current position relative to its environment.

From this it is possible to compare the 'fingerprint' against benchmarks of 'best practice' and make a judgement of the appropriateness of the infrastructures currently in operation against those of the best performing companies with similar environmental characteristics. System components with the appropriate degree of flexibility to cope with the potential set of demands on manufacturing
can then be selected.

This final stage of the implementation approach concerns bringing about the changes identified as appropriate and necessary. Intervention is again based upon guidelines drawn from best practice but can be thought of as involving change along a continuum from incremental to step function [11].

RESULTS TO DATE

The research team have begun by investigating the computing and informational infrastructures within two large electronic companies. The output from this phase of the work has been an understanding of how companies are developing computing and informational infrastructures to cope with changing manufacturing requirements.

Company A is a major UK computer manufacturer. The research focused on the manufacture and assembly of Printed Circuit Boards (PCB's) for their range of computers. They produce in excess of 10,000 PCB's a week with a potential variety in excess of 500 boards with approximately 150 components per board.

Company B is a major UK consumer electronics company. Here too the research has focused on the production of PCB's. This company employs 300 people and produces several thousand PCB's a day with an average batch size around 50.

Informational infrastructures

Company A have developed an extensive infrastructure set. Software development is carried out in accordance with a set of principles of good systems design [12]. Software is developed in a modular fashion and is implemented according to a three stage process which facilitates user involvement and prototyping. An example of the use of this approach is described below which concerns a recent extension to the existing manufacturing system.

A functional requirements specification was derived for a materials control system, WIP tracking system, a quality system and a production control system. Quality and WIP tracking systems were integrated into QUART (Quality and Route Tracking), which used bar codes and operation cards to track boards throughout the plant, materials control systems through the use of carousels and an automatic storage and retrieval system and a lower level production control system based around a pull control system.

The procedure for specification included in-house systems analysts. These analysts interacted with the project manager to specify requirements. Various working groups had the task of reviewing the functionality of the proposed systems and they reported to a project board which included a senior management representative from all those departments involved in the implementation of the proposed systems.

Each of the systems; WIP tracking, Quality, Production Control and Materials Control were implemented according to a prototyping plan. Quick build tools were used to generate 'rough and ready' menus which were then iteratively refined by the individual working groups until at near certainty the code was developed and then trials were run, department by department and database by database.
Additionally, the changes to the lower level systems resulted in enhancements to the higher level MRP system which incorporated WIP information to give on-line tracking of jobs, quality data which gave information on scrap, production control and materials control which gave information on status of boards and components.

All these enhancements take place within an integrated network and communications strategy. All systems have to be integrated within the company's MAP network and a strategy for software development which reduces database proliferation and helps ensure data integrity.

The design of the MAP system is based upon 6 considerations:

- Full support of the MAP 7 layer protocol standard
- Good performance and providing a basis for later expansion
- Short development timescales
- Modular structures
- Do not interrupt the production line and adopt an evolutionary replacement schedule
- Acceptable cost

Based upon these considerations any systems developments use the maximum amount of proprietary hardware and software to reduce development costs and timescales and any further developments will increase the performance of the system and provide the basis for expansion.

Company B have developed a very limited infrastructure for informational flexibility. They have purchased an "off the shelf" CAPM package based on an existing hardware capability. They have recently investigated the possibility of developing bar coding and WIP tracking systems. Because they have failed to update their existing package with new modifications they are finding it difficult to add on these new modules to their outdated software. Further as they have no strategy for communications they find it difficult to integrate other software to their existing package. Thus a lack of foresight in the original purchasing decision has constrained their flexibility in enhancing their existing system to meet changing CAPM requirements.

The method used by the external consultants for producing the system specification was based simply on interviews with all system users, and resulted in a specification which reflected the existing procedures and perceived information requirements. No strategic view of system operation was included, and certain elements were omitted from the specification. Middle management levels apparently failed to realise the necessity of their involvement in system design, and in any case were not given flexibility to cover their absence for participation.

CONCLUSIONS

The approach outlined in this paper addresses the need to develop flexible CIM systems to respond to rapidly changing environmental conditions. It is based upon the concept of flexible infrastructures as a means of coping with the uncertainty of the market place.

The paper has focused upon the development of Computing and Informational infrastructures within the Electronics sector as an example of the types of infrastructures required in markets which are undergoing particularly rapid change.
The authors postulate that those trying to design CIM systems in response to rapidly changing markets should focus on the means of achieving flexibility within infrastructures rather than designing CIM systems on the basis of existing requirements. The authors have recognised that it is not feasible to design infrastructures which are capable of dealing with all possible outcomes. Infrastructures should be contextually bounded by an external analysis and internal appraisal of the company and the environment in which it operates.

We conclude with examples from two major electronics companies operating in highly dynamic environments. Company A have attempted to respond by developing a strategy for flexible infrastructures based upon a set of principles for good systems design all within a set of guidelines designed to ensure that future systems will be implemented within an integrated CIM communications strategy.

Company B has taken a less pro-active approach based upon the purchase of off-the-shelf packages. They have found problems in responding to changes in the market place and in integrating extensions to their existing systems.

It would be simplistic to suggest that Company A had achieved success and Company B had failed. However the conclusion is that those companies who develop an approach to the design of CIM systems which facilitates flexibility through an infrastructure geared to respond to changes in the market place will have an improved chance of responding to transient market opportunities.

ACKNOWLEDGEMENT

This paper stems from research conducted under the CAPM programme of the ACME directorate of the SRC. The objective of the research is to develop a user led methodology for the implementation of integrated manufacturing systems within the electronics sector and is scheduled to conclude in September 1990.

BIBLIOGRAPHY

1 Soete, L., Technological Trends and Communications. SPRU Publication 1985.


4 Baines, R., Hughes, D., Quality and Production Systems: We should be Talking to Each Other, International Journal of Quality and Reliability Management, 1984.


8 For example; COPICS, MAPICS, GMAC etc.


APPENDIX C

Paper published in the International Journal of Production Management

Volume 10, Number 9, 1990
A Methodology for the Design and Implementation of Resilient CAPM Systems

R. Maull, D. Hughes, S. Childe, N. Weston

Centre for World Class Manufacturing, Polytechnic South West, and D. Tranfield, S. Smith

Change Management Research Unit, Sheffield Business School

Introduction
For a variety of reasons outlined within the body of this article, the approach taken to this research task has been strongly contextualist and strongly processual. In summary, this is because of the dynamic nature of many companies in an environment which is producing a requirement for rapid, idiosyncratic manufacturing and computer aided production management (CAPM) adaptability both in the design and implementation of systems.

The article begins by outlining the results of research into the reasons for CAPM systems failure[1]. Using these results, the research team have developed a methodology based on the concepts of flexible infrastructures — those policies, procedures and practices that support the hardware/software configuration of the CAPM system. The methodology is examined stage by stage to specify the context in which the CAPM system is installed and to focus on the implementation of an appropriate CAPM systems and infrastructure configuration. The article concludes with a brief case study based on a recent application of the methodology.

Fieldwork Results
From our discussions with CAPM practitioners, company visits and from surveying the literature, a number of factors which lead to immediate or eventual failure of CAPM systems have been identified.

- Requirements were defined incorrectly.
- Requirements were defined correctly, but the wrong system was implemented.
- Requirements were defined correctly, the right system was implemented, but requirements changed over time and the system failed.
- The correct system was defined and implemented, but implementation was badly managed resulting in failure.

Of these four principal causes of failure the third, involving changed requirements, is of considerable importance. It is important because even when requirements are defined correctly and the correct system is specified and implemented successfully, subsequent changes in requirements can lead to failure. Thus even
systems which are currently performing well, but which lack the flexibility to respond to new requirements, are potential failures. Such a characterisation of failure mode has particular significance for the fast moving electronics sector. Three primary reasons for changes in requirements have been identified:

- Large scale changes in manufacturing volumes;
- Changes in integration requirements;
- Changes in manufacturing strategy.

For our purposes we regard systems which do not meet the requirements and which need to be replaced as outright failures. Systems which only partially fulfil their requirements we regard as partial failures. Systems which are able to fulfil current requirements but which lack the flexibility to respond to new demands, the team regard as potential failures. Failure Modes are:

- **Outright** — System is replaced.
- **Partial** — System does not meet requirements.
- **Potential** — System cannot meet new requirements.

It is apparent from these failure modes that traditional approaches to CAPM implementation are unlikely to succeed. At best the outcome will be a system capable of meeting current requirements before decaying into partial failure and subsequent outright failure.

In highly stable manufacturing situations this process may take some time, however in other situations the mismatch between the system implemented and current requirements may develop so rapidly that almost immediate replacement is required. The lack of flexibility in many CAPM systems currently considered as potential failures is likely to result eventually in outright failure.

In our view, the manufacturing sector epitomises the need for flexible manufacturing of which so much has been written recently[2]. What is clear from our study of CAPM failures is that CAPM systems and their supporting infrastructures can be major constraints on the overall flexibility of manufacturing systems. Slack's[3] typology of flexibility into product, mix, volume and delivery are all critically affected by the type of CAPM system deployed and it is important that companies determine the flexibilities which underpin their strategic competitive edge.

**Infrastructures**

The research team believe that user companies need to move away from the development of a single point CAPM solution toward the development of CAPM systems which are capable of adapting to changing demands. However, the CAPM system is only one of a range of systems which support manufacturing and which needs to be considered as an integrated whole. Similarly, CAPM solutions are much more than software. They involve the policies, procedures and practices which govern the software use and which therefore restrict or enhance its flexibility. These support systems have been dubbed "infrastructures" and have been considered by several writers[3,4,5,6,7,8].
CAPM Infrastructures
The project team have applied the concept of infrastructures to computer aided production management. The CAPM infrastructure provides a set of policies, procedures, systems and knowledge that surrounds the processing of customer orders, to provide information such as work-to lists, job schedules, picking lists, batch cards, travellers and material orders.

An example of a flexible set of CAPM policies, procedures and controls is seen in Company A. They have designed an infrastructure which can support the CAPM activities required for two quite different manufacturing strategies. Part of their manufacturing system operates under a continuous flow just-in-time (JIT) strategy whilst the rest is controlled through a material requirements planning (MRP) push system. The CAPM system itself is a product of information systems policies, procedures and controls which are geared to securing a flexible solution. This is manifested in the use of a modular hardware and software design approach, and in the use of common data protocols to allow communication between the modules and to other systems.

Examples such as this are rare. More frequently, the group has found examples of systems that are currently successful but which have only restricted potential since they are the products of short-term CAPM policies. These systems appear to be restricted in terms of the manufacturing strategies that they can support, the integration that can be achieved and the volumes of data that can be processed.

CAPM vendors have traditionally tended to focus on the supply of the hardware and software of systems to the exclusion of the policies and procedures which must be put in place to ensure success. However we note that some vendors are now attempting to develop these elements through more emphasis on "service" rather than supply.

Principles of a Methodology
Because of these and our own fieldwork results, the research team have taken as a basic premise that electronics companies show sufficient idiosyncrasy to make individuality a working assumption in developing a generic methodology. Following this argument, the only feature common to all user companies is the process of introducing the CAPM system. Thus the methodology developed by the research team has to address the process of implementation within the whole range of electronic companies rather than developing a prescriptive solution for individual segments.

Implementation methodologies inevitably tend to be more extensive pieces of work than design methodologies because, if for no other reason, it is impossible to think of how to implement without prior consideration of what to implement. In this sense it is probably more appropriate to think of devising a CAPM development methodology than focusing only on implementation. However, any methodology needs to specify two main characteristics. First, it must identify the salient variables to be taken into account, thus dimensionising the problem. Second, it has to order these variables or dimensions to enable the user to progress in an orderly and understandable
way from an initial to a new situation (in this case from no CAPM or ailing CAPM to a flexible CAPM).

From the argument above, the primary design principles for CAPM tailored for electronics companies are that they should address the dimensions of context in which the CAPM is situated and should focus primarily on the process of introduction rather than the specification of a single point solution. Therefore, what is required is the development of an implementation methodology which:

- articulates the company's business strategy with respect to manufacturing;
- identifies the nature of the manufacturing system to support the business strategy;
- simplifies the CAPM task and then identifies the CAPM modules required;
- matches CAPM requirements against CAPM solutions (software plus infrastructures) to ensure a good business fit;
- ensures that the implementation of the methodology is managed according to good implementation practice.

All of these principles are followed through in the development of a user-led CAPM methodology.

**The CAPM Methodology**

The CAPM methodology has three main features:

- Resilience, developed through a top-down approach.
- Human factor considerations, in that the methodology is user-led.
- Facilitator provides guidance through the process.

Figure 1 represents the hierarchical framework of the methodology. Although represented schematically as such, it is non-sequential in operation, and there is considerable iteration between stages.

**Business Strategy**

The process begins by taking a company through a process of product rationalisation. Working in conjunction with the facilitator the company develops an understanding of its key stakeholders. A stakeholder is an individual or group who influences or is influenced by the company. This influence may stem from the possession of resources, the dictation of alternatives, or authority (possibly through legislation). Examples of stakeholders include competitors, suppliers, employees, and customers. Stakeholder analysis provides the strategic context for the specification of the manufacturing system and the subsequent CAPM requirements. It is a vital backdrop, difficult to undertake adequately from within the company, and usually needing a skilled facilitator to bring it to an effective conclusion.
The methodology then requires the company to take a strategic view of its product families, distinguishing between those that are profitable, those which may become profitable and those that are unprofitable. Data from the stakeholder analysis are used to identify the directions in which product families are expected to move. This stage enables a company to rationalise its product portfolio and identify potential market opportunities for new products.

The third element of the strategic analysis is to relate order winning criteria to each individual product family in turn. This uses a technique called “price of non-competitiveness” (PONCI). Here the facilitator derives an estimate of the gain to be made from improvements in order winning criteria. For example, by using this technique in a local engineering company the research team were able to identify that a 10 per cent drop in price on a particular product family would generate a 20 per cent increase in turnover.

**Manufacturing Strategy**

This stage begins with a manufacturing audit. This identifies both the structural (machines, labour, etc.) and infrastructural (policies, procedures, controls and systems) factors that have a direct bearing on production. These are then matched against individual product family order winning criteria in a resource impact analysis. The next activity is to identify those factors that can be changed to enable individual product families to meet the competitive criteria derived from PONCI.

Because of the complexity involved in developing a complete methodology...
for each of these manufacturing areas and because of the focus of the CAPM initiative, the research team have concentrated on developing a methodology which identifies an appropriate CAPM solution. The research team recognise that CAPM systems cannot be implemented in isolation. However, the broader based methodology is intended to be the focus of future work.

**CAPM Requirements**

This stage is about how to set up CAPM systems to produce those product families on the competitive criteria established earlier. It incorporates a simplification procedure following a number of "rules of thumb"[9]. For example, in Company B the lead time needed to obtain material from a supplier exceeds the planning time in which material must be made available to meet delivery dates. In this case these families need their inventory management systems to run according to re-order point logic. However, the danger with re-order point is that it is based on look back (previous use) criteria and could easily lead to stock-outs or high safety stock levels. The only alternatives are to extend delivery dates, or procure material more quickly or shorten the manufacturing cycle time.

In families where the material lead time is less than planning time a company can use look ahead logic. This may utilise MRP, MRPII or JIT where JIT attempts to bring safety stocks and safety lead times towards zero whilst developing lot for lot sizing[9]. Yet moving an existing MRP system towards this would have major implications for purchasing control systems, policies and procedures — in fact these and not the software may be the constraints on moving to a JIT system.

Another simplification procedure surrounds the choice of manufacturing control system and depends on predictability of demand. For example:

- Repetitive manufacturing — **Just-in-Time**
- Some repetitive — Mixed Kanban/MRP system, using MRP for material procurement
- Mostly non-repetitive — MRP
- Very non-repetitive — Project management tools.

The next stage is to match company profiles against CAPM modules. These may include bill of materials (BOM), sales order processing (SOP), capacity planning, work in progress (WIP) tracking, purchasing, shop order release, stock control, etc. These tasks can be accomplished either by software or by the infrastructure e.g. WIP tracking is a module available in most CAPM software packages, however it may equally well be undertaken as a shopfloor practice under a manual system.

Deciding whether or not the task is required is contingent upon the number and unpredictability of several manufacturing system variables including number of items per product, number of levels of BOM, degree of commonality of parts, number of sequential operations in a manufacturing routine and the number
of workcentres. Therefore, establishing whether or not, for example, a purchasing module is required is contingent upon the number and unpredictability of the variables required to support purchasing order processing.

**CAPM Solution**

This stage matches the CAPM task requirements against existing software packages to identify a best fit. A set of features of the major CAPM packages is compared against the requirements from stage three and an appropriate package selected. This fit is then improved through "tailoring" the software package. However, the principal business benefit is obtained through the improved fit offered by the infrastructures. For example, a company may have chosen a CAPM configuration based on an MRP system for material procurement. Clearly, accuracy of the BOM and inventory status files are of critical importance. The control of these data items has to be carried out through company policies, procedures and practices, such as locked stores, daily stock checking, improvements in the control of the BOM, change proposals and change notes.

**Implementation**

In implementing the CAPM methodology there are four key managerial activities:

*Audit and Vision Build* — This activity uses the stakeholder analysis of the strategic analysis phase to develop corporate mission statements and a business plan complete with a set of four to six central values with which company members can identify.

*The Cascade* — This activity spreads the word through the management team. The mechanism suggested is a series of workshops which allow the plans to be discussed and questioned. This may go on after structural reorganisation and may involve some training and development work.

*Sprinting* — In this stage, bursts of activity are paced with bursts of stability and consolidation. The activities (or sprints) are short discrete projects which each have measurable targets of success and a fixed time frame. They are managed from the top of the company and are seen to be so, involving all company members. Each sprint is focused on a key element of the changes required. The sprint is a high-energy burst which cannot be sustained over long periods. However its strength is that in a short time it can make a clear move from A to B (a morphogenic change). Support and enthusiasm are generated by the high energy and high profile of this stage.

*The Performance Ratchet* — This stage takes over from the sprints and continues to make incremental improvements to the performance of the company. Success of these morphostatic changes is ensured by getting the activities done by the most appropriate people. The performance ratchet is pushed onwards by making ever higher demands from the departments and individuals concerned — targets are continually raised.
Case Study

Background

The company is a small mechanical engineering manufacturer which dominates its UK marketplace with a 50 per cent share of the market. It also sells heavily into a variety of European countries, including France, Holland and Scandinavia. The company recognises that, while it appears to occupy the high ground in the market, revenues are being squeezed from two important directions. Competition, particularly from Southern Europe is rapidly intensifying. This is due, in part, to the use of more advanced casting methods. At the same time, raw material costs are spiralling. As a consequence, turnover has remained constant during 1989 and profits have fallen by 30 per cent.

Results

The research team undertook a rigorous application of the methodology over a period of three months. Each stage was taken in turn and worked through with the help of proformas and a series of technical briefings. Because of two severe constraints imposed by the company, i.e. cash restrictions and limited technical knowhow, a CAPM software specification was to prove impossible. However, it is interesting to note that the solutions that were identified (and being implemented) were based on the CAPM infrastructure.

The company was experiencing considerable variations in demand that had to be matched by an approach to CAPM capable of responding to this variety. The problem could be considered from two points of view. The variety could be reduced, and manufacturing could be enabled to meet the variety. A combination of these two approaches was attempted.

1) The company’s sales team were given a policy of reducing variety as far as possible, in this case by selling standard products. This was to be supported by a training or awareness scheme for sales staff together with the implementation of sales procedures which involved presenting the customer with the option of purchasing a standard product under more advantageous terms (of cost and lead time) than a special.

2) A short-term solution to the information system problem was generated by the workshop meetings. It consisted of a simple paper-based system for day-to-day scheduling, relying on a procedure in which each day’s capacity would be loaded to 80 per cent, the remaining 20 per cent being held open until noon on the preceding day to allow rush jobs to be fitted in. This provided an interim system solution which would help manufacturing to manage the variety.

In addition it was also recommended that a link between sales and manufacturing be established to identify problem areas. This would enable sales and production to agree on lead times and delivery dates over a monthly period. In combination with the manual card-based tool it would enable sales to estimate (fairly accurately) a lead time for an order.

For continued success and development it was clear that the boundary
between the sales and manufacturing functions must be monitored and lines of communication must be kept open. It was decided to implement this regular meeting between the two functions to look at the performance of current procedures.

**Conclusions**

There are a number of reasons why a methodology is the most appropriate way of improving manufacturing competitiveness. Typically, UK manufacturing has resorted to the use of outside consultancies to improve manufacturing. However, the consequences of this are that the consultant provides a "quick fix" without the user gaining a full understanding of his processes. The result is a company that has an increasing dependency on the consultant. By using a documented methodology, a company will have a record of its progress through the various stages and can return to the process as necessary without additional costs. Furthermore, the use of proven techniques in methodology reduces the risks of failure, prescribed deliverables help to gain management commitment and guidelines ensure uniformity of application by providing auditability and assisting in the transference of skills.

The CAPM methodology has been developed through funding provided by the ACME Directorate of the SERC through its CAPM initiative. The project team began by concentrating on why CAPM systems were failing. The team quickly identified the major reason — that requirements were changing over time. To cope with these changing requirements the research team have developed a methodology that places the CAPM purchasing decision in the context of the changing business needs which it has to support. This is achieved by taking a "look out" over the foreseeable planning horizon using the stakeholder analysis. Furthermore the CAPM requirement had to be seen as part of the complete manufacturing system. Consequently, the first two stages of the methodology address the business and manufacturing contexts. The third stage takes the output from the manufacturing analysis and matches this to a CAPM requirements specification. The final stage is to match this requirement against existing CAPM packages.

The application of the methodology has proved to be a particularly fruitful part of the research and has benefited both the company and the development of methodology. For the company, a series of policies, procedures and practices were identified that should enable the company to improve its ability to cope with demand fluctuations. For the research team the case study has highlighted the learning process needed in developing such a methodology. The further refinement of the methodology based on the case data is currently taking place and is expected to be included in the development of a software package to facilitate stages three and four.

**References**

APPENDIX D

Paper presented to the School of Management, Cardiff 1988
DESIGNING FLEXIBLE INFRASTRUCTURES FOR CAPM SYSTEMS

S J Childe, R S Maull and N Weston
of The CIM Institute, Plymouth Polytechnic

with acknowledgement to
D R Hughes,
of the CIM Institute, Plymouth Polytechnic and
J S Smith, D R Tranfield,
of the Change Management Research Unit,
Sheffield Business School

Introduction

This paper discusses some of the early results of a three year research project sponsored by the ACME directorate of the Science and Engineering Research Council. The research is multi-disciplinary in nature, incorporating ideas from the fields of Engineering, Computing, Management Science and Organisational Behaviour. The aim is to develop a methodology for the design and implementation of integrated manufacturing systems within the electronics sector and is focussed upon the range of applications known as Computer-Aided Production Management (CAPM).

Computer Aided Production Management

CAPM can be thought of as encompassing all computer aids supplied to the production manager. This includes three main information processing activities [1].

Specification
ensuring the manufacturing task has been defined and instructions produced.

Planning and Control
planning the timetable, adjusting resources and priorities and controlling production activity.

Recording and Reporting
recording and reporting production status and performance for liaison with other departments and future use in specification, planning and costing.

These activities are often performed by the following modules or functions:

Master production scheduling
Stock recording
Capacity planning
Detailed scheduling
Materials requirements planning
Order processing
Bill of materials processing
Work in progress monitoring
Costing
Performance analysis
Etc.

These individual functions may be implemented separately, e.g. in the form of "micro based spreadsheets" [2]; in an integrated environment such as through the full exploitation of MRPII, or in some intermediate level of integration.

Requirements for Flexibility

The research to date has indicated that the ability to respond flexibly to changing requirements is a key to competitive success. This appears to be true even in the areas where the products do not change quickly, change often coming from increased competitive pressure on delivery, cost and quality or from the challenges of implementing new technologies such as surface mounting.

Many companies seem to approach these problems by a combination of the three legs of Advanced Manufacturing Technology described by Hollier [3]: Computer Aided Design (CAD), Computer Aided Manufacture (CAM), and Computer Aided Production Management (CAPM). As part of ACME's CAPM initiative this research has focussed on the implementation of CAPM systems.

Research Method

The case study methodology was selected in order to identify and represent both the context in which CAPM systems are being introduced and the nature of the systems themselves, the content.

The principal means of data collection for the cases has been focused interviews with key personnel from collaborating companies. The aim of these interviews has been to elicit information on the following:

1. the historical account of the development of the current CAPM system
2. the level of integration and the interfaces to wider manufacturing and business systems.
3. the kind of computer support and information systems required for business planning and production management activities
4. the organisational and attitudinal issues which were important to the implementation
the complexity and dynamic characteristics of the CAPM implementation environment and the wider system environment

Outcomes of CAPM Implementations

It is apparent that failure rather than success is more often the outcome of CAPM implementations. This can be attributed to a number of causes:

. the CAPM requirements were not defined correctly;
. the CAPM requirements were initially defined correctly but they subsequently changed as a result of either a change in manufacturing strategy or new information requirements and subsequent integration difficulties;
. the implementation was badly managed.

Requirements definition was vague in many of the cases studied to date. This appears to stem from the fact that the reasons for implementing the system were unclear. Some of the more vague reasons for implementation of systems were because related companies used similar systems or because it was felt that manufacturing was out of control.

However from the findings to-date most failures would seem to be attributable to changes in the requirements of the system brought about by the need to satisfy two new demands. The first of these is as a result of changes in the manufacturing strategies employed, such as the change to a "pull" system involving the need to process orders and schedule work in new ways, physical reorganisation such as the removal of a part of the manufacturing facility to another site, or the introduction of a new product causing changes in production volumes. The second comes as a result of new information requirements and the need to integrate the CAPM system with other business systems such as quality and finance. Despite recent developments in the integration of information systems this is still a major problem area.

Traditional methods involving the specification of a system design are no longer valid because changing requirements mean that the envisaged end state is unlikely to be precisely what is required for any length of time, if at all. The focus of attention must therefore be directed at ensuring that the means are available to cope with the variety of potential demands on manufacturing by facilitating a range of system end states. Thus the focus of attention must move from the "ends" to look at the means to the ends, which points to a consideration of the system design features such as modularity (etc etc) but also it becomes vitally important to consider the support systems, the infrastructure. Thus, as was recognised in a CAPM State-of-the-Art Report [9], the key to full exploitation of CAPM does not lie in the implementation of a particular system to address a specific
need, since this implies a static solution. Rather we propose that the key lies in the development of flexible infrastructures within which organisations can continue to respond to change.

Infrastructures

Hill [4] has defined manufacturing infrastructures as the "controls, procedures, systems and communications combined with the attitudes, experience and skill of the people involved" whilst Skinner [5] has defined manufacturing infrastructures as the "policies, procedures and organisation by which manufacturing accomplishes its work. Specifically production and inventory control systems, cost and quality control systems, work force management policies and organisational structure".

Meredith [6] also considers the importance of the infrastructure in automation strategies, which must be seen to include CAPM. Meredith's definition of the infrastructure is "the network of non-physical support systems that enable the technical structure to operate".

More specifically the infrastructure can be defined by the functions it fulfills in facilitating, supporting and controlling manufacturing activities. There are six principal functional areas providing the six principal requirements for production. These are:

- Designs;
- Methods, routes and part programs;
- Orders, schedules, work lists;
- Maintained machinery, tools and equipment;
- Materials;
- Trained personnel.

In order to achieve flexibility in manufacturing, it is necessary to have the flexibility or capacity required in the infrastructure. For instance it has been observed that increased production rates have caused difficulties in the areas of material procurement; increased rates of new product introduction may cause problems in Design or Methods Engineering. Meredith [6] observes that automation is often held back by the managerial and infrastructural problems involved. It should be noted that the three legs of AMT mentioned earlier are in the infrastructure area:

- CAD - Design infrastructure
- CAM - Methods infrastructure
- CAPM - Order flow and Materials infrastructure

It is recognised that there is a trade off between flexibility and cost. To attempt to develop infinitely flexible systems able to respond to every change in the environment - even if this were technically feasible - would be prohibitively costly. It is therefore proposed that
contextually bounded infrastructures are developed which are circumscribed by the nature of the core business activities.

The challenge to those concerned with the creation of infrastructures involves firstly identifying and removing the barriers inhibiting the development of well structured, flexible, modifiable and maintainable systems and secondly, promoting the establishment of systems with performance parameters consonant with the requirements of the wider system.

Results to date

The research team have begun by investigating the infrastructures within electronics companies. The output from this phase of the work has been some initial understanding of how infrastructures help companies to cope with changing manufacturing requirements. Some examples of infrastructure flexibility have been apparent.

One components manufacturer employs staff on a "core and peripheral" basis with the peripheral staff on short-term contracts to allow numbers to be adjusted to match trends in production volumes. This is applied to staff of all types including office staff such as purchasing and finance. Another company producing electronic products makes much use of outworkers paid per piece and subcontractors to allow adjustment. Although both these systems add to the flexibility of the companies' infrastructures there is a price to be paid in terms of the skill level and commitment of people employed only intermittently. The latter solution also leads to a greater procurement activity.

The use of an expert system in the design area has allowed one electronic product manufacturer to cope with a demand for a very wide number of variations to a range of products in a very short time. This means that the design-supplying part of the infrastructure is very flexible. The same system can also perform cost estimating for the product although it has yet to be integrated with the CAPM system to automatically order the parts required.

The ability to reconfigure systems is an example of infrastructure flexibility. One company has deliberately expanded its data processing and programming staff in order to be able to reconfigure the CAPM system to suit any change in the business. However this has caused difficulties in incorporating software upgrades since their system has been customised to the extent that software supplied by the vendor is no longer compatible. Another approach to the same aspect of flexibility was shown by a company whose main criterion for the choice of CAPM system was the accessibility of the programmers and their arrangements for tailoring and updating the system.
Conclusions

This paper has attempted to show that changing requirements can result in the failure of a CAPM system developed as a static solution to a particular problem at an instant in a company's development, even when the system requirements are correctly defined and the system's implementation is well managed. It has attempted to highlight the importance of an approach to flexibility which ranges wider than the implementation of any single system and which involves the development of flexible infrastructures to allow companies to adapt and adjust. Infrastructures should be tailored to suit the nature of the business concerned and the next phase of the research will investigate further the details of infrastructure elements in order to assist companies to develop flexible infrastructures.
References


APPENDIX E

1.0 Introduction

The structure and stages of the process methodology devised by the Polytechnic South West group, the research findings and the rationale for the approach have been previously reported (1, 2). To aid understanding the main points and stages of the methodology are repeated in summary, although the focus of attention of this paper is on providing more detail of the concluding stage of the methodology. This stage utilises processes and techniques to define the CAPM system requirements and to specify an appropriate solution to meet both the current and future requirements for flexibility and thereby provide the resilience necessary to withstand change.

The overall methodology is a process based approach which aims to enlist the skills and expertise of the users in a way which can be applied to many different company types. The important mechanisms which are used to bring this about are pre-work activities, technical briefings and workshops - orchestrated by a facilitator who guides and manages the entire process. Pro-formas provide the necessary structure for users to carry out the tasks required and through the skilful construction of these, the questions asked and the data requested, provide the necessary guidance to ensure that the operation is carried out efficiently and effectively. The questions contained in the pro-formas can be thought of as the knowledge base contained in the methodology.

This paper describes and explains fully how the final stage of the methodology works in practice. The concepts and techniques of operational performance envelopes, task templates and computing and information processing infrastructures are introduced and the way they may be used for achieving resilience is explained.

2.0 The Process Methodology

The methodology utilises the concept of operational performance envelopes (OPE’s). These may be thought of as closures which circumscribe the range of conditions likely to be
experienced by a company. The boundary of the shape, in this case a cuboid although the geometries are irrelevant, which represents the envelope describes the likely extreme conditions that may be experienced. The concept graphically portrays the notion that in any dynamic manufacturing situation there are a number of requirements that must be accommodated. In this way the operating performance envelope is used as a conceptual tool to help managers and users dispense with their information systems stereotype i.e. the single point solution. In addition, the envelope is used as an analytical tool because the axis of the envelope represent the range and extent of flexibility required by the supporting infrastructure.

This concept clearly challenges conventional notions concerning the design and implementation of systems. The emphasis is not solely on understanding the existing system, and on forecasting future requirements. It is concerned with identifying the functionality, storage, processing and integration requirements for some time period that extends beyond the current requirements and thereby on providing a resilient solution.

The process begins, see Figure 1, by defining the strategic performance envelope. This envelope is established through consideration of the company’s markets, products and competitors and is constrained by the technical and economic factors which reduce or limit the range of possibilities.

This envelope sets the requirements for the manufacturing performance envelope that the manufacturing system must fulfil.

This, in turn, sets the condition for the CAPM performance envelope and the requirements of the system at this level.

Finally, the CAPM performance envelope sets the requirements for the computing and information infrastructure.

The aim of the process methodology is to provide a practical, efficient and cost effective method for users to select the most resilient CAPM system i.e. the system that is capable of supporting the requirements of a changing manufacturing environment. The dimensions of
change which CAPM systems must be able to adjust to have been identified as data volumes, data and information integration and new manufacturing philosophy requirements (3).

In terms of these three causes of CAPM systems failure, the axis of the CAPM operating performance envelope (see figure 2) mark the storage and processing requirements, the manufacturing ideology and control philosophy requirements and the data and information integration requirements.

Although the methodology employs this top down structure, the detail and focus of analysis at each of the performance levels is on the CAPM system requirements. The term CAPM systems is used in this context by the authors to describe the computing elements, the hardware and software, together with the manual policies, practices and procedures (PPP's) which make up the complete solution. The important distinction here is that CAPM systems are not regarded as merely technical systems but rather as complex configurations of technical and managerial policies, procedures and practices (PPP'). This distinction is important because in order to achieve a high degree of "fit", i.e. a match between the requirements and the solution, both customising the software and adjusting the manual PPP's may be necessary. In order to do this a number of problems must first be addressed.

3.0 The Design Dilemma

The problem of dealing with changing CAPM requirements is compounded in a situation, such as the Electronics sector, where the rate of change in product demand and developments in product and process technologies is difficult to predict. Current design approaches which focus on the creation of single point solutions are clearly inadequate in this context. Single point solutions are inherent in the traditional vendor driven approach which has five stages;

- Identify technical requirements
- Complete a cursory definition of modules
- Specify financial systems requirements
- Determine the scale of the package
- Visit an existing software location
Clearly, none of these stages is designed to cope with a fast changing demand and technological environment.

This raises a serious dilemma for the designers of new information systems, such as CAPM. One of the major findings from this research is that a new approach is called for which, instead, directs attention towards the creation of a computing and information processing infrastructure that possesses the capability of coping with change and the variety of potential demands.

However, in order to devise a methodology for creating this capability the research team had to solve a number of problems. The first of these concerned devising techniques for specifying the CAPM tasks required both now and in the future. The second problem concerned selecting an appropriate package which conformed as closely as possible to the functional/task requirements and which possessed the necessary flexibility to be modified as new changes demanded. If this is not possible then these changes must be accommodated through adjustments in the manual procedures. The third problem concerned carrying out both the above within the technological and social constraints of the organisation.

4.0 The Solution

Taking these problems in turn, the traditional method of defining requirements for a manufacturing company has been through the use of modelling techniques and by analysing the existing system. Many examples of this type of approach can be found in the literature (4,5,6). However, there are a number of drawbacks to this approach. The time required to model the system under consideration is often long and modelling existing structures is not always appropriate and can constrain the eventual solution. The underlying assumption of structured systems analysis and design methodologies do not necessarily encompass flexibility requirements - rather they are focused on the provision of solutions to meet current requirements. In addition they are often employed in a technologically deterministic way and as such neglect the benefits of including manual policies, practices and procedures in the overall solution.

The solution taken by the research group was to provide resilience at two levels. At the strategic level the methodology uses workshops and pro-formas to guide the user through a process which takes a "look out" at the company's business environment. This is based on an analysis of key customers, suppliers and competitors. At the CAPM level resilience is provided both through policies, procedures and practices and through the tailoring of software modules to meet the requirements of the manufacturing performance envelope. The key issues were to identify the extent of the flexibility required in the CAPM system and to decide where that flexibility should reside, i.e. in the software or in the PPP's.

The second and third problems are addressed explicitly in the CAPM stage of the methodology are outlined below.
4.1 Defining the CAPM Task Requirements

In order to provide a simple, yet effective solution to these problems the Polytechnic CAPM group investigated the notion of core and optional tasks. In effect the core and optional tasks represent a generic template, or CAPM production management architecture and an alternative approach to the more traditional, modelling based approaches. This provides a quick and effective starting point for users to identify and select an appropriate computing and information infrastructure.

The methodology provides the production manager with a pro-forma which outlines a list of core and optional tasks. The model of core CAPM tasks is based on the premise that in all manufacturing situations a number of tasks are always carried out. The process of identifying the optional tasks demands a detailed understanding of the environment in which product families compete, the complexity of manufacturing products and processes, demand patterns, lead times, manufacturing cycle times etc.

The CAPM task template (7), through providing users with a list of core and optional tasks, provides a quick and simple tool for defining the CAPM requirements. Previous stages of the methodology have been concerned with defining the product groups now and in the future and the control philosophies required for these product groups. These requirements are combined with the task template to provided a list of tasks required by the production management function to operate and control production of these product groups. The metrics associated with the task, the volumes and frequencies of data required to be processed can then be determined.

Further information is now required on the constraints which are to be imposed on the solution from the host company. The pro-forma used for this stage of the methodology contains a list of the technological constraints which must be adhered to. For example, compatibility and the preferred hardware platform, speed, access, usability, cost etc. Data is gathered through questions such as:

- What is the existing hardware platform?
- What are the software compatibility requirements?
- What is the level of DP skills?
- What are the security requirements?
- What numbering systems are used in the company?
- Are there any constraints imposed by the financial function?
- What is the company's budgeted spend on the project?

The conclusion of this stage of the methodology is a detailed template of CAPM tasks, along with a specification of the constraints to be imposed upon the CAPM software/hardware system.

4.2 Specifying an Appropriate CAPM Package

Once the requirements phase has been carried out the best software fit is sought. Frequently
the constraints imposed by hardware, compatibility requirements and the capacity requirements (identified through data storage and processing requirements) will limit the number of 'target' software options considerably. Although it is difficult to imagine a perfect fit, software suppliers do provide extensive flexibility through the use of tailorable software packages. Even then experience suggests that recourse to the manual policies, procedures and practices is required to enhance the system flexibility. The flexibility offered by policies, procedures and practices is critical to the fit of the software to the task requirements. Those tasks that cannot be supported by the software will need to be accomplished by the manual PPP's. A workshop now assesses each software option in turn and identifies the various trade-offs.

5.0 Conclusion

The CAPM methodology, outlined in this paper, has been developed through funding provided by the ACME directorate of the SERC through its CAPM initiative.

The project team began by concentrating on why CAPM systems were failing. The team quickly identified the major reason - that requirements were changing over time. To cope with these changing requirements the research team have developed a methodology that places the definition of a CAPM solution in the context of the changing business needs which it has to support. This is achieved by taking a 'look out' over the foreseeable planning horizon using the stakeholder analysis. Furthermore the CAPM requirement had to be seen as part of the complete manufacturing system. Consequently, the first two stages of the methodology address the business and manufacturing contexts. The third stage takes the output from the manufacturing analysis and matches this to a CAPM requirements specification. The final stage is to match this requirement against existing CAPM packages.

BIBLIOGRAPHY

APPENDIX F

Paper presented to the Factory 2000 Conference, Churchill College,
AN APPROACH TO CIM - CREATING A COPING SYSTEM

N WESTON*, R S MAULL*, S J CHILDE*

SUMMARY

This paper stems from an ACHE research project jointly held by Plymouth Polytechnic and Sheffield Business School which has the aim of assisting electronics companies to develop and implement integrated manufacturing systems.

In this paper we concentrate on those companies within the electronics industry developing CAPM systems. Early findings suggest that time horizons have shortened considerably and that these companies are facing particularly turbulent environments. We outline the requirements for flexibility and propose a solution based on the development of contextually bounded infrastructures.

1 Introduction

In recent years such emphasis has been placed on the importance of introducing advanced manufacturing and information technologies into British industries. These technologies result in an approach to manufacturing which differs from traditional approaches in the extent to which the computer is used in the design of products, in the design of the production process, in manufacturing and test and in the management and control of the manufacturing system. Undoubtedly, for those companies able to harness and utilise these technologies effectively the rewards derived from improvements in manufacturing competitiveness are substantial.

Unfortunately, the results of introducing Advanced Manufacturing Technology (AMT) and Information Technology in many companies have been unsatisfactory when evaluated against technical, user, business or organisational criteria and it is not unusual for the performance of the implemented system to differ markedly from that which was originally conceived. One of the reasons for this stems from the fact that the benefits from large scale investment in such technologies often cannot be fully exploited without also undertaking a major reorganisation of the company, involving a redistribution of activities and intelligence and a fundamental rethink of manufacturing strategy and systems. The problem of achieving these benefits is further compounded in an environment where it is difficult to define current requirements and near impossible to predict future ones.

2 The Electronics Sector

2.1 Background

Recent evidence [1,2] suggests that the UK electronics sector is one of the fastest growing industrial sectors in Europe. Turnover grew by 37% during the period April 84 to April 86 with a corresponding growth in net profit before tax. Return on capital employed in 1985/86 was 19% for the industry as a whole whilst the stock turnover ratio was 7:1, remarkably low when compared to Japanese figures which indicate ratios in excess of 25:1.

In comparison to the rest of UK industry, 1983 saw a growth in electronics output of 21% compared to 1.9% for manufacturing as a whole. Evidence such as this supports the view that whatever "recovery" took place in the UK during 1983 it was by and large electronics led. However, these figures mask an underlying malaise. In terms of international competitiveness, the UK had a trade deficit in electronics in excess of £2 billion in 1987 which is forecast to quadruple by 1993.

2.2 Research Method

The case study methodology was selected in order to identify and represent the rich picture in terms of content and context in which CAPM systems are being introduced.

The principal means of data collection for the cases has been focused interviews with key personnel from collaborating companies. The aim of these interviews has been to elicit information on the following:

- the historical account of the development of the current CAPM system;
- the level of integration and the interfaces to wider manufacturing and business systems;
- the kind of computer support and information systems required for business...
planning and production management activities;

- the important organisational and attitudinal issues;

- the complexity and dynamic characteristics of the CAPM implementation environment and the wider system environment.

Fieldwork sought to establish whether the following were significant in practice:

- that the environment faced by companies within the defined electronics manufacturing sector was complex, dynamic and perceived as highly uncertain by those involved in the implementation of effective CAPM systems;

- that the key to the successful implementation of CAPM systems lay in adopting a multi-disciplinary approach embodying a top down, business driven orientation rather than the installation of a software product;

- that successful implementation required a fundamental rethink of manufacturing strategy and systems and a redistribution of activities and intelligence.

3 Requirements for Flexibility

Recent research carried out by the authors in a number of companies engaged in surface mount, PCB connectors and in developing electronics for the automotive industry has indicated that the ability to respond flexibly to changing market requirements is a key to competitive success.

This requirement for flexibility is supported by a number of other research findings. Bentley [3] has pointed out the difficulties in predicting future market requirements in Electronics. Slack [4] has stated that "Flexibility is the least understood of manufacturing objectives", Burbidge [5] has focused on the development of a production control system for flexible production systems whilst Skinner [6] and Schonberger [7] both address the need for flexibility in making manufacturing competitive.

In such an environment a major problem for companies is coping with uncertainties in supply and demand on one hand and the need to utilise manufacturing facilities efficiently on the other. Experience suggests that companies are responding to these competitive pressures through the increasing use of AMT. Hollier [8] has described AMT has having three legs; Computer Aided Design, Computer Aided Manufacture and Computer Aided Production Management. As part of ACME’s CAPM initiative this research has focused on the implementation of CAPM systems.

4 Computer Aided Production Management

CAPM can be thought of as encompassing all computer aids supplied to the production manager. This includes 3 main information processing activities [9].

SPECIFICATION

- ensuring the manufacturing task has been defined and instructions produced.

PLANNING AND CONTROL

- planning the timetable, adjusting resources and controlling production activity.

RECORDING AND REPORTING

- recording and reporting production status and performance for liaison with other departments and future use in specification, planning and costing.

These individual modules may be implemented separately, e.g. in the form of "micro based spreadsheets" [3]; in an integrated environment such as through the full exploitation of MRPII, or in some intermediate level of integration.

4.1 CAPM Failures

A number of major Electronics companies have been investigated with the objective of determining the implementation success, or otherwise, of their CAPM systems. It is apparent that failure rather than success is more often the outcome. This can be attributed to a number of causes:

- the CAPM requirements were not defined correctly;

- the CAPM requirements were defined correctly but the wrong system implemented;

- the CAPM requirements were initially defined correctly but these subsequently changed as a result of either new manufacturing strategies or new information requirements;

- the implementation was badly managed;

From the findings to-date the most significant of these failures would seem to be attributable to subsequent changes in the requirements of the system and the need to satisfy, principally, two new demands. The first of these as a result of changes in the manufacturing strategies employed and secondly new information requirements and the integration of the CAPM system to other business systems such as quality and finance. Despite recent advancements and developments in the integration of information technology this is still a major problem area.
Thus, as was recognised in a CAPM State-of-the-Art Report [9], the key to full exploitation of CAPM does not lie in the implementation of a particular system to address a specific need but in the development of flexible infrastructures within which organisations can continue to respond to change.

5 Infrastructures

Hill [10] has defined manufacturing infrastructures as the "controls, procedures, systems and communications combined with the attitudes, experience and skill of the people involved" whilst Skinner [6] has defined manufacturing infrastructures as the "policies, procedures and organisation by which manufacturing accomplishes its work. Specifically production and inventory control systems, cost and quality control systems, work force management policies and organisational structure". Interestingly Skinner differentiates between structural elements, the number, capacity and location of plants, and the equipment and process technology. The infrastructure includes the people, systems and procedures.

The authors believe that the deficiency with both definitions is that they fail to include equipment, although Skinner includes this within his definition of structure. The authors believe that machines and equipment are part of the infrastructure. For instance, flexible machining and modular conveyor systems can add to the flexibility of a manufacturing enterprise. In recognition of this deficiency we propose an eclectic definition incorporating machines, people, systems, procedures, controls, communications and organisational structure.

When the environment is highly dynamic and the markets turbulent single point solutions are inappropriate and ineffective. In such a situation the authors propose that the way forward lies in the development of infrastructures to provide adaptability and flexibility and to facilitate the continual evolution of the organisational system. Evidence from research so far undertaken suggests that these infrastructures need to address computing and informational, technical and organisational factors in an integrated manner in order to achieve the necessary level of responsiveness to changing and often unpredictable demands.

The implications for the design of CIM systems are revolutionary. Traditional methods involving the specification of a design are no longer valid because of the difficulty, or impossibility, of defining the "ends" required - when the "ends" are subject to continual change. The focus of attention must therefore be directed at ensuring that the "means" are available to cope with the variety of potential demands on manufacturing. This can only be achieved through the development of an appropriate set of flexible infrastructures.

The authors recognise that there is a trade off between flexibility and cost. To attempt to develop infinitely flexible systems able to respond to every change in the environment - even if this were technically feasible - would be prohibitively costly. It is therefore proposed that contextually bounded infrastructures are developed which are circumscribed by the nature of the core business activities.

The challenge to those concerned with the creation of infrastructures involves firstly identifying and removing the barriers inhibiting the development of well structured, flexible, modifiable and maintainable systems and secondly, promoting the establishment of systems with performance parameters consonant with the requirements of the wider system. Modular design strategies, modular CAPM packages, fourth generation languages, fault tolerant computers etc. are examples of current technologies which facilitate this desired system state.

The premises under investigation within this, and the overall research project [11], have implications that challenge conventional notions concerning the design and implementation of integrated manufacturing systems. It is proposed that the focus of attention should no longer be placed on gaining a good understanding of the existing system state and forecasting future requirements, but rather on the process of creating appropriate infrastructures.

5.1 An Approach to the Design and Implementation of Infrastructures

An approach to the design and implementation of infrastructures is currently being developed whose theoretical foundation is based upon contingency theory [11]. The objective is to provide users and practitioners with a structured set of guidelines for the implementation of infrastructures whose features will be contingent on the organisational environment. The attributes of the infrastructures relate to the degree of flexibility needed to meet new requirements. For example the level of flexibility of the informational infrastructure is dependent upon the compatibility of the system components and the level of data and informational integration [9].

The approach begins with an external appraisal and internal analysis of the company carried out with company staff. Users articulate current and future degrees of flexibility along a series of dimensions such as changes in manufacturing strategy, changes in integration requirements, etc. along with the limitations imposed by the existing manufacturing facilities. The output of this
Stage is a "fingerprint" of the company and its current position relative to its environment.

From this it is possible to compare the "fingerprint" against benchmarks of best practice and make a judgement of the appropriateness of the infrastructures currently in operation against those of the best performing companies with similar environmental characteristics. System components with the appropriate degree of flexibility to cope with the potential set of demands on manufacturing can then be selected.

The final stage of the implementation approach concerns bringing about the changes identified as appropriate and necessary. Intervention is based upon guidelines drawn from best practice [12] but can be thought of as involving change along a continuum from incremental to step function.

6 Conclusions

The approach outlined in this paper addresses the need to develop flexible CIM systems to respond to rapidly changing environmental conditions. It is based upon the concept of flexible infrastructures as a means of coping with the uncertainty of the market place.

The paper has focused upon the development of infrastructures within the Electronics sector as an example of the types of infrastructures required in markets which are undergoing particularly rapid change.

The authors postulate that those trying to design CIM systems in response to rapidly changing markets should focus on the means of achieving flexibility through the implementation of appropriate infrastructures rather than designing CIM systems on the basis of existing requirements. The authors have recognised that it is not feasible to design infrastructures which are capable of dealing with all possible outcomes. Infrastructures should be contextually bounded through the environment in which it operates.

These early investigations have extended our knowledge of infrastructures and their desirability for flexibility. The research team have begun to apply the approach in evaluating individual companies and are attempting to develop a situational variety matrix which will place individual companies within a framework of variety. From this a reference model of best practice will be derived which will assist other electronics companies to determine the appropriate degree and type of flexibility required for their environment.

ACKNOWLEDGEMENT

This paper stems from research conducted under the CAPM programme of the ACHE directorate of the Science and Engineering Research Council. The objective of the research is to develop a user led methodology for the implementation of integrated manufacturing systems within the electronics sector.

The authors would like to thank the other members of the project team: D R Hughes, Chairman, CIM Institute, Department of Computing, Plymouth Polytechnic and D R Tranfield and J S Smith, Directors, Change Management Research Unit, Sheffield Business School who have made an invaluable contribution to many of the ideas outlined in this paper.
BIBLIOGRAPHY


APPENDIX G

Summary of the CAPM Systems of Companies Visited
<table>
<thead>
<tr>
<th>Name</th>
<th>Hardware</th>
<th>CAPM Type</th>
<th>Prod'N Mode</th>
<th>Product Range</th>
<th>Prod'N Method</th>
<th>Customers</th>
<th>Implementation</th>
<th>Software</th>
<th>Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation</td>
<td>none</td>
<td>job/sml batch</td>
<td>Wide 1000s</td>
<td>M/C + assy</td>
<td>MoD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr IBM MR P</td>
<td>batch</td>
<td>Narrow</td>
<td>assembly</td>
<td>Domestic</td>
<td>overload, &amp;</td>
<td>lacked flex</td>
<td>elsewhere in</td>
<td>company</td>
<td></td>
</tr>
<tr>
<td>MFr IBM MR P</td>
<td>batch</td>
<td>Narrow</td>
<td>assembly</td>
<td>Domestic</td>
<td>bought + mod</td>
<td>Mac Pac</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IBM PC-Net a sched.</td>
<td>batch</td>
<td>narrow</td>
<td>process</td>
<td>industrial</td>
<td>inadequate</td>
<td>req't def'n</td>
<td>developed by</td>
<td>AIMS</td>
<td></td>
</tr>
<tr>
<td>MFr HP MRP+sched.</td>
<td>batch + flow</td>
<td>narrow</td>
<td>M/C + assy</td>
<td>industrial</td>
<td>lacks flex</td>
<td>bought for all sites</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apricot PC-Net</td>
<td>batch</td>
<td>wide</td>
<td>assembly</td>
<td>industrial</td>
<td>Not in yet</td>
<td>bought</td>
<td>TIMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchase OP</td>
<td>batch</td>
<td>wide</td>
<td>M/C + assy</td>
<td>industrial</td>
<td>inadequate</td>
<td>functions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IBM MFr</td>
<td>batch</td>
<td>wide</td>
<td>M/C + assy</td>
<td>industrial</td>
<td>bought</td>
<td>COPICS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr ICL SOP + Accounts</td>
<td>batch</td>
<td>narrow</td>
<td>process, assy, industrial + factoring</td>
<td>more functions</td>
<td>bought</td>
<td>SAFES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr ICL SOP + Accounts +stock + SOR</td>
<td>batch</td>
<td>narrow</td>
<td>process, assy, industrial + factoring</td>
<td>more functions</td>
<td>bought +</td>
<td>SAFES + additions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr ICL + Apricot PC-Net replacement</td>
<td>batch</td>
<td>narrow</td>
<td>process, assy, industrial + factoring</td>
<td>more functions</td>
<td>bought +</td>
<td>SAFES etc dBase II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardware</td>
<td>CAPM Type</td>
<td>Prod 'n Mode</td>
<td>Product Range</td>
<td>Prod 'n Method</td>
<td>Customers</td>
<td>Implementation</td>
<td>Software Program</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
<td>--------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-----------</td>
<td>----------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Datapoint mini</td>
<td>Purchasing BOM + accounts</td>
<td>batch</td>
<td>narrow</td>
<td>assembly, M/C, fabrication</td>
<td>industrial</td>
<td>lacked integration</td>
<td>developed by MARPACS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr ICL</td>
<td>BOM + stock</td>
<td>batch</td>
<td>narrow</td>
<td>assembly</td>
<td>domestic</td>
<td></td>
<td>COPICS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr IBM</td>
<td>MRP</td>
<td>batch</td>
<td>narrow</td>
<td>assembly</td>
<td>domestic</td>
<td>inappropriate to JIT, costly</td>
<td>bought</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr HP</td>
<td>MRP</td>
<td>batch</td>
<td>narrow</td>
<td>assembly</td>
<td>domestic</td>
<td>poor req. defn -&gt; unmodifying</td>
<td>bought, mod'ed, MM3000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr ICL</td>
<td>MRP</td>
<td>batch</td>
<td>wide</td>
<td>assembly</td>
<td>industrial</td>
<td>lacked flex,</td>
<td>and unmodified</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr ICL</td>
<td>MRP</td>
<td>batch</td>
<td>wide</td>
<td>assembly</td>
<td>industrial</td>
<td>changed prod'n modified</td>
<td>OMAC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr ICL</td>
<td>JIT/MRP</td>
<td>batch</td>
<td>wide</td>
<td>assembly</td>
<td>industrial</td>
<td>modified OMAC-JIT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr HP</td>
<td>MRP</td>
<td>batch</td>
<td>narrow</td>
<td>assembly</td>
<td>domestic &amp;</td>
<td>bought</td>
<td>MANMAN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr HP</td>
<td>MRP</td>
<td>batch</td>
<td>wide</td>
<td>assembly</td>
<td>industrial</td>
<td>changed h/ware bought to ICL</td>
<td>MM3000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFr HP</td>
<td>MRP</td>
<td>batch</td>
<td>narrow</td>
<td>assembly</td>
<td>industrial</td>
<td>imp'n failure bought</td>
<td>MM3000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX H

CAPM Packages
IBM produce two of the most well known of the CAPM software packages, namely COPICS and MAPICS II (IBM 1990). They claim that MAPICS II, the Manufacturing Accounting and Production Information Control System is appropriate for first-time computer users who manage smaller plants, or for remote facilities of larger organisations. COPICS, the Communications Orientated Production Information and Control System, is for larger companies and supports the following 'activities':-

**Figure A.1**
**COPICS Activities**

- Order entry
- Materials
- Production
- Shop Operations
- Purchasing
- Receiving
- Inventory
- Design
- Manufacturing Engineering

COPICS consists of a number of integrated, modular applications that "address these areas:

**Figure A.2**
**COPICS Modules**

- Bill of Material
- On-line Routing
- Facilities Data Management
- Product Cost Calculations
- Inventory Accounting
- Customer Order Servicing
- Inventory Planning And forecasting
- Master Production Schedule Planning
- Advanced Function Material Requirements Planning
- Purchasing and Receiving
- Capacity Requirements Planning
- Shop Order release
- Shop Order Load Analysis And Reporting
- Plant Monitoring and Control" (IBM, 1990)
MAPICS II offers nineteen integrated applications that "address these areas:

**Figure A.2**

**MAPICS II Areas of Support**

- Product Data Management
- Inventory Management
- Production Control and Costing
- Material Requirements Planning
- Capacity Requirements Planning
- Data Collection System Support
- Forecasting
- Purchasing
- Financial Analysis
- Master Production Schedule Planning
- Location/Lot Management
- Inventory Management for Process
- Cross Applications System Support
- Order Entry and Invoicing
- Accounts Receivable
- Sales Analysis
- Payroll
- Accounts Payable
- General Ledger" (IBM, 1990)

Of the production systems supported, IBM claim that the COPICS software is equally suitable for repetitive, job shop or any combination of these two modes of production. The product embodies the "latest Just-in-time planning techniques with the simplicity and effectiveness of operation KANBAN to pull material into the plant only as required" (IBM 1990).

One of the benefits of the product is described as its ability to maintain KANBAN operation in situations where demand for the component or material fluctuates on an hour by hour or day by day basis. The package automatically turns customer schedules into a series of balanced schedules and just-in-time supplier schedules. This has been achieved by providing "new user controlled functions,
supplementing some of the original MRP philosophies, with new
functions which are more appropriate to the just-in-time environment" (IBM 1990). The result, it is claimed, is a product which equally
supports the needs of continuous/repetitive and job shop production.

One of the most expensive packages in the CAPM market is Protos, sold
by Powell Duffryn Systems, a division of Strategic Systems
International. The package consists of a range of modules which vary
widely in size (Benwell 1988). They are upwardly compatible, can be
used with Decnet (DEC) and run under the VMS (DEC) operating system.
For an explanation of networking protocols see McDonald (1986).

The company claim that the Protos 2000 range of products supports
CIM, MRP11 and JIT "extending these techniques to provide complete
business control systems" (Protos 1990).

Another strength of Protos is its graphics capability, which meets US
standards and is available for interactive graphical input, plotting
networks, Gantt charts and other displays. "Effective graphics are a
good way of overcoming resistance to high technology systems in the
board room and amongst line managers (Benwell 1988).

The product range covers the requirements of design, engineering,
sales, materials production management, production, quality,
maintenance and project management. The following areas are supported:
Figure A.4
PROTOS Areas Supported

Master Production Scheduling
Bill of Materials
Part Number Selection and Scratch Pad
Inventory Control
Traceability and Lot Control
Purchasing
Manufacturing Orders
Materials Requirements Planning
Methods and Resources
Work-In-Progress
Shop Scheduling and Capacity Planning
Industrial Data Collection
CAD Interface
Sales Order Processing
Product Costing
Purchase Invoice Clearance
Purchase Ledger
Sales Ledger
Contract Cost Collection
Project Management
Maintenance Management

CAPM Modules

The following represent typical modules found in many CAPM packages.

Manufacturing Database
Sales Order Processing
Sales Forecasting
Master Scheduling Report
Inventory Control
Materials Requirements Planning
Capacity Requirements Planning
Shop Loading and Scheduling
Purchasing
These can be broken down further into tasks, some of which are represented as follows:

Sales Order Processing

The main objective of the SOP system is to provide an efficient and accurate means of processing customer orders.

Enter orders

1. Customer number
2. Part number
3. Quantity ordered
4. Type of order (spares, contract, other)

Check order status - at the following levels

1. Order accepted
2. Order acknowledged
3. Order in work (with expected completion date)
4. Order completed
5. Order completed but on hold
6. Order despatched
7. Order invoiced

Check customer credit

1. At point of entry
2. At order acceptance
3. Prior to despatch

Create invoice from despatch confirmation data

Analyse sales by:

1. Customer
2. Product
3. Product group
4. Contract
5. Market

Monitor and control orders for:

1. Overdue shipments
2. Outstanding items by age, value and volume with revised delivery dates
3. Actual sales against budget by customer, product and markets
4. Contribution analysis
Materials Resource Planning

Balance Supply with demand
  Calculate gross requirements
  Calculate net requirements

Record and maintain MRP data
  Lead times
  Batch sizes
  Safety stocks

Order material
  Fixed order quantity
  EDQ
  Period of supply
  Re-order point (independent)
  Lot for lot

Schedule material

Produce reports
Monitor and control performance
  Shortage reports
    Raw materials
    Components
    Proprietary items

Orders status
  Deferred
  Cancelled
  Injected into the firm horizon

Action message
  New orders to be released (batch cards, raw material requisitions)
  Defers orders (back schedule), expedite orders

Inventory Control

Technical precedence. Most modern packages require this module to be in place before the other modules can be installed.

Maintain parts records
  Enter
  Amend
  Delete

List parts details
List parts for selected items

Update technical descriptions
List technical descriptions

Process stock transactions
  Issue item
  Allocate item
  Receive item

Produce status reports
  Stock status
  Stock valuation
  Exception reporting
  Audit trail
  Record shortages

BOM - Bill of Materials
(Maintains the relationship between items making up assemblies)

Maintain parts
  Structure relationship between parts and component parts

Produce reports
  Single level
  Indented
  Costed BOM for a part

Support Engineering Change Control

Job Costing

Establish costs
  From component costs
  Operation costs to cost roll up

Monitor costs
  Variance calculation
  Scrap valuation

Forecasting

Forecast demand

Monitor demand
Capacity Requirements Planning

(Provides a prediction of work centre demand based upon the schedule determined by MRP or other system.)

Calculate capacity available

Shop Floor Control

Monitor/track WIP
  Order progress
  Record shortages
  Operation progress
  Work centre loads

Provide a work-to-list for each work centre
  Job status
  Work centre details

Purchase Order processing

Maintain
  Supplier details
  Purchase order details

Raise purchase order

Produce reports
  Orders outstanding

Master Production Schedule

 Carry out rough cut capacity planning
 balance demand (forecast and customer orders) with supply in the form of purchase and manufacturing replenishment


**CAFM Package Features**

**Compatibility and Portability**

i.e. What hardware the software will run on

- IBM
- DEC
- HP
- ICL

**Programme Language/code**

What language is the package written in and/or is it 4GL based. If it is 4GL based it should be possible to modified the programs more easily and therefore this type of software offers the greatest potential for enhancing the flexibility of the CAFM system.

**Expansion Potential**

To what extent can the software can be expanded? i.e. some CAFM systems may be configured as a start up system with a single micro and then be subsequently expanded to a multi-user mini system.

**Mode of Production Supported**

Discrete parts manufacture, make-to-stock, make-to-order, flow line/repetitive manufacture, batch production.

**Control Philosophy Supported**

- MRP
- JIT/Kanban
- OPT

**Modules, Functions Supported**

- e.g.
- Order entry
- Materials
- Production
- Shop Operations
- Purchasing
- Receiving
- Inventory
- Design
- Manufacturing Engineering

Are these fully integrated?

**Integration Capability**
i.e. can the CAFM system interface with financial and other business systems

**Company Size**

Small/large/medium

**Special Features**

i.e. Split batch capability
APPENDIX I.

Examples of Pro-formas.
**PRO-FORMA 10  COMPETITOR POWER**

Use a simple 0-10 scale to identify the extent of competitor power.

<table>
<thead>
<tr>
<th>Factor</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economies of scale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proprietary product differences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brand identity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to distribution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threat of retaliation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute cost advantages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative price performance of substitutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buyer propensity to substitute</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage market share</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value added</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product differences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brand identity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diversity of competitors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit barriers eg joint ventures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PRO-FORMA 11 COMPETITOR UNCERTAINTY

To derive an understanding of competitor uncertainty find answers to three basic questions:

LACK OF INFORMATION

How often do you believe that the information you have about your competitors is adequate for your decision making?

Very often Rarely
1 2 3 4 5

UNCERTAINTY OVER OUTCOMES

How often do you feel you are unable to predict how competitors will react or be affected by your decisions?

Very often Rarely
1 2 3 4 5

PROBABLE EFFECT OF A GIVEN FACTOR ON SUCCESS/FAILURE

What is the probability of your competitors affecting your ability to function as a business unit?

Low Prob High Prob
1 2 3 4 5

RANGE OF EFFECTS

What is the size of the range you were considering when looking at the ability of your competitors to affect your business operations?

The combination of these results should enable you to make a judgement on the degree of uncertainty you associate with your competitors.
PRO-FORMA 12  CUSTOMER POWER

For each product family and each key customer in turn use a simple 0-10 scale to identify the extent of competitor power.

<table>
<thead>
<tr>
<th>Buyer concentration (industry)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td></td>
</tr>
<tr>
<td>Buyer information</td>
<td></td>
</tr>
<tr>
<td>Ability to backward integrate</td>
<td></td>
</tr>
<tr>
<td>Substitute products</td>
<td></td>
</tr>
<tr>
<td>Price/total purchases</td>
<td></td>
</tr>
<tr>
<td>Product differences</td>
<td></td>
</tr>
<tr>
<td>Brand identity</td>
<td></td>
</tr>
<tr>
<td>Buyer profits</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL:
PRO-FORMA 13 CUSTOMER UNCERTAINTY

To derive an understanding of customer uncertainty, find the answers to three basic questions:

LACK OF INFORMATION

How often do you believe that the information you have about your customers is adequate for your decision making?

Very often
\[ \begin{array}{c|c|c|c|c}
1 & 2 & 3 & 4 & 5 \\
\end{array} \]
Rarely

UNCERTAINTY OVER OUTCOMES

How often do you feel you are unable to predict how customers will react or be affected by your decisions?

Rarely
\[ \begin{array}{c|c|c|c|c}
1 & 2 & 3 & 4 & 5 \\
\end{array} \]
Very often

PROBABLE EFFECT OF A GIVEN FACTOR ON SUCCESS/FAILURE

What is the probability of a your customers affecting your ability to function as a business unit?

Low Prob
\[ \begin{array}{c|c|c|c|c}
1 & 2 & 3 & 4 & 5 \\
\end{array} \]
High Prob

RANGE OF EFFECTS

What is the size of the range you were considering when looking at your customers’ ability to affect your business operations? The combination of these results should enable you to make a judgement on the degree of uncertainty you associate with your customers.
PRO-FORMA 14  SUPPLIER POWER

Use a simple 0-10 scale to identify the extent of competitor power.

Differentiation
Switching costs
Presence of substitutes
Supplier concentration
Importance of volume
Cost relative to total purchases
Impact
Threat of forward integration

TOTAL:
<table>
<thead>
<tr>
<th><strong>CLASSMARK:</strong></th>
<th>670 427 WES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AUTHOR OF BOOK:</strong></td>
<td>WESTON / NEIL</td>
</tr>
<tr>
<td><strong>TITLE OF BOOK OR JOURNAL:</strong></td>
<td>Development of a computer information systems infrastructure for</td>
</tr>
<tr>
<td><strong>for Journals:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>YEAR:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>VOLUME:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>MONTH OR PART:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>NAME OF BORROWER:</strong></td>
<td>STUART BOULTON</td>
</tr>
<tr>
<td><strong>DATE and TIME REQUIRED:</strong></td>
<td>7.3 AP</td>
</tr>
</tbody>
</table>
FOR LIBRARY STAFF ONLY

NAME OF USER BOULTON, S

DATE COLLECTED FROM STORE 3/2/94

If an item is not found in store please check Libertas and tick relevant box(es) below.

☐ On loan

☐ Should be in main library not book store

☐ Title found in store but not particular issue requested

☐ Being held for another user called:

_____________________________________________________________________________________

Other - please specify: 
To derive an understanding of supplier uncertainty, find the answers to three basic questions:

**Lack of information.**

How often do you believe that the information you have about your suppliers is adequate for your decision making?

```
Very often  Rarely
I---------------------x---------------------
1           2           3           4           5
```

**Uncertainty over outcomes**

How often do you feel you are unable to predict how suppliers will react or be affected by your decisions?

```
Very often  Rarely
I---------------------x---------------------
1           2           3           4           5
```

**Probable effect of a given factor on success/failure**

What is the probability of your suppliers affecting your ability to function as a business unit?

```
Low Prob  High Prob
I---------------------x---------------------
1           2           3           4           5
```

**Range of effects**

What is the size of the range you were considering when looking at the ability of your suppliers to affect your business operations? The combination of these results should enable you to make a judgement on the degree of uncertainty you associate with your suppliers.