METHODOLOGIES FOR
CIM SYSTEMS INTEGRATION IN
SMALL BATCH MANUFACTURING

By

Andrew N Walton

A Doctoral Thesis
Submitted in partial fulfilment of the requirements
for the award of
Doctor of Philosophy of the Loughborough University of Technology
April 1990

DECLARATION

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgements or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a higher degree.

DEDICATION

To Monica, Emma and Jennifer for their understanding.

ACKNOWLEDGEMENTS

I would like to thank Professor R.H. Weston for the invaluable guidance and encouragement he has given throughout the period of this research. I would also like to thank all other members of the Department of Manufacturing Engineering who provided help and advice.

I am most grateful to Rockwell PMC Ltd. (formerly Baker Perkins) for their sponsorship of this research work. I particularly wish to thank A.H. Eldred and R.H. Jackson for their help and guidance.

I am also grateful to M. Densham, B. Watson and D.T. Wilson of the Computer Aided Engineering Department, D.C. Clarke and M.L. Leeton of the Computer Department at Rockwell PMC for their assistance in software programming.

SYNOPSIS

This thesis is concerned with identifying the problems and constraints faced by small batch manufacturing companies during the implementation of Computer Integrated Manufacturing (CIM). The main aim of this work is to recommend generic solutions to these problems with particular regard to those constraints arising because of the need for CIM systems integration involving both new and existing systems and procedures. The work has involved the application of modern computer technologies, including suitable hardware and software tools, in an industrial environment.

Since the research has been undertaken with particular emphasis on the industrial implementor's viewpoint, it is supported by the results of a two phased implementation of computer based control systems within the machine shop of a manufacturing company. This involved the specific implementation of a Distributed Numerical Control system on a single machine in a group technology cell of machines followed by the evolution of this system into Cell and Machine Management Systems to provide a comprehensive decision support and information distribution facility for the foremen and operators within the cell. The work also required the integration of these systems with existing Factory level manufacturing control and CADCAM functions. Alternative approaches have been investigated which may have been applicable under differing conditions and the implications that this specific work has for CIM systems integration in small batch manufacturing companies evaluated with regard not only to the users within an industrial company but also the systems suppliers external to the company.

The work has resulted in certain generic contributions to knowledge by complementing CIM systems integration research with regard to problems encountered; cost implications; the use of appropriate methodologies including the role of emerging international standard methods, tools and technologies and also the importance of 'human integration' when implementing CIM systems in a real industrial situation.

TABLE OF CONTENTS

Contents | Page

CHAPTER 5. Phase 1 DNC System Implementation

CHAPTER 6. DNC System Extension for Shopfloor Graphics

LIST OF FIGURES

ABBREVIATIONS

AGV	Automatic Guided Vehicle
AMRF	Automated Manufacturing Research Facility
AMT	Advanced Manufacturing Technology
ANSI	American National Standards Institute
ARCNET	Attached Resource Computer Network
ASRS	Automatic Storage and Retrieval Systems
ATE	Automated Test Equipment
BDAS	Basic Data Administration System
BOM	Bill of Material
BTR	Behind the Tape Reader
CAD	Computer Aided Design
CADCAM	Computer Aided Design and Manufacture
CAM	Computer Aided Manufacture
CAPE	Computer Aided Production Engineering
CAPM	Computer Aided Production Management
CAPP	Computer Aided Process Planning
CAPR	Computer Aided Planning and Ratefixing
CASC	Computer Aided Shop Control
CHIM	Computer and Human Integrated Manufacturing
CICS	Customer Information Control System
CIM	Computer Integrated Manufacturing
CIM-OSA	CIM Open Systems Architecture
C.M.S.	Cell Management System
CNC	Computer Numerical Control
DBMS	Data Base Management System
DDAS	Distributed Data Administration System
DDBMS	Distributed Data Base Management System
DEC	Digital Equipment Corporation
DFD	Data Flow Diagram
DG	Data General Corporation
DNC	Direct / Distributed Numerical Control
DOS	Disk Operating System
DTI	Department of Trade and Industry
EDIF	Electronic Design Interchange Format
EIA	Electronic Industries Association

ESPRIT	European Strategic Programme for Research and Development in Information Technologies
FAS	Flexible Assembly System
FMC	Flexible Manufacturing Cell
FMS	Flexible Manufacturing System
F.M.S.	Factory Management System
FTAM	File Transfer, Access and Management
GKS	Graphical Kernel System
GOSIP	Government OSI Profile
GRIP	Graphics Interactive Program
GT	Group Technology
IBM	International Business Machines
ICAM	Integrated Computer Aided Manufacturing
IDEF	ICAM Definition
IEEE	Institution of Electrical and Electronic Engineers
IGES	Initial Graphics Exchange Specification
IISS	Integrated Information Support System
IMDAS	Integrated Manufacturing Data Administration System
ISO	International Standards Organisation
IT	Information Transfer
JCL	Job Control Language
JIT	Just in Time
LAN	Local Area Network
MAP	Manufacturing Automation Protocol
MDAS	Master Data Administration System
MHS	Message Handling System
MMFS	Manufacturing Message Format Standard
MMS	Manufacturing Message Services
M.M.S.	Machine Management System
MRP	Material Requirements Planning
MRPII	Manufacturing Resource Planning
MSDOS	Microsoft Disk Operating System
NBS	National Bureau of Standards
NC	Numerical Control
NCTP	NC Tape Programming
NIST	National Institute of Science and Technology
ODA	Office Document Architecture
OPT	Optimised Production Technology

OSI	Open Systems Interconnection
PC	Personal Computer
PDDI	Product Data Definition Interface
PDES	Product Data Exchange Specification
PLC	Programmable Logic Controller
RDBMS	Relational Data Base Management System
RJE	Remote Job Entry
SADT	Structural Analysis and Design Technique
SET	Standard d'Exchange et de Transfer
SNA	Systems Network Architecture
SQL	Structured Query Language
STEP	Standard for the Exchange of Product Model Data
TCP/IP	Transmission Control Protocol/ Internet Protocol
TOP	Technical Office Protocol
UGFM	Unigraphics File Management
VDA	Verband des Automobilindustrie
VM	Virtual Machine
VSAM	Virtual Sequential Access Method
VT	Virtual Terminal
XBF	Experimental Boundary File

CHAPTER 1

Introduction

The aim of this research work has been to investigate the constraints and problems which may need to be overcome during the implementation of Computer Integrated Manufacturing (CIM) in a live manufacturing situation. The research is based upon CIM systems integration work undertaken at Rockwell PMC Ltd., Peterborough, a manufacturer of high speed heatset web offset presses for the colour magazine and commercial printing industry. Rockwell PMC operates within the small batch production sector of the manufacturing industry. The constraints and systems integration problems encountered when implementing CIM at Rockwell PMC are likely to be similar to those faced by other companies dealing with small batch manufacture. In the course of this research a number of issues have been addressed which may serve to highlight some of the generic problems of CIM systems integration and recommend possible solutions which are suitable not only for Rockwell PMC but also for other companies.

In view of the 'industrial flavour' of the work undertaken this research is reported within the context of certain underlying themes:

(i) The view of the Industrial Implementor;

(ii) The constraints realised because of existing systems;

(iii) The use of currently available 'off the shelf' hardware and software solutions wherever possible to provide simple solutions;

(iv) The balance between the introduction of CIM technology and its effect on the human operators;

(v) The possible generic considerations resulting from the specific solutions used and their transferability internally and externally to Rockwell PMC Ltd.

The strategic needs of the work can be considered within the context of theme (i) which inevitably provides a focus for the direction of the specific implementations involved. Themes (ii) through (v) provide key considerations for the actual tactics which are employed.

The work reported in this thesis begins with an investigation into the current use of computer systems in manufacturing and the role of CIM. System modelling and analysis methods are reviewed together with appropriate system tools and methods which can help in the implementation of the suitable applications, information management and communications facilities required by evolving CIM systems. The technology available has also been reviewed with particular regard to information management and communications. Those emerging solutions which are being accepted as international standards are identified. Some of the 'non technical' aspects involved in financial and human factors, which must be addressed during CIM systems integration, are also considered. The review has been made with particular reference to the small batch production sector of manufacturing industry which is of interest to Rockwell PMC.

The constraints and problems faced by Rockwell PMC during live CIM systems integration are investigated with reference to a two phased implementation of computer based control systems on the shopfloor. The work has been carried out as a part of a company initiative towards CIM leading to the creation of a 'linked business system' from customer enquiry through to despatch. The specific implementations involved the installation of a DNC System on a single numerically controlled machine tool followed by a Cell and Machine Management System to control the operation of a Group Technology cell of machines within the Rockwell PMC machine shop. The constraints and problems encountered are highlighted with particular regard to the needs for integration between these systems, the Factory level manufacturing control system and the CADCAM interface.

Finally the implications that this specific work has for further application of CIM within other areas of the Rockwell PMC business and other companies operating in the small batch production sector of manufacturing industry are considered. The potential problems of transferring the specific CIM systems integration solutions used at Rockwell PMC to other sites are considered with reference to the implications of possible alternative solutions - including the potential importance of emerging international standards.

CHAPTER 2

Manufacturing Information Integration using Computer Systems

2.1 Introduction

The aim of this chapter is to review the literature which is relevant to the application of Computer Integrated Manufacturing (CIM) within the manufacturing industry and in particular the 'Discrete Engineering' or 'Metal Cutting' sector of which Rockwell PMC Ltd is a member. The review is made with specific regard to the needs of the research work documented here.

A general review of the use of computer systems in manufacturing and the role of CIM is followed by a section indicating the need for appropriate tools and methods to help in the application of CIM systems. Individual reviews are then presented of some of the modelling and analysis tools which can be used in the design and implementation of CIM. The technology available for use in CIM systems is also reviewed with particular regard to the possible functionality of the system in terms of applications, information management and communications mechanisms (using local area network technology).

The survey continues with a study of the 'non technical' aspects involved in the financial and human factors which should also be considered when CIM is implemented in a manufacturing company. The chapter ends with a short discussion on the application of these reviewed technologies and methods in the implementation of CIM at Rockwell PMC Ltd.

2.2 The Application of Computer Systems in Manufacturing

Computers have been applied in manufacturing installations from as early as 1958, when the first were used for the control of chemical plants, oil refineries and other similar large industrial applications. During the 1970s and early 1980s computers progressed through a number of generations of improvements and were applied in many other situations [American Machinist 1978] [Williams 1983]. Few would argue, however, that the falling price of computer hardware coupled with its increasing capability has had a particularly dramatic effect within manufacturing industry over the past ten years [Computers 1987] [Zorpette 1989]. The use of computers is no longer confined to the large corporations but is available to small and medium sized companies who would like to improve the effectiveness of the various company departments. The improvements in Personal

Computer (PC) technology in particular have made computerised applications more easily justifiable for such companies [Stevenson 1985] [Young 1989]. Past surveys of manufacturing organisations suggest that contrary to 'popular opinion' a wide variety of activities had already begun to use computers by the early 1980s. These included, for example, Product Design, Manufacture, Production Management and Financial Accounting [Besant 1983] [Wild 1984].

The challenge for companies to compete effectively in the market place has never been stronger than it is at present. Local influences are becoming less important as the need to compete in worldwide markets increases [Nelleman 1989] [LaMarsh 1989]. This has led to the realisation that the integration of all the functions involved in the manufacture of a company's products is necessary to provide a business which can cater for the needs of its customers [DTI 1987] [Weinberg 1989]. A DTI [DTI 1987] report suggests that the key to this integration is information - the most valuable asset within a company - and availability of realistic, up to date information is becoming the most important factor in a company's success or failure. The importance of computer-based systems to control and distribute this information cannot be overstressed [Hess 1985] [Beale 1988].

The demand for computer aids in manufacturing industry has prompted the creation of a large range of systems software from many different suppliers who have their own interpretation of how software should operate and be configured. On top of this the number of computer hardware platforms on which this software will operate is equally large [Survey Supplement 1988]. Weston [Weston 1988] suggests that this has the effect that not only is software written to different levels of functionality by different suppliers it is also written to different standards because many computer manufacturers also have their own differing design philosophies.

2.2.1 Computer Integrated Manufacturing

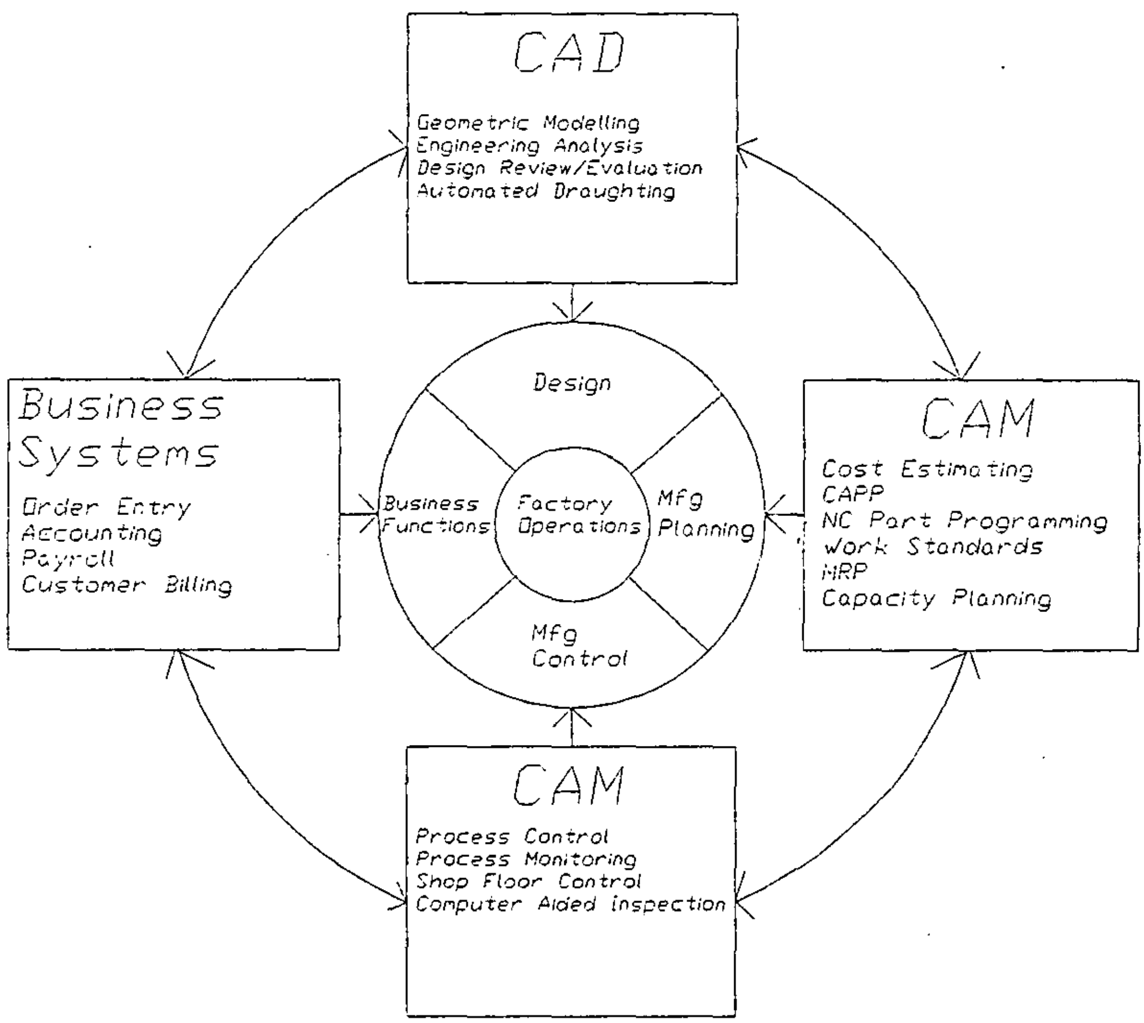
In manufacturing the areas which have been computerised have been treated in isolation, sometimes intentionally, to allow for departmental control of the computing function as well as of the work function. This has led to so called 'islands of automation' which can have productivity gains in the related areas of work independently, but cause problems for the business function as a whole because of the disjointed distribution of information management and control functions [Jackson 1983] [Ingersoll 1985] [CIMOSA 1988]. The main impact of the large range of solutions as aids for job functionality, coupled with the fact that these solutions have often been considered for particular company departments in isolation, is that they become increasingly difficult to integrate with each other. The computers are not able to communicate with each other and the information provided by each system is not in a form that the other can understand [Weston 1988].

The available computer system resources must be integrated into a coherent structure which will allow information to flow to the right place at the right time [Hess 1985]. In order to achieve this the separate computer systems for different company functions must be integrated together successfully so that information can flow between them completely uninhibited [DTI 1987]. The now familiar term 'Computer Integrated Manufacturing', commonly referred to as CIM, is used to describe this concept [Bunce 1985] [Ingersoll 1985] [Ranky 1986]. Groover [Groover 1987] proposes that CIM should address the total integration needs of a company from the receipt of an order through to its shipment and incorporate all the tasks and strategies involved, see Figure 2.1. However as Casey [Casey 1986] observes, because few companies actively looking forward with CIM strategies are without computerisation already, the problem still being faced is how to choose and implement the correct techniques to couple together the isolated yet related solutions to functional needs to give the greatest advantage.

2.2.2 The Need for System Modelling and Integration Tools

Young [Young 1989] points out that the successful integration of manufacturing systems needs careful investigation, thorough analysis and the application of appropriate modelling and integration tools. He discusses some of the analysis and design tools which are available to 'discrete-parts manufacturing companies for CIM development' in a paper based upon the work undertaken for the Danish CIM/GEMS project (GEneral Methods for specific Solutions). This project focusses on the 'engineering methods used to engineer CIM systems'. Referring to the work done by the US Air Force ICAM project [System 1983] on the 'CIM development lifecycle model' Young describes the use of this model which consists of eight primary technical tasks grouped in Four Phases as follows:

Figure 2.1 Computer Integrated Manufacturing



[Groover 1984]

Phase 1 Understand the Problem	Problem Analysis Requirements Definition
Phase 2 Formulate & Justify Solution	Preliminary Design Detail Design
Phase 3 Construct &Integrate Solution	Construct & Verify Integrate & Validate
Phase 4 Implement &Maintain Solution	Implementation & User Acceptance Maintenance & Support

Elavia [Elavia 1985] earlier condensed this approach into a three step process to provide a 'simple framework of awareness' and identified the essential elements of analysis crucial to CIM implementation for use by company executives:

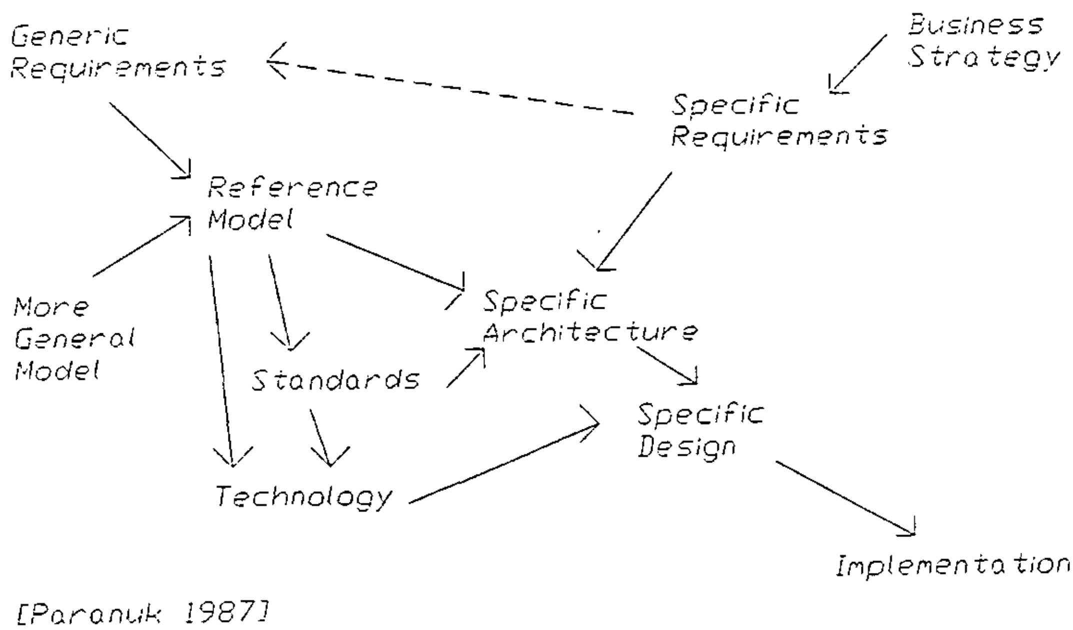
Step 1 Complete 'As-Is' Analysis
Step 2 Design of a 'To-Be' Scenario
Step 3 Implementation

Young and Elavia emphasize particularly that careful and detailed planning is a pre-requisite for the successful implementation of any CIM system [Elavia 1985] [Young 1989]. The need for appropriate modelling tools is also emphasized in Parunak's paper on Factory Reference Models [Parunak 1987] which indicates the interaction between Generic and Specific requirements and models leading through to the successful implementation of CIM systems, see Figure 2.2.

2.3 Modelling and Analysis of Manufacturing Systems

The successful integration of manufacturing systems, therefore, needs careful investigation, thorough analysis and the application of appropriate tools. The implementation of CIM needs a model on which to plan and against which the resultant benefits can be assessed [Paranuk 1987] [CIMOSA 1988] [Young 1989]. As indicated above, a number of 'reference models' or 'conceptual frameworks' for manufacturing have been proposed [Paranuk 1987] and several manufacturing systems analysis methods have been developed [Young 1989]. Models and Tools particularly relevant to this research are reviewed here.

Figure 2.2 Integration of CIM Systems



2.3.1 Models of Manufacturing Systems

By analysing the available manufacturing reference models Paranuk [Paranuk 1987] developed a multifacted framework for these models where 'each facet or "view" represents a different technical or organisational dimension of a manufacturing enterprise'. The five views which were identified are: implementation; organisation; physics; control and sequential. Paranuk suggests that these views do not appear in isolation but as combinations in the different reference models. In particular he observes that the Organisational View is not represented in the models but that a 'Functional View' which incorporates other view characteristics is common. For the purpose of the work reported here the Control, Organisational or Functional and Implementation views are considered further.

A. A Control View: Hierarchical and Heterarchical Approaches

Paranuk [Paranuk 1987] suggests that the Control View is the most common and in particular that manufacturing systems are often viewed in the form of a hierarchy consisting of a number of levels each of which operates within its own timescale. It has been suggested that the use of hierarchical models [Mesarovic 1970] [Singh 1980] offers the best approach for the design of manufacturing control systems [Bourne 1984] [Gershwin 1986]. Work undertaken at the US National Institute of Standards and Technology (NIST, formerly known as the National Bureau of Standards, NBS) is probably the most widely known example of this approach. This work has been pursued using a small, integrated, Flexible Manufacturing System (FMS), the Automated Manufacturing Research Facility (AMRF), which was constructed to serve as a test bed for research into the 'automated factory of the future' [Simpson 1982]. The research has led to a proposed five layer Hierarchical Control Model for use in the management of manufacturing factories [Jones 1984] [McLean 1985]. The layers specified in this model are facility, shop, cell, workstation and equipment, as illustrated in Figure 2.3.

(i) Factory Control implements the 'front office' functions typically found in small batch manufacturing facilities, involving manufacturing engineering functions, information and Production Management.

(ii) Shop Control is responsible for the coordination of production jobs on the shop floor together with the allocation of resources to those jobs.

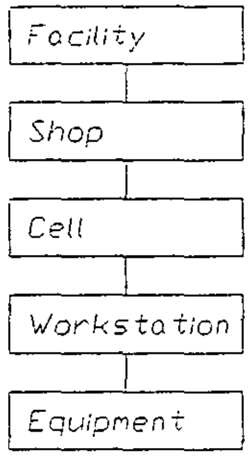
(iii) Cell Control is responsible for the sequencing of jobs through particular workstations and supervising support services such as material handling.

(iv) Workstation Control coordinates the activities of a small integrated group of shop floor equipment.

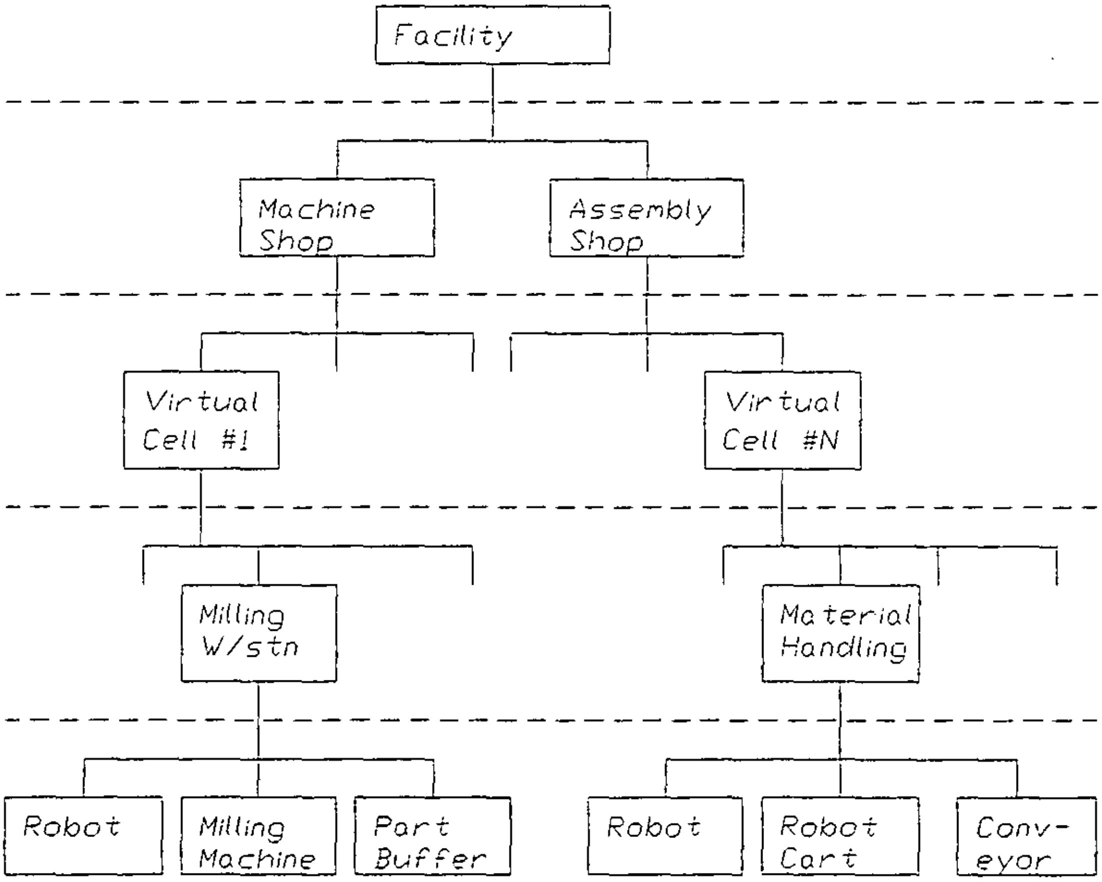
(v) Equipment Control supervises the operation of discrete items of shop floor machinery such as robots or machine tools.

Other work has proposed alternative hierarchical models particularly in terms of the number of layers used to the describe the control systems needed [Paranuk 1987]. Gershwin [Gershwin 1986] proposes three layers, Bourne [Bourne 1984] four. The hierarchy proposed by Digital Equipment Corporation and Philips [Digital 1987] argues the need for as many as seven layers for some enterprises. The CIM architecture proposed by ISO [ISO 1986] consists of a six layer hierarchical structure where an 'Enterprise' level is included above the AMRF 'Facility' level. This level establishes the company goals and coordinates strategic planning and activities between the plant and external bodies. McGinnis suggests that all of these hierarchical models imply the 'notion' of a 'command unit', at each level, representing a self-contained control system which has a single interface with the outside world [McGinnis 1989].

Figure 2.3 **AMRF Control Hierarchy**



(a) Control Levels



(b) Expanded Control Hierarchy

[Jones 1984]

Parunak [Parunak 1987] points out that, although the levels in these hierarchies may have different terminologies in the various models, they can be 'mapped' against each other in a realistic way. Therefore in the context of the work reported in this thesis the ISO model is used as a basis for comparison, with particular reference to the lower five levels of the model which highlight the functionality within a single factory unit.

However some researchers argue that heterarchical models describing systems which cooperate on a 'peer to peer' level [Hatvany 1985] can provide a better approach in many situations. They find that hierarchical systems tend to be inflexible and difficult to expand [Vamos 1983] [Duffie 1986]. Duffie [Duffie 1986] suggests that the heterarchical approach can provide systems with reduced complexity and software cost, higher modularity and improved fault tolerance. Research into the use of distributed control systems also illustrates this heterarchical approach [Shaw 1987] [Malley 1987]. Solberg [Solberg 1989] suggests that each strategy has both strengths and weaknesses subject to the context in which they are examined. Naylor adds that an appropriate combination of hierarchical and heterarchical strategies should therefore provide the most flexible design methodology [Naylor 1988].

The author agrees that a hybrid of these two models chosen as appropriate for a particular application layer within an overall manufacturing system may prove the most effective. For example use of a hierarchical model may be suitable as the major framework for a machining shop control system. However as Solberg suggests heterarchical interaction between control systems at one or more of these layers, e.g. cell system to cell system, may provide a better platform for communications which need not involve the higher level shop control system [Solberg 1989].

B. The Organisational or Functional View

Paranuk [Paranuk 1987] identifies a number of models which exhibit a functional view. One of these is the European Strategic Program for Research in Infomation Technology, ESPRIT, Pilot Project 5.1/34 - 'Design Rules for CIM (Computer Integrated Manufacturing)'. The objective of this project was to 'propose a European CIM Systems Structure' which could be used to define the functionality of CIM systems [Yeomans 1986]. In order to limit the scope of the problem the work was constrained to address only the 'machining' sector of the mechanical engineering industry, those activities directly related to manufacture of machined products. The activities considered were grouped under five headings and each of areas was detailed using a 'Flowchart Technique'. The detailed tasks shown on each flowchart were then grouped into CIM 'activities' or 'sub-systems'. The activities defined are as follows:

(i) Design;

(ii) Production Engineering;

(iii)Production Planning;

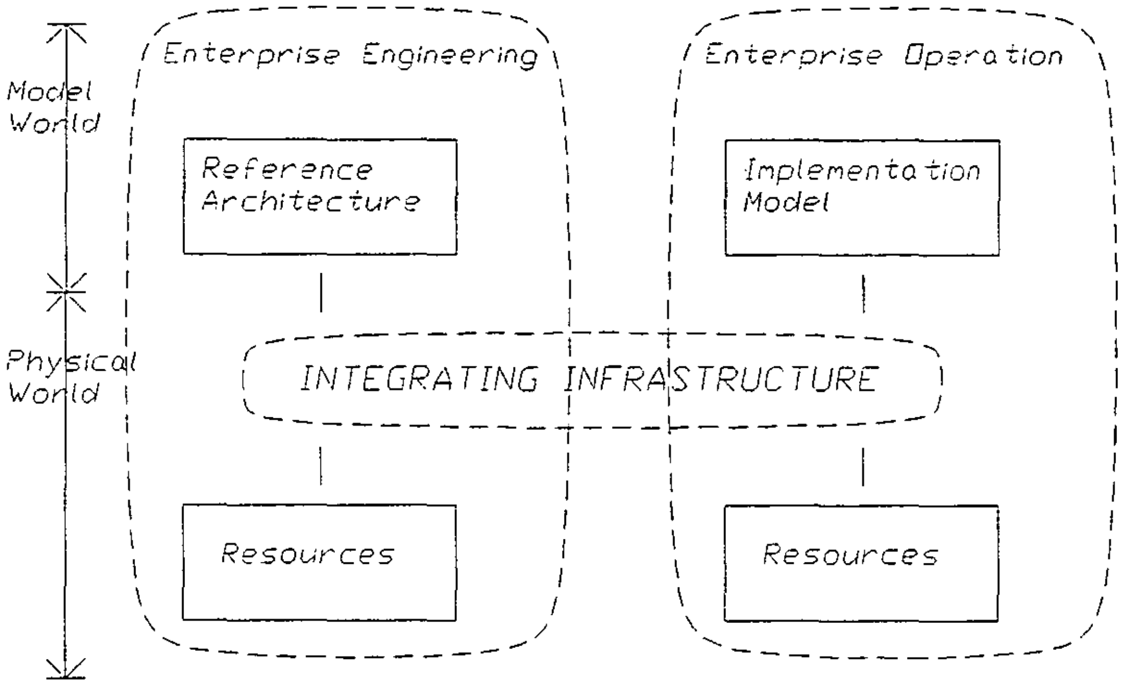
(iv)Manufacture;

(v) Storage and Transport.

The author considers that the five activity areas selected can be used to represent the functions of manufacture very well at the 'conceptual' level and that the strategy maxims proposed are sound. However in the authors opinion the flowcharts produced for each of these areas are of limited use in a 'real systems design situation' due to their inherent complexity. In addition to this, although the 'CIM-structure presented' is very detailed, Yeomans acknowledges that it is not 'either definitive or final' because a 'general consensus' would be needed and the 'technology is dynamic and innovative' [Yeomans 1986].

This work has now been superceded to some extent by the ESPRIT CIM Open Systems Architecture project (CIM-OSA) [CIM-OSA 1988] which has the objective of defining a European standard for CIM implementations. CIM-OSA provides a 'Reference Framework' made up of a 'Reference Architecture' which contains the generic building blocks and guidelines and a 'Particular Architecture' which contains the specific building blocks for a given enterprise [CIM-OSA 1988]. CIM-OSA also provides an 'enterprise wide operating system' which controls people and machines as well as the traditional data processing systems. This operating system, which is called the 'Integrating Infrastructure', binds together the 'model world' with the 'physical world' and the enterprise engineering' with the 'enterprise operation' as illustrated in Figure 2.4 [CIM-OSA 1988]. Systems built according to the OSA rules and methods are open. Their components are made such that collaboration with other functions is straightforward with the intention that integration is simply 'plug in and use' [Kenny 1989].

Figure 2.4 CIM-OSA Enterprise Environments



[CIM-OSA 1988]

C. An Implementation View: The Three Architecture Concept

The ESPRIT pilot project is also identified by Paranuk [Paranuk 1987] as having an explicit implementation view. The ESPRIT work [Yeomans 1986] distinguishes support functions from application functions. In particular ESPRIT identifies data management and communications as support functions. The work of Digital Equipment Corporation [Digital 1987] also identifies the human interface and material transport as support functions.

Weston et al. also describe an implementation view based on the 'three architecture' approach for CIM systems integration [Weston 1987b] [Sumpter 1987]. The integration problem was decomposed into three supporting architectures [Weston 1988] as follows:

(i) An Application Architecture which serves as 'the "activating" layer within which decision making, actions and responses to the manufacturing system state occur'. All system supervisory, management and user functions are implemented by this layer.

(ii) An Information Architecture which is 'responsible for providing the information required by application entities for decision and control actions'.

In this context the emerging standards for message handling, data formats and data base adminstration functions are particularly important.

(ii) A Network Architecture which is 'responsible for establishing virtual connection between manufacturing entities which may be located remotely from each other'.

Snodgrass [Snodgrass 1989] discusses the role of an alternative definition of a three architecture framework which can be used for the implementation of an 'Information Asset Management' concept for engineering and manufacturing environments:

(i) An Information Architecture which 'defines the user view of the information required to support various functional processes'.

(ii) A Computer Systems Architecture which 'defines the computer systems technology necessary to automate the required information'.

(iii) A Control Architecture which 'defines shared data standards and integration procedures for maintaining alignment between the Information and Computer Systems Architectures'.

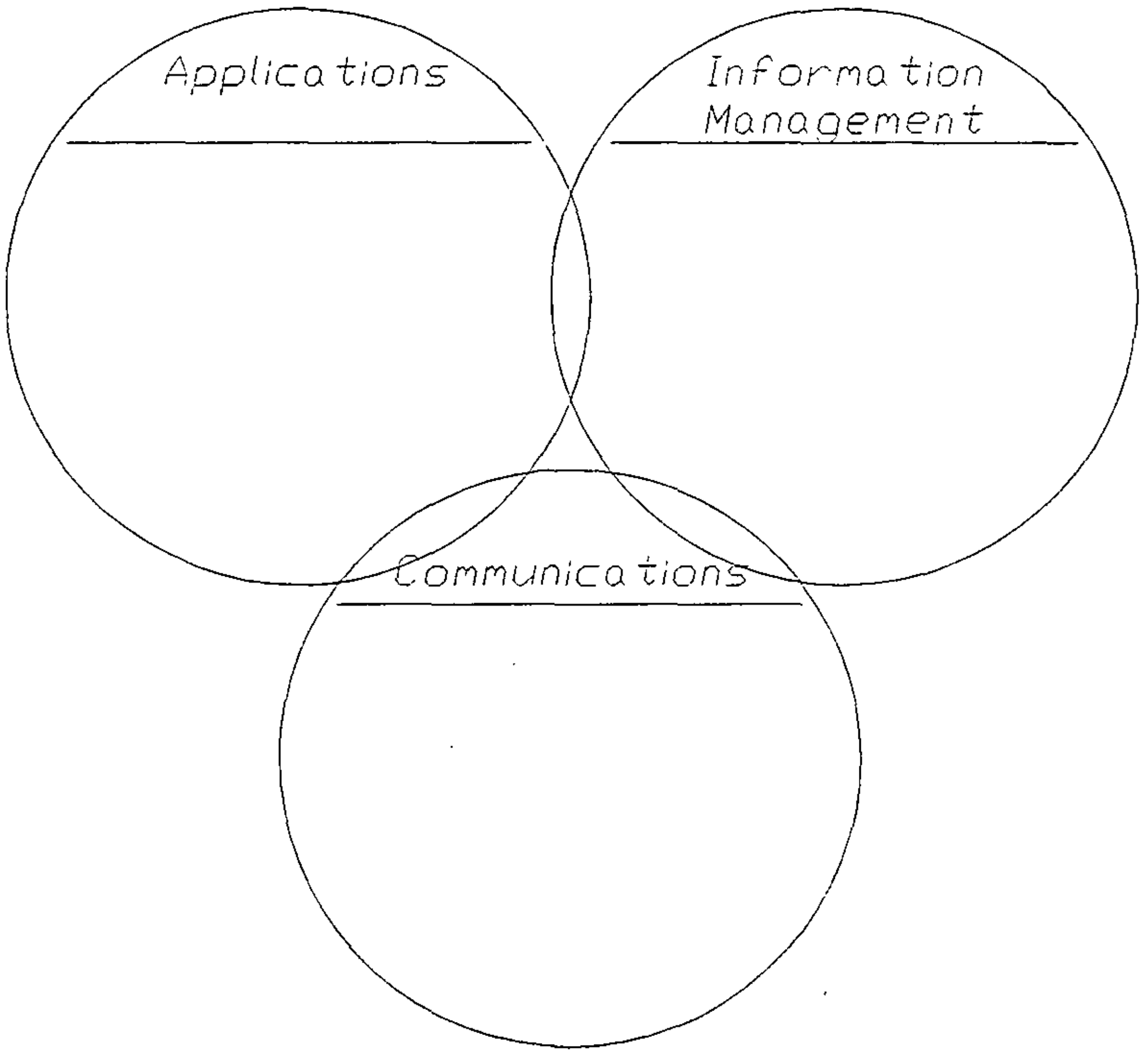
The author considers that these concepts relate to the same issues but differ specifically in the functions defined for each of the architectures. In particular the Computer Systems and Information Architectures described by Snodgrass seem to include the functionality of all three architectures described by Weston. Snodgrass describes the Control Architecture for specifying 'business rules that are independent of specific user requirements (defined by the Information Architecture) and of specific applications, databases, hardware, and software implementations (defined by the Computer Systems Architecture)'.

For the purpose of the methods and tools discussed in this chapter the author prefers and makes particular reference to Weston's three architecture concept as a framework for presenting some of the Applications, Information Management and Communications functionality which is applicable to the implementation of CIM systems. Figure 2.5 illustrates the conceptual approach.

2.3.2 Analysis of Manufacturing Systems

Young suggests that the principle tools available for the analysis and design of manufacturing systems have evolved from work done by the US Air Force [Young 1989]. This was perhaps the first organisation to use structured design methodologies (originally developed for software engineers) for manufacturing

Figure 2.5 Three Architecture Approach



systems design in the ICAM project. The SADT methodology was used as the basis for their development of the IDEF methodology [ICAM 1983].

A. SADT

The Structural Analysis and Design Technique, SADT, was originally developed by SoftTech Inc. and has been used in a variety of systems problems [Yeomans 1985] [Marca 1988]. The method classifies schematically the relationship between system entities ('objects, documents or data') and system functions ('activities performed by people, machines and computers') [Banerjee 1988]. It views the system as a series of diagrams from the top 'general abstract description of the entire system' exploded through a number of sub diagrams with each representing decomposition of the preceeding layer into greater levels of detail. Each layer is partitioned into three to six main functional elements which 'father' the next lower layer. See Figure 2.6.

B. IDEF

The Integrated Computer Aided Manufacture, ICAM, project carried out by the US Air Force since the early 1970s gave birth to the ICAM Definition, IDEF, modelling language used for conceptual design of CIM systems. A total IDEF model views the manufacturing system as consisting of three integrated structures: activities, information and dynamics. These are modelled individually using clearly defined disciplines: IDEF0, IDEF1 and IDEF2 respectively. The three methods allow for a model which represents all system aspects [ICAM 1983].

IDEF0 [Ross 1985] [Wallace 1987] modelling is essentially SADT with the support of detailed guidelines for the use of the technique. Figure 2.7 shows an example functional diagram created using IDEF0. Banerjee suggests that the model is useful for depicting structural relationships and processing requirements of a system but, on its own, fails to identify the flow paths of entities [Banerjee 1988].

IDEF1 [Ruoff 1984] [Wallace 1987]modelling is used to identify the actual information needs and helps in the design of databases that are needed to support the functions classified by the IDEF0 model. The outcome of the technique is also graphical in the form of 'entity relationship diagrams' supported by a textual 'entity relation matrix' and an 'attribute class diagram'.

Figure 2.6 SADT Diagram

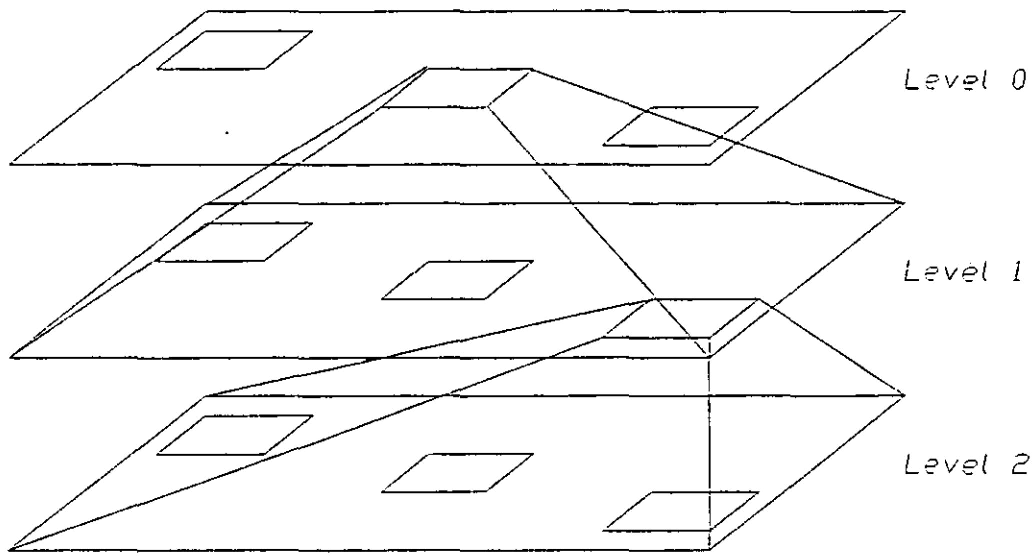
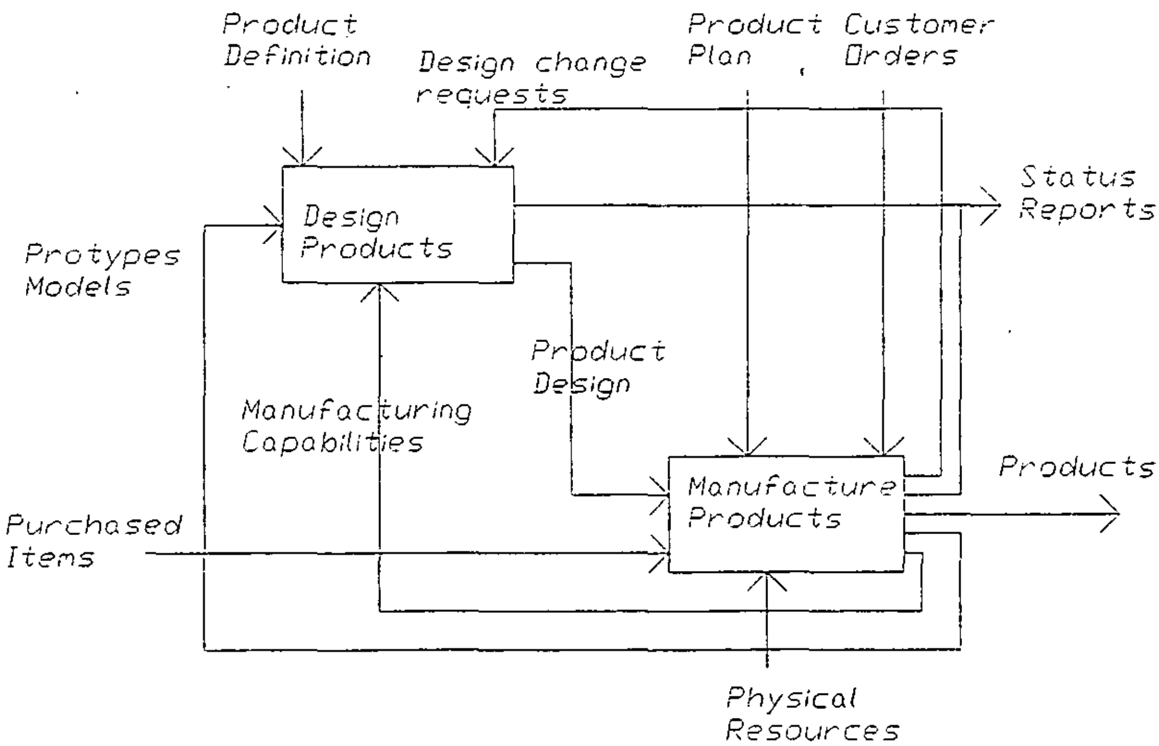


Figure 2.7 IDEF0 Diagram



IDEF2 [Yeomans 1985] modelling aims at describing the time-varying behaviour of the system of manufacturing systems. An IDEF2 model can be seen as a network combining logical representation with the actual movement of material and its associated information in the factory. A total IDEF2 model consists of a 'facility diagram', a series of 'entity flow networks' supported by 'resource disposition trees' for each of the resources used and 'control networks'.

Banerjee [Banerjee 1988] considers that IDEF0 and IDEF1 are essentially 'conceptual' modellers whereas IDEF2 is more 'physical'. Banerjee also concluded that the IDEF2 process is particularly time consuming and may not be cost-effective in real life applications unless a suitable software tool is produced. Young [Young 1989] agrees that other commercially available simulation tools may now be more applicable for CIM implementation.

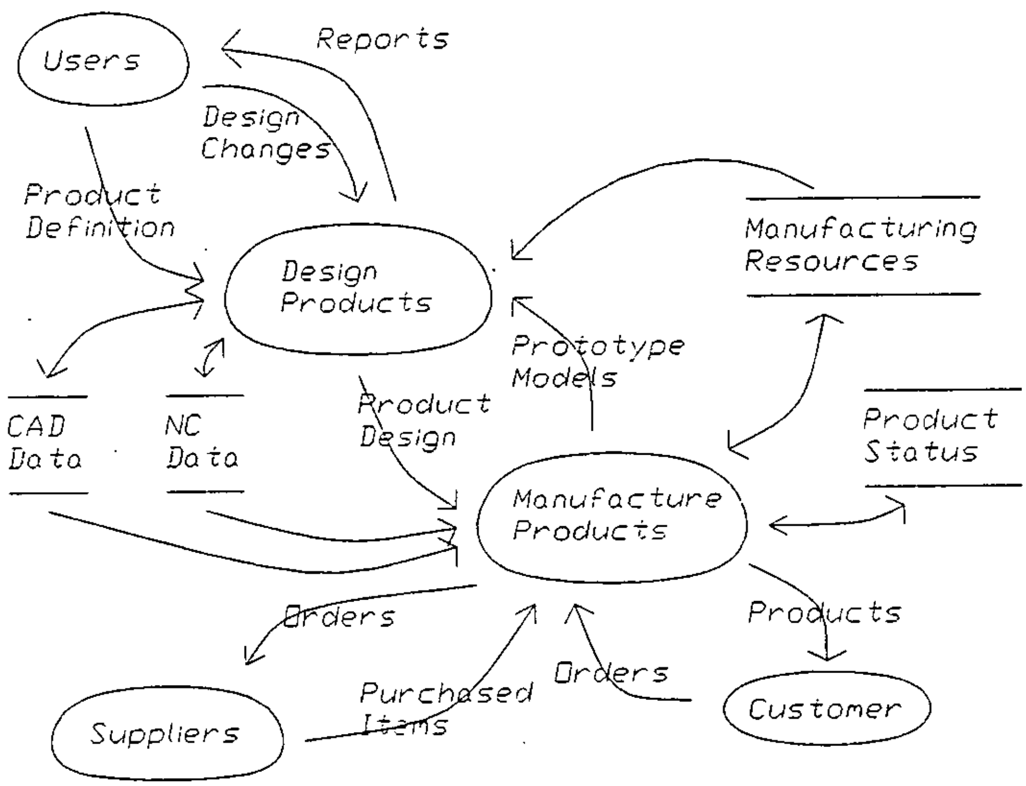
C. DFD

The Data Flow Diagram (DFD) [DeMarco 1988] approach was initiated at Improved Systems Technologies [Gane 1982] and is based on the same hierarchical principles as SADT. Banerjee [Banerjee 1988] has used the IDEF methodologies for performing the functional analysis of Flexible Manufacturing Systems (FMS's) to produce a model for use in system simulation. He used the IDEF0, or SADT, technique but replaced the IDEF1 methodology with DFD. Banerjee explained the preferred use of DFD for presentation reasons since he considers that DFDs are 'relatively easier to construct and to implement as they involve only one format'. Banerjee states that IDEF1 is more appropriate 'as a tool for designing the relational databases required' rather than system information flows. Figure 2.8.

2.4 Applications

The first of the three architectures considered as a framework for some of the presentation in this thesis is concerned with the applications available in CIM systems. In the context of the work presented here particular computerised applications are worthy of discussion since they impact directly on the functions involved in the discrete engineering sector of manufacturing of interest to Rockwell PMC. These functions can be considered in relation to the five activities identified by the ESPRIT pilot project, i.e. Computer Aided Design (CAD); Computer Aided Production Engineering (CAPE); Computer Aided Production Planning (CAPP); Computer Aided Manufacturing (CAM) and Computer Aided Storage and Transport (CAST) as discussed earlier [Yeomans 1986].

Figure 2.8 DFD Diagram



Unfortunately, as the ESPRIT researchers have acknowledged, the popular acronyms are often given different and even conflicting meanings. In particular although the term CAM is used in the ESPRIT definition to refer to those functions involved in the use of machine tools such as DNC and FMS, it is more popularly used in conjunction with the term CAD (as in CADCAM) to refer to NC programming functions. The acronym CAPP is also normally used to refer to Process Planning which again conflicts with the ESPRIT definition. In the author's opinion the ESPRIT researchers have only added to the confusion by not using the popular definitions. In this thesis the terms CADCAM, CAPE and CAPM (Computer Aided Design and Manufacture, Production Engineering and Production Management respectively) will be used to discuss appropriate 'Engineering Office' applications. Where necessary the term CAPP will be used as the acronym for Computer Aided Process Planning.

2.4.1 Engineering Office

In the 'engineering office' business management software dominates the market with the Financial Accounting / Costing functions and Inventory / Stock Control emerging as the most computerised. It has been suggested that CADCAM and Production Planning and Control functions are the next most popular applications [Survey-CIM 1986] [Survey Supplement 1988]. Engineering office applications are particularly involved with developing products from initial concept into engineering design; specifying manufacturing processes and making plans for production sequencing. Each of these functions has been enhanced using computer technology.

A. CADCAM

The use of computers in the design and drawing office, Computer Aided Design (CAD), has evolved considerably over the past 20 years [CAD 1969] [CAD 1972] [CAD 1974] [CAD 1978] [Groover 1984] [Besant 1986] [CAD 1987]. Despite recent changes in the number of system suppliers there are still about 400 different systems in use worldwide [Lawrence 1989]. The systems on offer differ in many ways: facilities offered can include 2D, 3D, solid and surface modelling and cover different sectors of design. A number of systems also offer extensive software modules for machining applications (CADCAM) [Kurland 1989]; the computer hardware used also ranges from small personal computers (PCs) [Wohlers 1985] through workstations to large minicomputers and mainframes involving corresponding ranges for system costs [Buyers Guide 1989].

In the case of most companies CAD has been applied to improve the efficiency of the draughting rather than the design function [Hordeski 1986] [Clarke 1987]. Productivity improvements of up to 10:1 have been reported particularly where CADCAM has been applied [Groover 1984]. The larger companies have gained further advantage by the use of 'parametric programming' to automate certain repetitive applications [Harrison 1986] [Hawkes 1988]. However some recent work has focussed on improving the design function and particularly to provide the engineering designer with tools to help in the 'conceptual' stages of the product design process [Black 1987] [Kleeman 1989]. The use of knowledge based systems to provide 'intelligent' CAD is bringing great benefits to the design process [Hampshire 1988] [Santalla 1988] [Warner 1988] [Gregory 1989].

B. CAPE

Computer Aided Production Engineering (CAPE) is the process of deciding how to manufacture a product to the specification created by the design function. The ESPRIT work identifies five main areas involved in the production engineering function namely: Process Planning; Plant Layout; Part Programming; Production Tool and Fixture Design and Material Handling [Yeomans 1986]. Of these

Process Planning and Part Programming are of particular interest in the context of this thesis and hence a definition of the terminology involved is included.

The process planning function is the activity concerned with deciding which manufacturing processes and machines should be used to perform the various operations necessary to produce a component and the sequence that those processes should follow. The use of CAPP systems offers significant advantages to the Production Engineering function [Becker 1989]. Weill indicates that early attempts to computerise the process planning function by the introduction of Computer Aided Process Planning (CAPP) systems tended to be 'superficial' and difficult to link into other systems [Weill 1982]. Evans indicated the need for integration of CAPP with more mature functions such as CAD and CAPM at an early stage [Evans 1984]. More recently research has concentrated on the possible use of 'knowledge engineering' and 'expert systems' techniques for improved process planning [Major 1987] [Graves 1987] [Rahman 1987] [Marks 1987] [Tsatsoulis 1988] [Granville 1989]. Other work has considered the linking of CAD and CAPP by replacing the 'detailed draughting' approach with a 'feature definition' approach and so inherently integrating CAD, CAM and CAPP [Cotter 1985] [Case 1987] [Genord 1988] [Callihan 1989].

Part programming is the activity concerned with producing the instruction set required by Numerically Controlled (NC) machines for the automatic machining of a component. It is often included as a function within CAD systems (see above) where the detailed design/drawing information is used to automatically produce 'cutter location files' which are then 'post processed' into NC machine readable control programs. These dual purpose systems are usually referred to by the term CADCAM [Bowman 1984] [Hubbard 1985] [Besant 1986] [Hordeski 1986] [Hawkes 1988]. Recently work has focussed on improving the productivity of NC code generation using other programming techniques such as Object Oriented Programming and Expert Systems [Suzuki 1988] [Ito 1988] [Kramer 1989].

C. CAPM

Bonney [Bonney 1987] defines Computer Aided Production Management as the set of methods used to plan and control production. This includes order entry, demand forecasting, ordering, transaction recording, progressing and the decision methods used , whether algorithmic or based on experience.

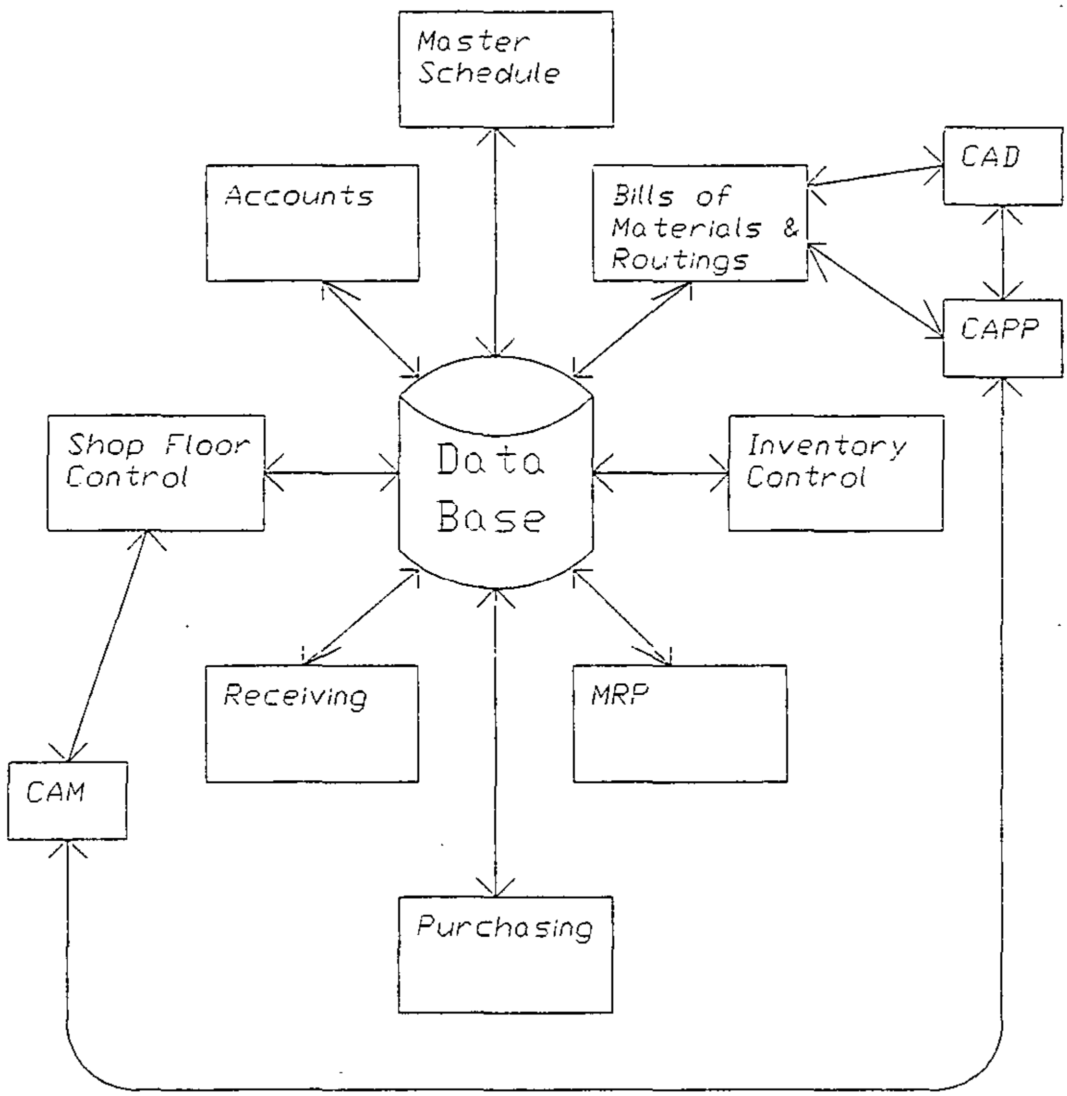
The ESPRIT research [Yeomans 1986] identifies four sub systems to the production planning system: the Long Term Forecasting of demand; Production Planning of requirements generated by the demand; Production Scheduling in the short term for manufacture taking account of associated resource constraints and the real time Production Sequencing of machines as they become available and the Monitoring of production output.

Arguably a clearly defined production management strategy is a prerequisite requirement of success when integrating manufacturing functions. Yet the author considers that it is an area in which the experts seem to disagree on many fundamental points. Plenert observes that three classes of production management strategy have dominated the literature namely: Manufacturing Resource Planning (MRPII), which has evolved from the original Material Requirements Planning (MRP) strategy; Just-In-Time (JIT) manufacturing and Optimised Production Technology (OPT) [Plenert 1986].

Manufacturing Resource Planning (MRPII) is the central production management system for computerised manufacturing for many companies [Wright 1984] [Survey Supplement 1988] and the systems available in the market place usually comprise the functions identified by ESPRIT together with bill of materials, process routings, purchasing and cost management [System Selector 1987]. Saxe [Saxe 1985] reports that the functionality of MRPII systems had developed rapidly during the early 1980s and indicated that the next important step was to link MRPII with other systems such as CAD, ASRS and ATE in order to support the evolution of CIM. As Hurwitz [Hurwitz 1985] points out MRPII systems rely on information feedback from the shopfloor and data capture systems, such as bar code readers [Beck 1986] [Eatwood 1989], are often used to provide a more reliable system than 'keyboard data entry'.

Harhalakis has proposed that 'MRPII should serve as the coordinating and controlling medium' for CIM, Figure 2.9, because it has the 'position of processing data common to most of the computer aided tools available [Fox 1984] [Harhalakis 1988]. Hence Harhalakis considers that MRPII could be seen as the 'hub' of any CIM system. Harhalakis further suggests that the integration between CAD [Harhalakis 1987], CAPP [Ssemakula 1987] and MRPII is fundamental to integrated manufacture.

Figure 2.9 The MRPII Data Base as the Hub of a CIM System



[Harharlakis 1987]

JIT is 'a system which emphasizes quality in workers, materials, facilities and end products. It uses existing technology but rearranges production equipment into cells for hand-to-hand manufacturing' [Manoochehri 1985]. Hence JIT is based on a 'pull' of materials which is responsive to production line demand [Kimura 1981]. Fundamental to the success of JIT is the Japanese 'Kanban' or ticket which is used as the material flow control initiator [Malley 1988]. The use of JIT has been shown to be able to cut inventory and lead times and improve labour productivity [Mullins 1989].

OPT is a relatively new manufacturing philosophy first developed in Israel in the 1970s [Goldratt 1984]. OPT is different from MRPII and JIT in that it calls for a fundamental change in attitude not only in the production process but also in basic accounting principles [Lawrence 1987]. Factory scheduling is at the centre of OPT and the critical factor is the identification and elimination or management of 'bottlenecks', since time saved on such a resource is time saved throughout the whole system. OPT assumes that lead times and lot sizes should be variable according to the fixed capacity of any resource available at any given time. OPT also specifies that the productivity of the plant as a whole should be measured and not that of individual machines or departments [Lawrence 1989].

Some current research proposes that MRPII and JIT techniques are 'synergistic' and can be integrated to obtain the 'best of both worlds' [Lee 1989] [Wejman 1989]. The 'push' strategy of MRPII can be used as the planning tool while the 'pull' strategy of JIT is used as the execution function [Woodgate 1989] [Mather 1989] [Musolf 1989]. The concept calls for a mixed material flow system where some parts are considered as 'MRPII parts' which are master schedule controlled whereas others are 'JIT parts' which are 'effectively an extension of the assembly line' and are 'phantom for planning purposes' [Edwards 1988]. Piciacchia [Piciacchia 1989] relates MRPII and JIT to a hierarchical model of a factory showing that MRP addresses the needs of the 'corporate and factory' levels whilst JIT in the form of 'Plant Operations Control' addresses the 'area and cell' levels. Advocates of OPT also argue that many of MRPII's shop floor scheduling functions can be better achieved using OPT's specialist scheduling software acting on an MRPII database [Savage 1985] [Manufacturing Control 1989] [Lawrence 1989].

2.4.2 Factory Floor

Computer technology has been used in an equally wide variety of applications on the factory floor within the 'metal cutting' manufacturing environment of interest to this research. Robots [Engelberger 1980] [Rathmill 1985] [Husband 1989], Numerical Controllers (NCs) [Pressman 1977], Computer Numerical Controllers (CNCs) [Pusztai 1983], Direct Numerical Control (DNC) [Crossley 1978], Programmable Logic Controllers (PLCs) [Dorf 1983] [Johannesson 1985] have all been used to make the production machine more efficient. Automatic Guided Vehicles (AGVs) [Maxwell 1982] [Koff 1987] and Automatic Storage and Retrieval Systems (ASRSs) [Hill 1980] [AS/RS 1986] have improved material handling functions.

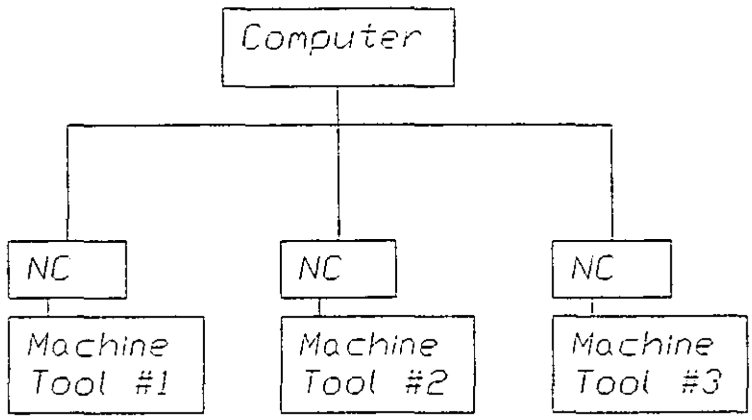
The Group Technology approach [Graves 1985] [Klopp 1985] [Hyer 1989] has long been recognised as an appropriate method for configuring 'cells' of machine tools into groups which provide significant improvements in the planning and execution of component manufacture. Applying computer technology to such configurations of machine tools together with these other support machines have been used to produce Flexible Manufacturing Cells and Systems (FMCs, FMSs) [Bilalis 1985] [Hatvany 1983] in addition to Flexible Assembly Systems (FASs) [Makino 1983]. In the context of this work the functions DNC and FMS are of particular interest.

A. DNC

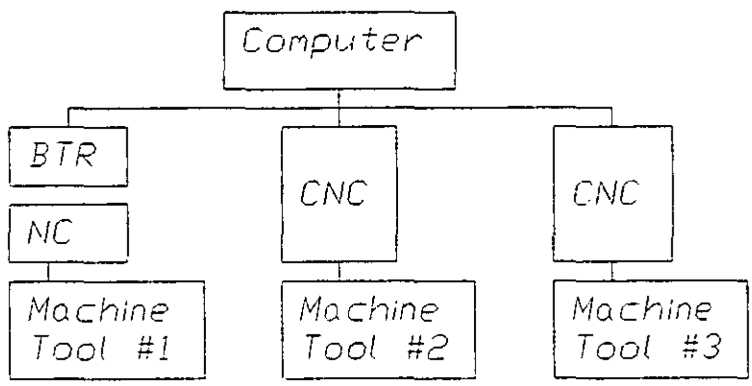
Crossley indicates that systems for the Direct Numerical Control (DNC) of machine tools have been under development and in use for over 20 years. The basic definition of a DNC system is 'one which connects a set of numerically-controlled machines to a common memory for part program storage with provision for on-demand distribution of part program data to the machines' [Crossley 1978]. Crossley also records the Sundstrand Omnicontrol System installed at General Motor Co. in 1968 as the world's first DNC system. The original concepts of DNC involved the use of a central computer to replace the individual 'hard-wired' and 'expensive' NC controllers at each machine and eliminate troublesome paper tape handling, Figure 2.10a, [Crossley 1978]. Early systems necessarily involved large expensive minicomputers [Schaffer 1978].

As the price of computer devices reduced these centralised systems were replaced with others using Behind-the-Tape-Reader (BTR) devices where small 'process control type' computers were used as a 'black box' interface into the machines

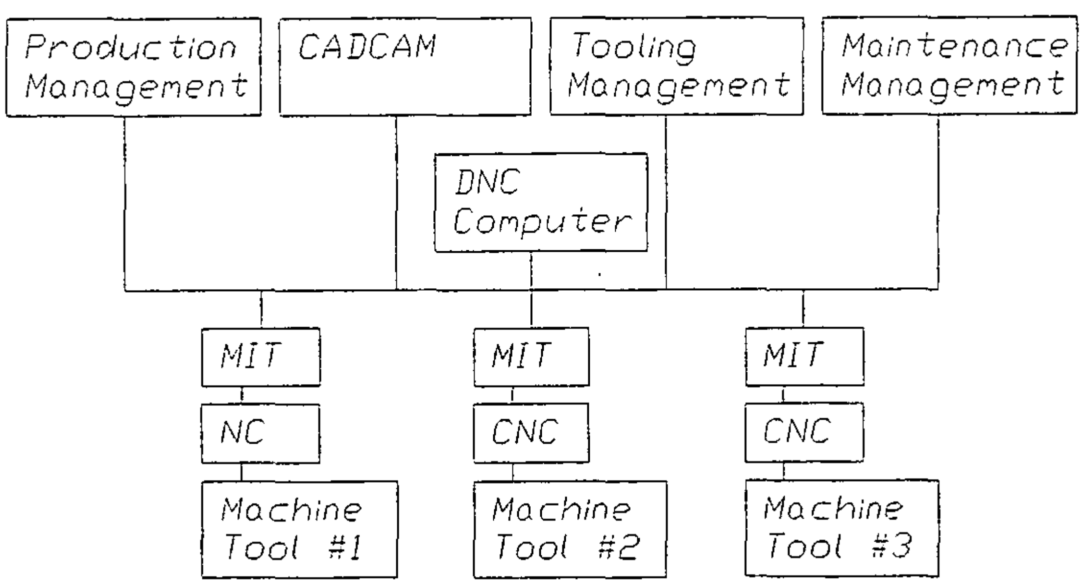
Figure 2.10 DNC Implementations



(a) DNC



(b) Distributed DNC



(c) Networked Management System

existing NC input interface in place of the tape reader itself [Crossley 1978]. However as in the early systems this still involved transferring the part program data from the central computer byte by byte. When CNC systems became available for machine control, DNC systems progressed to feature transfer of whole part programs from the central computer to local storage within the CNC at the machine. These 'second generation' DNC systems, better referred to as Distributed rather than Direct NC, provided quantifiable cost savings which made them more attractive especially to the smaller companies [Schaffer 1979] [Folkman 1982]. See Figure 2.10b.

In the early 1980s it was suggested that conventional DNC systems should 'be augmented by a real-time monitoring, communication and information network integrating all aspects of manufacturing and production support activities' in the form of a 'Networked Management System' [Hancock 1983] [Duncan 1983] or 'Integrated Direct Numerical Control' (IDNC) system [Astrop 1983] [Browne 1985] [Mizlo 1985]. See Figure 2.10c. Recently Buckley [Buckley 1989] reinforces the view that the functions provided by DNC are a key component in the successful implementation of CIM as long as it considered an integral part of a factory wide data communications system.

B. FMS

Warnecke [Warnecke 1984] reports that considerable work was done in the early 1980s on the configuration of Flexible Manufacturing Systems (FMS). Jablonowski [Jablonowski 1985] claims that the first ever attempt to build an FMS was made in the UK in the mid 1960s by Molins Ltd. 'System 24' was designed to incorporate many of the principles which are now accepted as important in this kind of system. However it failed to be implemented because software and control snags proved too difficult to overcome. Many different types of FMS have been installed throughout the world [Bilalis 1985] [Bonnetto 1988] [Greenwood 1988] [Talavage 1988], although Browne argues that there was some confusion under which circumstances the early systems could be called 'flexible' [Browne 1984]. Kochan indicates that the majority of installed systems have been concerned with metalcutting followed by metalforming, welding and assembly [Kochan 1986].

The cost of installation of FMS is usually large even though the potential benefits may be considerable [Kochan 1985] [Bessant 1986] and so they have tended to be installed only by large companies, particularly those which have relatively small families of parts (e.g. automobiles, pumps and valves). For smaller companies the relatively less expensive FMCs are more easily justifiable [Bessant 1986]. In common with other computerisation in manufacturing the design of the computer control system is extremely important to the successful implementation and subsequent running of an FMS and will necessarily dictate whether a system is only 'versatile' or truly 'flexible' [Costa 1985] [Carrie 1988].

2.5 Information Management

The second of the three architectures considered as a framework for this thesis is concerned with the management of information within CIM systems. The evolution of CIM has stimulated much interest in this area [Lillehagen 1984] [Spur 1984] [Weber 1988]. The widely used approach since the early 1980s to making information available within a manufacturing organisation is commonly to store it in a central database [Kutcher 1983] [Weston 1988]. This information is often used primarily for the control of manufacture and many installations allow for this data to be accessed and updated to reflect the status of the manufacturing process [Weston 1988] [Fritsch 1989]. It is also common that the only other major data base involved is used for the storage of design information especially when a CAD system is actively used [Chorafas 1988]. The 'Simultaneous Engineering' approach to manufacture, which stresses the need for coordination of company disciplines and especially the need for improvement in the interface between design/engineering and manufacturing, is becoming increasing popular [Foreman 1989] [Charles 1989]. However Salzman [Salzman 1989] points out that the implementation of isolated computer aided functions have resulted in increasing use of independent databases from different suppliers.

Weber [Weber 1989] argues that 'information, and its control, present the strongest integrating influence on the system, and currently available, and used data management tools cannot provide the capabilities that are required by manufacturing systems of the future'. Hsu [Hsu 1987] suggests that true integration has to go beyond the simple interfacing of different software packages to transfer data between existing data bases and that an 'underlying data model' is required to integrate the differing views required by different manufacturing functions. Reviewing some of the literature Weber [Weber 1989] suggests that distributed database systems offer many advantages in the implementation of CIM systems. He proposes an information model whereby the functionality of traditional control systems is split into two providing for a decision processing system which is separate from the information control system. Barkmeyer

[Barkmeyer 1989] also agrees that data flow should be separated from control flow functionality so that suitable data system control architectures can be chosen independently for a given application but stresses the importance of standard data models to allow for successful data sharing. Oliva [Oliva 1989] also proposes that the implementation of data and related standards into a company is critical to survival.

2.5.1 Distributed Database Management Systems

Date [Date 1986] considers that a distributed database management system 'is any system involving multiple sites connected together into some kind of communications network, in which a user .... at any site can access the data at any site'. Therefore the aim of a distributed database management system is to control the access and sharability of data distributed across a computer network, which in the case of manufacturing would normally be a Local Area Network (LAN) [Rowe 1989].

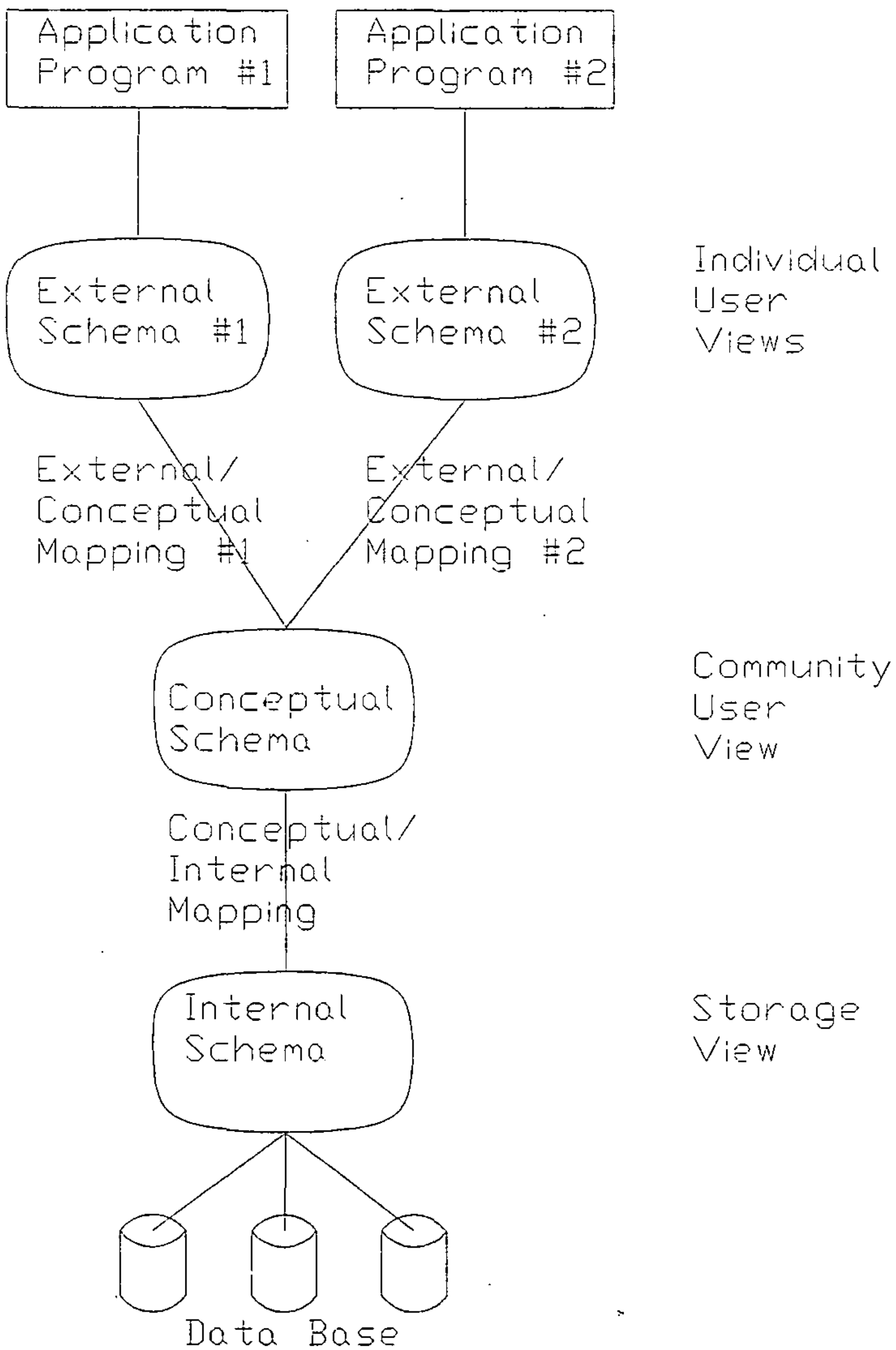
A. Three Schema Concept

The 'three schema' concept has been accepted as an architecture which fits the majority of database systems in the field. The architecture is divided into three layers as illustrated in Figure 2.11. The 'internal' level is concerned with the way the data is physically stored; the 'external' level is concerned with the way the data is viewed by individual users and the 'conceptual' level is concerned with the way the data is viewed by the 'community' forming the link between a required user view and the physical store [Date 1986]. Weston and Snodgrass [Weston 1988] [Snodgrass 1989] build on this concept to propose three schema information administration systems for the manufacturing environment in their differing approaches to the three architecture concept, see above.

B. Data Management in CIM Systems

The US Air Force ICAM programme has sponsored work in the use of distributed database management systems in manufacturing environments. The research has resulted in the evolution of an Integrated Information Support System (I^2S^2) which originally addressed the problems of controlling information access at the 'enterprise' and 'plant' levels of manufacturing [ICAM 1983] [Althoff 1987]. Work at the AMRF facility at the US National Institute of Standards and Technology has also led to the evolution of a hierarchical Integrated Manufacturing Data Administration System (IMDAS) which can operate at all of the five plant levels specified by their research and incorporates the three schema

Figure 2.11 Three Schema Concept



architecture [Krishnamurthy 1987] [Libes 1988]. The architecture of IMDAS is a 4-level hierarchy, as illustrated in Figure 2.12, with each level having a particular scope of responsibility. The bottom Data Base Management System (DBMS) level is the actual data repository. This in turn is supervised by a Basic Data Administration System (BDAS). The BDAS and its DBMSs execute data manipulations. A group of BDASs is integrated into a 'segment of the global database'. The Distributed Data Administration System (DDAS) is the data manager for a segment and can provide an interface to certain user programs. In order to integrate segments managed by DDASs a single system is designated the Master Data Administration System (MDAS).

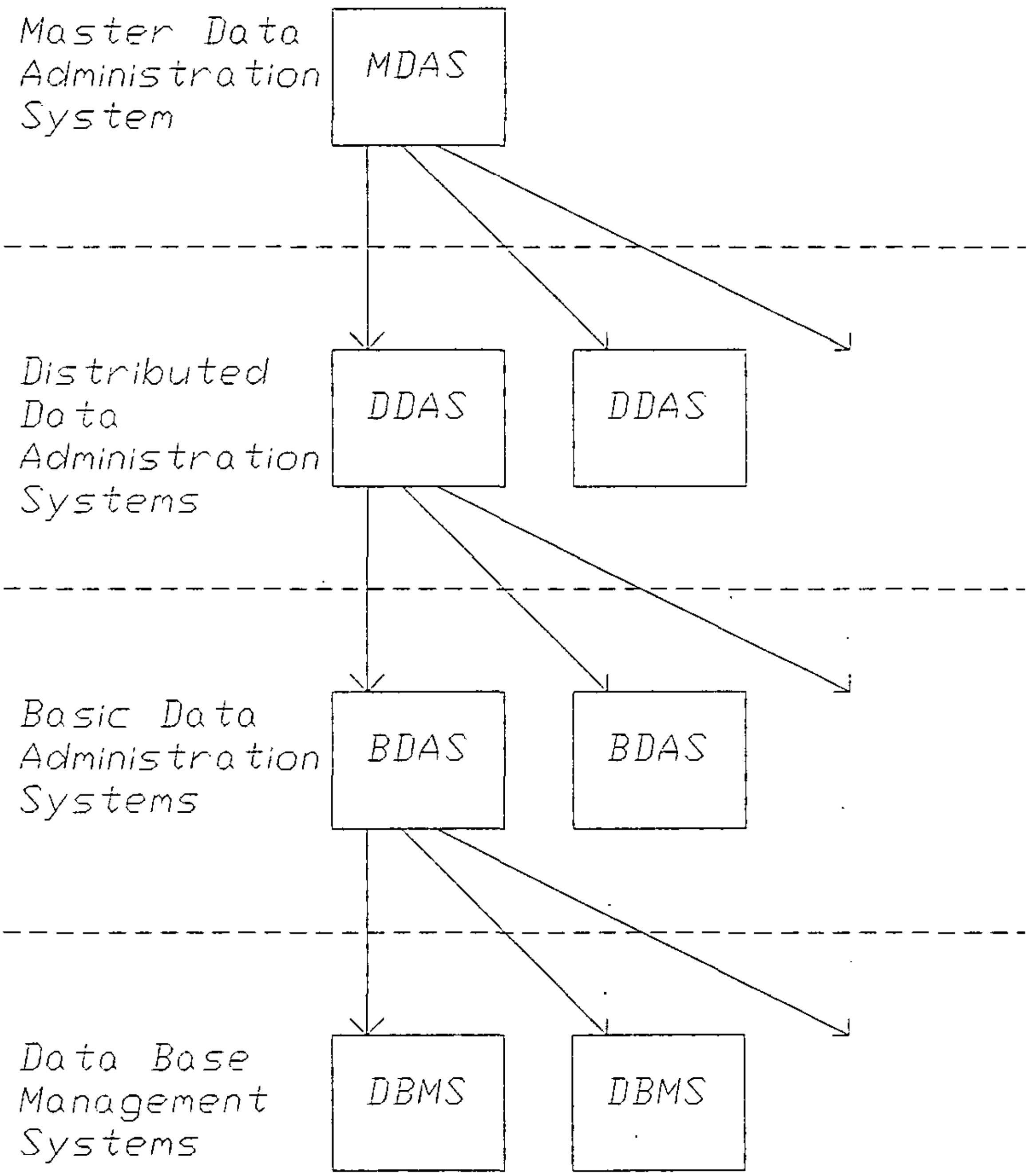
Weber [Weber 1988] summarises the hierarchical concept as systems where local databases continue to service their local users independently while superior levels maintain global access. However he suggests that such systems, although solving some problems, suffer from unreliability and inefficiency and proposes that the two system approach, incorporating separate control and information systems as mentioned above, together with the use of knowledge based systems will lead to systems giving 'consistancy of information and reliability'.

Rowe [Rowe 1989] states that distributed database systems have only recently been introduced to the commercial marketplace and that most available products are therefore primitive. Rowe also points out that, although these distributed systems solve the problem of building information systems which need to use geographically separate databases, they do not solve the problem of managing the transition from existing applications or integrating data which is not stored in databases (e.g. geometric models stored in a file). He proposes the use of heterogeneous distributed database systems which include gateways from the distributed system into the older systems as illustrated in Figure 2.13.

2.5.2 Data Definition Standards

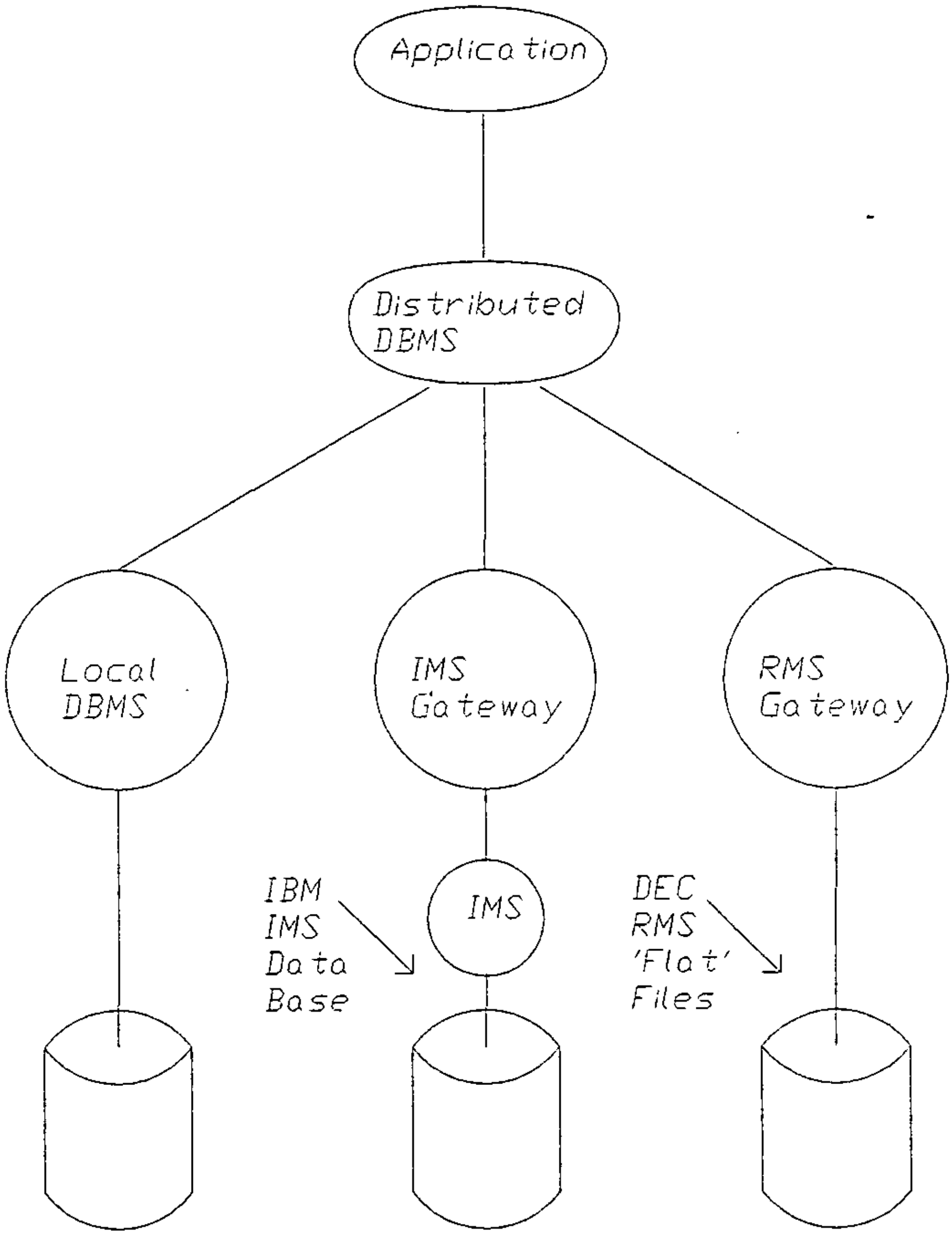
Significant amounts of work have also been done on standardisation of information formats especially in the CADCAM field. This work started with the US ICAM programme IGES initiative and has been followed by others such as SET/VDA, PDDI/XBF, PDES/STEP. The goal of each of these initiatives is to be able to transfer information between different systems with translation of formats as appropriate with no loss. The approach is to use a 'neutral format' standard through which each systems format is translated. This requires two translators to be written for each different system for 'pre- and post-processing' of the data

Figure 2.12 The IMDAS Hierarchy



[Libes 1988]

Figure 2.13 Integration of Existing Data Bases



[Rowe 1989]

during transfer. The alternative of writing specific translators between each individual system would result in a 'proliferation' of translators [Dwyer 1986] [Owen 1987]. The alternatives are illustrated in Figure 2.14. Descriptions of some of the developing standards of interest in this research follow:

A. IGES

The Initial Graphics Exchange Specification (IGES) [Liewald 1985] [Mayer 1987] is the most widely used neutral format for transfer of product data between different CADCAM systems. There are various versions of IGES in use from versions 1.0 through 5.0 with appropriate improvements to data formats and scope etc. being introduced in each version [Owen 1987].

B. SET, VDA

The Standard d'Exchange et de Transfert (SET) is of a more compact form than IGES. It has been developed and is widely used in France as the preferred alternative. The Verband des Automobilindustrie (VDA) is the German car manufacturers preferred standard [Owen 1987].

C. PDDI, XBF

The Product Definition Data Interface (PDDI) was also initiated as part of the US ICAM programme and builds upon the IGES work by including manufacturing information i.e. covering 'product data and product life cycle data' [Birchfield 1985]. The Experimental Boundary File (XBF) is a format developed specifically for transmission of solid modelling data. The work has been incorporated into IGES V4.0 [Wilson 1985] [Weston 1988].

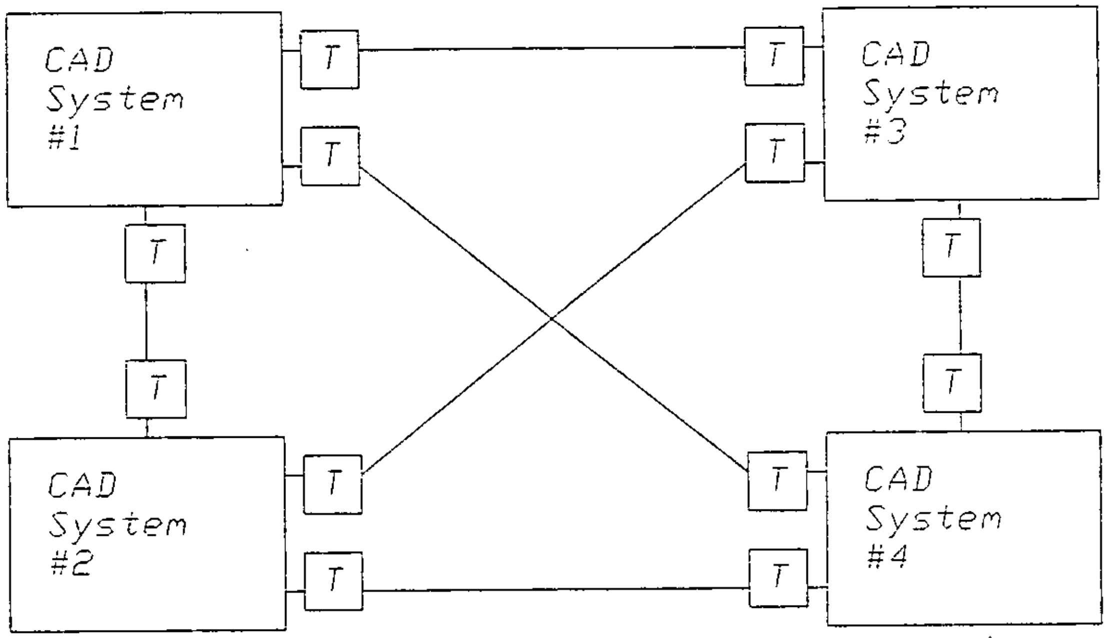
D. PDES/STEP

The work already undertaken on IGES, PDDI and XBF led to the intention of providing the Product Data Exchange Specification (PDES) as a successor to IGES [Stauffer 1985]. This would incorporate a wide spectrum of product modelling information. Alternative work under the ESPRIT CAM-I project in Europe has led to to the Standard for the Exchange of Product Model Data (STEP). The focus now is on a joint PDES/STEP standard sponsored through the ISO [Owen 1987].

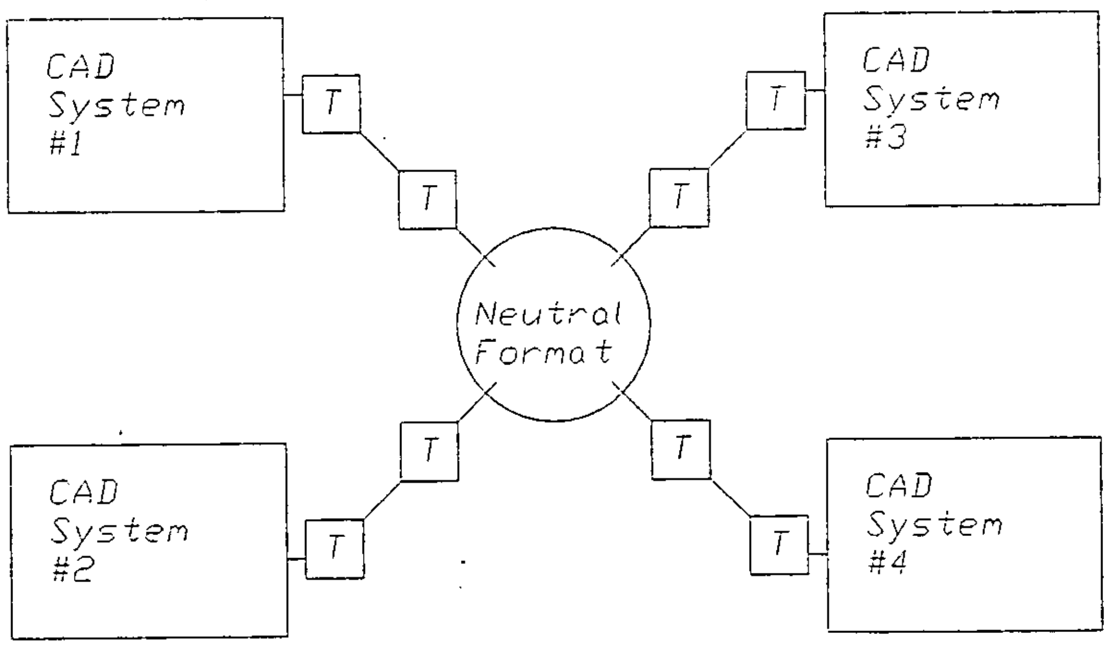
E. EDIF

The Electronic Data Interchange Format (EDIF) developed in the US by six electronics companies independently of all the other formats has become a 'de

Figure 2.14 CADCAM Data Transfer



(a) Dedicated Translator Approach



(b) Standard Format Approach

facto' standard for the interchange of electronic design information [Hillawi 1986]. However the EDIF and PDES/STEP initiatives have remained seperate for political reasons [Owen 1987].

F. GKS, ODA

The Graphical Kernel System (GKS) is different to IGES in that it is used for the transfer of drawings rather than the information which the drawing represents. The Technical Office Protocol (TOP), see below, layer 7 services will use GKS, for printing graphical data transfers, and Office Document Architecture (ODA), for office documentation data, together with the PDES/STEP information protocols [Weston 1988].

2.6 Communications Mechanisms

The third of the three architectures considered as a framework for this thesis is concerned with the communication of the information available to CIM systems. There are many advantages with using Local Area Network (LAN) technology for data communication in the CIM environment [Moller 1985] [Groover 1987] [Shapiro 1988]. LANs are 'generally owned by a single organisation; local, over distances less than a few miles, and contain some type of switching element technology' [Thurber 1981]. The technology has grown steadily over the past twenty years. A number of network systems have evolved differing in transmission mediums and protocols and there are over 90 different suppliers in the UK alone [Clarke 1978] [Huggins 1985] [Kelly 1987].

2.6.1 Local Area Network System Standards

The existence of different Local Area Network technologies causes many problems for CIM, since these differences are apparent in the various computing systems applied in different business functions which need to be integrated [Ingersoll 1985] [Weston 1988]. The foundation for a standard networking system was laid in 1978 by the International Standards Organisation when it issued its seven-layer Reference Model for Open System Interconnection (ISO-OSI) [Zimmerman 1980] [Day and Zimmerman 1983]. This was the start of a massive initiative to provide standards for all aspects of data communications.

A. ISO-OSI

The OSI architecture is an internationally agreed seven layer model for communications between separate devices. It is organised as a hierarchy of independent, yet supportive, functional levels. The levels can be viewed as an assembly of functional blocks with layers 1-4 acting as Interconnection Standards and layers 5-7 as Interworking Standards [Strom 1988]. Each of the layers provides a service to the layers adjacent to it and maintains a relationship with the corresponding layer of the system it is communicating with. See Figure 2.15. Splitting the model into layers in this way allows each function to be made 'transparent' (i.e. independent of the existance of the others) and enables any layer to be modified without disturbing any other. However ISO-OSI is an abstract reference model, although the functionality at each layer is defined, the implementation of the function of each layer is not specified. There have been, therefore, many implementations of LANs using the OSI model and many more examples where the layered functionality of the model has not been implemented [Weston 1986].

The lowest levels of the model, layers 1 and 2, are concerned with the network hardware connections. They determine how station access to the network is controlled and ensure that physical transmission errors are detected and rectified. Nearly all the standards work in this area has come from the IEEE 802 committee set up in 1980. This work is set up in nine groups, 802.1 through 802.9. The 802.2, 802.3, 802.4 and 802.5 standards have been taken up by ISO [Strom 1988]. The relationship between the ISO/OSI model and 802 standards is shown in Figure 2.16 [Lefkon 1987].

B. MAP/TOP

The Manufacturing Automation Protocol (MAP) initiative begun by General Motors in 1980 has stimulated much interest among network users and suppliers [Hollingum 1986]. This initiative was conceived when General Motors calculated that half the cost of introducing automation was spent on producing specialised communications. By the end of the 1970s GM already had 20000 programmable controllers, 2000 robots and over 40000 intelligent devices in use in manufacturing. Only 12% of these devices were capable of communication beyond its own automation system [DTI 1986].

The Boeing Corporation also announced that it required standard communications for engineering office networks. Its plan, known as Technical Office Protocol (TOP), is complimentary to MAP. Although the two standards are developed by separate groups, they have been controlled by a joint steering committee to ensure compatibility [Rouse 1985]. General Motor's MAP initiative is aimed at factory networks where time critical short messages are commonplace

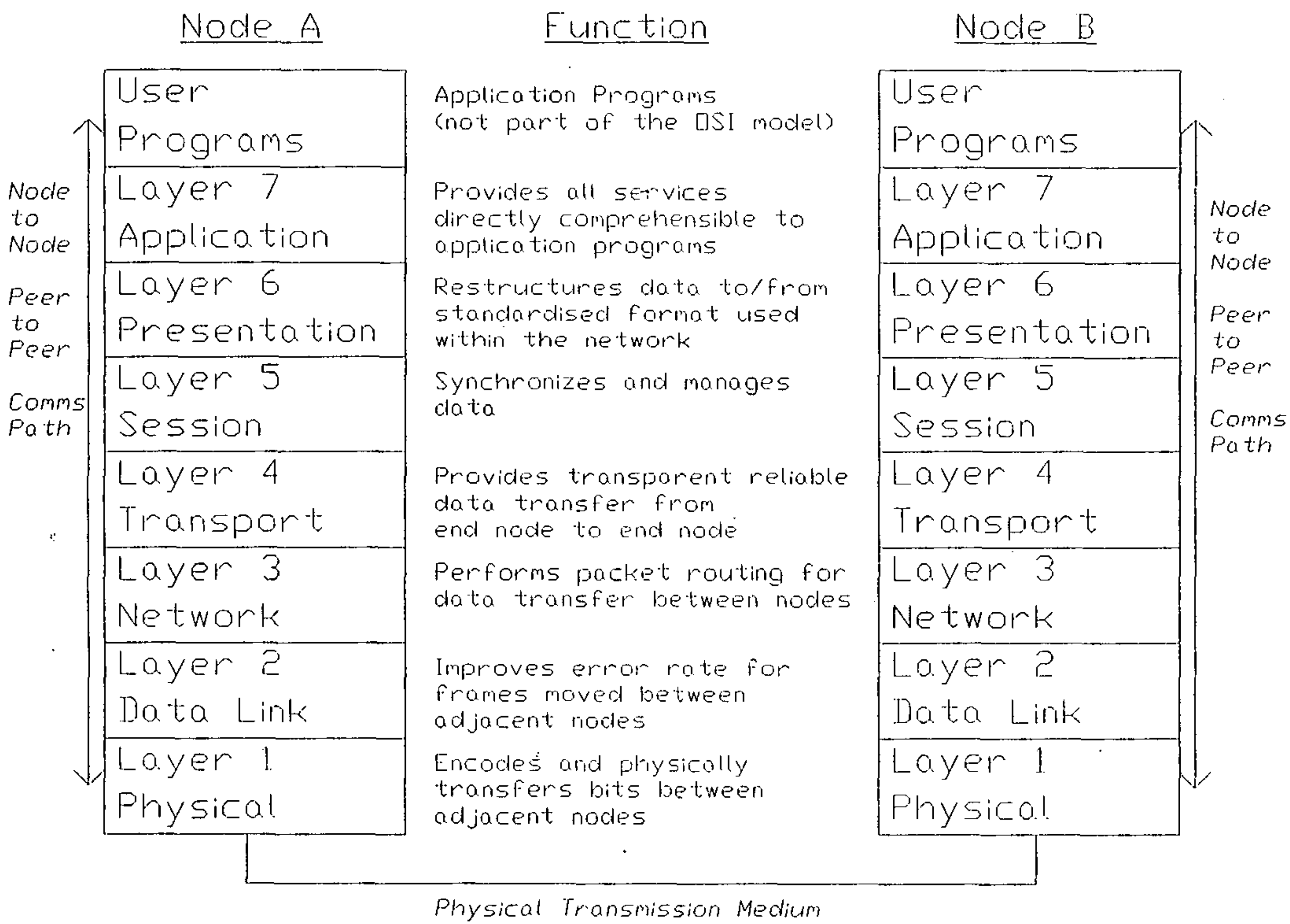
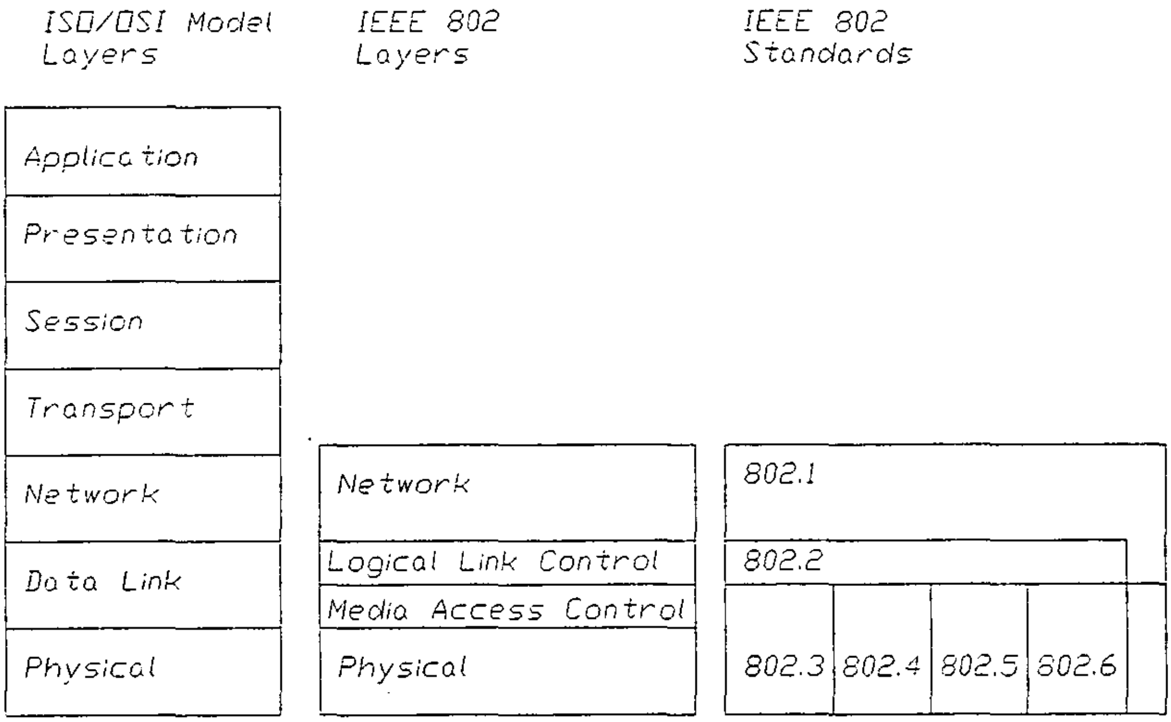


Figure 2.15 **The ISO-OSI Reference Model**

Figure 2.16 IEEE Network Standards



resulting in the specification of the 802.4 Token Bus standard at Layer 1. Boeing's TOP is aimed at the engineering office environment where transfer of large files is necessary but the transfer time is non-critical, hence the 802.3 CSMA/CD Ethernet standard was originally specified at Layer 1 [Boeing 1985]. Layers 2 through 5 of MAP and TOP are equivalent. However various flavours of the MAP/TOP standards are emerging such as MAP-EPA and Mini-MAP which are designed to suit differing applications more effectively [DTI 1986] [Deadman 1986] [Pearson 1987].

MAP/TOP has developed through a number of implemented standard versions to the current Version 3.0 [MAP 1987] shown in Figure 2.17. The services now provided in Layer 7, the application layer, incorporate a number of the information standards previously discussed. A significant development is the Manufacturing Message Specification (MMS) which has replaced the earlier Manufacturing Message Format Standard (MMFS) [EIA 1987]. MMS has evolved to offer kernal message handling services. The development of MMS 'has mirrored the realisation that the secure delivery of information represents only a start to the generic integration problem' [Weston 1988]. In the TOP environment the file transfer (FTAM), message handling (MHS) and virtual terminal (VT)

Figure 2.17 MAP and TOP Version 3.0 Standards

<table>
<tr><td>Layer</td><td colspan="3">Application Interfaces</td></tr>
<tr><td rowspan="3">7</td><td>TOP</td><td>TOP and MAP</td><td>MAP</td></tr>
<tr><td>GKS
PDES
ODA
EM
VT
CCITT
X.400
MHS</td><td>DUA
Directory
Services

ISO DIS
8571
FTAM</td><td>EIA
1393
MMS</td></tr>
<tr><td colspan="3">ISO DIS 8650/2 Kernel</td></tr>
<tr><td>6</td><td>CCITT
X.409
Syntax</td><td>ISO
DIS 8823
Kernel</td><td>ISO 8824/5
ASN.1
Syntax</td></tr>
<tr><td>5</td><td colspan="3">ISO 8327 Basic Combined Subset</td></tr>
<tr><td>4</td><td colspan="3">ISO IS 8073 Class IV</td></tr>
<tr><td>3</td><td colspan="3">ISO IS 8473 PCLNS Internet</td></tr>
<tr><td>2</td><td colspan="3">ISO DIS 8802.2 LLC1</td></tr>
<tr><td rowspan="2">1</td><td colspan="2">TOP</td><td>MAP</td></tr>
<tr><td>IEEE 802.3
CSMA/CD
10MB
Baseband</td><td>IEEE 802.5
Token Ring
4MB
Twisted Pr</td><td>IEEE 802.4
10MB
Broadband
5MB Basebd</td></tr>
</table>

[Stuckey 1988] services complement the PDES, GKS and ODA information standards discussed earlier.

The MAP initiative has gained increasing momentum through the 1980s largely due to the purchasing power General Motors, helped by other large companies such as Boeing, McDonnell Douglas and Ford, has over the major system vendors [Capes 1985]. John Deere, McDonnell Douglas and Kaiser Aluminium followed General Motors in installing MAP networks in the US [Mizlo 1985] [AM&AM 1985] and recently Jaguar have installed a MAP network at Castle Bromwich, MAP is also is due to be installed at General Motor's Ellesmere Port in the UK [Farish 1989]. Many vendors have also shown support by investing large sums of money in MAP/TOP demonstrations at Autofact '85, CIMAP '86, Autofact '87 and ENE 1988 [Beale 1988]. These demonstrations have stimulated much interest in the user community [Dwyer 1987] [Round Table 1987]. However the number of vendors offering MAP solutions has been somewhat slow to 'take off' [Becket 1986] [Taylor 1988].

C. GOSIP

The US, Canada and the UK have each developed a Government OSI Profile (GOSIP) which specify which of the standards are to be used for inter-government department communications. These profiles are important because the central governments are large purchasers of computers and networking products and thus products conforming to the specifications are more likely to become readily available. The GOSIPs are complimentary to MAP/TOP and build on the standards already defined, especially the TOP protocols. They are also aimed at different application areas [Purdue 1989].

2.6.2 Public Standard and Proprietary Local Area Network Systems

Strom [Strom 1988] suggests that the move toward OSI compliant standards is bound to take some time while the different computer system vendors develop products. Until then the various 'de facto public standards' and proprietary networks will continue to flourish. These are categorised by differing hardware, ISO Layers 1 and 2, and protocol , Layers 3 and 4, implementations. The protocol levels are more concerned with the successful transport of data; the transfer of message segments or 'packets' between communicating stations. Strom also states that in the past vendors have implemented their own proprietary protocols. Since the work reported here has been limited by the network technology already available for the computer systems used by Rockwell PMC Ltd., the particular hardware and software levels appropriate are reviewed.

A. Hardware Levels:

The direct point to point link is still the most commonly found method of linking individual system elements together within manufacturing systems, standards such as RS232 are generally used in CADCAM and FMS environments [Weston 1987a]. The outcome is a classic star topology where every new link requires another network interface at each device [Clarke 1978]. The star topology has long been standard in IBM system environments where a central mainframe, for example, serves as a host to other computer systems, intelligent communications devices and user terminals using twisted pair or coaxial cables [Tanenbaum 1981].

Ethernet, a 10 MBit/s CSMA/CD baseband standard, [Metcalfe 1976] [Ethernet 1980] and its derivatives such as Starlan, which operates at 1 Mbit/s on twisted pair cable, has dominated the Local Area Network market [LAN Survey 1985]. Ethernet has effectively become a de facto network standard which was promoted and developed initially by DEC, Intel and Xerox. Many other manufacturers were issued Ethernet licences [Urwick 1981]. Clare [Clare 1988] reports that the IEEE 802.3 standard was modelled on the original Ethernet standard. (However Clare also states that there are slight differences between the two in the packet frame formats and the fact that Ethernet occupies the whole data link level, ISO Layer 2. Even so systems using the two standards can cooperate successfully on the same hardware [Clare 1988]).

IBM's Token Ring [Strole 1983] [Huggins 1986], a 4 MBit/s 'star wired ring' network based on a twisted pair cabling system, has also become something of a de facto standard for LANs although the sales of Token Ring interface cards is still only half that of Ethernet in the UK [Broadhead 1989]. Token Ring has been incorporated into the IEEE standard as 802.5 and included in ISO standards [Strom 1988]. A 16 MBit/s version was announced by IBM in 1988 [Announcements 1988]. Token Ring has made particular in-roads in the Personal Computer networking arena to rival other popular choices [PC Weekly 1988].

Conner [Conner 1988] suggests that Arcnet may well be taken up as a low cost alternative network hardware for the factory floor because of its deterministic nature. Arcnet (the Attached Resource Computer Network) is a 2.5 MBit/s baseband Token Bus network (actually linked up as a'string of stars') originally developed by Datapoint. It uses coaxial cable primarily although it can also be implemented on twisted pair. The Arcnet network technology has been popular for personal computer networking because of its ease of configuration, low cost and particularly at 'IBM sites' because it normally uses the same coaxial cable, RG62/U, as IBM 3270 mainframe terminals [RDS 1988].

B. Protocol Levels:

IBM's (proprietary) Systems Network Architecture (SNA) has been the dominant network standard for the 'large computer user' sites operating IBM mainframes. SNA operates over 3270 2780 protocol sets [Schwartz 1987] [Tanenbaum 1981]. Strom [Strom 1988] reports that many other computer system vendors support the 802.3 or ethernet hardware standard but provide their own differing protocol software. Digital Equipment Corporation (DEC) promote their own Digital Network Architecture implemented via DECnet over ethernet [Networks 1989] and Data General (DG) also have their own networking product XODIAC [XODIAC] which can operate over ethernet but is based on the X.25 standard [Schwartz 1987]. TCP/IP (Transmission Control Protocol/ Internet Protocol) has become a 'de facto standard' for communications over ethernet. This standard is the result of many years of research in the US with the ARPANET [Roberts 1970]. It has been a US Department of Defence standard since 1978 and was officially adopted for defence department networks in 1983 [Rouse 1985]. Many vendors support TCP/IP applications and see them providing the temporary standard solution to multi vendor internetworking until ISO products emerge [Vizard 1988] [Strom 1988].

Microsoft's Disk Operating System (MSDOS), packaged by IBM as Personal Computer Disk Operating System (PCDOS), has been the dominant operating system for micro / personal computers (PCs) since its release in the US in 1981 [Personal Computers 1989] [What Personal Computer? 1989]. The early versions of DOS had no inbuilt support for multiuser or network applications until MSDOS version 3.1 was released including these functions built in as high level network primitives. The introduction of DOS 3.1 has provided a standard network interface for applications software. Three network operating systems were the first to support the new DOS 3.1, and subsequent DOS 3.X, standard. Microsoft Networks (MSNET), the IBM PC Network Program (PCNP) and Novell Netware. Each is based on a 'File Server' system approach [LAN Software 1985]. Each system supports certain File Server Utilities at the OSI application layer 7, interface through DOS 3.X and a 'Redirector', which differentiates between local

Figure 2.18 PC Network Standards

ISO/OSI Model Layers	Microsoft MS-NET	IBM PC Network Program	Novell Netware
Application	File Server Utilities	File Server Utilities	File Server Utilities
Presentation	DOS 3.x and Redirector	DOS 3.x and Redirector	DOS 3.x Shell
Session	Specified by Network Vendor	Netbios	Netware Netbios Emulator or Netbios
Transport			
Network			
Data Link		Token Ring	Specified by Network Vendor
Physical			

and network requests, at the presentation layer 6 and then through different software at lower layers. The implementations are shown in Figure 2.18. IBM's PS/2 microcomputers and OS/2 operating system, released in 1987, may eventually replace the use of the PC and MSDOS but the indications are that this will take some time to achieve [Sharpe 1988].

MSNET is intended to be licenced by LAN vendors and therefore provides only basic functions at the presentation layer and no functionality below layer 5. This and the particular hardware implementation is left up to the vendor [LAN Software 1985]. IBM's PCNP offers improved facilities at the presentation layer to MSNET and also includes the use of a now de facto standard Network Basic Input Output System (NETBIOS) which implements the OSI network, transport and session layers 3 to 5 [LAN Software 1985]. The PCNP was originally supported on Systek's broadband scheme but is now supported primarily on Token Ring [RDS 1988].

Novell's Netware has become the dominant operating system software for Personal Computer LANs [Broadhead 1989]. Novell Netware is a proprietary networking system. The major difference between the Novell and other approaches is that the File Server software operates in a different way to user 'workstation' software. In the workstation netware works through the accepted DOS 3.X presentation layer. However in the server Netware provides all of the functionality from layer 3 through layer 7 [LAN Software 1985]. Communications is based on the Xerox Network Systems (XNS) protocol set originally developed for use on ethernet with the Internet Datagram Protocol (IDP) at the network layer and Sequenced Packet Protocol (SPP) at the transport layer [RDS 1988]. Novell Netware's popularity is partly due to its 'hardware independence' [LAN Software 1985] since it has been ported to over 30 different network hardware topologies [Netware 1985]. Novell also supply NETBIOS emulator software which provides a common interface to applications based on this IBM standard [LAN Software 1985].

2.6.3 Merging Standards

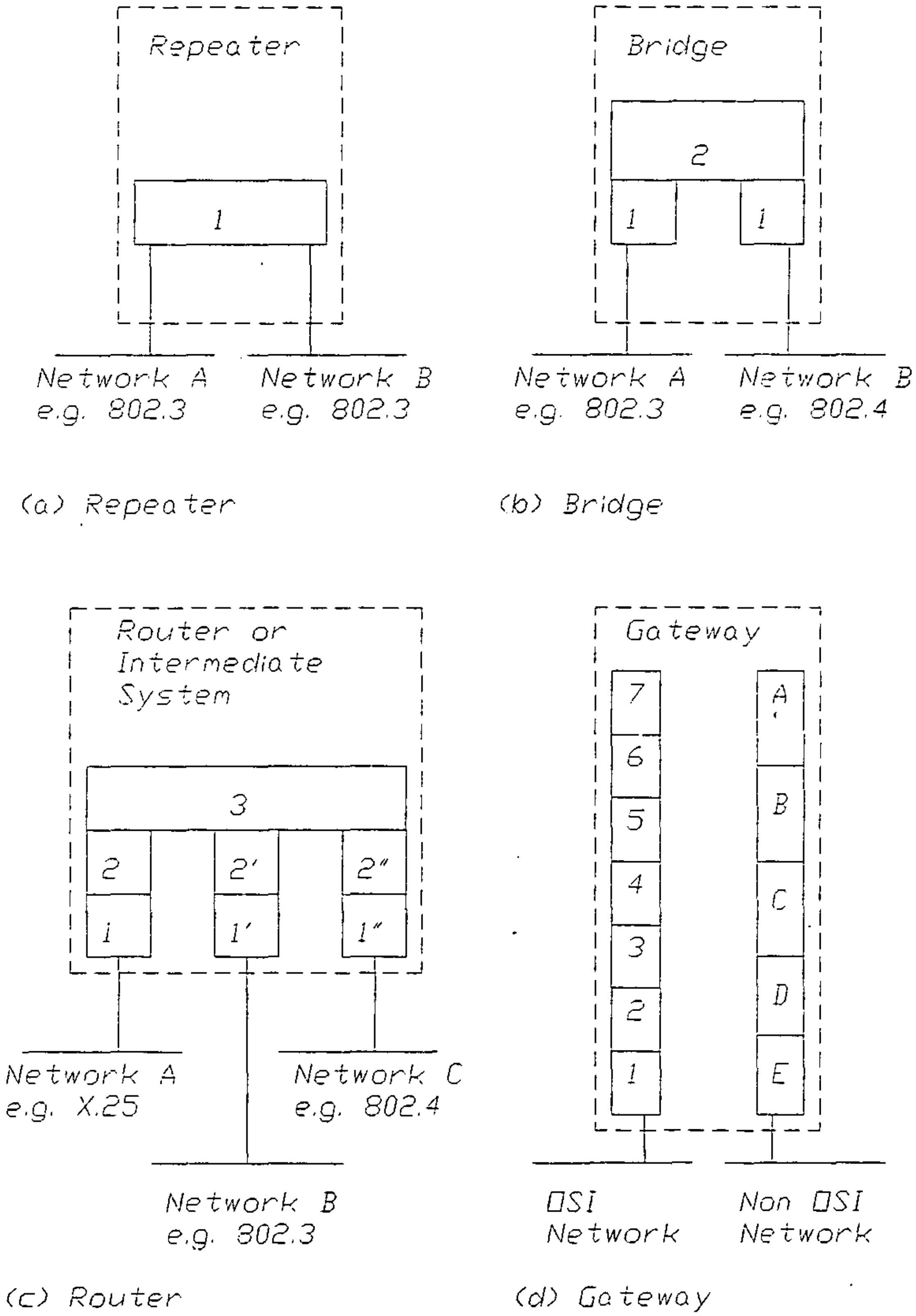
A. Internetworking

The MAP/TOP initiative has explicity acknowledged the need for four types of communication relay which are needed to interconnect separate networks and network segments. See Figure 2.19. The Repeater is used to connect segments of the same network type and operates at the OSI physical layer 1. The Bridge allows for the connection of two physically distinct networks, which can be of different types, and operates at the data link layer 2. The Router allows for the connection of two or more physically distinct networks, which can be of different types, and operates at the network layer 3 therefore not restricting layer 1 or 2 protocols. The Gateway connects different network architectures providing protocol conversion through all 7 layers. They are commonly used to connect non-OSI to OSI networks [DTI 1986] [Weston 1987b].

B. OSI Compliance

The literature suggests that the different computer system vendors each have their own approach to the adoption of OSI standards for computer communications. However the author considers that the majority are committed to introducing systems which can interwork reliably with minimum fuss. Laws [Laws 1987] reports that IBM leads other vendors in terms of announced OSI products although they may not be the most fully featured available. Laws suggests that IBM's commitment may be limited due to the vast investment in SNA. He argues that IBM believes that the way ahead is to allow SNA and OSI protocols to co-exist and the OSI software already announced 'will only run in a sort of sandwich with SNA as the bread and OSI the filling' [Laws 1987].

Figure 2.19 Communication Relays



DEC [Commitment 1988] has announced that it is also concentrating effort on full integration of OSI products with its own Digital Network Architecture (DNA). DEC plans to achieve this by migrating DECnet products towards OSI but without disturbing the DNA functionality. DEC firmly intends to enhance DNA to provide more advanced features than are available within OSI [Ablett 1987] [Commitment 1988]. DG reports a tradition of supporting industry, and de facto, standards in an effort to offer customers open systems. The proprietary aspects of any DG protocol will essentially disappear migrating XODIAC networking architecture to full OSI compliance. However DG also believes that SNA and OSI must coexist and intends to support this, and other de facto standards, as appropriate, to position itself in the marketplace in a flexible way [Data General 1988].

Novell has also announced commitment to an 'Open Systems' strategy providing internetworking with other vendors products, e.g. Netware VMS for Digital VAX computer connection [Mardesich 1988], and have recently announced 'Portable Netware' designed to run on minicomputer and mainframe hosts. 23 vendors have announced support for the product [Walkenhorst 1989].

2.7 CIM Implementation

Chater suggests that, because CIM (by its very nature) involves the application of advanced technology, it is all too easy to focus on the technical aspects of a proposed system and effectively ignore other equally important factors. Weinberg [Weinberg 1989] proposes that there are three distinct levels of integration in CIM: Strategic, Managerial and Technological Integration and adds that, in order to achieve significant benefit from CIM implementation, companies must develop a plan which addresses all of these levels. Putrus [Putrus 1989] suggests that CIM should be considered as a strategic program and not as a point solution justified only by cash flow analysis. Chater considers that the financial justification of advanced manufacturing technology is becoming more difficult and now calls for a different approach [Chater 1986]. Equally important is the recognition that the 'socio-technical' aspects of manufacturing must now be a principal feature in the strategic approach to CIM implementation [Smith 1988]. Wood [Wood 1989] suggests that the relationship between automation and manpower costs must be fully understood when CIM investment is made adding that a correct blend of automation and human resources can often maximise process effectiveness.

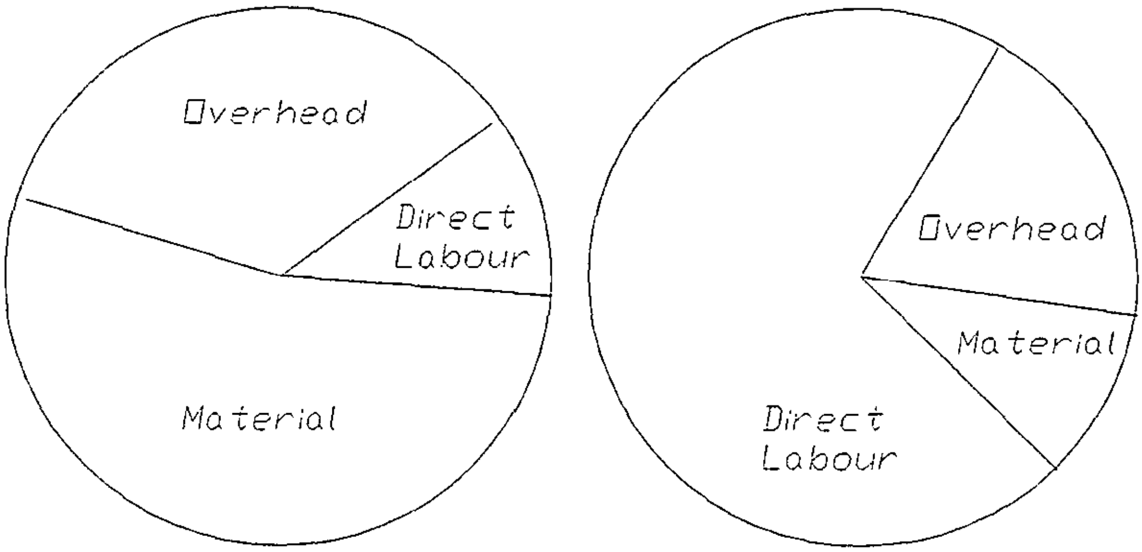
2.7.1 Financial Considerations

Dunn proposes that many now believe that the established approach to costing and financial justification of projects is preventing companies from making the most of advanced manufacturing technology. He suggests that the current framework of cost accounting, followed for over a century, is inappropriate to today's factories which have 'changed out of all recognition' because of automation. This has resulted in a dramatic decrease in the number of 'shopfloor workers' employed to make any one product. Thus whereas production costing is still based on large labour cost in relation to material and overhead costs, today's situation reflects large material and overhead and relatively small direct labour costs, Figure 2.20 [Dunn 1986].

It is now often suggested that companies are unable to determine whether the implementation of advanced manufacturing systems is financially justifiable [Primrose 1985a] unless 'unquantifiable benefits' are used as the deciding factor. Folkman adds that 'Performance improvements offered by advanced DNC systems are far reaching, but largely intangible. This makes conventional justification techniques nearly impossible or inappropriate. The kind of benefits available through this kind of automation clearly calls for a strategic decision by top management' [Folkman 1982]. Putrus [Putrus 1989] agrees that most CIM benefits are intangible and 'do not lend themselves to being quantifiable in traditional evaluation'. Putrus proposes a non financial justification method based on the Analytical Hierarchy Process [Saaty 1980] where a company business plan matrix is constructed. This plan should encompass all the functions of the company and the integration of these functions, Figure 2.21. Weighting factors are then constructed to rank each of these factors according to the percentage of perceived benefits versus perceived risk for each in order to compare the net benefit of a particular CIM implementation path [Putrus 1989].

However Primrose maintains that 'contrary to established opinion the factors comprising the "intangibles" can, in fact, be quantified' [Primrose 1985b]. The work of Arnott [Arnott 1983] (which reports that 'of the first two companies who tried to introduce FMS, Herbert Ingersoll passed into receivership while Molins were nearly bankrupted') is also referenced to warn that major investment without financial justification can result in severe consequences. Primrose's research, beginning with appraisal of single machine installations and moving on to the justification of FMS [Primrose 1984a] [Primrose 1984b], suggests that traditional methods of investment appraisal usually understate the financial

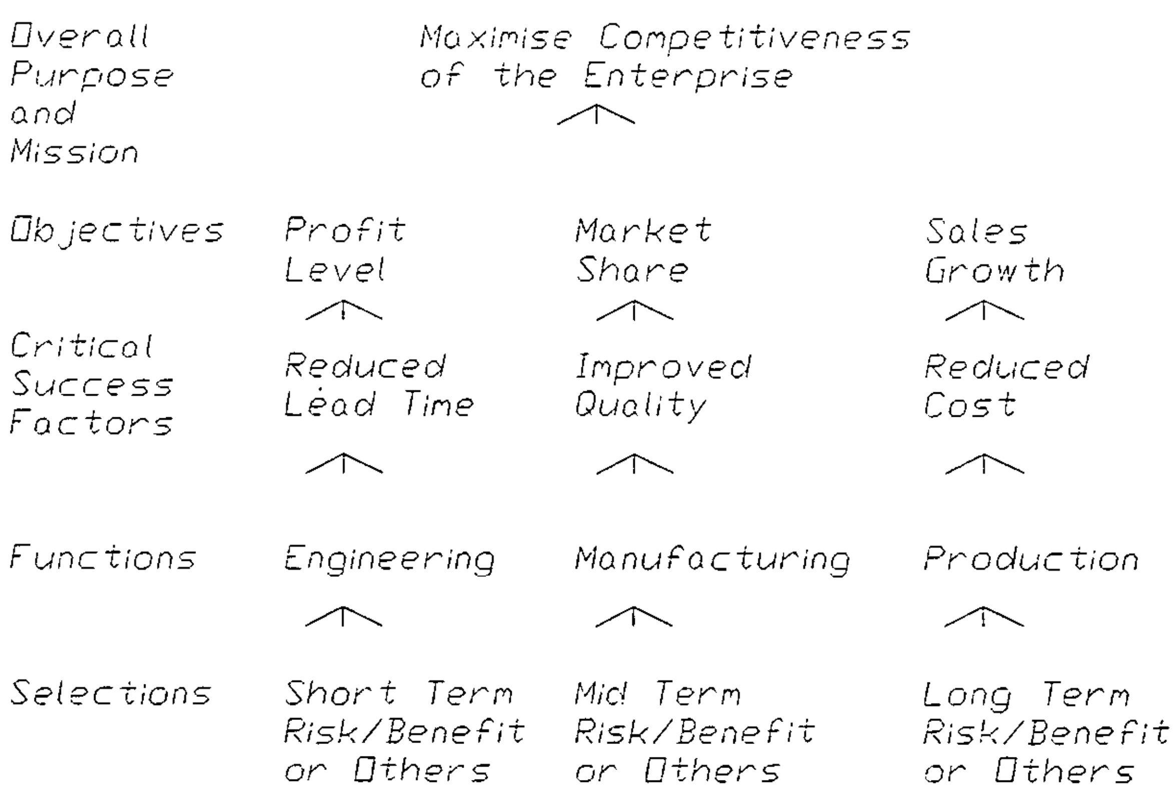
Figure 2.20 Manufacturing Cost Views



(a) Present Cost View (b) Traditional Cost View

[Dunn 1986]

Figure 2.21 Manufacturing Enterprise Representation



[Putrus 1989]

advantages available so that perfectly sound investments in technology are often ignored. The approach specifies that Discounted Cash Flow (DCF) analysis should be used rather than the normally applied 'Payback'. Swindle [Swindle 1985] agrees that methods using discounting techniques are the best approach. Troxel suggests that the Activity Based Cost approach, where those activities which cause cost are assigned the overhead costs rather than the direct labour or machine hours, is most appropriate to CIM [Troxel 1989]. Nelleman [Nelleman 1989] proposes that 'World Class Cost Management' should be applied for CIM justification. This separates Cost Accounting from Management Control and Reporting systems each of which is fed from a different view of the costs focussed on strategic, operational and functional areas.

2.7.2 Human Resource Considerations

Young [Young 1989] suggests that CIM is often 'perceived as a collection of manufacturing process changes, robotics, computing equipment, sophisticated manufacturing software and networks rather than as a change in the way an organisation accomplishes its tasks'. He proposes that CIM should focus on all aspects of the work environment including the 'psycho-social' aspects of an organisation and requires a different approach to human resource management than that generally used in manufacturing companies. Knight [Knight 1985] agrees that the blending of social and technical systems is the challenge for today's industrial environment. Tucker [Tucker 1989] suggests that a manufacturing system's output in terms of quality and productivity is the measure of success. He adds that the achievement of a long term 'marriage' between people and technology may prove to be a critical factor in a system's success and reports that a study (in The Economist 1988) of automotive plants in various countries indicates that 'levels of technology have nothing to do with productivity'.

Majchrzak reports that research studying the way advanced manufacturing systems have been implemented in companies in the past has shown that planning for 'human systems' in a factory is more often done after the technical decisions have been made rather than being a fundamental part. Even then 'consideration of human systems is often handled on an "as needed" basis only' [Majchrzak 1988]. However creating and maintaining an 'effective human infrastructure' is now seen to be of paramount importance in the strategic approach to CIM. Smith proposes that the concept of CIM should be replaced by CHIM (computer and human integrated manufacture) [Smith 1988]. Kemp agrees that 'organizations do have choices over the human aspects of their systems. Technical systems may constrain choices but they do not determine them' [Kemp 1984].

Brodner [Brodner 1988] proposes that, of the two 'opposing production concepts' for CIM evolution, the 'human centred approach' is superior in both economic and 'people' respects to the 'technology centred approach'. The approach proposed is to focus manufacturing, especially in the job shop situation, towards 'Group Technology' principles not only on the shop floor but also in the office environment where design, planning and control would be organised around 'part family' groupings. Tucker [Tucker 1989] supports this view by proposing that successful implementation strategies rely on 'installation and operation of new equipment using cross-disciplinary teams'. Tucker suggests that the simultaneous engineering concept (discussed previously) is helping to integrate the process to some extent but argues that the actual production personnel who will use the new equipment are still not involved sufficiently especially in the design stages. Kemp adds that the human centred approach still relies on the same CIM architecture involved in the 'technocentric' approach in that adequate and integrated computer based information systems need to be available. However, instead of incorporating as much knowledge and control function as possible in the computer system, human 'flexibility' is exploited to the full adding that some of the 'human designs are dependent on technical choices' [Kemp 1984].

In the factory floor environment Majchrzak [Majchrzak 1985] proposes that the implementation of 'integrated programmable automation' found in CIM systems has a different effect on the human resources than implementation of independent 'programmable automation' and that a different approach to dealing with CIM implementation is required. Majchrzak suggests that a planned, tactical strategy for handling the short and long term human resource consequences must be developed before implementing integrated systems. Young [Young 1989] suggests that the introduction of CIM on the shop floor may in some instances make 'workers feel that "big brother" is watching them'. However he adds that, on the other hand, CIM systems which provide direct access to information can provide an increased sense of autonomy and control for the individual increasing the potential of an individual's flexibility.

Brodner proposes that the implementation of CIM can only be successful by overcoming 'the prevailing thinking which believes improvements in production can only be achieved by replacing human capability with machines' [Brodner

1988]. Majchrzak adds that managing the effective implementation of CHIM is seen as a necessary pre-requisite to the selection of appropriate technology and organisational changes in order to identify the problems which may occur [Majchrzak 1988].

2.8 Summary

The implementation of CIM systems is becoming an increasing requirement for many manufacturing companies in order that they may continue to compete effectively in world markets. In the Discrete Engineering sector of industry the potential productivity benefits arising from the successful integration of CADCAM through Production Engineering and Production Management to factory floor level controls systems are becoming increasingly apparent. CIM systems integration is therefore being actively pursued by many engineering companies.

This chapter has reviewed some of the many tools which are available to the systems engineer for the modelling and analysis of manufacturing systems. The author suggests that the 'Three Architecture Approach', focussing on applications, information management and communications, may be a particularly appropriate method for decomposing the integration problem into manageable parts for the successful design and implementation of CIM systems. Many different approaches are available in each of these architectures including emerging standards and 'vendor proprietary' products.

The task facing manufacturing companies is to choose the most appropriate tools from available technology for the successful integration of existing and future systems. This integration must be controlled with reference to a predefined strategy taking due account of local circumstances or restrictions. In many cases the emerging standards may not be sufficiently defined for cost effective application by the systems engineer and so other 'non standard' products may well have to be used in the interim period. Systems will have to be designed with due regard to this restriction so that their future evolution towards acceptable standard solutions is made simple.

CHAPTER 3

Background Situation within Rockwell PMC Ltd.

3.1 Introduction

This research is based upon work which forms an integral part of the overall systems improvements planned by Rockwell PMC Ltd in the company's evolution towards the goal of Computer Integrated Manufacture. The company has set about the move towards CIM by starting to integrate systems in many areas of the business. In the past the company has been quick to grasp on new technologies which show promise for the improvement of market competitiveness. This is shown clearly by the introduction of computer systems as early as 1962 followed by the implementation of computer-based systems in such areas as manufacturing and CADCAM throughout the 1970s [Jackson 1983] [Jackson 1987]. It is important to mention that Rockwell PMC has made great efforts to ensure that, with all systems implementations, company personnel have not been adversely affected. New technology and systems have been brought into the company with the full knowledge and cooperation of the workforce.

However this early entry into the 'computer age' also has its drawbacks when it comes to systems evolution. The company is no longer a 'green field site' where new systems can be implemented without additional constraints. The effort and expenditure involved in existing systems cannot be just 'thrown away'. New technology and ideas have to be considered with due regard to the current situation and compromises must often be made. This problem is also faced by many other companies operating within the Discrete Engineering sector of manufacturing industry. The research reported in this thesis has been 'bound' to some extent by the prevailing situation within the company and therefore some background information is presented here.

3.2 Company Structure

In the early 1960's Baker Perkins Ltd (from which Rockwell PMC evolved) formed three main operating divisions responsible for trading in different market sectors. The gradual development of this approach via product management during the 1970's enabled the company to withstand the pressures of recession.

Following on from this significant changes have again been made to the company and management organisation structure since the project on which this research is based was begun in the early 1980's. In April 1985 these divisions were made into corporate companies in their own right by the formation of two new companies. Baker Perkins Bakery Ltd., to offer services and products for the Bakery industry worldwide, and Baker Perkins BCS Ltd., to serve the international Biscuit, Confectionery and Snack Food markets. Baker Perkins Ltd. was renamed Baker Perkins PMC Ltd. to concentrate on Printing Machinery products.

In 1987 Baker Perkins integrated with the APV, Pasilac and Rosista companies to form an enlarged APV group. With effect from January 1988 the APV group was reorganised and Baker Perkins PMC Ltd. became APV Baker PMC Ltd. In March 1989 Rockwell International purchased APV Baker PMC Ltd. from the APV group and the company was renamed to Rockwell PMC Ltd.

Rockwell PMC is a world leading supplier of high speed heatset web offset presses for colour magazine and commercial printing. It operates as part of Rockwell Commercial Graphics, the commercial printing equipment part of the Rockwell Graphics Systems Group, from the original Baker Perkins site at Westwood in Peterborough. Manufacturing is based at Peterborough together with sales, marketing, design, spares, service and administration. North American sales and service are co-ordinated from Schaumburg, Illinois with other sales offices in Canada and West Germany. There is also a comprehensive network of agents around the world.

3.3 Planned Improvement of Small Batch Manufacture

A 'growth market' situation in the early 1980's was forcing the company to look keenly at ways of increasing supply of special purpose equipment whilst reducing overall delivery times.

As part of the overall initiative for Rockwell PMC's evolution towards CIM, four key projects were planned which would lead to the improvement of small batch component manufacture by using Advanced Manufacturing Technology (AMT) techniques. The projects involved: the installation of a material centre, the installation of a cell for the manufacture of link components, the implementation of a Machine Management System and the rationalisation of the main company data base facilities.

These projects were planned to lead to the creation of a 'linked business system... to provide an integrated response from customer enquiry through manufacture to completion on site to customer satisfaction' and to enhance competitiveness by reducing delivery cycle time, work in progress stocks and improving productivity.

This research is based upon the project for the implementation of the Machine Management System in the Rockwell PMC machine shop which begun as part of this initiative. The four projects are briefly described here in order to provide additional background to this thesis. The following sections of this chapter give further background information on core company systems and procedures for manufacturing control which prompted the need for these projects and in particular the Machine Management System work.

3.3.1 Material Centre

The increased use of group technology cells (see below) for component manufacture sharpens responsiveness in the machine shop but is reliant on equally responsive material infeed systems. The traditional methods of delivery of bar and section from the bar stores and sheet and plate from the plate stores were causing bottlenecks in the feed of materials into the manufacturing areas, with lead times in excess of manufacturing lead times in many cases.

In order to overcome these bottlenecks a Material Centre would be created equipped with CNC saws and computer controlled storage which would allow for automated handling of stock from receipt to issue. This would provide a material issue service on the principles of 'cut today and use today'. The material centre would also provide for guillotining and profile burning.

3.3.2 Link Cell

Product development over many years concentrating on design for manufacture has led to an increasing number of components profiled from plate materials. A cell of machines operating as an integrated unit for the production of these components was proposed. The cell would comprise a material store, a plasma cutting machine, a surface grinder, two machining centres and associated handling equipment.

A feasibility study analysed the various options in five stages from basic group technology through to a fully automated F.M.S. system. The second stage of automation involving the use of stand alone machining centres, each with a multi pallet store, was chosen as the most cost effective solution.

3.3.3 Machine Management System

The creation of cellular manufacturing units brings about the need to integrate management control with information flow in order to maximise the potential benefits of low cost small batch production with high flexibilty and minimum cycle time. A Machine Management System was proposed to link the CADCAM (geometry) and Mainframe (manufacturing) computers and databases through to the machining cells on the shop floor. In order to move towards a 'make today' situation.

The system would handle geometric details, machine condition monitoring, scheduling, tool management and status reporting. This system would improve upon the non-cell based core systems described below by integrating three levels of information flow and management control: Factory, Cell and Machine management.

The project was planned in three stages:

(i) a machine management system linking one machine to the database;

(ii) a cell management system linking machines within a single GT cell;

(iii) a factory management system linking a number of cells to the manufacturing database.

3.3.4 Data Base Development

Advanced mainframe computer based systems have been an integral part of the company's structure for over twenty years. There has been notable success in developing software in house for a number of applications before suitable commercial packages have been available, including those mentioned below. An extensive suite of data bases is in use but the system architecture needed drastic revision and updating.

The integration of the company's systems to lead to the 'Linked Business System' was forcing considerable strain on the existing data base systems. The current systems are a mixture of terminal independent batch and terminal dependent interactive routines (see below) and these needed to be changed into applications which provide for acceptable response times and increase the flexibility of operation. The extending manufacturing data base needed to be fully integrated with the expanding use of CADCAM, the Machine Management Systems and micro-electronic products software development and management.

The Material Centre and Link Cell projects would be key applications for the use of the cell and machine management systems and the Data Base project would obviously also become involved at later stages.

3.4 Rockwell PMC Computer Systems

The current Rockwell PMC computer systems layout is illustrated in Figure 3.1 which shows the main computer hardware used and existing interconnections. This consists of a Comparex 7/88 mainframe computer, which is 'plug compatible' with an IBM 3090/150 computer, a Texas 990/12 minicomputer, two DG minicomputers, a DEC Microvax minicomputer clustered with five DEC Microvax workstations and a DEC Vax 11/750 minicomputer.

Figure 3.2 shows the core software modules used for manufacturing which were in place at the beginning of 1990. The diagram has been adapted from a paper describing the Baker Perkins CADCAM system as it was at the outset of this research [Jackson 1983] and illustrates the interaction between Drawing Office (CAD), Production Engineering (CAM, CAPE) and Production Management (CAPM) functions and their mutual interaction with the central MRP function and Bill of Material data base. This view is similar to that of Harhalarkis [Harhalarkis 1987] illustrated earlier in Figure 2.9. All of the core manufacturing control modules shown are based on the mainframe computer with the exception of CAD and certain parts of the CAM function.

All computer systems at Rockwell PMC are manually driven. There is no automatic dialog between computer systems distributed within the factory. Systems are driven by the users via either interactive terminal sessions or preprepared terminal independent batch routines as appropriate to the processing task required.

The availability of existing systems has forced certain constraints on the implementation of CIM at Rockwell PMC as described in the later sections of this thesis. Many of these constraints are arguably representative of those common to other companies when implementing CIM in live situations. As indicated a number of changes have been made to the computing systems used at Rockwell PMC since the start of this research work. Some of these changes have been influenced by the project work reported here whilst others have had a direct influence on this work.

Figure 3.1 Computer Systems Structure

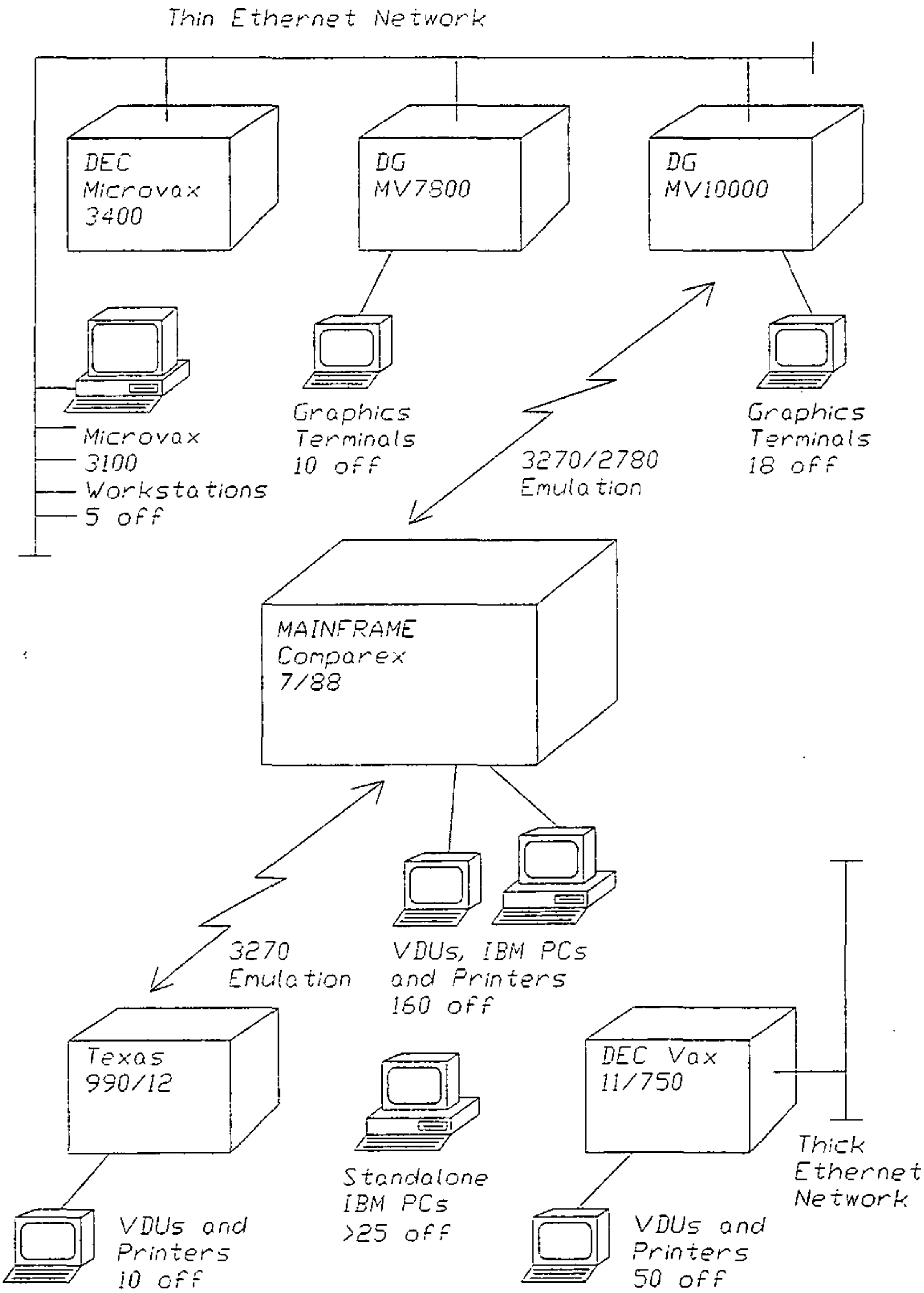
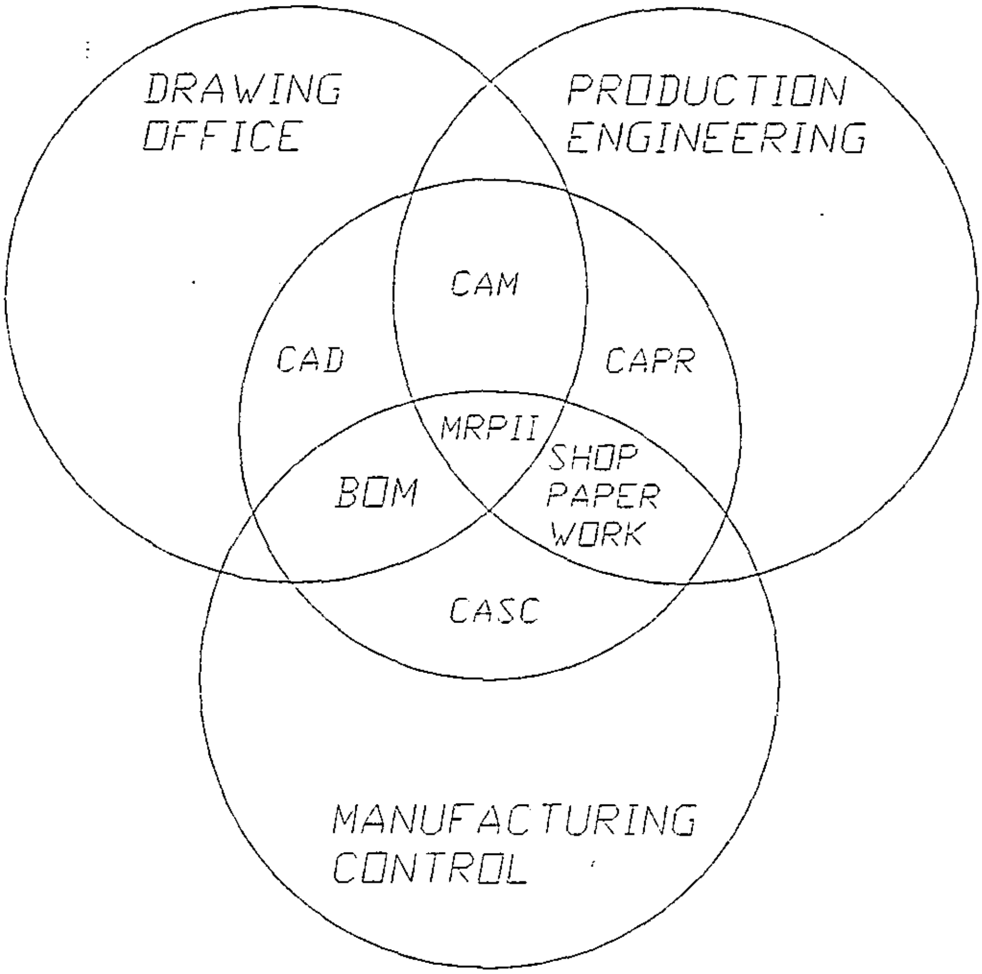


Figure 3.2 Core Manufacturing Systems Software



Legend:

CAD	Computer Aided Design (installed 1977)
CAM	Computer Aided Manufacture (installed 1977)
MRPII	Manufacturing Resource Planning (Cincom) (replaced ROSI installed 1974)
BOM	Bill of Materials (Cincom) (replaced BOM and RAPID installed 1971/1977)
CAPR	Computer Aided Planning and Ratefixing (installed 1977)
CASC	Computer Aided Shop Control (installed 1979)
[ROSI	Requisitioning]
[RAPID	Parts Lists]

[Based on Jackson 1983]

3.5 Central Manufacturing Control

As stated above the major information systems (with the exception of the financial ledgers and CADCAM) used within Rockwell PMC including manufacturing control are centred on the mainframe computer which holds the main manufacturing data base files. Much of this data is manipulated using routines which have been developed in house over a number of years to suit the way the company operates. All the programs for general user data enquiries and updates have been written to operate interactively using the IBM 3270 Teleprocessing environment Customer Inquiry Control System (CICS) [CICS] [Xephon 1988] wherever possible although some process functions are run in non interactive batch mode. When CICS is available over 150 terminals, including printers and some IBM compatible personal computers, can be used to interrogate the systems.

3.5.1 Systems in Use

Several changes have recently been made to the main MRP systems. These have involved replacing the existing systems, previously developed in house, by the introduction of a number of modules from the Control:Manufacturing software marketed by Cincom [Cincom UK Ltd.]. In particular the original Baker Perkins' developed software has been replaced by Cincom's Bill of Materials, BOM, (for RAPID), MRPII (for ROSI), Inventory Control and Purchasing and Product Costing modules. Interfaces have been produced to link between the new modules and the remaining older systems. Further implementation of Master Production Scheduling, Engineering Change and Shop Floor Control (for CASC) modules will be addressed in later phases of the project.

In addition to the impact of the change in the main MRP modules and BOM data base particular systems are of particular interest here:

A. Shop Paper Work

Shop floor control is dependent on a manufacturing paperwork system. The paperwork for each component needed for a requisitioned printing press sub-assembly is printed off by the mainframe during batch print runs when a contract for a given batch of the components is released for manufacture. This paperwork consists of a number of documents, mostly printed on card, relating to material and parts issue, working instructions and progress recording. Figure 3.3 shows examples of a Route Card and an operation ticket. The route card shows a summary of the operations involved for the particular component (further

Figure 3.3 Manufacturing Paperwork

ROUTE CARD | DRAWING No. 62413771I | WORKS ORDER No. 2340/007 | P.W.C. No. H 12210 | ROUTE CARD I

PART NAME: RAM CAM LEVER | BATCH QTY. 6 | ALLOCATIONS: H12159 6

FIRST MATERIAL ITEM: 6 OFF
1133-430 L 153
BLK HS ROD BS4360 GR43A
110 DIA

OP	GROUP	TOT TIME	START	FINISH	COMPLETED	QTY REC.	QTY PASS	QTY REJ	SCRAP/CO R.	SUB CONTRACTORS/INSPECTOR
			79075							
05	S079	0.43	79081	79081						
08	A52	1.43	79084	79084						
10	J20	1.62	79085	79085						
20	H02	5.26	79093	79094						
30	K01	4.16	79102	79103						
40	H02	2.00	79111	79111						
50	H70=	1.90	79114	79114						

79/06/14

(i) Route Card

SPECIFIED OPERATION | DRAWING No. 6238321F | WORKS ORDER No. 767/001/25 | P.W.C. No. P 89279 | OP START 77161 | OP COMP 77161

PART NAME: BRACKET
W.O. DATES 77 17 19 27
BATCH QTY 1 | OP. 70 | DEL TO. | GROUP E60

UNIT TIMES: OP. 0.85 SET 0.50
TOTAL SPEC. TIME 1.35
AMENDED TOTAL SPEC. TIME

OP No 60 GROUP E05

OPERATION DESCRIPTION
OPITZ CODE..
SET IN FIXTURE TOL 6787 AND DRILL THREE 18 DIA. DRILL AND REAM ONE 12H7 DIA. DRILL THREE 5.5 DIA. USING DRILL PLATE TOL 6786 DRILL AND TAP EIGHT M6 X 15 DEEP. DRILL AND CSK FOUR 5 DIA TO MARKING. SPOT FACE THREE HOLES TO 32 DIA

INSPECTION REPORT
QTY TO BE PAID FOR
QTY REJECTED OPERATOR ERROR
QTY REJECTED NOT OPERATOR'S ERROR
QTY CHKED. AND PASSED
PART FINISHED OTHER ERROR

ALLOWANCES

SIG	CODE	TIME
	0	
	0	
	0	
	0	
	0	

INSPECTOR'S SIGNATURE
GROUP TRANSFERRED TO ;C | 0 369
OR No 0 77/05/12 | MACHINE No ;0 | 0 370

BAR CODE TRANSLATION 23089279106005

(ii) Operation Ticket

operations are listed on extra cards as necessary) and is used to record the progress of the component on the shop floor. Each operation on the route has an operation ticket which contains specific details for the machine operator about the work required. These cards together with other 'service operation' tickets travel with the components as necessary. The route card is also accompanied by a Route Description Sheet as shown in Figure 3.4. This sheet lists all the relevent materials needed together with a complete description of all operations on the route.

B. Live Load , the Loadfile and CASC

The Live Load system provides a means of recording operation status changes, including for example operation completions and material and operation issues to the shopfloor, on the main work in progress file, the Loadfile. The system caters for real time update from terminal screen input information which is either keyed in by the operator or read from barcodes on the shop paperwork. A transaction logging facility is used to buffer input whenever the loadfile is unavailable for update.

Work to lists are printed out daily for the majority of the workcentres in the machine and plate shops. The priority of contracts on these work to lists is calculated according to the recorded completion of previous operations together with the due dates of the items involved.

In the machine shop group technology cell areas (described below) where parts move quickly from one operation to the next the printed lists soon get out of date. The Computer Aided Shop Control (CASC) system provides work to lists for many of the machine shop workcentres which are available as CICS enquiries on the progress/foremen office terminals, see Figure 3.5. The system works directly from an index into the loadfile using the calculated job priority. CASC also allows for an alternative method for direct update of the mainframe loadfile to the live load system.

C. CAPR

The Computer Aided Planning and Ratefixing (CAPR) system is used to plan and ratefix the routing and operation details required to produce a component or assembly which has been specified on the bill of materials. The system contains synthetic details for different types of machine tools and labour. It uses these

Figure 3.4 Route Description Sheet

```
ROUTE DESCRIPTION SHEET       W.O. 2340/009      PWC N 12210      6 OFF PAGE  1

RAM CAM LEVER                 PART NO.      6241377H

  PLANNED BY  CM 78.03.21     WEIGHT       0.000      OPITZ CODE 00000-00-000

         REF    QTY  . DRG/CODE/PATT                  DEL. TO   DIMENSIONS CLASS
                                DESCRIPTION            OP. GRP

    M     1      6        1133-430                    008   A52    L        153 S
                         BLK MS ROD BS4360 GR43A
                         110 DIA
                         *PRE-DRILL 57 MM DIA 0.36

    M     2      6        1151-320                    010   J20    L        204 S
                         MS PLATE BS4360-40A COLD                  W        103
                         FLANGING QUALITY 12.5 THK

    M     3     12        1151-320                    010   J20    L        152 S
                         MS PLATE BS4360-40A COLD                  W        103
                         FLANGING QUALITY 12.5 THK

   OPN CENTRE        OPERATION DESCRIPTION                      TIME ALLOWED

    05   S02                                                     OP.     0.06
               CUT REF 1 SQ TO LENGTH -SAW D-                    SET     0.07

    08   A52                                                     OP.     0.18
               FACE EACH END TO 148 M/M LENGTH AND               SET     0.35
               TURN TO 109 M/M DIA REF 1

    10   J20                                                     OP.     0.25
               MS.PLATE 12.5.MM.THICK.CUT PLATES.REF.2           SET     0.12
               AND 3 TO LINE DRG TEMPS 6241377H/F 2 AT
               A TIME

    20   H02                                                     OP.     0.83
               DRESS AND FLATTEN PLATES POSITION AND             SET     0.20
```

Figure 3.5 CASC Work to List

```
                WORK TO LIST FOR GP44 LATHE SHAFT HEID CNC  RAC   PAGE   1 OF   1
QUEUED WORK.PLEASE SELECT NEXT ACTION
PWC NO. P.R  NC QTY DESCRIPTION      OP  PART NUMBER P.WCEN    SCRATCH PAD
R 01903  710 Y    1 LAYSHAFT G44 940  20      6488079J F10Q#
X304142  554 N    1 STUB SHAFT (DRIV  20      6484339G F10Q#WTG,TAPE F16 F23
X340575  477 N    2 PAN ROLLER        30      6289110F F11Q#
M 93050  223 Y   16 FILLING BAR - 96  30      6231476A F10Q#MAT.AV.IN MAT.CTRE
M 80671  195 Y    7 RUBBER ROLL STOC  20      39981183 F10Q#MAT.AV.IN MAT.CTRE
M 88230  188 Y    2 RUBBER ROLL STOC  20      39981183 F10Q#MAT.AV.IN MAT.CTRE
X346424  184 Y    1 SHAFT (BRUSH ROL  20      6475246D F10Q#
X346440  183 Y    1 HORIZ DRIVE SHAF  30      6475368A F11Q#MAT.AV.IN MAT.CTRE
X345111  155 Y    2 IDLER ROLL-NYLON  30      6432671F F11Q#MAT.AV.IN MAT.CTRE




NEXT ACTION   PAGE     (1) ABORT  (2) PRINT  (3) UPDATE
```

synthetics to calculate the operation times and generate operation description information from suitable planning detail input by the production engineer.

D. NCTP

The Numerical Control Tape Programming (NCTP) system is part of the CAM facility. It is a simple text editing system used by the production engineers for the creation of the machine code level information needed by the NC workcentres. This system is generally used only for those workcentres where the NC programs are straightforward and do not involve complex machining sequences, e.g. for point to point drilling and simple lathe work, and allows for the storage of the NC control programs in mainframe database files. The system is complemented by the CAM modules available within the CAD system which are used for the more complex machining centre work.

3.5.2 System Downtime

Although many of the mainframe systems can be used interactively though CICS, as described above the use of a number of batch routines is still necessary for certain file housekeeping and update routines. These batch routines often need to access files which are also used by CICS. Sharing files for update between two different systems at the same time, e.g. batch and CICS, could cause severe data integrity problems and so CICS is taken off line after each working day. During weekdays the CICS system is shut down at 6.00pm until some time after 10.00pm at the earliest and the manufacturing systems are usually not available for update until about 6.30 a.m.. Many systems are also unavailable throughout the weekend.

The constraint of mainframe system downtime creates a major problem for manufacturing personnel many of whom work outside the 'system availability window'. This constraint has had a major influence on the project work reported in this thesis.

3.6 Non Mainframe Based Computer Systems

The minicomputers and IBM compatible personal computers shown in Figure 3.1 are used for other activites which support the mainframe facilities. These include CADCAM, the financial ledgers, press control software development and personal user systems.

3.6.1 Computer Aided Design and Manufacturing

Two DG Minicomputers and a DEC Microvax supporting a total of 33 design stations, five of which are microvax workstations, are used exclusively for the McDonnell Douglas Unigraphics CADCAM software [McDonnell Douglas] and associated routines. Some of these associated routines have been written in house for particular applications outside the scope of the Unigraphics software. Most new design is done using Unigraphics so that the majority of the part drawings are available through the system, although because of the amount of file space needed by the large number of live data files data is stored on magnetic tape if not in immediate use.

The MV10000 minicomputer available at the outset of this research was joined by the MV7800 in 1988 and the 6 Microvax minicomputers in 1989. All of these minicomputers have been linked together through an Ethernet network and using Xodiac [Xodiac], Decnet [Networks 1989] and TCP/IP [Fusion] [TCP] protocols.

Part programs for the larger CNC machines and/or more complex parts are produced using the CAM facility on the Unigraphics system and not using the mainframe NC editor as mentioned earlier. These NC programs have then traditionally been transferred to the machines on the shop floor using paper tapes.

3.6.2 Finance Ledgers and Maintenance Management

The Texas minicomputer is used to run the company accounting systems providing Purchase, Sales and Nominal Ledgers. A plant maintenance system covering plant records and maintenance costing is also run on this machine.

The computer is linked through to the mainframe with 3270 emulation software using a modem connection. This allows any terminal on the Texas computer to emulate a Mainframe 3270 screen and thus provides data access facilities.

3.6.3 Press Control Systems Software Development

The Vax 11/750 Minicomputer is used for the development of software for the control systems of manufactured printing press products and for the programming and testing of microelectronic equipment. Many of Baker Perkins customers have expressed a preference for DEC equipment for their systems over the years.

A thick ethernet 'backbone' cable has been installed to link the Vax 11/750, two terminal servers and two Tektronix microprocessor emulators for press control software testing and debugging.

3.6.4 Personal User Software

IBM Personal Computers (PCs) and compatible microcomputers are used extensively within PMC. The majority of these are used for off the shelf packaged software such as 'Wordstar' for word processing, 'Symphony' for spreadsheet and 'DBase' for data base applications.

3.6.5 Network Links between Computer Systems

Prior to this research the only links between different computers were point to point. No 'networks' were installed. However 3270 emulation has been used on IBM PCs and compatible computers, as well as on the Texas minicomputer, to allow for standard CICS enquiries. File transfer software is also used to pass data between the PCs and the mainframe. Terminal emulation and file transfer software are also available for PCs connected to the DEC VAX and DG minicomputers.

During the early part of 1989 ethernet networks were installed on the VAX system and the CADCAM system computers to improve information transfer mechanisms in line with the developing CIM initiative involved in this research.

3.7 Machine Shop Floor Layout

Since the main focus of the project work reported in this thesis relates to the control of manufacturing in the machine shop areas some additional background on shop floor layout is reported here. The Rockwell PMC machine shop has traditionally been laid out as an engineering job shop where machines are grouped and located according to their function, e.g. drills in one bay, lathes in another. However this approach has been changing over a number of years to one based on machining cells using group technology (GT) principles. The GT approach is more favourable for the kind of part manufacture used within PMC and improves work flow through the shop. The disc and shaft cells were installed during the 1970s.

Several GT cells are now in operation although there are still a number of bays laid out in the job shop manner. The cells manufacture shafts, discs, cylinders, gears, sideframes and link components. A mixture of CNC, NC and manual machines is involved. The majority of components which flow through these cells enter as raw material and leave as finished components. The manufacturing layout is shown schematically in Figure 3.6.

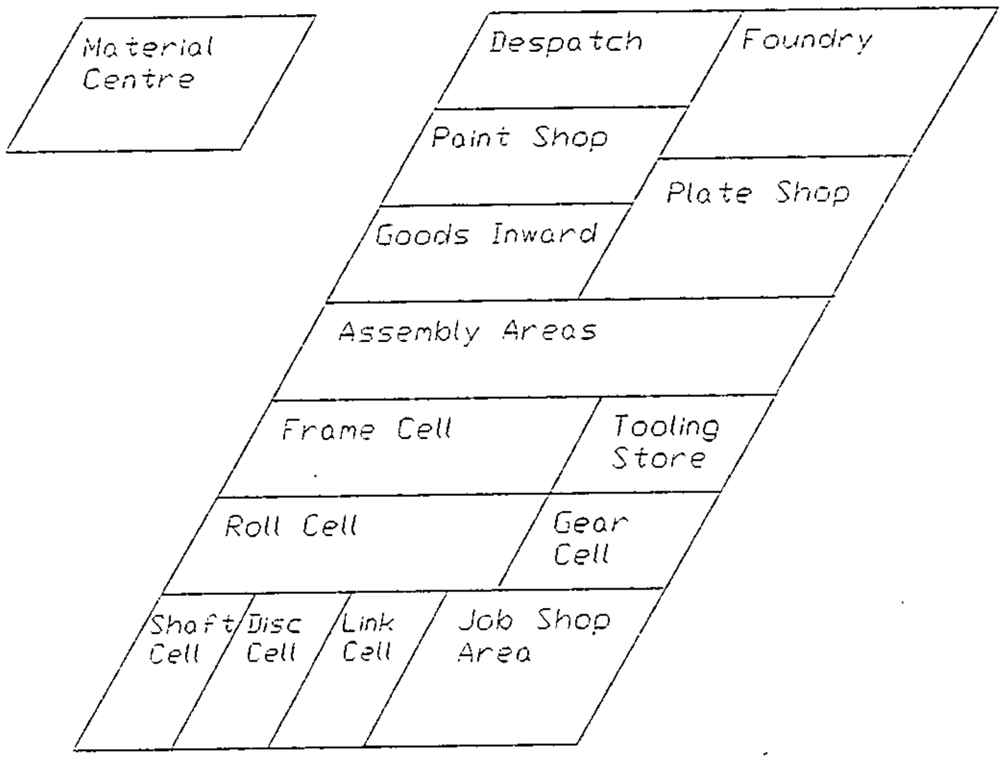
3.8 Summary

This chapter has introduced some of the background information which is applicable to the work which forms the basis for this research. In particular the need for further development of some of the manufacturing control systems has been indicated.

The chapter has shown that Rockwell PMC has been using computer systems to improve manufacturing for a considerable length of time. Many of these computer systems have been produced 'in house' and are specific to the company. The computer systems used have been reviewed with particular regard to manufacturing software functionality. This review has identified certain constraints to CIM implementation realised because of the existing systems and especially the limitations of these systems with regard to their unavailability to the user during particular periods. These constraints are representative of those faced by other companies within the Discrete Engineering sector of manufacturing.

The constraints identified have led to consideration of the need for a hierarchical system to improve manufacturing control. The introduction of Cell and Machine Management Systems with localised functionality has been identified as a possible solution particularly for the group technology cell areas.

Figure 3.6 Manufacturing Facility Layout



CHAPTER 4

Machine Management System Options

4.1 Introduction

The previous chapter has introduced some of the general background considerations which led to the proposal by Rockwell PMC management, prior to commencement of this research, for the implementation of a hierarchical computer-based manufacturing control system which would be formed by extending the existing computer system facilities. The investigations undertaken by company personnel had suggested the possible implementation of Cell and Machine Level Management Systems.

The major impetus behind this proposed hierarchical approach was the need for shop floor independence from mainframe computer downtime. As stated above a number of the mainframe routines are performed by non-interactive batch routines and during the processing time involved the mainframe enquiry system is made unavailable to the users to preserve data integrity. The two shift system worked by the factory floor personnel, together with potential overtime working, means that shop floor systems need to be available,for use by the cell supervisor and operators for up to 22 hrs in 24.

In view of the large variety of parts going through the machine shop the company's senior management had already decided that automation in the 'FMS' sense would not be viable nor cost effective and had therefore adopted a group technology approach to component manufacture. It was considered that the implementation of 'FMS without unnecessary automation', where the operator was preserved as the 'flexible' part of the manufacturing system, would provide 'pareto-like' results so that '80% of the benefits of FMS could be achieved for 10% of the cost'. The facility should involve DNC links to the NC machine tools, control of work flow and 'cell specific' functions to aid the decision process (as available in an FMS) but material handling would be left to the operator in addition to the actual control of the machine tool itself.

This chapter describes further investigations carried out as a part of this research to identify the scope of the proposed hierarchical control system. The existing shop paperwork and computerised work in progress reporting systems are considered in order to identify the specific functionality needed for localised control in the machining cell areas and an outline system specification is presented. Particular constraints to system implementation are also identified and the possible system solutions discussed.

4.2 Existing Manufacturing Control Systems

In order to produce a suitable specification for the proposed systems it was necessary to investigate the inputs, outputs and interactions of the various shop floor facilities involved in the control of work flow around the machine shop with particular reference to the existing paperwork systems. Figure 4.1. illustrates the interactions between shop floor functions involved in the manufacture of a component.

The basic functions involved in manufacturing control at Rockwell PMC are: the Central Progress Office which is effectively the instigator of all component orders on the machine shop as appropriate for press assembly builds; the Cell Supervisor who is responsible for the control of all machines in his area; the Machines involved in the actual component manufacture and the Material Centre for cutting and delivery of raw material together with the Tooling Store for presetting and delivery of tooling, jigs and fixtures as appropriate. Each of these functions is obviously also fed by other supporting departments such as Design and Production Engineering.

Figure 4.2 shows the data flow which is involved between the control functions. This diagram illustrates how the mainframe data files are used to store and distribute the necessary manufacturing information between the functions and in particular the use of the Loadfile, or work in progress file, to handle priority constraints.

For the purpose of this work the targetted functions suggested for the possible implementation of systems were 'Cell Control' and 'Machine Control' and therefore these functions are described further.

4.2.1 Cell Control

The information flow to each machine is 'channelled' via the cell supervisor's progress office. The operation tickets provided for the machine operators by the shop paperwork system are distributed to the appropriate progress office where they are stored until the material, drawings etc. become available for the machining operation. The cell supervisor is responsible for checking that all the

Figure 4.1 Control Functions Interaction

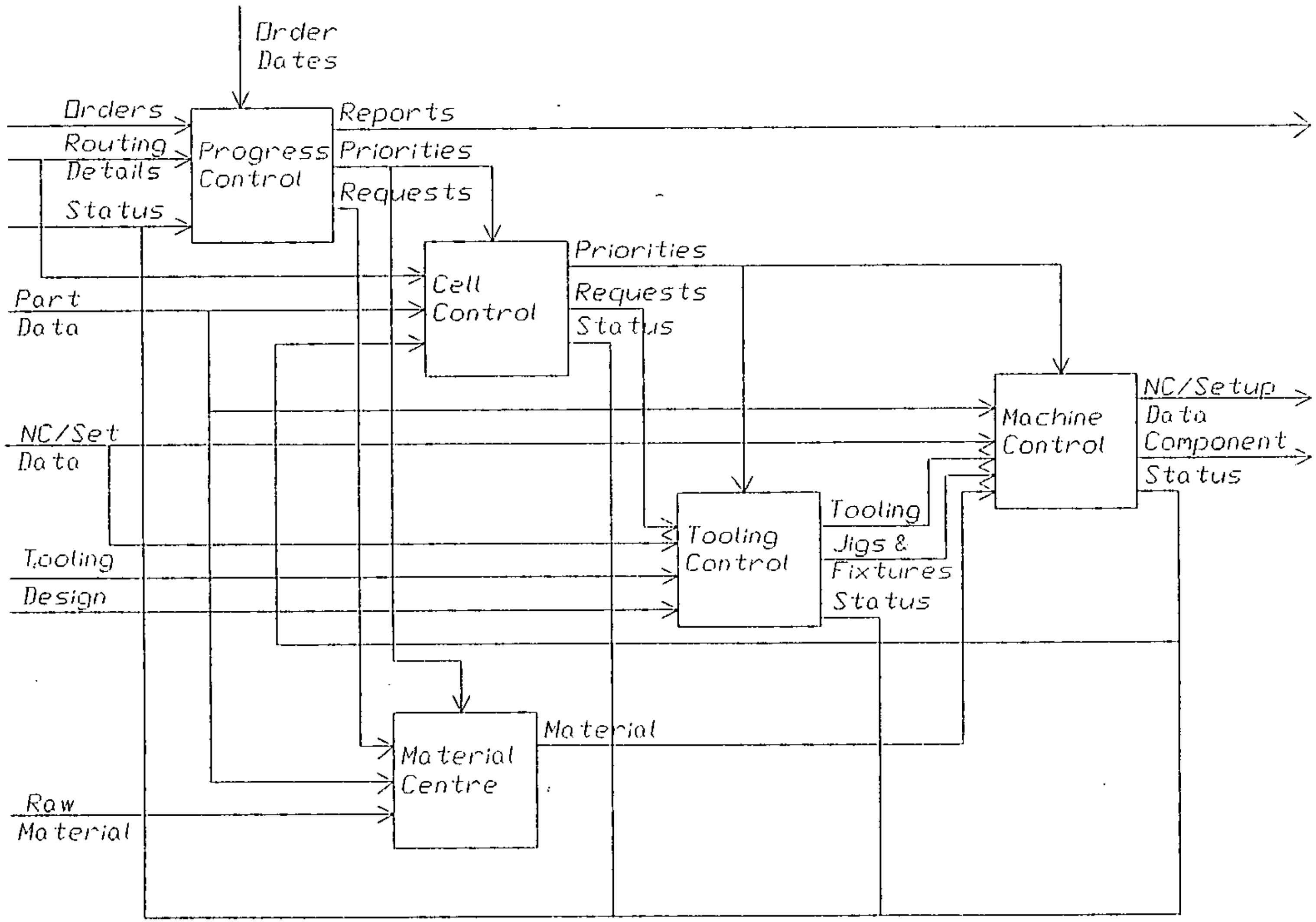
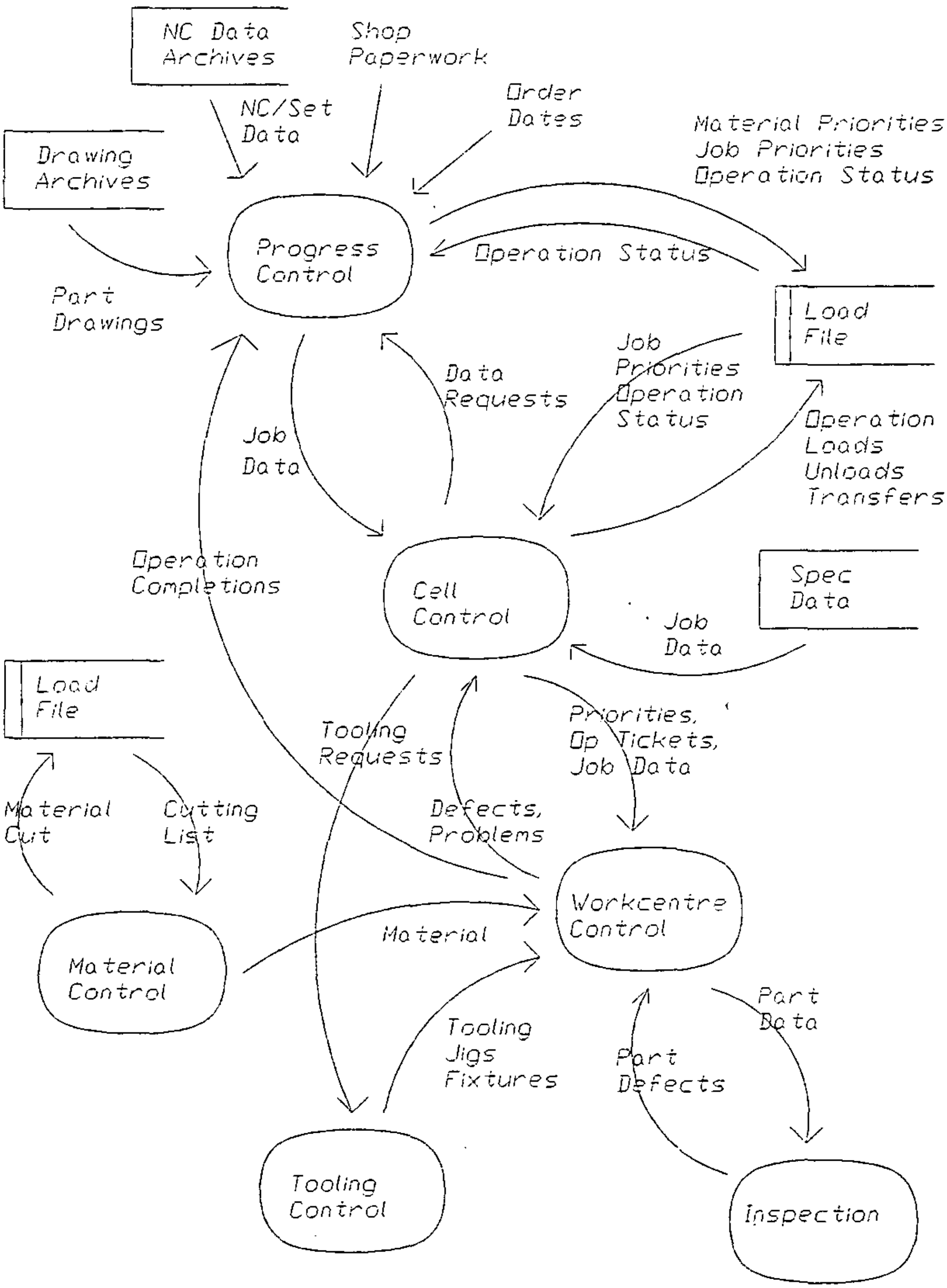


Figure 4.2 Data Flow Between Control Functions



inputs needed at the machine for a given operation are available, requesting special items such as NC tapes, tools, fixtures etc. as necessary.

The supervisor is also responsible for loading each job onto the relevant machine according to priorities displayed on the work to lists as calculated by the mainframe systems. He ensures that jobs move to the machines in the correct sequence and updates the mainframe Loadfile as required. In practice, in the cells, operations are signalled as loaded to the machine by the cell supervisor but signalled as completed by central progress staff when tickets are collected at specified times throughout the day. This can lead to a delay in reporting the movement of work around the cell. Although these delays are measured in hours rather than days, they are still too long for the kind of work and information flow management needed in the cells.

4.2.2 Machine Control

The machine operator is responsible for the actual manufacture of each component according to the priorities assigned by the cell supervisor. He uses the drawing and operation ticket to determine the work which must be performed on the raw material. He may also need to use set up information, jigs, fixtures or special tools. In the case of an NC controlled machine NC programs are necessary and cutting tool offset data may also be required.

The machine operator has no direct involvement in the use of the manufacturing control systems on the mainframe. He reports job completions by handing in the operation ticket at the appropriate time. In the cells the machine operator is also usually responsible for the inspection of the finished components working with quality inspectors and cell supervisors as necessary to report defects.

4.3 Specification

The investigations made during the research into the existing shop paperwork and computerised work in progress reporting systems supported the view that a hierarchical system is appropriate for the control of the Rockwell PMC machine shop. It was considered that the implementation of such systems would allow for increased overall functionality, particularly for the cell supervisors and operators, for example relieving them of some of the more tedious aspects of their work.

The work also indicated the need for a three layer hierachical system thus demonstrating many similarities to the ISO hierarchy. A comparison is shown in

Figure 4.3. This hierarchy would consist of 'Factory Management', 'Cell Management' and 'Machine Management' level systems broadly comparable to the ISO Factory, Cell and Workstation control levels.

The functionality required for the Factory Management System (F.M.S.) is already largely in place on the mainframe computer, in the form of many existing systems as described previously. Some changes are being made to the specific functionality of these systems, as also noted earlier. There is no particular reason why the basic functionality of these systems should be altered, although the way the functions are used may well be affected by the new systems. In addition many of the functions appropriate to a 'Machine Shop' level control system, as suggested by the work at NIST, are also incorporated in the mainframe systems and so such a level is not yet seen to be necessary. Further work in the evolution of the cell to factory level system interface following on from this research is expected to provide an indication of any need for a separate shop level system.

Therefore the task of this research work involved building suitable Cell and Machine Management Systems which provide 'follow on' functionality to the evolving factory level MRP systems and adding extra functionality to the factory level only where necessary. It was considered that the implementation of cell systems would not be restricted to machining cells alone but would also be applied to other support functions such as material control, nc programming, tooling and maintenance. See Figure 4.4.

A draft outline system specification ('The Machine Shop Control System', see Appendix A) was produced early in the project which was then used to assess possible alternative solutions. This specification was purposely left general in scope rather than trying to make it definitive because there was a reluctance within the company to specify the exact system requirements. The specification produced described the general functionality of the Cell and Machine Management Systems required but did not attempt to define in detail how this functionality might be implemented.

4.3.1 Cell Management System Functionality

The Cell Management System (C.M.S.) is responsible for controlling the flow of work within a given cell of machines by providing information to the individual Machine Management Systems as requested. The system needs to be independent of the factory level for reasonable periods of time because of the

Figure 4.3 Three Layer Systems Hierarchy

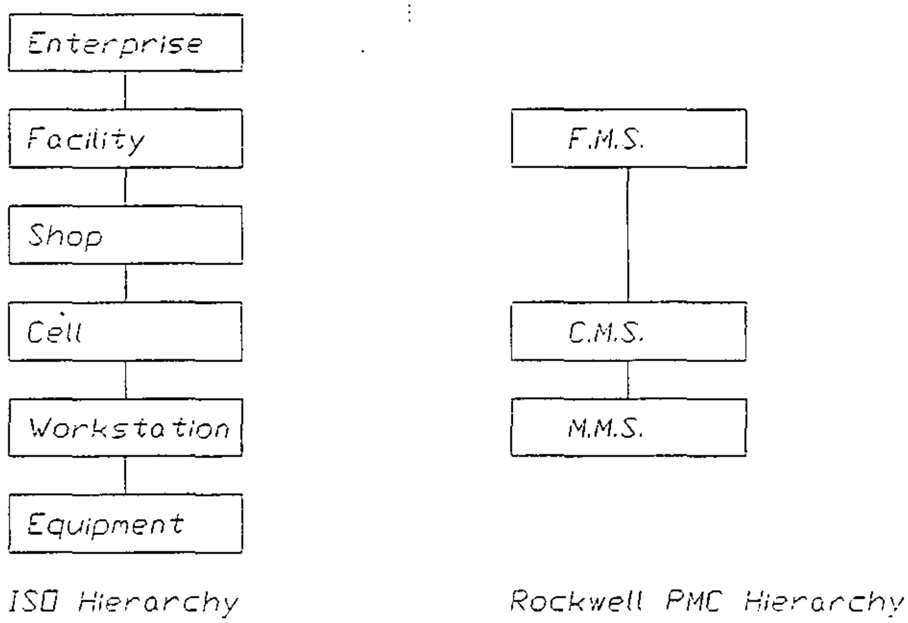
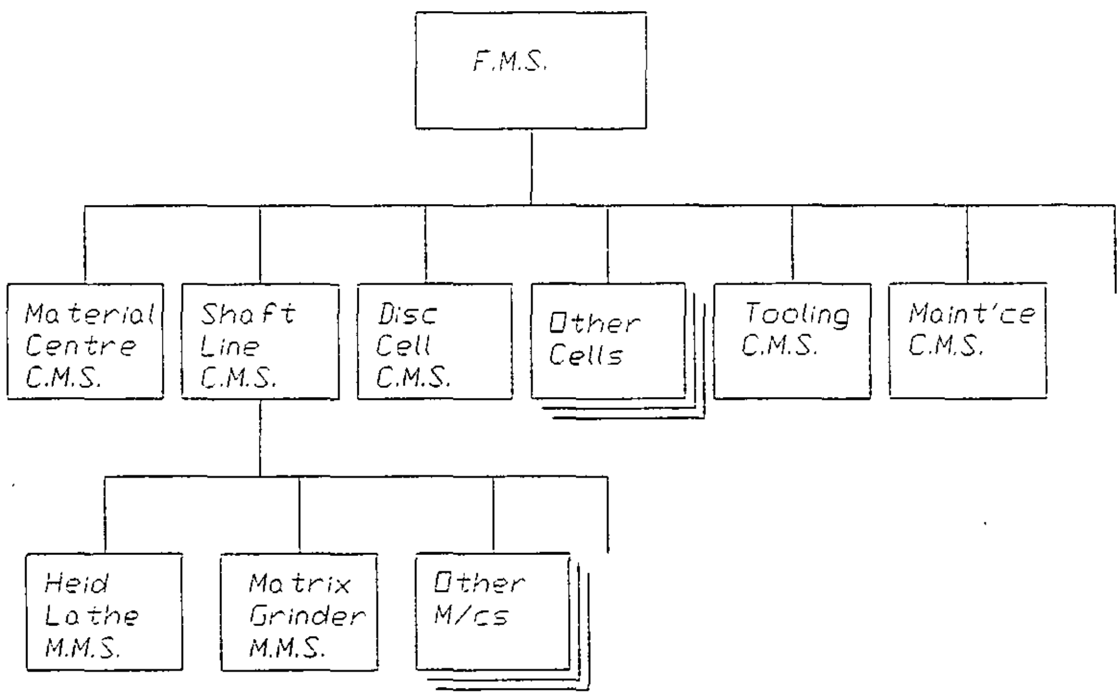


Figure 4.4 Expanded Rockwell PMC Control Hierarchy



computer downtime problems discussed earlier. Hence the C.M.S. needs its own independent data store as well as its own functionality. The data store is required to hold all the information needed for each job operation to be performed by the cell machines over the given time period.

The C.M.S. needs to communicate with the factory system in order to extract all the necessary information to cover a given time period. It was envisaged that the C.M.S. should be able to hold enough information to maintain independency from the factory level for a period of at least one or two shifts. The C.M.S. needs to report all job operation progress back into the factory level system files together with any other information required. The C.M.S. also needs to communicate with other systems such as Tool Management to specify any jigs, fixtures or tooling requirements, Maintenance Management for service to machine breakdowns and NC programming for part program data control, see Figure 4.5.

Particular application functions envisaged for the C.M.S. were the provision for 'availability flags' and job scheduling.

A. Availability Flags

The C.M.S. needs to provide a number of 'availability' checks so that a sure indicator can be given to the cell supervisor that a particular job can be released into the cell i.e. that all necessary data and physical items such as material, tooling, jigs, nc information etc. are available within the cell. This relieves the cell supervisor of the 'tedious' responsibility for vetting certain constraints which can be readily identified by the system.

B. Job Scheduling

The work to lists provided by the factory level system may need to be processed by the C.M.S. to provide schedules of work flow through the cell or simple 'pick lists' which can optimise important parameters local to the particular cell e.g. the optimum utilisation of a bottleneck machine. This process will use the availability flags previously discussed and will help the cell supervisor by taking account of any restrictions automatically. A suitable output format (probably graphical) is needed for the cell supervisor to show how any particular job loading strategy may affect cell performance. The function would only be used to assist the supervisor to ensure efficient flow of work through the cell. The supervisor would still have the 'final say'. Figure 4.6 illustrates a possible scheme for the use of a scheduling

Figure 4.5 Cell Management Concept

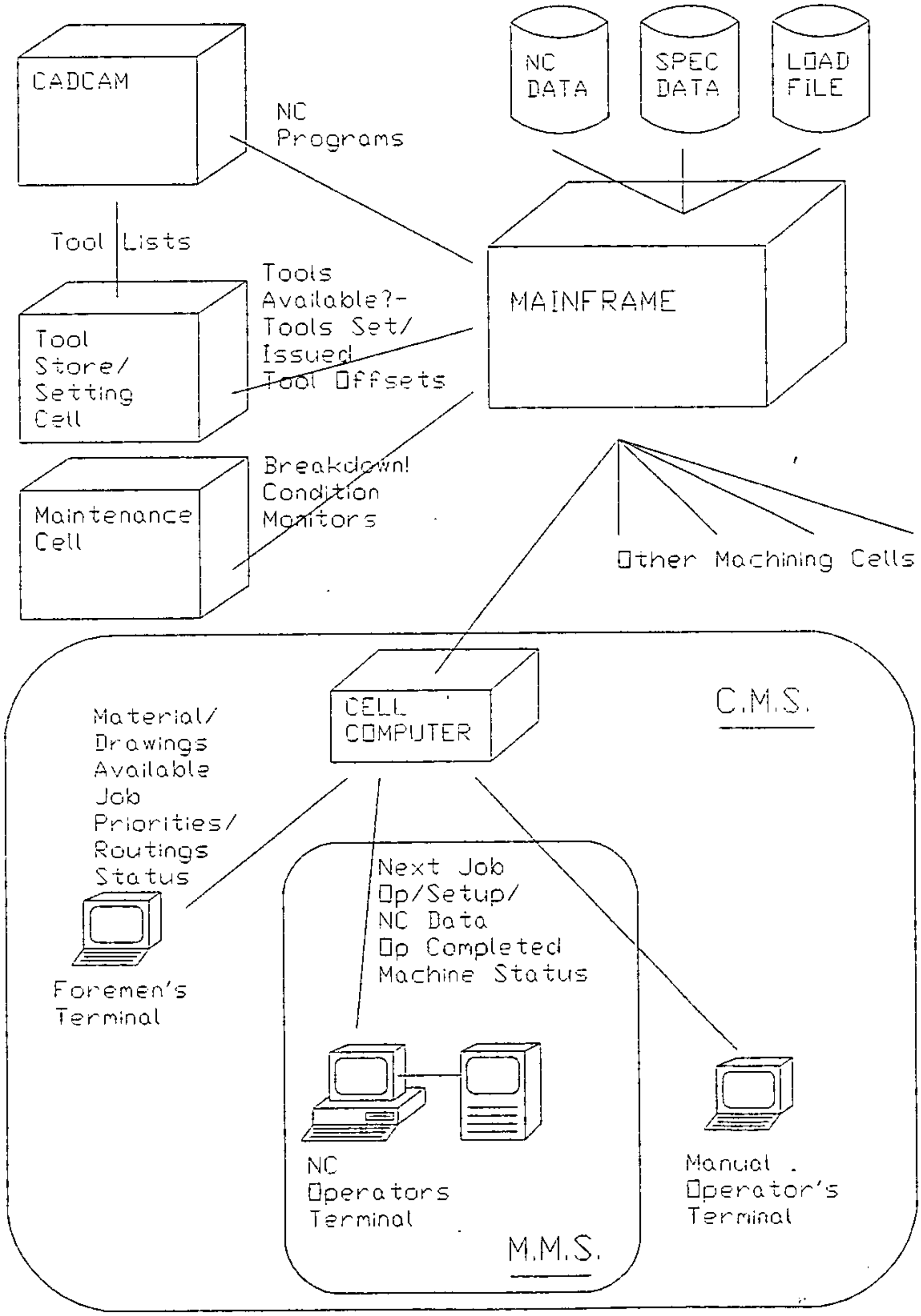
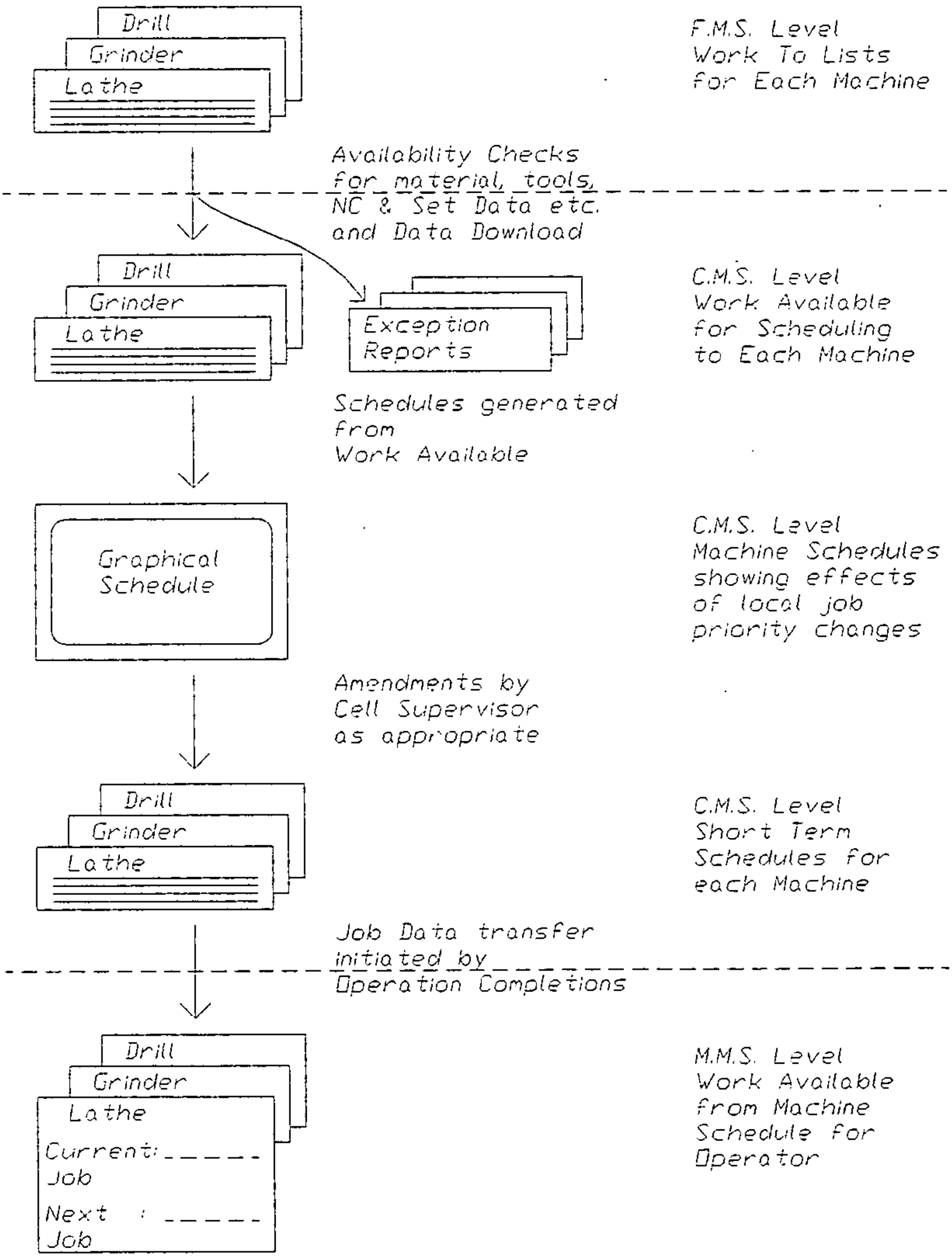


Figure 4.6 Possible Scheduling Scheme



system based on the existing work to lists and incorporating the use of availability flags.

4.3.2 Machine Management System Functionality

The Machine Management System (M.M.S.) is responsible for controlling work at a given machine by providing the operator with the information he needs to do each job. Machine in this context is used to imply nc machine, manual machine or simple workbench as appropriate i.e. the facility used to progress a job operation. The M.M.S. needs some data independence from the cell system for resilience.

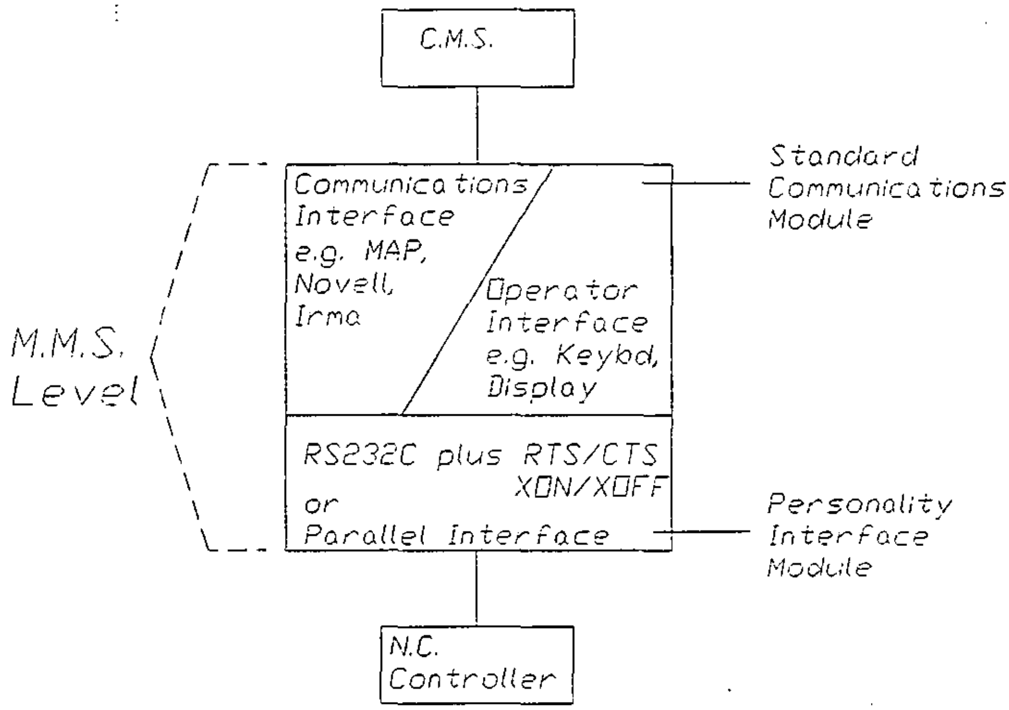
The device used for the M.M.S. needs to provide a suitable terminal display and keyboard for use by the operator (standard 80 by 25 vdu display, and alphanumeric keyboard facilities were envisaged), together with transfer of NC data and machine monitoring capability as appropriate. It was proposed that an 'intelligent' device incorporating a two layer communications strategy would be required as shown in Figure 4.7. The upper layer needs to provide a standard communications module for interaction with the next higher level in the system hierarchy (i.e. the cell system) and the operator, whilst the lower layer provides a 'personality module' for interaction with any particular machine. This arrangement will serve to minimise the changes which need to be made when a new machine is linked into the system.

The M.M.S. application needs to provide certain operator controlled functions including logon/logoff; job operation priority assignment; job operation status reporting; downtime problem reporting; operation data information displays and printouts and nc data transfers to the machine controller. Any given subset of these application functions would be used as appropriate by any operator using the system. At first only the transfer of textual data displays were considered but graphical data displays have since proved particularly useful in some circumstances.

4.3.3 Constraints

The evolution of the cell and machine levels systems were subject to a number of constraints imposed by existing company standards, especially in terms of the hardware and software used. The high rate of change in the computer industry was also an important factor which needed to be taken into consideration. Each of these constraints is likely to be indicative of the problems faced in CIM implementation in other areas of the business and in other companies.

Figure 4.7 Two Layer Communications Strategy



A. Hardware Standards

Since Rockwell PMC is predominantly an 'IBM mainframe site' the preferred choice of computer hardware for any systems implementation is IBM. The favoured route for system evolution was to use software running on the mainframe itself which could then interact easily with existing factory level systems. The next best alternative was the use of other IBM computers such as IBM minicomputers or IBM Personal Computers (PCs). Experience with the use of IBM PCs was available in house but there was doubt over whether these computers were suitable for the shop floor environment. Experience of DEC systems made the use of DEC computers another possibility. The use of any other vendors equipment, including Texas and Data General, was seen as a potential management problem by the main computer department.

B. Software Standards

Mainframe software for systems created in house has been predominantly written in the IBM programming language PL1 [PL1] to operate in the CICS 3270 protocol teleprocessing environment. However with the recent introduction of Cincom's Control Manufacturing Software programs are now being coded in

Cobol for compatibility. The other main programming software available is Job Control Language (JCL) [RJE] which is used for all jobs submitted for processing by the main operating system especially for batch work. The main system which is used for linking to external systems, particularly for file transfer applications, involves the 2780/3780 Remote Job Entry [RJE] protocols which allow for transfer of JCL programs into the mainframe job spooler queue. Therefore integration with the mainframe needs to be via 3270 or 2780 protocol emulators. Where data interaction is necessary over a short time scale 3270 emulation is preferable.

No programming languages were standard for the IBM PC environment at the outset of the work. The only compilable language readily available for the PC was IBM Basic. Currently Dbase has become the preferred language for file intensive work while cobol, basic, pascal and c are all used for programming as appropriate.

4.4 Alternative System Solutions

There were two basic approaches available for system implementation:

(i) Buy in systems from any available 'off the shelf' range;

(ii) Build systems using commercially available or special purpose hardware and use software written 'in house'.

The company management considered that the implementation should follow a pilot scheme approach. A single machine system giving simple DNC functions would first be installed. This would need to integrate directly with the factory level, i.e. the mainframe computer, for information transfer. Expansion of these functions to form the machine management level would then be followed by the insertion of the cell management system level at which time the interfaces at the factory and machine level systems would need to be altered.

4.4.1 'Off the Shelf'

Initial contact with external suppliers for suitable 'off the shelf' packages was a long and drawn out process. This was principally because there were few companies which had implemented the kind of control system that Rockwell PMC were looking for, although a number of larger companies had FMS implementations. Indications were that Rockwell PMC was using up to date technology in terms of computerised management systems and that only a relatively small number of other companies were known to have systems with the same degree of sophistication especially in terms of work flow control and progress recording.

Initial enquiries were made with eighteen possible suppliers of DNC/M.M.S. packages during early 1984. The solutions offered varied from simple DNC interface units through to 'bespoke' computer systems software. The merits of each solution were judged with particular regard to their suitability to evolve from a single machine DNC system through to the full Cell Management System. Out of these possible suppliers thirteen were rejected fairly quickly.

Hence five suppliers remained who could potentially offer a reasonable part of the M.M.S. required by the company. Three of these were offering software packages together with particular hardware devices specifically for the control of work on NC machines: BEC; GEC and Tangram. The other two were computer manufacturers who offered existing software modules which could be 'tailored': DEC and Honeywell. The offered solutions are compared against each other and a possible in house solution later, see Figure 4.8.

A series of site visits was made to assess the potential of each offering. In view of the computer hardware standards preferred by the company Honeywell were not considered a good choice, although their offering was fairly comprehensive. Both BEC and GEC expressed an interest in the possibility of converting their software to run on DEC computer equipment which, although not preferred, was considered acceptable by the company management.

4.4.2 'In House'

Because Rockwell PMC began to use computers early in the 1960's when few manufacturing systems, with limited functionality, were available in the marketplace, the company has a history of developing its own bespoke software. This has meant that the manufacturing control systems which have evolved are unique in structure and have been written to suit specific company objectives. It was apparent at an early stage that it may prove difficult to integrate any 'bought in' package with the existing mainframe systems. Hence the option of also developing the M.M.S. 'in house' was relatively attractive.

The main problem seen with this approach was choosing a machine level system, with suitable operator interface, which could be linked easily with both the mainframe and the production machines whilst being suitable for the shopfloor environment. A microcomputer seemed the most appropriate choice as this is able to provide the kind of intelligent dual level interface which was considered necessary. However there was still the choice between purpose built microcomputers and commercially available units. Of the latter the IBM PC, which was fast becoming a de facto standard since its release, was the most obvious choice especially in view of company hardware standards.

A. Purpose Built Microcomputers

Baker Perkins had already been involved in the design of a system, purpose built in house, which was being used for the control of Bakery products.The equipment was modular utilising a standard card cage in which suitable microprocessor and function cards could be installed. Other suppliers also offered to produce units of this kind made to our specification. This approach was considered to be a possible solution for the machine interface unit from the functionality point of view but, as non standard items, there was doubt over the possible lifetime of such products.

B. IBM Personal Computer

The IBM PC was seen as a particularly appropriate choice for the machine level system. The PC offered suitable screen and keyboard. Communication software packages were also already available which would allow the PC to link to CICS in the IBM mainframe. The IRMA [IRMA 1989] 3270 emulation card and software, which was being used in the company for other applications, allows the PC to be switched between operation as an independent microcomputer and a mainframe terminal by a simple keypress. The emulation software also allows for the creation of suitable, although potentially specific, interfacing software with the minimum of effort by providing a number of general purpose subroutines written in Basic. One of these interface cards could therefore provide the standard communications module for the link to the mainframe system. Hence specific software would only need to be created for the 'personality module' for the machine involved. The form of the PC also ensures that the IRMA interface could easily be changed for a suitable alternative when the cell level system was inserted in the hierarchy. The only concern with the PC was whether it would stand up to the factory environment. The early PCs available at the time were meant for use on the 'office desk'. However portable PCs were starting to be produced. These included a number of ruggedised units which could prove quite suitable.

Of the two alternatives for possible 'in house' system implementation the IBM PC approach was seen as more appropriate for several reasons including:

(i) It was available 'off the shelf' and relatively cheaper;

(ii) As a 'de facto' standard it offered a consistent long term future;

(iii) It fitted in with company standards;

(iv)Suitable communications software was already available;

(v) Software programming would be straightforward.

4.4.3 Alternative Solution Chosen

Figure 4.8 shows a comparison between the 'bought in' and 'in house' alternative solutions for the implementation of a pilot scheme approach. The basic functionality of each solution is compared together with specific hardware to be used and the incremental implementation cost of a single machine system.

The comparison indicates that the incremental cost of implementation of a pilot scheme 'in house' using an IBM PC would be considerably less compared to 'bought in' solutions. (The high cost of the Honeywell system resulted from the extensive facilities that were being offered from the outset.) Each possible solution would also require an interface into the existing mainframe systems involving comparable amounts of work. In addition none of the suppliers seemed to be able to offer a solution which covered all the aspects considered necessary for the longer term evolution of the system. Other factors which resulted in the decision to proceed with 'in house' implementation included the difficulty of producing a full specification of the system, as required by any vendor and the potential difficulty of integrating 'bought in' packages into existing systems. The 'in house' solution also offered scope for the refinement of concepts leading to a more controllable upgrade path and the potential for 100% satisfaction for the company.

4.5 Summary

This chapter has considered the implications of the application of a three layer hierarchical system for the control of the Rockwell PMC machine shop as suggested by company management prior to this research. Investigations carried out as part of this research into the existing control methods based on a shop paperwork system support the view that this hierarchical system is appropriate.

This work has produced a basic specification for the functionality of Cell and Machine Management Systems which will support the existing functions of the

Figure 4.8 Implementation Costs of DNC/ M.M.S. Pilot Schemes *

	Tangram	BEC	GEC	Honeywell	In House
Hardware:					
DNC Computer	PDP 11/23	Burroughs	GEC	DPS	IBM PC **
	(Existing)	B26	4150	6/ 45	
M/F Interface	2780 / 3270	2780	2780	2780	3270
Operator Terminal	M.I.T.	M.I.T.	VDU	VDU	IBM PC **
Screen	40 x 12	80 x 25	80 x 25	80 x 25	80 x 25
Keyboard	'ABC'	'Qwerty'	'Qwerty'	'Qwerty'	'Qwerty'
Software:	Proprietary	Proprietary	Proprietary	Proprietary	In House
M/F Interface	Required	Required	Required	Required	Required
Functionality for					
Operator:					
Jobs available	One in	One in	Many in	Many in	Many in
	MIT	MIT	Mini	Mini	PC
NC Data	Yes	Yes	Yes	Yes	Yes
Mfg Data	Yes	Proposed	No	No	Yes
Status Data	Yes	No	No	Yes	Yes
Shop Messages	No	No	No	No	Yes
NC Edits	Yes	Yes	Possible	Possible	Possible
M/c Monitor	Yes	Proposed	No	No	Possible
Graphical	No	No	Yes	No	Possible
Scheduler					
Pilot Scheme Cost	£17500	£22450	£25700	£130000	£10000**

* Costs given at 1985 Price Levels

** A single IBM PC would act as both the operator terminal and the DNC System Computer. The implementation cost includes the cost of a second PC which can be used as a replacement in the event of a hardware failure.

Factory Management System on the mainframe computer. This research work indicates a minimal requirement for change to be made to the Factory System other than the changes already being made to the main MRP system modules. The specification calls for 'information control' rather than 'machine control' thus taking account of the human aspects of CIM implementation wherever possible and providing for the enhancement of the operator's role in manufacturing. A 'top down' approach has also been applied by considering the possible interactions of the systems from the Factory through Cell and Machine levels. However the implementation has been planned from the 'bottom up' by proposing an 'in house' pilot scheme in order to gain productive impact at an early stage.

System implementation at Rockwell PMC is subject to specific constraints, which have been identified by this work, particularly with regard to the computer hardware and software preferred by company management. This leads to the potential use of 'off the shelf' products which are not regarded as international standards but can provide a simple solution for the specific functionality required. However this research does indicate the need for a modular approach such that available standard solutions can be more easily introduced at a later stage as appropriate.

CHAPTER 5

Phase 1 DNC System Implementation

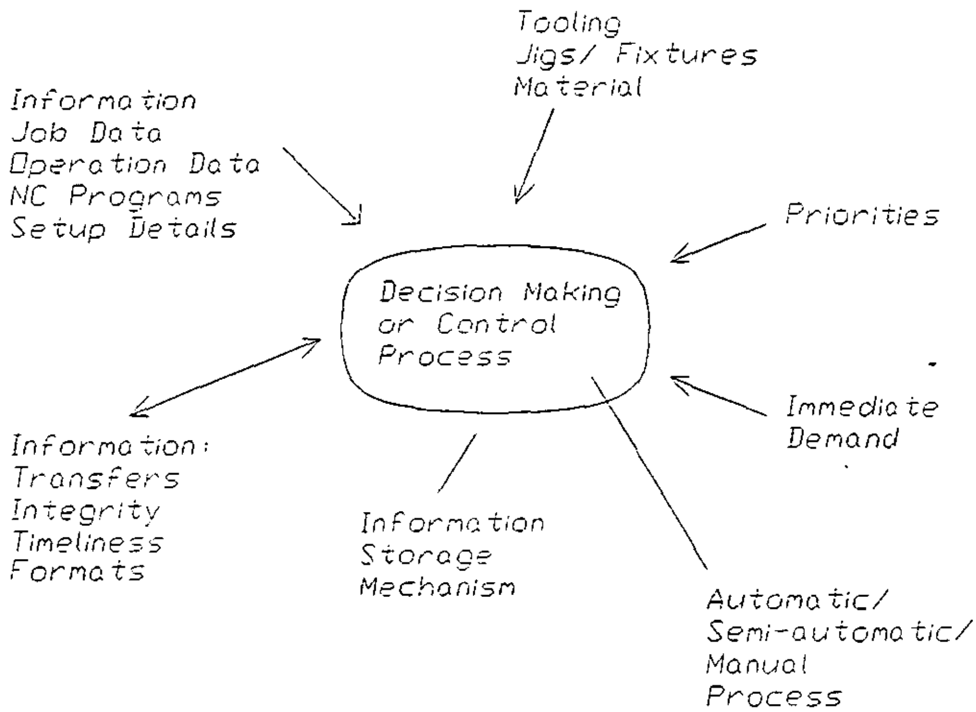
5.1 Introduction

This chapter describes the initial phase of evolution of the machine shop management system hierarchy at Rockwell PMC. The work involved the specific implementation of a Distributed Numerical Control system on a Heid CNC Lathe in the cell producing 'shaft' components using IBM PCs and software written in house, as proposed in the previous chapter. The system has subsequently been applied to a Matrix CNC Grinder in the same cell and a Falcon CNC Burner in the material centre. At this stage the strategy was to help the decision making processes involved in machine operation while retaining the operator as the overall control mechanism. The system is geared to the distribution of job operation information rather than to the control of the machine in the sense of conventional mechanised automation. However the principles involved are fundamentally similar as illustrated in Figure 5.1.

The importance of evolving factory control methods which recognise the design constraints faced must be stressed, particularly when the aim is to enhance the operation of existing manufacturing systems. The work reported in this and subsequent chapters recognised the need to use emerging CIM tools to support, rather than replace, man and/or indeed any other conventional installed manufacturing system components which could not be discarded for business, technical or other reasons. The 'human centred approach' to CIM, which has been used in previous system implementations within Rockwell PMC as indicated earlier, has again been a major consideration.

The decision making processes themselves can be automatic, semi automatic or manual and may involve application software processes in order to perform the appropriate tasks. Physical items such as the material, tooling, jigs and fixtures need to be delivered to the machine. Information also needs to be available in the correct format. This requires information storage facilities and a reliable transport mechanism. Materials and information need to be delivered in a timely manner according to the priorities set by the factory level which may well be adjusted locally by the foremen.

Figure 5.1 Principles of Machine Control Systems



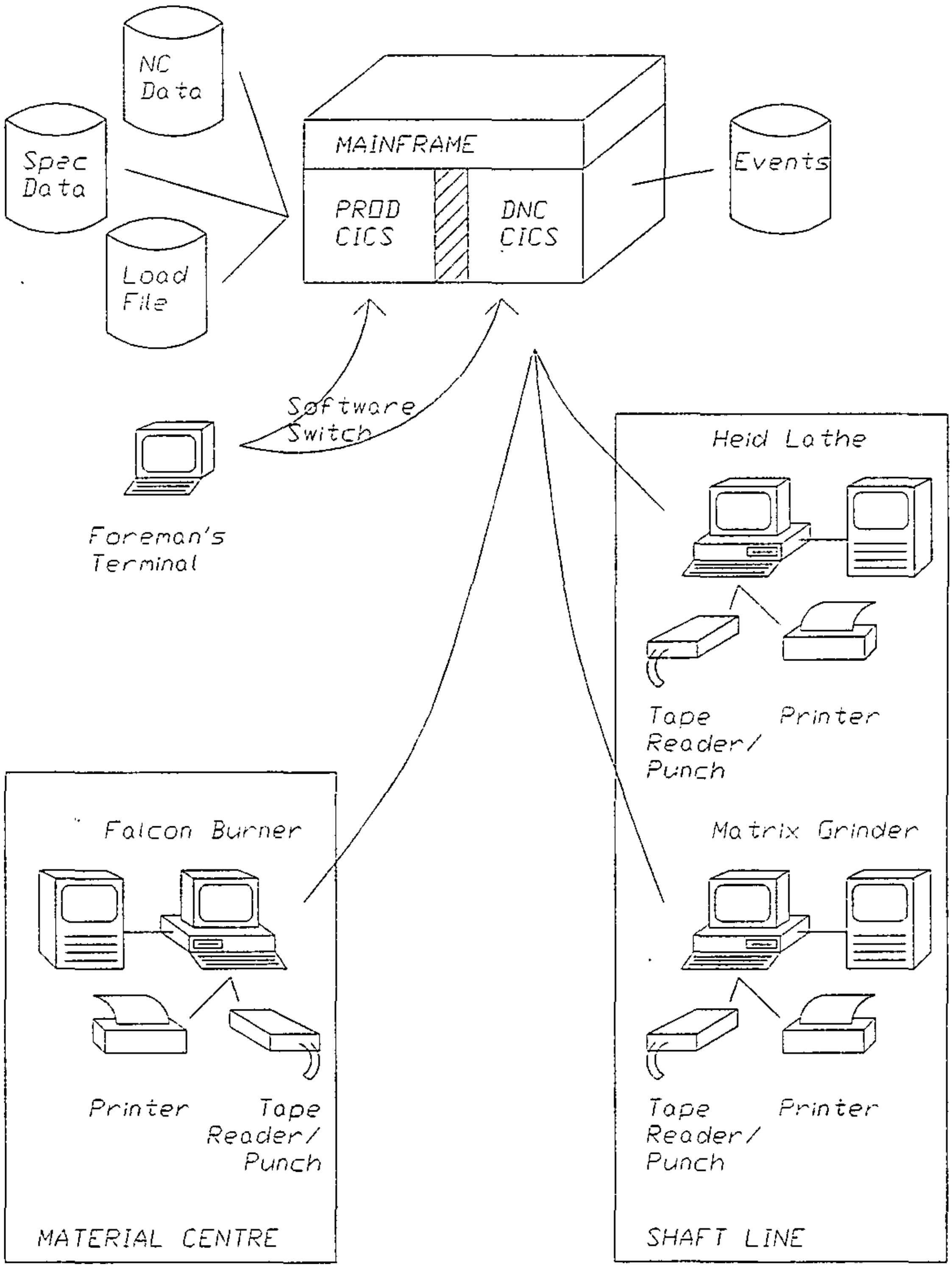
By creating a system with due regard to the basic functionality and necessary interaction mechanisms, the building blocks can be designed such that changes can be made more easily to specific modules at a later stage. Hence the evolution here to the next stage, which includes a cell level, can be made with a much reduced need for change. This approach can also be applied to situations where more automation is involved where appropriate.

5.2 DNC System Configuration

The author was responsible for managing the implementation and for the overall design of the DNC system. This included the installation of all system hardware and parts of the detailed program design as explained later in this chapter. However it is important to point out that the shopfloor foremen and machine operators were fully involved in the system design with regard to the required system functionality and visible user interfaces. The specific nature of the system is described in Appendix B. The system configuration is illustrated in Figure 5.2 and discussed here.

The system consists of IBM PCs on the three machines, linked to the mainframe, acting as intelligent terminals for the operator. Operation information, including

Figure 5.2 DNC System Configuration



machine control data in the form of part programs, is transferred into local storage at each PC. Once stored the information can be viewed by the operator to help in job setup etc. and the part program data can be transferred to the machine control in order to perform the cutting operation. Hence the core activity of the system is the replacement of paper tape input of NC data by using electronic transfers as described in the specification earlier. However a backup mechanism is provided via paper tape input.

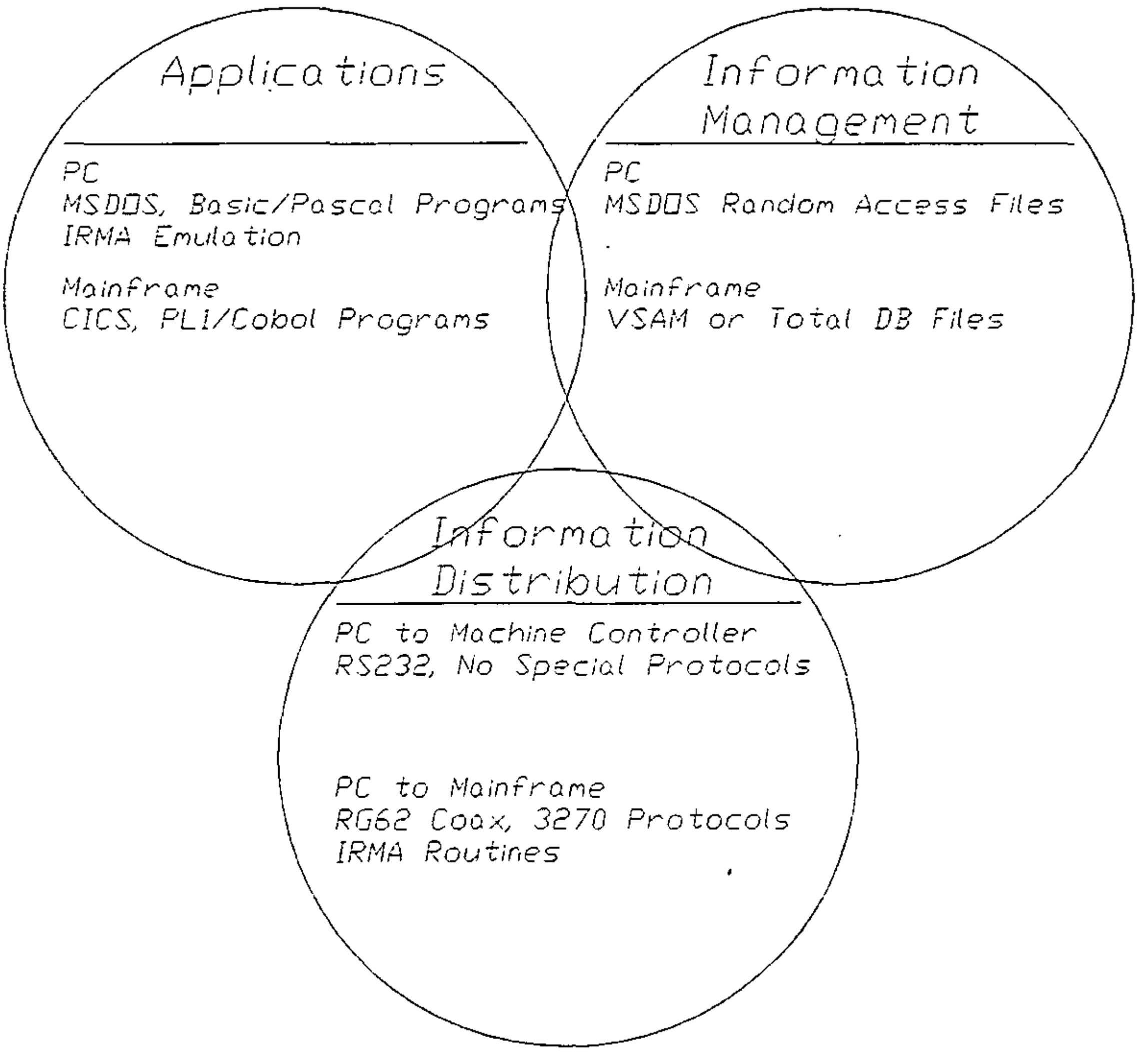
The IBM PCs therefore operate at the M.M.S. level and the Mainframe at the F.M.S. level of the Rockwell PMC hierarchy. These levels correspond to the Workstation and Facility levels of the ISO hierarchy as described earlier in Chapter 4. The C.M.S. level of the Rockwell PMC hierarchy, corresponding to the Cell level of the ISO hierarchy, was not implemented at this stage of the work for the reasons discussed in the previous chapters.

The set up and potential of the system is suitably illustrated in Figure 5.3 in the form of a three architecture model which is used in this and subsequent chapters as a suitable framework for describing the evolving systems and assisting in the comparison between these systems. The model used here is based on the Three Architecture Approach referred to earlier in Chapter 2. However the functionality attributed to the three architectures has been modified because of the limitations of the information management functions available for the specific implementations involved in the research described in this thesis. In particular the functionality apportioned to the information management architecture has been limited to the information storage facilities and the facilities for meaningful transfer of information between devices has been shifted into the communications architecture.

The communications architecture model used here is therefore concerned not only with the transfer of data via a given cable configuration and data transfer mechanism but also the commands, action or requirements statements at each end of the link to ensure meaningful information transfer. Hence for the purpose of comparison in this thesis an Information Distribution Architecture is identified.

The model is used to indicate the actual products used in the information management, information distribution and applications architectures implemented at each stage of the work. Where appropriate alternative solutions are also described here thus expanding on the explanation for the actual

Figure 5.3 Three Architecture Model of DNC System



implementation plan put forward in Chapter 4. However the issues of possible future solutions to implementations following on from the work reported in this thesis will be considered further at a later stage.

5.2.1 Information Management Architecture

The Information Management Architecture implemented in the DNC system described here involves specific data files controlled and accessed separately by the PC and the mainframe computers.

The main files involved at the PC level hold information about the jobs to be progressed; part program, tooling / setup and operation details and parameter data relating to the particular machine control type involved which is used by the 'personality module software'. These files have been designed specifically for the DNC applications by the author and are structured as standard MS-DOS [MS-DOS 1987] random access files.

At the mainframe level the files involved hold information about job status and priority; operation specification and routing; part programs; tooling / setup and DNC events. These files already exist within the functionality of the mainframe manufacturing control software and are stored as IBM VSAM [VSAM] files or in the Cincom TOTAL or SUPRA [Cincom] databases as appropriate for the application.

Other information management systems may have been more appropriate if the particular constraints applicable to systems evolution within Rockwell PMC had not been an issue. Several localised database products are already available for standalone PCs e.g. DBase, Oracle, Btrieve [Barron 1989] [Green 1990] which could be used to improve the handling and security of the information involved at the shop floor level. The possible application of these and other products is discussed further later in the thesis.

However database products have not been applied to the implementation of the Rockwell PMC DNC system described in this chapter. not only because of the constraints but also by choice, relating to the pilot approach described previously, the information management tools used here were purposely chosen to function at the most basic level. Providing functionality for the operators and foremen at the application architecture level was considered to be more important.

Another possible approach would have been to only call up the part programs and associated information from the central data store on demand and not hold any data locally at the operator's terminal. This is the more common approach where NC information is stored on minicomputer systems e.g. in some of the early links in the large DNC system installed at British Aerospace, Preston [Anstiss 1988].

5.2.2 Information Distribution Architecture

As explained earlier the Information Distribution Architecture model used here involves not only the transfer of data but also the commands, action or requirements statements at each end of the link. Both of these aspects of the DNC system implementation are therefore considered here.

The interfaces between devices in the DNC system are all point to point. The PC is connected to the mainframe via a standard IBM 3274 controller with RG62 coaxial cable using IBM 3270 synchronous protocols. The link between the PC and the mainframe is based on the use of the PC in mainframe terminal emulation mode using the IRMA interface card and software. The data extraction program run at the PC includes a routine which initiates the mainframe transactions (as indicated earlier these are, by necessity, programs written in the IBM PL1 or Cobol programming languages which are run in the mainframe Teleprocessing System CICS) which are necessary to extract the data from the mainframe files. This data is then transferred into the PC files by reading the data produced by the CICS transaction from the 'virtual mainframe' screen. Similarly the event recording program at the PC initiates a transaction at the mainframe which stores the event code information in mainframe files. This mechanism is explained further in Appendix B and illustrated below.

On the shop floor the PC interfaces to the CNC unit of the machine (and paper tape unit if required) are via a standard RS232 cable using character oriented asynchronous data transfer. The only communications protocols used with the Heid Lathe [Siemens] are those embedded in the part program format corresponding to the EIA RS358 standard e.g. such as the '%' character to signal the start of data. However the Matrix Grinder [TI Matrix] and Falcon Burner [BURNIV] CNCs do also contain 'protocols' at a low level. None of the controllers use any kind of error checking protocols above the basic character parity check. The link to the printer is via a Centronics interface [Epson 1985].

Alternative information distribution tools could also have been used. Between the PC and the mainframe other 3270 emulation products are available [Finkelstein 1988]. As indicated above in the more general case NC information tends to be stored by other companies on independent minicomputers rather than mainframe systems. Here the interfacing between the PC and minicomputer can be via RS232 links using other common file transfer products [Westbrook 1987] [Micro 1988]. Other solutions are discussed further later in the thesis.

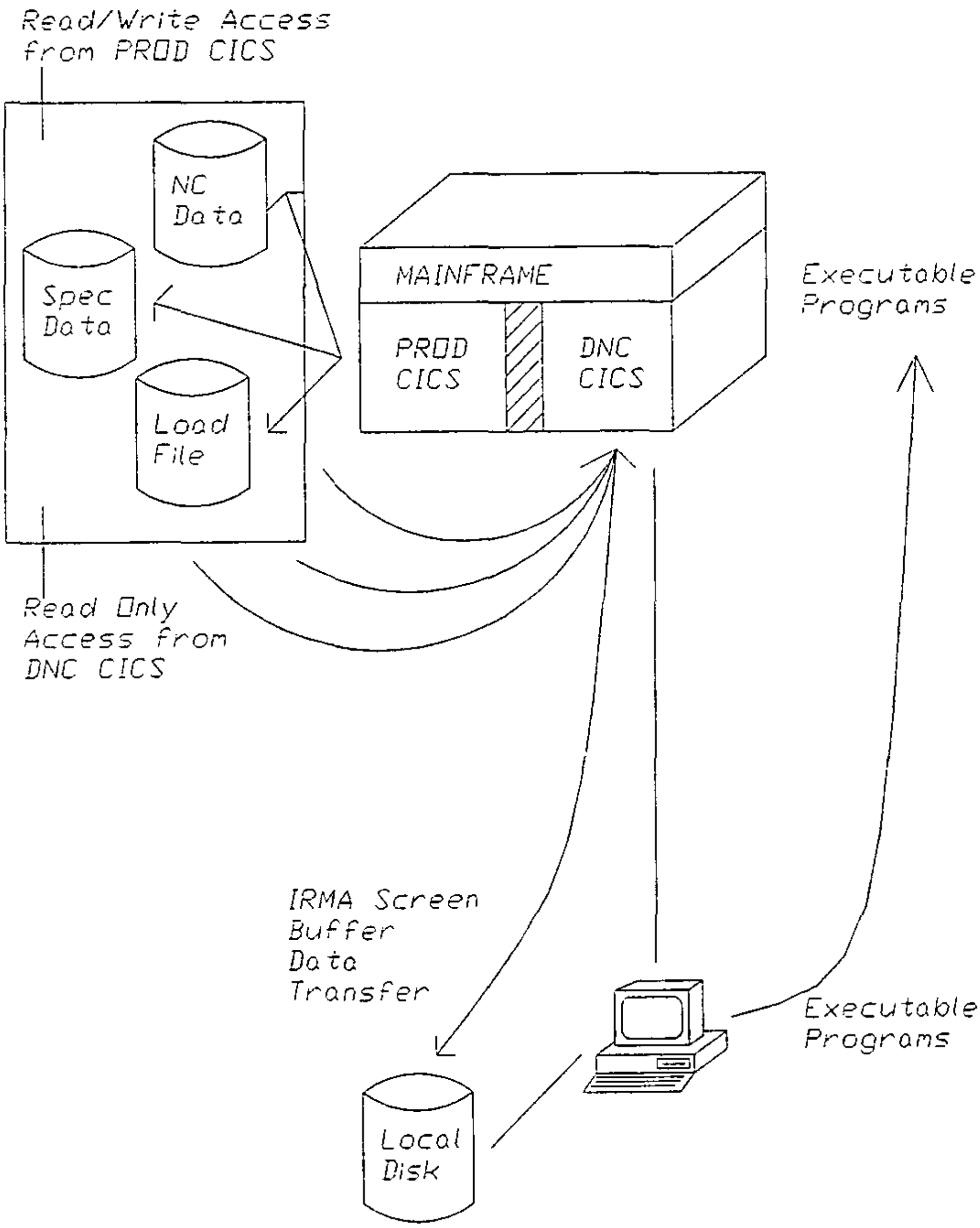
5.2.3 Applications Architecture

The DNC application programs are run independently at either the PC or mainframe levels. As explained above the link between the two levels is based on the use of the PC in 3270 terminal emulation mode. In this sense the PC is the initiator of each applications program on the appropriate computer system. Figure 5.4 illustrates the concept of this interaction. The data extraction program run by the operator at the PC uses the facility of the 3270 terminal emulation screen to initiate an application routine at the mainframe which extracts the data from the mainframe files and displays it on the PCs 'virtual mainframe' screen as described above.

The author was responsible for specifying the functionality of all application routines used in the system. In addition all routines used at the PC level were designed and written by the author. The routines used at the Mainframe level were designed and written by members of Rockwell PMC's computer department.

The application programs used directly by the operator at the PC were originally written in Compiled Basic but Pascal has also been used as appropriate to the functionality needed. The programs form an interlinked set of routines which are executed as required by the machine operator, see Figure 5.5. Figures 5.6 through 5.9 illustrate some of the functionality of the DNC System functionality. The main DNC System screen used by the operator is shown in Figure 5.6. From this screen the operator can call up on demand operation, NC part program and tooling/ setup information for the part number and operation number combination of the job he has to progress. He can then use this information from the local PC data store at the machine independently of the mainframe system by selecting the local data file required. Figure 5.7 illustrates the options available for the current job selected enabling the operator to view the data or transfer the appropriate NC information to the machine controller. At present the data stored locally is limited

Figure 5.4 The PC as Application Routine Initiator



to operation descriptions, tooling and NC data as shown in Figure 5.8. The NC program data display available is shown in Figure 5.9. The operator can page through the data displayed and print off hard copies as required.

The use of application programs produced by outside suppliers has been considered at some length in Chapter 4 together with an explanation of the reasons for 'in house' software being used at this implementation stage. However it is fair to say that the DNC system packages now available from commercial vendors, e.g. [BAeCAM] [Coscom] [RWT], are more comprehensive and one of these packages may well have been chosen if implementation had not proceeded at an early stage.

5.2.4 Application of the DNC System in other Factories

The DNC System described here has been implemented to meet the specific requirements of the Rockwell PMC machine shop. However parts of the system could certainly be used without change by other factories within the Rockwell Corporation or indeed by other companies. The suitability of PCs for this kind of application is becoming more widely acknowledged [Skinner 1989].

The subsets of the Information Management and Applications Architectures which are related to the IBM PC functionality could be used unchanged. This would provide all the local DNC facilities to the machine operator which are available in the Rockwell PMC system. This includes all functions involved in viewing the operational, NC and tooling/setup information at the PC.

However the problems of transferability of the Rockwell PMC solution to other factories involve the functionality available at the Information Distribution Architecture and those aspects of the Information Management Architecture which relate to the storage of the 'master' information. The information distribution facilities used between the PC and the master information store and the PC and the machine controller would probably have to be replaced by other 'site specific' routines. This includes the machine operator's 'Get New Data', 'Transfer NC Data' and 'Paper Tape System' routines, see Figure 5.5. The provision of a suitable information distribution facility between the PC and the master information store would obviously depend on the differences in the Information Management Architecture.

Figure 5.5 DNC System Functionality

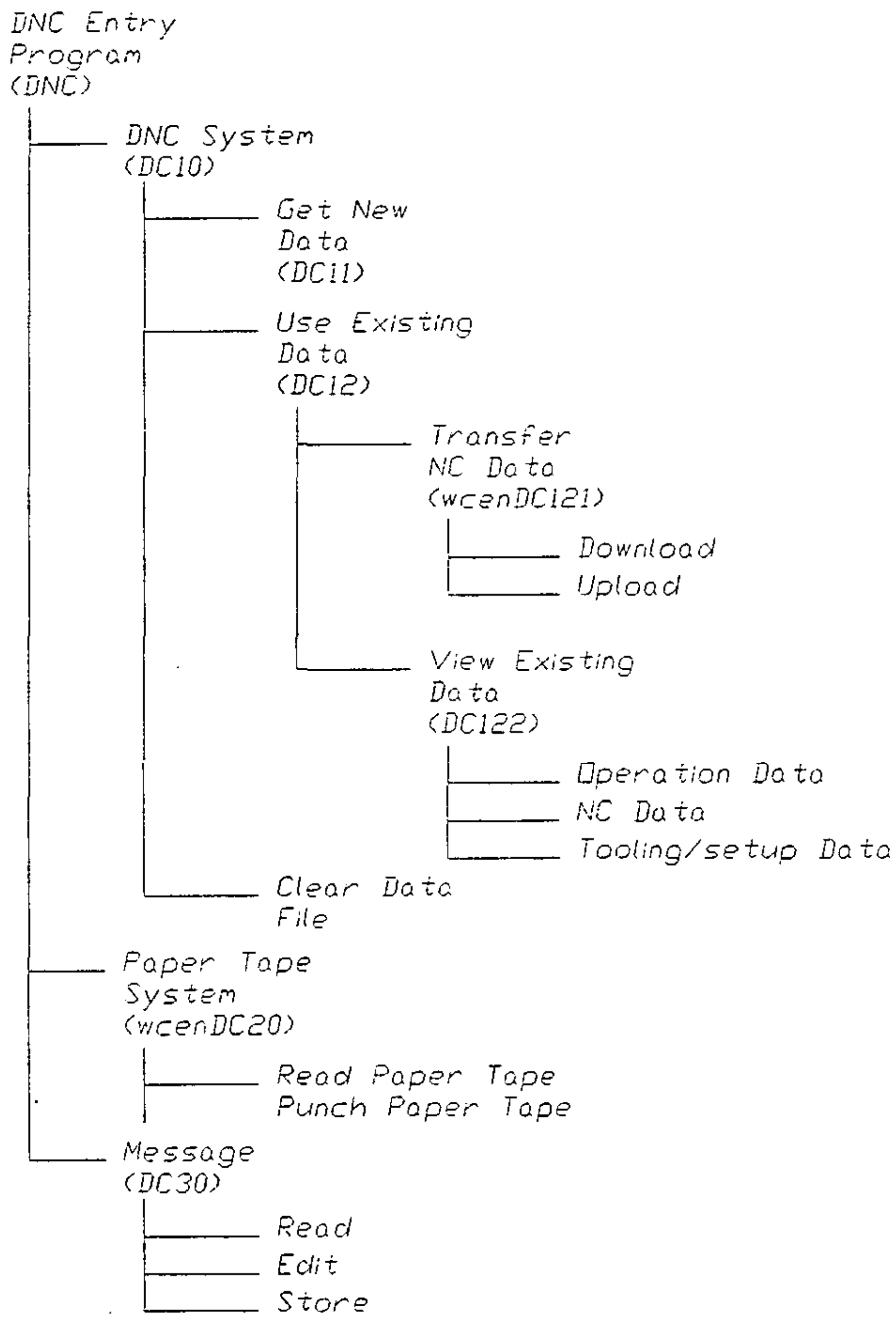


Figure 5.6 DNC System Main Operator Screen

```
                    BAKER PERKINS DNC
Machine:Matrix Grinder      | Work Centre F23 | Operator
                    DNC System

Job data on file:

File  Part Number    Part Description                 Op       Number
                                                      Number   of Tapes
  1   6435851L       LAYSHAFT                          040       2
  2   No data in file.
  3   No data in file.
  4   No data in file.
  5   No data in file.
  6   No data in file.
  7   No data in file.
  8   No data in file.
  9   No data in file.
 10   No data in file.

1  GET NEW DATA   2  USE EXISTING DATA   3  CLEAR DATA FILE      10  EXIT
```

Figure 5.7 DNC System Use Existing Data Screen

```
                    BAKER PERKINS DNC
Machine:Matrix Grinder      | Work Centre F23 | Operator
                    Use Existing Data

CURRENT JOB
PART NUMBER      : 6435851L
PART DESCRIPTION: LAYSHAFT
OPERATION NUMBER: 040

1  VIEW JOB DATA    2  SEND NC PROGS                      10  EXIT
```

Figure 5.8 DNC System View Job Data Screen

```
                 BAKER PERKINS DNC
Machine:Matrix Grinder     | Work Centre F23 | Operator
                 View Job Data

CURRENT JOB
PART NUMBER       : 6435851L
PART DESCRIPTION: LAYSHAFT
OPERATION NUMBER: 040




CURRENT JOB  1  OP DESCRIPTION   2  TOOLING LIST   3  NC PART PROG   10  EXIT
```

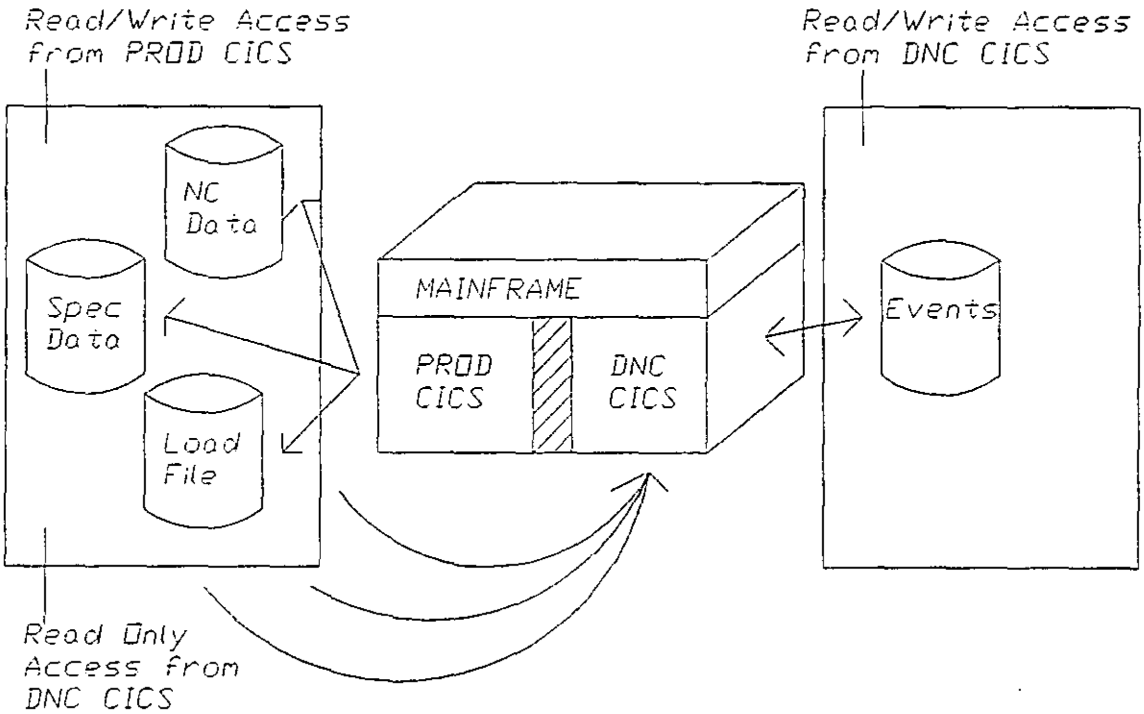
Figure 5.9 DNC System View NC Data Screen

```
NC Tape Number: 1   Number of blocks:  36    Tape status: Proven


start of program
N010                                (6435851L-TAPE-1-OP40)
N020G90                             L1                                    M43
N030                                (DRESS-WHEEL)
N040G45   X-.04                     U0.02     D350.00   F500.   E30.0 J0.8  M00
N050G26                             L2                                    M4602
N060                                L1                                    M02
N070                                (GRIND-COMP)
N080                                L2                                    M43
N090                                (PROBE-RH-SHOULDER)
N100G56   X60.00     Z-56.100                                             M62
N110                                (PLUNGE-AND-GAUGE-WITHOUT-UPDATE-55-H6)
N120G00   X55.800    Z-54.10                            S60     M08       M04
N130G17   X55.600                              F.80
N140G17   X55.024                              F.30             M58       M72
N150G17G52X54.994                   P58.20     F.02                       M72
N160G00   X58.200    Z-55.900       P58.20


  1  FORWARD   2  BACKWARD   3  PRINT FULL COPY            10  EXIT
```

Figure 5.10 Mainframe Systems Configuration



5.3 Mainframe Configuration

The nature of the DNC system at mainframe level is illustrated in Figure 5.10. The main change made during this phase involves the use of a further CICS partition which operates exclusively for DNC information extractions and transfers. The downtime associated with Production CICS, as highlighted earlier in Chapter 3, causes particular problems for shopfloor personnel since the system is often unavailable for much of the night shift and also during the weekend.

The use of an alternative CICS exclusive to DNC has gone some way to relieve this problem. This system shares the files owned by Production CICS so that DNC data extractions can be serviced even when Production CICS is unavailable. However this access is restricted to Read Only, no updates are possible through DNC, for the reasons given previously. The facilities available to the shopfloor are therefore limited.

5.4 Additional Application Programs for the Cell Foremen

A number of extra facilities have been made available for use by the foremen in order to start to introduce some of the machine management aspects required.

The functionality available from the existing Production CICS transactions remains unchanged.

5.4.1 DNC CICS Transactions

The introduction of DNC CICS as a round the clock system independent of the existing production enquiry facilities has proven to be very successful. In order to further extend its use a number of production enquiry transactions were made available in DNC CICS so that the foremen could use them during the periods of Production CICS downtime. Unfortunately the recent systems change to Cincom's Control Manufacturing software has reduced the number of routines which can be made available due to update access restrictions. During the intial phase the foremen were also able to use the existing Production CICS enquiries for part specification and loadfile details.

The foremen's terminal allows for the use of the 'software switch' for access to either Production CICS or DNC CICS as required as illustrated in Figure 5.2.

A. DNC Events Enquiry

An events enquiry transaction is available in DNC CICS which shows the events logged by any DNC work centre for the current and previous day. (The file is cleared out daily.) The display shows (with latest event first) the date and time of the event, the program number involved (part, operation and tape numbers) and an event description, see Figure 5.11.

B. Work To Lists

A work to list transaction, based on the existing enquiry available in Production CICS, has also been made available in DNC CICS. The enquiry is currently only available for those work centres in the shaft line and adjacent disc cell and has a slightly different format for the screen display. The differences between the Production and DNC CICS work to list enquiries are illustrated by comparing Figures 5.12 and 5.13. The DNC lists have been set up to show job routing within the cell together with the specified total time for each operation in order to help the foremen assess the possible effect on other machines in the cell of loading any one job on the specified machine in lieu of the implementation of any scheduling package as discussed earlier.

Figure 5.11 DNC Events Enquiry

```
          D.N.C. EVENTS ENQUIRY FOR F23            PAGE   1 OF  2
 PLEASE SELECT NEXT ACTION
DATE  HH MM SS  TAPE NUMBER         EVENT DESCRIPTION  DNC READR PUNCH MISC


870430 11 14 48     6435851LF23 0402 PROVEN TAPE
870430 11 14 48     6435851LF23 0401 PROVEN TAPE
870430 05 55 35     6435863DF23 0301 NO MATCHING W/C OP
870430 05 54 04       754927F23 0501 PROVEN TAPE
870430 05 51 48     6311916DF23 0451 PROVEN TAPE
870430 05 41 41                      CICS DOWN          1
870430 05 49 23     6411749AF23 0301 PROVEN TAPE
870430 01 17 16     6435851LF23 0401 TAPE PASSED TO CNC
870429 23 21 28       754237F23 0502 TAPE PASSED TO CNC
870429 22 17 28     6435851LF23 0401 PROVEN TAPE
870429 22 17 28     6435851LF23 0402 PROVEN TAPE
870429 21 44 14     6440596JF23 0401 PROVEN TAPE
870429 21 44 14     6440596JF23 0402 PROVEN TAPE
870429 04 30 41       753238F23 0601 TAPE PASSED TO CNC
870429 03 37 21                      CICS DOWN          2               1
870429 03 37 21       753238F23 0601 PROVEN TAPE
870429 03 25 37     39915152F23 0401 TAPE PASSED TO CNC
870429 02 48 50     6374134EF23 0801 TAPE PASSED TO CNC
NEXT ACTION:    PAGE      (1) EXIT
```

Figure 5.12 Production CICS Work to List Format

```
              WORK TO LIST FOR GP44 LATHE SHAFT HEID CNC  RAC   PAGE   1 OF   1
QUEUED WORK.PLEASE SELECT NEXT ACTION
PWC NO. P.R  NC QTY DESCRIPTION      OP  PART NUMBER P.WCEN    SCRATCH PAD
R 01903  710 Y   1 LAYSHAFT G44 940  20      6488079J F10Q#
X304142  554 N   1 STUB SHAFT (DRIV  20      6484339G F10Q#WTG,TAPE F16 F23
X340575  477 N   2 PAN ROLLER        30      6289110F F11Q#
M 93050  223 Y  16 FILLING BAR - 96  30      6231476A F10Q#MAT.AV.IN MAT.CTRE
M 80671  195 Y   7 RUBBER ROLL STOC  20      39981183 F10Q#MAT.AV.IN MAT.CTRE
M 88230  188 Y   2 RUBBER ROLL STOC  20      39981183 F10Q#MAT.AV.IN MAT.CTRE
X346424  184 Y   1 SHAFT (BRUSH ROL  20      6475246D F10Q#
X346440  183 Y   1 HORIZ DRIVE SHAF  30      6475368A F11Q#MAT.AV.IN MAT.CTRE
X345111  155 Y   2 IDLER ROLL-NYLON  30      6432671F F11Q#MAT.AV.IN MAT.CTRE




NEXT ACTION   PAGE     (1) ABORT  (2) PRINT  (3) UPDATE
```

Figure 5.13 DNC CICS Work to List Format

```
              WORK TO LIST FOR  F16  LATHE SHAFT HEID CNC  ANW  PAGE   1 OF   3
AVAILABLE WORK.PLEASE SELECT NEXT ACTION
PWC NO. P.R  QTY  PART NUMBER   DESCRIPTION  OP WCEN    TIME NC SCRATCH PAD

 R 01903  710    1 6488079J      LAYSHAFT G44  20(F10Q)   0.75 Y
                                               30 F13     1.40

                                               50 F23     0.57 Y
 X304142  554    1 6484339G      STUB SHAFT (  20(F10Q)   0.83 N WTG,TAPE F16 F23
                                               30 F13     0.59
                                               40 F12     1.00
                                               50 F23     0.41 N
                                               60 F20     0.36
                                               80 F13     1.07
 X340575  477    2 6289110F      PAN ROLLER    30(F11Q)   1.85 N
                                               40 F11Q    0.00
 M 93050  223   16 6231476A      FILLING BAR   30(F10Q)   4.82 Y MAT.AV.IN MAT.CT
                                               40 F11Q    0.00
 M 80671  195    7 39981183      RUBBER ROLL   20(F10Q)   3.03 Y MAT.AV.IN MAT.CT
                                               30 F11Q    0.00
                                               40 F23     1.65 Y
NEXT ACTION   PAGE     (1) EXIT  (2) PRINT
```

5.4.2 NC Availability Flag

The first of the envisaged 'availability flags' has also been implemented so that the foremen can see whether NC part programs are available in the mainframe files for any particular job operation. The work to list displays, see Figures 5.12 and 5.13, have been modified to include an NC Marker column which uses a single character to show for each operation whether the NC data:

(i)	exists and is available	Y;
(ii)	exists but is set unavailable (stopped)	S;
(iii)	does not exist	N.

These markers were created for use by the DNC system. Each of the NC part programs is now allocated a marker of Unproven, Proven or Stopped as appropriate. The stopped status is used by the NC programmer to stop an existing program from being accessed by the operator e.g. if a drawing alteration is pending. The unproven and proven status markers signal to the machine operators whether special care should be taken e.g. during the first run of a program or when a program has been altered after being run successfully for some time.

5.5 Problems Encountered

A number of problems were encountered during this phase but particularly with the information distribution facilities required between the PC and the mainframe and the PC and the machine controllers .

5.5.1 Interfacing with the Mainframe

As indicated previously all the mainframe CICS transactions used in the DNC system can be executed at any mainframe terminal whether it is a PC or not. The DNC system functionality relies upon the PC's ability to control the operation of the mainframe screen buffer memory used by the IRMA emulation software. The problems encountered with the DNC routines for information transfer from the mainframe were related to the way that the mainframe screen reacts to user transactions rather than the use of the IRMA routines in themselves.

A. Response Characteristics

The response characteristics associated with mainframe interfaces can cause some problems. These characteristics can vary for a number of reasons. If the interface involves the use of a 'remote' terminal controller which uses a synchronous modem link the response times are permanently increased due to the lower transmission speeds available through the modems. The load on the system can also change response characteristics but in a less predictable manner because of the varying times needed to service each users request. In certain situations the mainframe transaction may not react in the way expected. An error may occur which causes the transaction to abort or 'hang' because of some unforeseen circumstance.

B. Implications for IRMA Based Application Programs

The reliability of routines which use the IRMA mainframe screen buffer depend upon their resilience to changes in the response characteristics. Because the routines are being run 'behind the scenes' in a program their effects are not visible to the application user. The program itself has to cope with any changes in response between separate runs of the program. By comparison if the terminal is being used in 'mainframe mode' the user can see for himself the mainframe response and react accordingly.

Any routines using the IRMA interface need to be written so that they emulate what a user would do if he were entering the commands himself. They must also be able to react in the same way that a user does if an unexpected response is obtained. The routines therefore need some inbuilt 'intelligence' to function reliably and a 'knowledge based' approach may well be more appropriate. However it is difficult to foresee and emulate all the possible reactions that the mainframe terminal can give and so a system which could 'learn' would be required. There is some indication that research work on Knowledge Based and Artificial Intelligence systems may formulate approaches which could be applied to these difficult communications problems [Jones 1988].

5.5.2 Interfacing with the NC Machines

All the implemented DNC systems use RS232 input / output ports available at the machine control for information transfer and the PC has been configured to emulate the paper tape unit originally used. However the functionality of these interfaces as produced by the different control system developers which have an influence in this implementation have differing facilities. Although the use of an RS232 interface is common, the transmission control features are different.

A. Control Lines and Protocols

The actual control lines of the RS232 standard [Seyer 1986], i.e. CTS/RTS and DSR/DTR, are used differently by the control system developers to provide 'hardware handshaking' during data transmission. None of the controls in the current mode provide for 'software handshaking' using the popular XON/XOFF protocol [Seyer 1986].

Although each control conforms to the EIA 358 NC standard [Batchelor 1985] for example using the sequence M02 as end of tape, no 'higher level protocols' are used except in the Falcon Burner machine which uses simple data start/stop transmission messages and the Matrix Grinder which allows for the 'EOT' end of text character to signify end of transmission. The existing control transmission schemes are also lacking in any transmission error checking facilities except for single character parity checks.

B. Older NC Controllers

The older NC machines, which may need to be integrated into the system at a later stage, tend not to have RS232 interfaces but instead use parallel interfaces designed by the control system developer. The data transmission control problems for these machines will be increased. A specially designed parallel interface will have to be used, possibly different in each case, to fit in between the RS232 port of the PC and the machine control.

C. Need for Standards

This apparent lack of standards illustrates the need for a 'personality module', described previously, which provides the link between each of the NC machines and the system functionality. As discussed these modules have to be designed to suit the NC machine involved in terms of both hardware connection and transmission 'protocols'. The need for specific 'personality modules' is also highlighted in the literature available from DNC system suppliers e.g. Coscom Systems Ltd. [Coscom] list a total of 112 existing CNC controls and communication protocols for which they have experience of providing DNC connections. These generic problems, which are faced by all CIM system integrators, would be greatly relieved if the control system developers would accept open standards becoming available and integrate them into their machine control systems functionality rather than design their own.

5.6 DNC System Benefits

As described in Chapter 3 the original concept for 'Machine and Cell Management' was a part of Rockwell PMC's overall initiative for evolution towards CIM in order that the company might take the opportunities available in a growing market by increasing supply whilst reducing overall delivery times. The project is one of a number planned to lead to a 'Linked Business System' which would enhance competitiveness by providing reduced delivery cycle time, work in progress stocks and improved productivity. The DNC system is the first stage of a multistage implementation of shop floor and cell control systems. As such it is seen as a strategic implementation required for progress towards the overall goal of CIM and can only be expected to impact on some of the many factors which can provide real benefits in line with the original business objective.

The benefits arising from this implementation are not easily quantified. Use of electronic data transfer provides benefits in terms of time savings for the NC programmers, foremen and operators. Each saves time from not having to handle paper tapes and having more information available on demand using his own terminal. The response time of part programmers to shopfloor problems is also improved. Further time savings are realised through the use of NC markers available on the master NC data files. For example if a drawing alteration is made on any part the NC programmer need only set the NC marker to stopped. This will prevent the program from being used on the shopfloor until he has made any necessary alterations thus ensuring that no faulty parts are produced. The foremen can also see directly from the work to lists whether an NC program is available for a particular operation. This will prevent them from loading jobs to the operators which cannot be progressed thus the local cell work in progress levels are reduced and related problems minimised. Overall quality levels are improved, rework and scrap levels reduced by ensuring that the 'master' NC program for any job operation is always downloaded from the central files.

However an attempt to quantify the benefits of the DNC System implementation is illustrated in Figure 5.14. This shows the cost of the DNC System implementation in the Shaft Line, at 1985 prices, together with a 'classical' calculation of the savings available due to the increased machine utilisation related to the time savings described above. This suggests that the implementation cost could be paid back in about 4.7 years. This payback period could be reduced if the DNC system were applied to more machines to spread out the estimated software costs further. However as discussed below the system was specified as a strategic move towards the cell control concept and there was no intention to install the system on a large number of machines. In addition, in view of the reducing cost of computer hardware and the increasing cost of machine overhead, the payback period would be much reduced at present day price levels.

Figure 5.14 DNC System Justification (at 1985 Price Levels)

DNC System Implementation Costs	
F16 Heid PC	£4949
Cable Installation	£178
F23 Matrix PC	£3829
Cable Installation	£193
Spare PC	£3775
Total Hardware Cost	£12924
Software Development Costs	£15000
Total System Cost	£27924

Recoverable Costs Due to Increased Machine Utilisation	
Lost Time per shift due to Loading Paper Tape	0.25 hrs
No. of Machines	2
No. of Shifts	2
No. of working days per year	300
Machine Overhead Rate	£20 per hour
Total Cost of Machine Downtime	£6000 per Year

5.7 Further Implementation

There has been no further implementation of the DNC system described here particularly because, in line with the initial project terms of reference, the intention has always been to integrate the system into a full Cell Management System in the first machining cell before extending to other shopfloor cells. The system has been designed, as intended, with portability in mind. In order to implement a further DNC system the only changes which need to be made are to the 'personality module'. Within the Information Distribution Architecture level a new NC data transfer program may need to be written for the new controller and the interface between the PC and the controller needs to be configured. All other modules can stay the same.

One major disadvantage of this DNC system approach arises because of the interfaces used at the information distribution levels. In order to have systems available to operators at multiple machines there need to be multiple point to point coaxial connections between the PCs and the mainframe. This would multiply the cost of connections by the number of DNC systems involved and the complexity of the wiring layout would rapidly cause maintenance problems. The cost of additional controller ports would also be important. The alternative installation route is to use a Local Area Network of PCs linked back into one 'gateway' into the mainframe system. This is the approach which has been taken in the next implementation stage at Rockwell PMC as described later in the thesis. Again these problems are also illustrated by the approach taken by other companies [Anstiss 1988] and external vendors of DNC systems [BAeCAM] [Coscom] [RWT].

However the evolution of the DNC system into a Cell Management System is made easier by the modular approach taken. At the Applications Architecture level the functions available to the machine, cell and factory levels, involving the operator, foremen and mainframe, need to be extended; at the Information Distribution Architecture level the facilities for the cell level need to be integrated with those existing and at the Information Management Architecture level information storage facilities for the cell need to be addressed. All of these can be achieved by building onto the facilities already implemented in the DNC system.

5.8 Summary

This chapter has described the implementation of a Distributed Numerical Control system at Rockwell PMC. The DNC system has been specific to the needs of the company with respect to the hardware and software used but nevertheless offers a partial solution for similar implementations at other manufacturing facilities. In particular changes would need to allow for differences in the management functions of the main information storage system and the information distribution functions between this storage system, the PCs and any specific machine controllers used. Wherever possible 'off the shelf' products have been used in this implementation to simplify the solution subject to prevailing company constraints. Alternative approaches have been identified for comparison purposes.

The system has been designed and implemented to provide suitable functionality for the shopfloor personnel with due regard to 'human aspects' by fully involving the foremen and operators in the design process. The basic concepts of the implementation in terms of transfer of information and enhancement of system functionality for shopfloor personnel using PCs can certainly be applied in many other situations.

The specific implementation work has led to the recognition of certain constraints which are generic in nature. These relate particularly to the information distribution facilities available for communication with machine controllers on the shopfloor and the central information storage system. The machine control manufacturers in particular do not appear to adhere to common standards for controller interfaces but to produce specific solutions. These specific solutions make the interface of DNC systems to the machine controls different in many cases and further complicate the application of CIM on the shopfloor.

The DNC system implementation has produced real benefits in terms of reductions in machine downtime, time savings for production personnel, improved availability of information and response times. In addition the level of work in progress in the local area and the risk of poor quality have been reduced.

CHAPTER 6

DNC System Extension for Shopfloor Graphics

6.1 Introduction

The previous chapter has described the implementation of a DNC system within the Rockwell PMC machine shop. The system consists of an IBM PC, linked to the mainframe, acting as an intelligent terminal for the operator. Operation information, including machine control data in the form of part programs, can be transferred into local storage at each PC on demand. Once stored the information can be viewed by the operator to help in job setup etc. and the part program data can be transferred to the machine controller in order to perform the cutting operation.

However the system is only capable of handling textual information whereas all the machine operators normally need a drawing of the required component for reference purposes. In addition to this some machine operators are also supplied with drawings showing the required machine setup. This chapter deals with the specific evolution of the DNC system to allow for the 'view only' display of graphical information on the operator's PC. The short term aim of providing 'shopfloor graphics' on a terminal screen was to allow for the DNC system to be used on the machines which need setup drawings. More importantly the longer term business aim is to allow for the reduction and possible elimination of all shopfloor paperwork.

As described previously some of the NC machines, for example lathes and drills, are normally programmed using a simple text editing system on the Mainframe computer whilst the more complex part programs needed by the machining centres are produced using the McDonnell Douglas Unigraphics CADCAM facility. The Falcon Burner in the Material Centre is also programmed using CADCAM because of the complex profiles which are sometimes produced and especially when one or more different parts is involved in a burning out operation. Whereas the mainframe generated NC information is held in online data files, the lack of storage space on the CADCAM computers means that CAM generated NC information is generally punched onto paper tape and then the Cutter Location (CL) Source data, not the NC machine code, is archived onto magnetic tape for longer term storage. CADCAM part programs therefore need to be re-postprocessed each time a new NC program tape is required.

The information needed by the burner operator is effectively the same as that needed by the DNC machine operators in the shaft line except that the setup details used are given in graphical form showing the placing of the plate on the machine table relative to the burner zero datum position, see Figure 6.1.

The Falcon Burner was specified as a particularly suitable candidate for the implementation of DNC because of the distances involved between the part programming area and the Material Centre and the large number of programs produced which cause a problem in terms of paper tape data storage by the machine. However in order to allow for the use of DNC two problems needed to be addressed:

(i) The DNC system is centred on and uses information from the mainframe data base. Hence the necessary NC and setup information has to be transferred from the CADCAM computer to the mainframe;

(ii) A facility is needed at the machine to show the graphical setup details on the PC screen for the operator.

6.2 DNC System Configuration Changes

Since the information required by the Falcon Burner operator is essentially the same as already provided for by the DNC system (except for the need for graphical displays), the evolution described here involved specific enhancements to the existing system configuration. Hence the procedures involved in the transfer of graphical DNC information have made use of existing routines wherever possible. This has helped to minimise the effort involved. The routines chosen for this system evolution are proprietary in nature, rather than taken from those included in the developing standards, but have been chosen and used such that they can be replaced by standard procedures as appropriate with minimum effort.

The set up and potential of the system is illustrated in Figure 6.2 in the form of the modified three architecture model. This model is used as suggested earlier to allow for comparison with the base system already described. Where appropriate alternative solutions are also discussed.

The author was again responsible for managing the implementation and for the overall design of the changes required for the existing DNC system in addition to parts of the detailed program design as explained below.

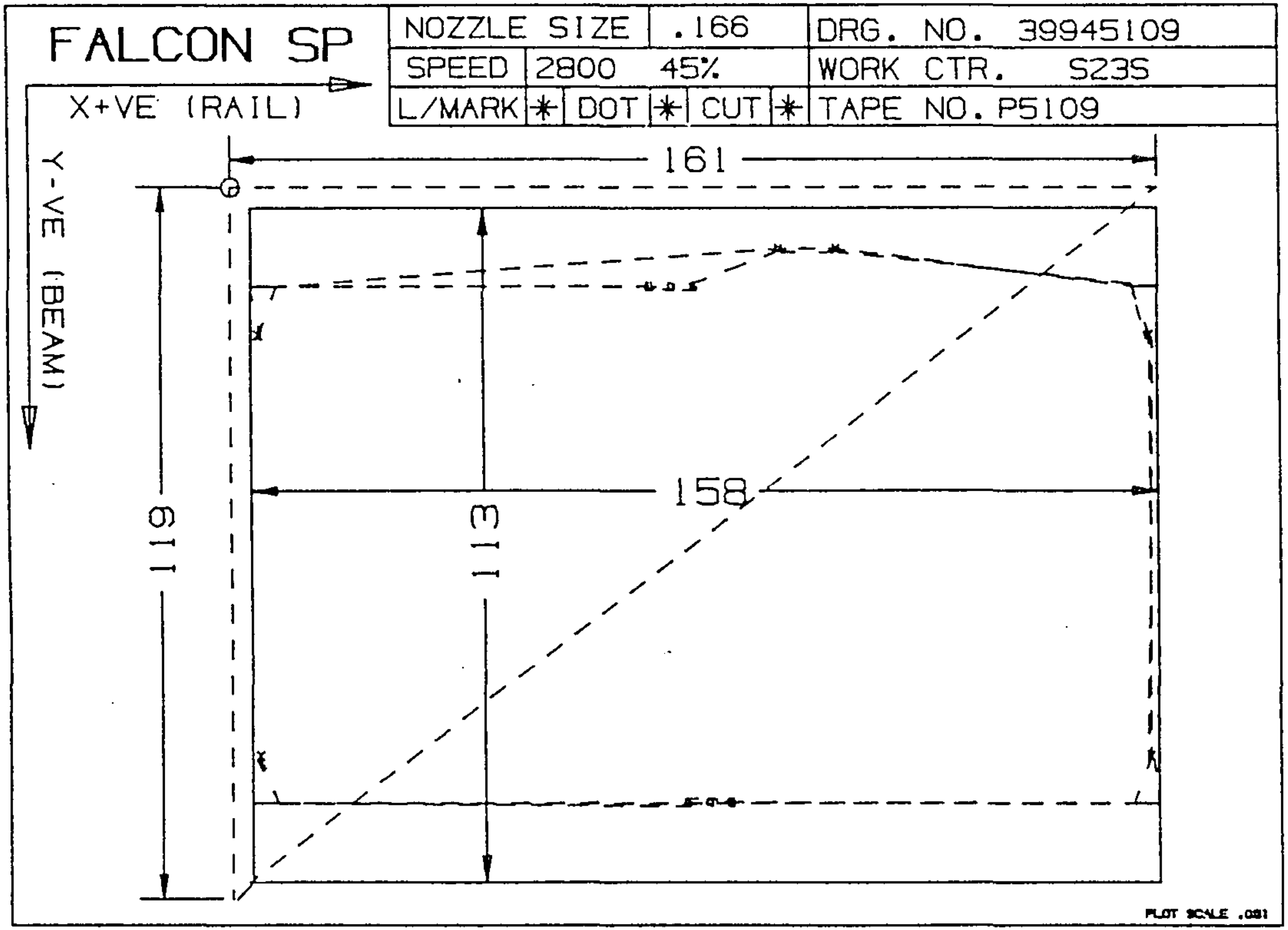
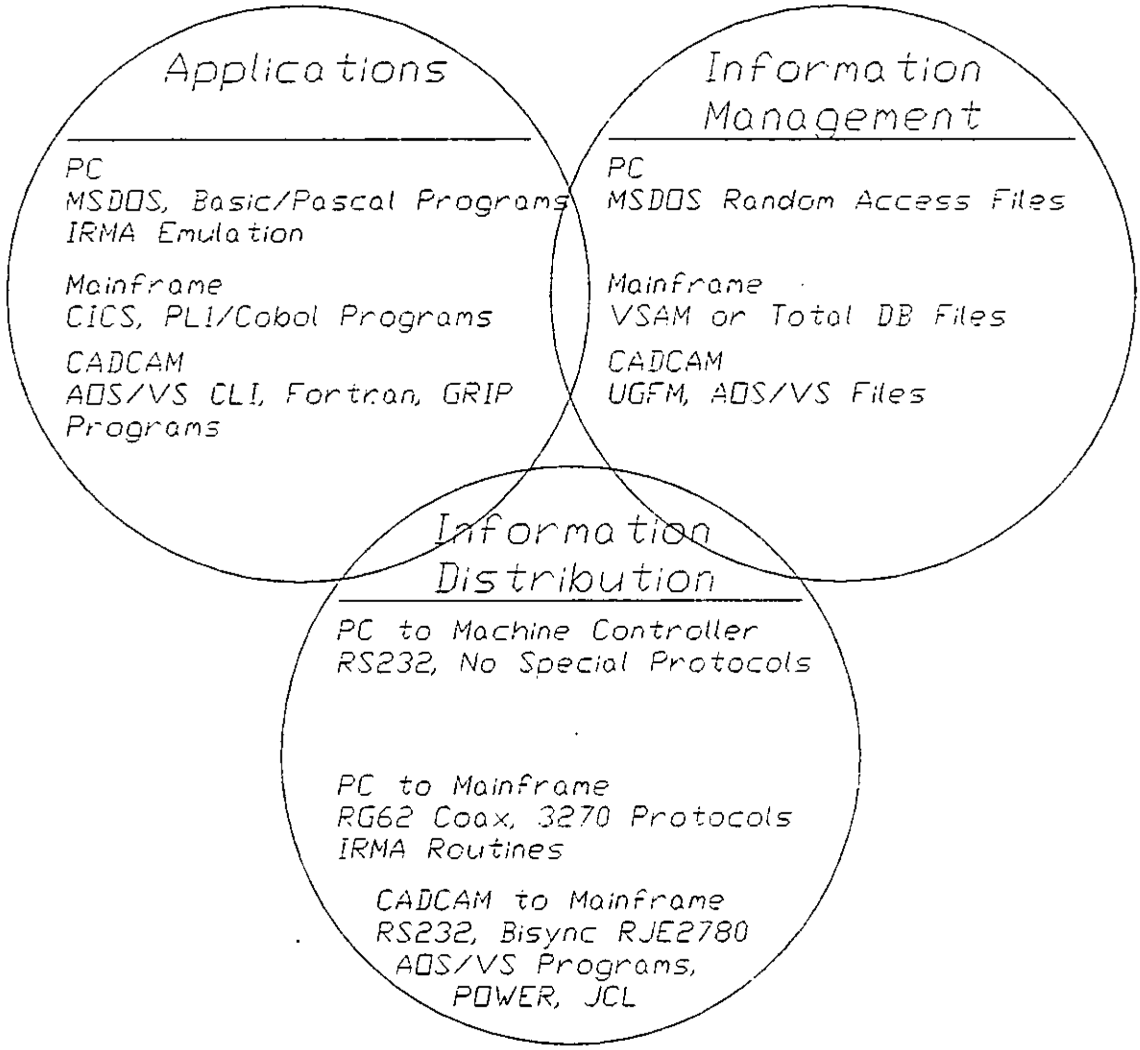


Figure 6.1 Falcon Burner Setup Sheet

Figure 6.2 **Three Architecture Model of Enhanced DNC System**



6.2.1 Information Management Architecture

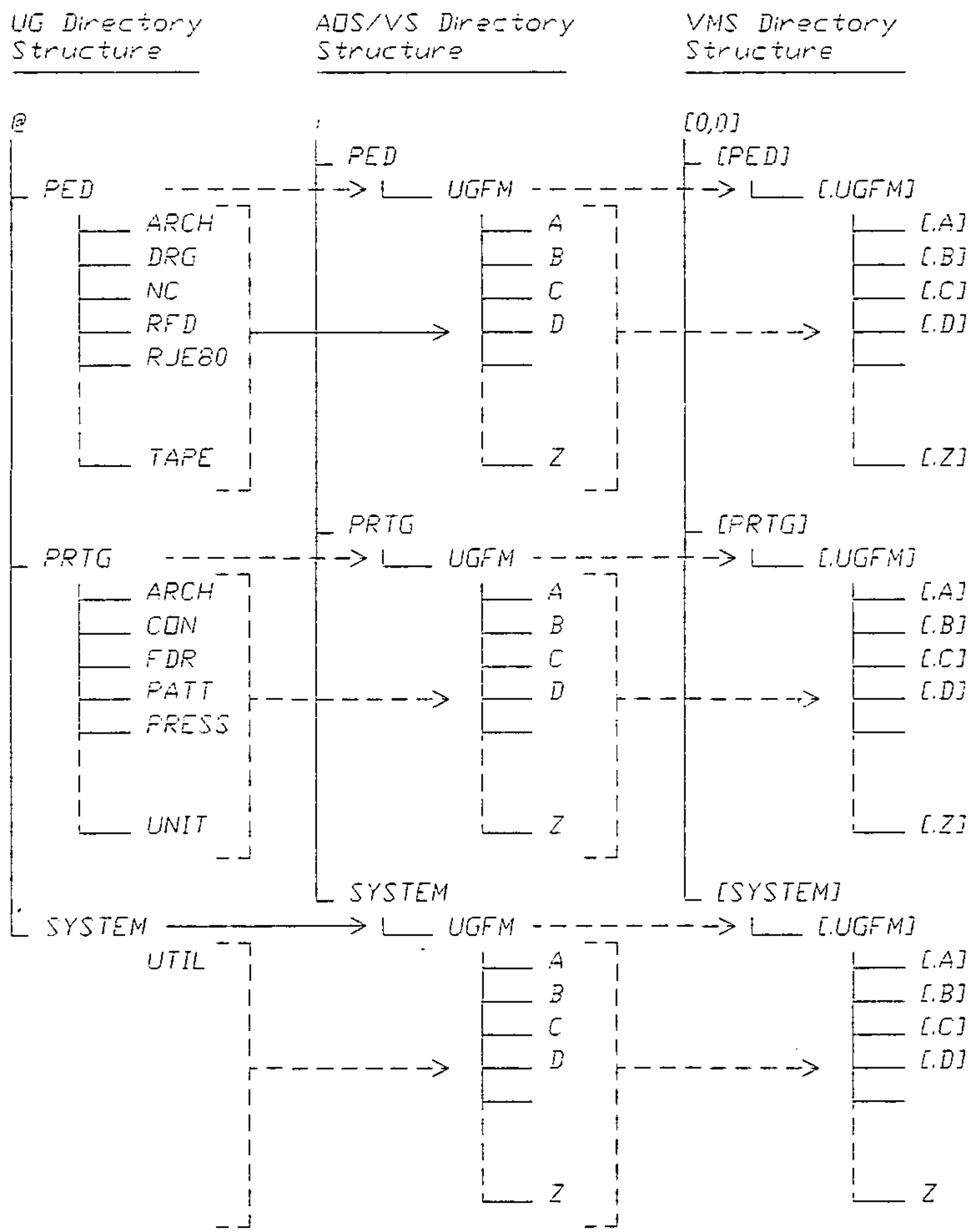
Comparison of Figure 6.2 with Figure 5.3 illustrates that the evolution of the DNC system to provide shopfloor graphics has not needed any change to the information storage facilities at the PC. The only changes necessary have been at the CADCAM and mainframe computers. As discussed above the NC part program and setup diagram information used by the DNC system on the Falcon Burner is stored in a mainframe NC data file and not in CADCAM system files. However the information is stored on the CADCAM computer during the transfer process.

A. CADCAM

The McDonnell Douglas Unigraphics software uses information stored in its own Unigraphics File Management (UGFM) system [UGFM] which is 'built on top' of the existing operating system filing structures. This allows McDonnell Douglas to port the CADCAM software and particularly Unigraphics file management to a number of different hardware platforms whilst giving the user a consistent view of the way his files are stored. Information in UGFM is stored as individual files in a UGFM directory structure which is configurable by the user to suit his application. Figure 6.3 illustrates this approach. The @ directory is the root of the UGFM directory structure on any particular computer. At Rockwell PMC the UGFM structure has then been subdivided into subdirectories for particular user groups e.g. @PRTG is the master Mechanical Drawing Office subdirectory, @PED is the master Production Engineering Department subdirectory. In Data General's AOS/VS [AOS/VS] operating system the @PRTG subdirectory may be actually contained in the :PRTG:UGFM subdirectory, whereas in Digital's VMS [VMS] operating system the same @PRTG subdirectory could point to the VMS [UGFM] subdirectory. Within UGFM the user is then able to create other subdirectories e.g. @PRTG:CON, @PRTG:FDR. These are mapped by the UGFM programs, together with the files they contain, into the native operating system A to Z directories under PRTG as appropriate. The files are evenly mapped through these directories such that each uses approximately the same amount of disk space to optimise disk access times. These files can be stored as either simple text files or binary files, e.g. part files, formatted for use specifically by the Unigraphics software. The actual operating system filename for each UGFM file can be found by using the appropriate Unigraphics routines and therefore the 'host' file can be used directly at operating system level if required.

NC part programs needed by the DNC system are stored on disk in the CADCAM user's directory within the UGFM file structure. These files, in RS358 [Batchelor 1985] text format, are produced and stored during postprocessing of the CL source files. The setup diagrams needed by the DNC system are stored on disk in the host operating system file structure. The files are produced from the appropriate view of the setup sheet, from within the existing Unigraphics part file. The information is stored in text files in a specially designed format consisting of a hexadecimal character representation of the binary data file created using the Unigraphics plot routines. The routines used to create, manipulate and store this information are discussed further below.

Figure 6.3 McDonnell Douglas UGFM Structure



Although text files formatted specifically for this application are used in this implementation, there are again other alternatives available. The IGES [Liewald 1985] [Mayer 1987] and GKS [Weston 1988] standards discussed in Chapter 2 are the most obvious alternatives. IGES would provide for the storage of the raw product data whereas GKS would provide for the storage of the Graphical Image itself (a similar approach has actually been taken here, see below). In this implementation the use of these standard formats is constrained by the lack of suitable software available for the PC and the extra cost involved in providing the software for use on the CADCAM computer.

B. Mainframe

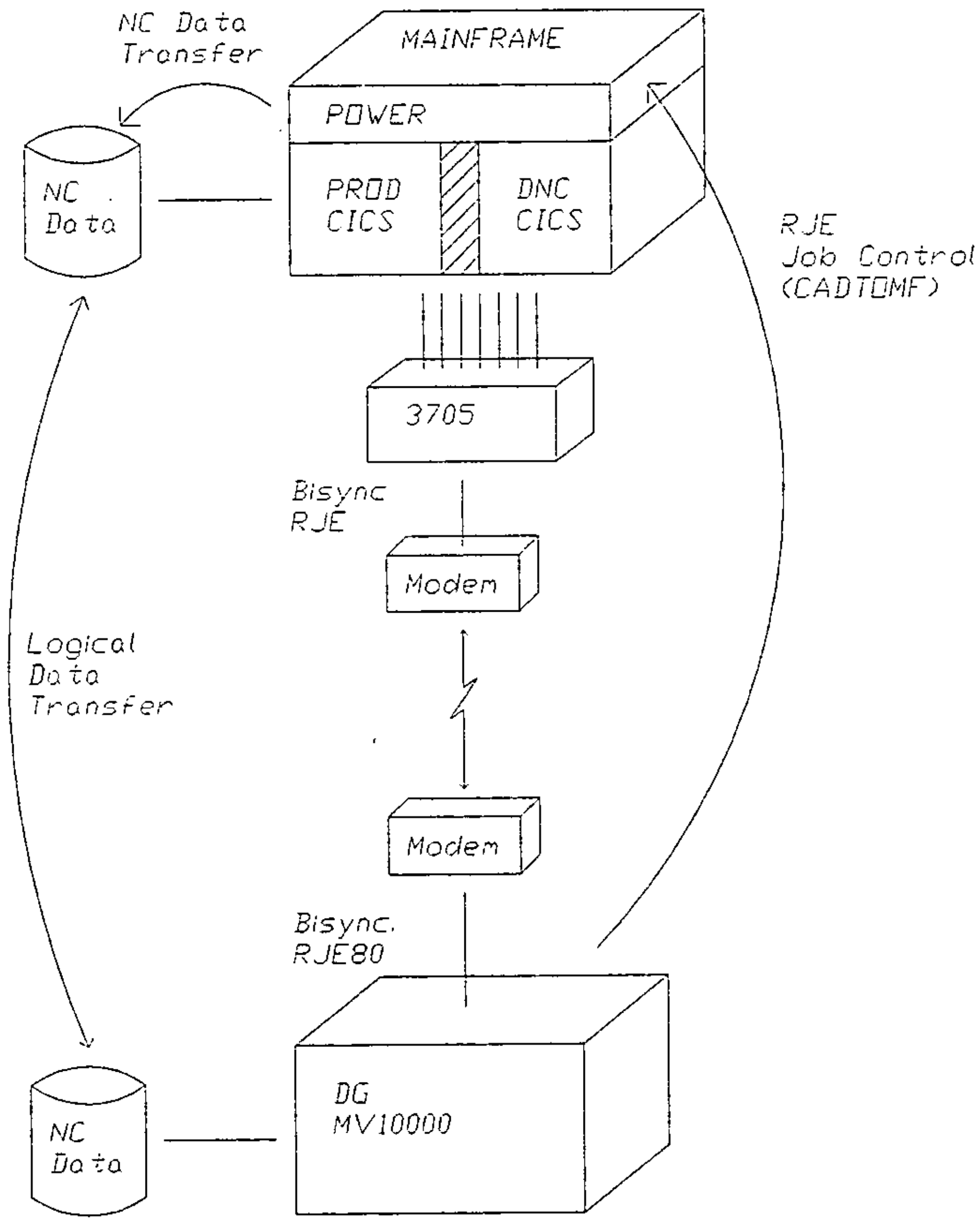
The NC part program and setup diagram information transferred from the CADCAM computer is currently stored on the mainframe in the same form as any other NC data. However a single VSAM [VSAM] data set specifically reserved for CADCAM data has been provided. This data set is separate from those used by the NC part programmers for mainframe text edited files because of the potential for update security problems if the file is accessed by users at the mainframe and at the CADCAM system in a similar way to the interactive and batch updates considered earlier. As discussed in the previous chapter suitable database facilities on the mainframe might provide for an improved information management facililty at this level.

6.2.2 Information Distribution Architecture

Comparison of the three architecture figures as before shows that the only changes made to the information distribution functions involve providing an interface between the CADCAM and mainframe computers. This is based on the IBM Remote Job Entry (RJE) system [Xephon 1989] [RJE]. A synchronous serial interface in the CADCAM computer is linked to the 3705 'front end processor', which provides for remote communications to the mainframe, via a pair of synchronous modems connected by twisted pair cable. The connection therefore is point to point. See Figure 6.4.

The link uses the Binary Synchronous Communications (BSC) protocol [Xephon 1989] for character level data transmission. On top of this the IBM RJE 2780 protocol [RJE80] is used to communicate with the POWER system [VSE/POWER] on the mainframe. Specific information transfer and storage routines have been produced for the mainframe and CADCAM computers as

Figure 6.4 CAD to Mainframe Computer Communications



described below. These routines package the data into a suitable format for transfer using the RJE 2780 protocol routines as stated.

Here also standard file transfer mechanisms such as FTAM [Stuckey 1988] may prove useful in the future. However FTAM provides a file communications mechanism rather than a message services mechanism and so may be difficult to implement in such a situation as the one described here. MMS [Dwyer 1989] may prove to be a better alternative due to its ability to activate and/or coordinate applications programs.

6.2.3 Applications Architecture

Comparison of the three architecture figures as before illustrates some of the changes made for this implementation at the applications level. A number of application programs were written at the CADCAM, Mainframe and PC computers to provide the necessary functionality at each point. However the main programming effort required was needed at the CADCAM system to produce the necessary information in a form suitable for transfer. The programming effort required at mainframe and PC level was substantially less.

The author was responsible for specifying the functionality of all application routines used in the system. In addition all routines used at the PC level were designed and written by the author. The routines used at the Mainframe level were designed and written by members of Rockwell PMC's computer department. The routines used at the CADCAM computer were firstly designed and written by the author to prove out the mechanisms required and then the working programs were designed and written by members of the Computer Aided Engineering Department to provide the final solution.

A. CADCAM System

The programs involved at the CADCAM system allow for the generation of NC part program and setup diagram information, concatenation of this data into a single file for transfer to the mainframe, encapsulation of this transfer file between Job Control Language (JCL) statements which specify how the mainframe system should process the data and routines which ensure that the information is successfully transferred.

B. Mainframe

Programs involved at the mainframe allow for the input of the transfer file and subsequent storage in the CADCAM designated NC data set. The information is then available for transfer to the PC at the Falcon Burner in the same way as the other DNC information.

C. Operator's PC

The programs involved at the operator's PC allow for the transfer of the setup diagram information from the mainframe via the same routines as used for transfer of 'textual' DNC information. The only 'extra' routine required allows for the display of the diagram on the PC screen.

The alternative solutions available for the basic DNC system applications were discussed in the previous chapter. The author is unaware of any other alternative routines particularly with regard to the functionality implemented on the CADCAM system.

The DNC system packages available from commercial vendors, e.g. [Coscom] [RWT], [FACTORYnet-DNC] offer some functionality at the shopfloor level for the display of graphical information on PC hardware and could therefore be used as an alternative to the in house solution described here. At the CADCAM system the DNC product available from McDonnell Douglas [FACTORYnet-DNC] offers some functionality.

6.2.4 Application of Shopfloor Graphics in other Factories

The possible application of the DNC System in other factories has already been discussed in the previous chapter and the conclusions are equally applicable here. The possible implementation of shopfloor graphics external to Rockwell PMC is therefore considered in isolation. The provision of shopfloor graphics is recognised by the author as a generic requirement of the evolution of shopfloor systems towards CIM in many other manufacturing situations. This view is supported for the discrete engineering sector of manufacturing industry by the DNC system vendors who offer shopfloor graphics facilities within their products [Coscom] [RWT].

The problems of transferability of the Rockwell PMC solution to other factories involve the functionality available in all of the three architecture levels which relate to the CADCAM system and to the information distribution facilities between this system and the master data store. The routines written for the solution described here are produced specifically for the Unigraphics environment. Hence these aspects of the system (together with those already considered in the previous chapter) may well have to be replaced by other equally specific routines for other CADCAM environments.

The problems of transferability of the shopfloor graphics system described here to a different environment coincide with those recognised in the previous chapter for the DNC system. These problems again relate directly to different computer hardware and software standards used by vendors and point to the need for a rapid acceptance of commonly recognised standards by these different vendors.

6.3 CADCAM Programs

The programs used on the CADCAM system have been written wherever possible to allow for their use in the creation and transfer of information for any of the machines on the shop floor as required, even though they are currently used only for Falcon Burner information. Figure 6.5 illustrates the facilities provided for the NC part programmer at Applications Architecture level.

6.3.1 Creation of NC Part Program Files

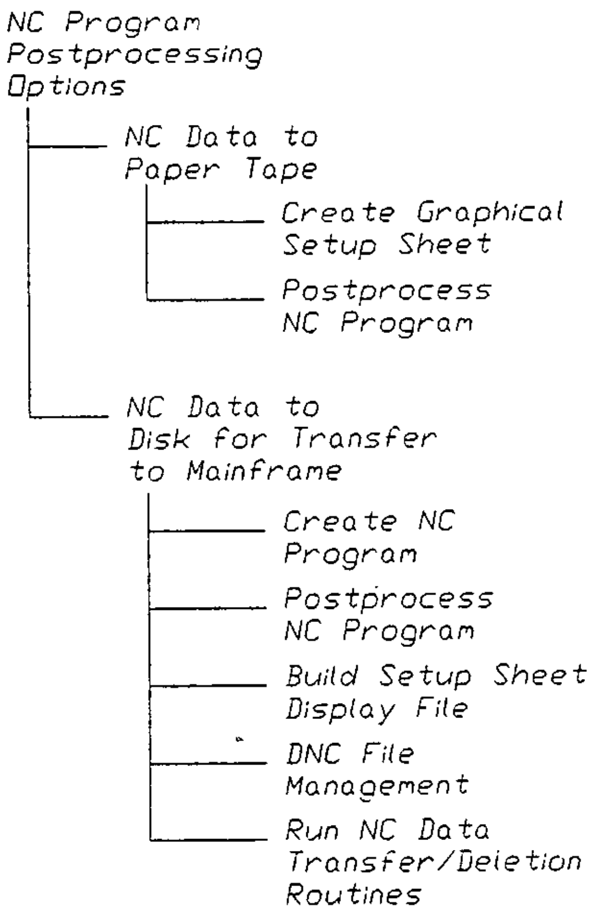
Existing routines are used for the creation of NC part program information. The only modification to these routines needed was to provide the programmer with the option to output information generated by the post processing programs directly onto paper tape or to store it on disk in a UGFM text data file as required.

6.3.2 Creation of Setup Diagram Files

Prior to this work the setup diagrams used by the Falcon Burner operators were produced by 'dumping' a setup sheet view directly from the screen of the CADCAM terminal to a Hard Copy Unit. The setup sheet views themselves are stored within the existing Unigraphics part file.

Instead of producing the hard copy diagram from the screen view a routine written in the Unigraphics GRaphics Interactive Program language (GRIP) [GRIP] is used to create an 'image' or 'plot' file which is stored on disk within the UGFM file structure. The information file stored is in a binary Unigraphics format and is equivalent to the file created when the normal plot routine is used

Figure 6.5   NC Programmers Applications Routines



for output of an A6 size image to the plotter. The Unigraphics plot file format, described in Appendix C, is a representation of the graphical screen image, comparable to the GKS standard, rather than a part file format such as IGES, as noted above, and was used because it is standard routine available within the existing Unigraphics routines.

Although the RJE protocol transport mechanism (if used in 3780 mode [RJE80] rather than 2780 mode) allows for the transmission of binary data to the mainframe the DNC transfer routines (using 3270 protocols) only allow for the transfer of normal 'printable' ASCII character text data to the PC. The GRIP program therefore also includes a routine to convert the binary plot information and store it in a data file containing a specially formatted 'hex representation' of the original data values e.g. the original binary data value ASCII 1Eh is stored in the formatted file as the characters '1' and 'E'. This does obviously double the size of the data file required, however the file sizes are relatively small and this overhead is not a problem. The formatted files are stored by the GRIP routine within the computer operating system file structure directly rather than within the UGFM structure to allow for quicker retrieval by the information distribution routines.

6.3.3 Creation of the Mainframe Job Control File

The creation of the Job Control File (JCL) needed by the mainframe involves the concatenation of all NC and setup information files which are ready for transfer. The NC information files as described are stored within the UGFM structure and so a routine is needed to extract these files from within UGFM and store them within the transfer file in the operating system file structure. Setup diagram files are already available and can therefore be concatenated straight into the transfer file.

This concatenated information is then encapsulated within a number of JCL statements which specify the way the data should be processed by the mainframe job reader system. Figure 6.6 shows the form of the encapsulated file.

6.3.4 Transmission of the JCL Transfer File

The transmission of the transfer file involves the use of the Data General RJE80 program [RJE80]. In order to use this a routine was created using GRIP which starts up the Data General bisynchronous communications program GSMGR [AOS/VS] followed by the RJE80 program. GSMGR provides supporting protocol communications layers for the RJE80 application routines. Hence the transfer can be activated by the CADCAM programmer from within the Unigraphics environment. The RJE80 program allows for the use of IBM Remote Job Entry routines with either 2780 or 3780 protocols. In this case the simpler 2780 protocols are used because the data for transfer is in text format.

Specially written Fortran programs are used via the GRIP routine to establish communications with the mainframe and transfer the information. This involves sending 'Signon' JCL followed by transfer of the data file itself when the mainframe acknowledges. Once the file is transferred 'Signoff' JCL can be transmitted to terminate the communications session [RJE].

Routines are also available to delete existing data files from the mainframe data set if they become superfluous.

Figure 6.6 CAD to Mainframe Data Transfer File

```
* $$ JOB CADTOMF,,,A                          ! Job run in batch partition A
* $$ PRT DA,1PT                               ! One listing file released on demand
// JOB CADTOMF                                ! Job name
// DLBL DOUT,'CAD NC TRANSFER',N,K,R,T=20     ! Stores data in temporary file
// EXEC OP14                                  ! reserving 20 disk tracks
CD    80   80  80  80
// FS 1,80,1
// END
{start of data}
%                                             ! Start of new data file
S23-762885-010-1                              ! Part program file name for m/c S23
N10....                                       !
N20....                                       ! NC machine control functions
N......                                       !
%                                             ! Start of new data file
S23S-762885-010-1                             ! Setup diagram file name for m/c S23
01....                                        !
....                                          ! Unigraphics plot file data
....                                          !
{end of data}
/*
// DLBL CADIN,'CAD NC TRANSFER',0,D           ! Reformats data file contents
//DLBL NCOUT,'CAD FILE',N,K,R,T=10,B=9360     ! and stores in new temporary file
// EXEC NC44
/*
// DLBL SDIN,'CAD FILE',0,D                   ! Stores data file contents
// UPSI 11
// DLBL PROGDS,'PMC.KTAPE.DATA.SET',S         ! in PMC CADCAM NC data set
// EXEC NC09
/*
/&
*  $$ EOJ
```

Figure 6.7 CAD to Mainframe Data Transfer Output Listing

```
***SPMBATCH***     <DELETE>CS23 762885      0101
CS23 762885      0101    PROGRAM DELETED

***SPMBATCH***     <COMPRESS>
CS23 762885      0101    PROGRAM ADDED TO COMPRESSED LIBRARY       CARDS = 0025

***SPMBATCH***     <DELETE>CS23 762885      0101
CS23S762885      0101    PROG NOT IN DIRECTORY

***SPMBATCH***     <COMPRESS>
CS23S762885      0101    PROGRAM ADDED TO COMPRESSED LIBRARY       CARDS = 0119
```

N.B. CARDS = 0025 indicates that 25 records or lines of information were added to the NC data set.

6.3.5 Confirmation of Successful Transfer

The CADCAM routines also allow for the confirmation of successful information transfer by reading the job listing file, produced by the mainframe when the transfer file is processed, and checking that the data transmitted has been stored in the mainframe NC data set. Figure 6.7 illustrates the file format.

The listing file is always checked before any new information is sent to the mainframe. The CADCAM communication routines are set up so that if the mainframe processes the transfer file quickly the listing file is retrieved and checked before the transfer communications session is terminated, otherwise the listing file is retrieved during the next communications session before any new transfer is permitted.

6.4 Mainframe Programs

As indicated above the amount of effort required in mainframe programming has been kept to a minimum by using the standard IBM RJE 2780 data transfer routines. This transfer mechanism allows for the submission of suitable Job Control statements into the mainframe reader queue which are then processed in a batch partition. No ISO standard mechanisms are yet available which will allow for this process and so there was no alternative but to use the proprietary routines. In addition these routines had already been used in a number of different applications and were therefore 'tried and tested'.

The JCL file transferred into the reader queue corresponds to a job file, as shown in Figure 6.6, containing a number of discrete routines which the mainframe executes sequentially:

(i) The OP14 program reads JCL input and stores the encapsulated information in a temporary disk file for subsequent processing;

(ii) The NC44 program then reformats the transferred information into a suitable form for storage in the NC data set;

(iii) The NC09 program takes the formatted data and stores this in the NC data set, performing data compression and updating the file index as appropriate.

OP14 and NC09 are general purpose data manipulation routines which already existed and are used in many other programs. NC44 was specially written for the CADCAM transfer mechanism to deal with the specific data format of the transfer file created by the CADCAM system. NC44 first of all deletes any existing data file with the same name as the file transferred before adding the information into the data set as requested, see Figure 6.7.

A second mainframe data manipulation routine NC57 has also been produced to allow for the deletion of data from the mainframe data set as appropriate. The JCL format of the CADCAM transfer file is similar to that for the data storage routines. The only difference is that the encapsulated transfer information contains only NC data file names and NC57 is executed instead of the NC44 program.

6.5 Operator's DNC Programs

Modifications made to the existing DNC system programs were limited to those needed to allow for the display of graphical information on the PC screen. The mainframe data extraction and transfer routines did not need to be altered at all because the setup diagram information is stored in text format in a mainframe NC data set as described above in exactly the same way as the textual setup information used by the other DNC machines.

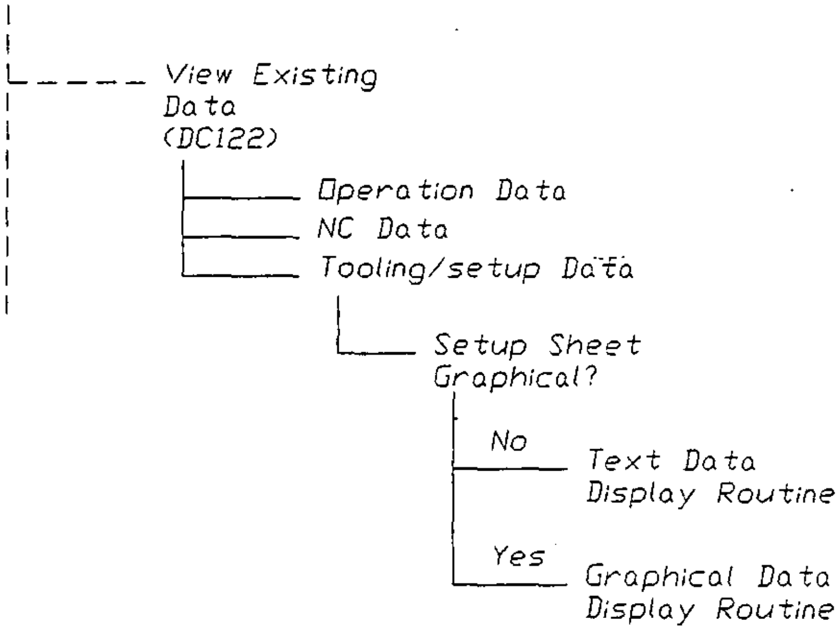
The DNC 'setup information display routine' is now configured to check the machine type set in the parameter file and route the display request to either the textual display or graphical routine as appropriate, see Figure 6.8.

The graphical display routine, written by the author, reads the characters in the setup information file and decodes the 'two character hexadecimal' representation produced by the CADCAM program back into the binary plot file data values. These binary values are then decoded using the Unigraphics plot file format described in Appendix C to drive screen display routines which reproduce the necessary image of the original diagram on the PC screen, see Figure 6.9. This can be compared with the original hard copy version shown in Figure 6.1.

6.6 Benefits

The benefits of the implementation of the DNC system on the Falcon Burner are similar to those recognised in the previous chapter for the machines in the Shaft Line area. The specific benefits of the evolution of the DNC system to provide

Figure 6.8 Changes to DNC Routines for Falcon Burner



shopfloor graphics facilities are difficult to quantify in isolation. However the application of the DNC system on the Falcon Burner without routines providing displays of graphical setup sheets on the PC would have been of little advantage.

The particular benefits of this implementation include improved response by the NC programmers because of a reduced need to travel the large distance involved between the NC part programming area and the Material Centre to overcome problems; elimination of the difficulties related to reading the large NC part programs using paper tape and the virtual elimination of NC part program and setup diagram storage by the machine and marshalling difficulties associated with keeping this information synchronised with the master information.

Further potential benefits which have not yet been realised include the possibility for shopfloor component graphics in general which would allow for the virtual elimination of shopfloor paperwork. In addition it may be possible to use the graphical information available for each component to provide suitable PC application routines for the Falcon Burner which may help the machine operator to optimise the cutting and use of material by 'nesting' a number of suitable components on each plate [Wildish 1986].

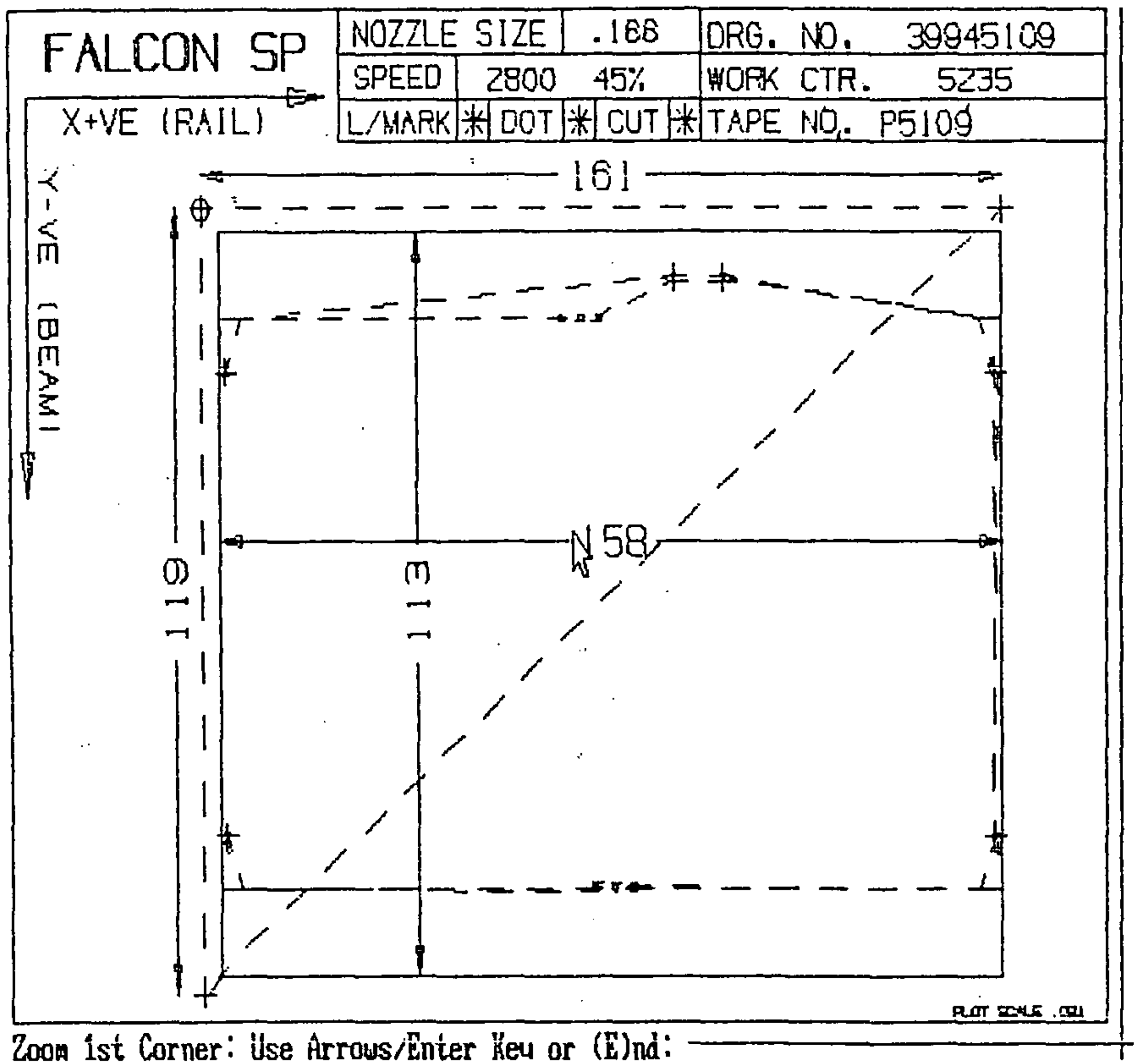


Figure 6.9 Operator Setup Sheet Display

6.7 Summary

This chapter has described the evolution of the Distributed Numerical Control system at Rockwell PMC to provide for an interface with CADCAM and the specific implementation of this system on the Falcon Burner in the Material Centre. This enhancement of the original facilities provides for the display of graphical setup information generated by the CADCAM system on the shopfloor for use by the operator and paves the way for the transfer of any graphical information such as component drawings. The solution implemented has again been specific to the needs of the company with respect to the hardware and software used but as before offers a partial solution for similar implementations at other manufacturing facilities. Again 'off the shelf' products have been used to simplify the solution. The basic concepts for transfer of graphical information and enhancement of system functionality for shopfloor personnel have been identified as a generic requirement for the overall implementation of CIM.

The specific implementation work has again led to the recognition of constraints which are generic in nature. These relate particularly to the information available from CADCAM systems but also to the different standards adopted by the various computer system vendors and the difficulty in using the available products to realise CIM implementation in general.

The implementation of a DNC system on the Falcon Burner has provided real benefits including improved response by the NC programmers; elimination of the difficulties of using paper tape and the virtual elimination of information storage at the machine in addition to the general benefits discussed in the previous chapter.

CHAPTER 7

Phase 2 Cell Management System Implementation

7.1 Introduction

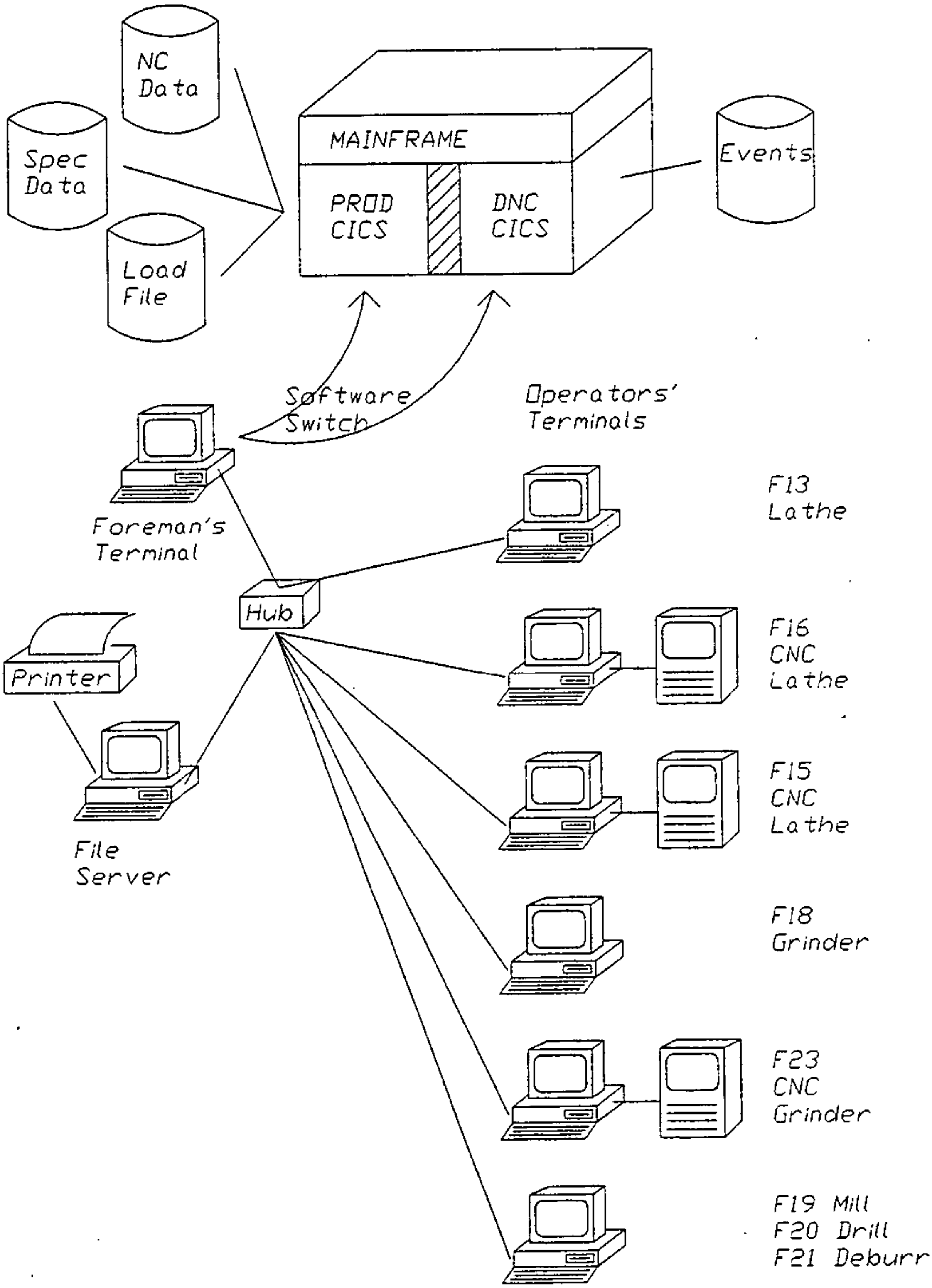
This chapter describes the second phase of the evolution of a machine shop management system hierarchy at Rockwell PMC. The work has involved the specific implementation of a Cell Management System (C.M.S.) in the shaft line. This implementation forms a part of the overall goal at Rockwell PMC for the creation of the linked business system, described previously, with the aim of maximising the potential benefits of low cost small batch production whilst retaining flexibility and reducing cycle times. The specific aim of this implementation is to help the decision making processes involved in cell operation with particular regard to the control of work flow around the cell while retaining the foremen as the overall control mechanism by providing them with suitable application routines to aid the decision process. The system is also aimed at providing independence from the mainframe systems for appropriate periods of time so that the downtime associated with these mainframe systems has a limited effect on the foremen's ability to control the cell. However it is still important that the cell system is integrated fully with the existing and developing manufacturing control procedures available through the mainframe systems and also with the functionality created by the DNC system as described in the previous chapters.

The system has been produced as an extension to the initial DNC system installed on the Heid Lathe. However after initial work on the evolution of the system it was decided that, contrary to the initial four stage plan described previously, a machine management system covering a single machine would be unworkable in a real production environment since the single machine is not independent of the others in the cell. Therefore this phase involved the extension of the single machine DNC system on the Heid Lathe to a C.M.S. covering all of the workstations in the shaft line including both NC and manual machines.

7.2 C.M.S. Configuration

The specific nature of the shaft line cell management system is described in detail in Appendix D and its configuration is illustrated in Figure 7.1.

Figure 7.1 Cell Management System Configuration



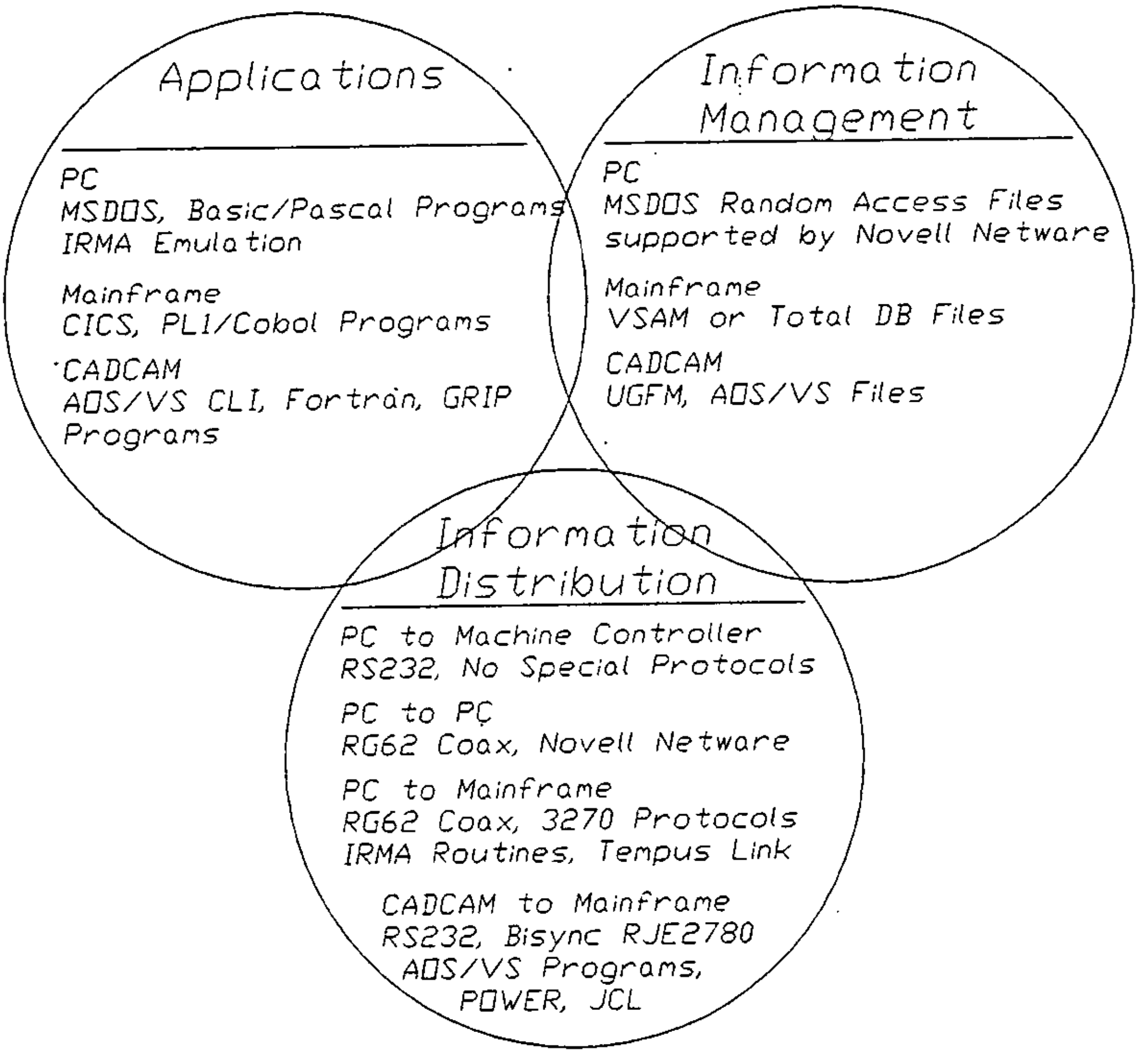
The system installed in the shaft line consists of eight IBM compatible PCs which are linked together in a local area PC network. One PC acts as an intelligent terminal for the cell foremen, six as terminals for the operators and the other PC on the network acts as a dedicated File and Print Server. The user PCs need only be low cost 'diskless network workstations' since they need no local disk storage facilities. The foremen's PC acts as the 'gateway' between the mainframe and cell level systems. It also provides a consistant interface between the foremen and the C.M.S. functionality. The six operator PCs are shared between the ten workstations / machines within the cell. One PC is located at each NC machine and used by the NC operator exclusively whereas the manual machines share suitably located PCs as appropriate. The current estimates of the number of PCs which may be involved in the potential implementation of the C.M.S. in other group technology cells within the Rockwell PMC machine shop varies between three and thirteen.

The IBM PCs used by the operators function at the M.M.S. level and the Mainframe at the F.M.S. level of the Rockwell PMC hierarchy. These levels correspond to the Workstation and Facility levels of the ISO hierarchy as described in the previous chapters. The IBM PC used by the foremen functions at the C.M.S. level of the Rockwell PMC hierarchy, corresponding to the Cell level of the ISO hierarchy, thus completing the three level hierarchy proposed by Rockwell PMC in the original system specification.

As before the set up and potential of the system is suitably illustrated in Figure 7.2 in the form of the three architecture model which shows the actual information management, information distribution and applications architectures implemented for comparison with the previous implementation stages. It can be seen that the functionality of the DNC system has been extended or changed as necessary in certain areas to allow for the evolution of the DNC system into the C.M.S. Where appropriate alternative solutions are again discussed.

The author continued to be responsible for managing the implementation and for the overall design of the changes required in addition to parts of the detailed program design as explained below. As in previous system implementations the shopfloor foremen and machine operators have been fully involved in the system design with regard to the required system functionality and visible user interfaces. The successful implementation of the C.M.S. has depended particularly on ensuring the full cooperation of the foremen, by providing them with control

Figure 7.2 Three Architecture Model of Cell Management System



functions which they consider necessary, and of the operators, by allaying any fears of 'big brother' with regard to the reporting of job status at the machines. Maintaining full involvement of these system users has been of considerable importance in this system implementation.

7.2.1 Information Management Architecture

The information management architecture involves specific data files controlled and accessed separately by the user PCs and the mainframe computer.

The files involved at the machine operators' PC level are based directly on the files used in the original DNC system and are concerned with the jobs that are actually being worked on at the machine or those which are due to be worked on in the near future.

The files used by the foremen's PC have been newly designed for the C.M.S. by the author and are involved with information describing the whole cell operation. These include files describing the cell set up and shift working patterns, job priorities, routing and operation information for all jobs which are physically in the cell either in buffer stores or on the machines.

At the mainframe level the same files involved in the DNC system are again used. These hold information about job status and priority; operation specification and routing; part programs; tooling / setup and DNC events. In addition Tempus Link [Tempus Link] files are used by the data transfer mechanism between the mainframe and the cell systems as discussed below.

The functions used in this implementation have again been constrained by the circumstances at Rockwell PMC. However other information management systems as discussed in Chapter 5 may be even more appropriate at this stage of the implementation. In particular since PC network technology has been applied at this stage the available PC based SQL database servers [Finkelstein 1989] [SQL 1990] could possibly be used to good effect by building on the functionality of stand alone database products in order to centralise the search, retrieval and data processing functions required by user workstations and provide an even more secure information management platform for such systems. The evolution of distributed data base technology [Date 1986] (and associated information distribution functions) would also have a beneficial effect on the availability and access of master data used by the shopfloor by providing for the integration of data between the shopfloor computer systems and the mainframe. For example the INGRES [Morris 1989] suite of products are designed to provide distributed relational database facilities over networks including DECnet, TCP/IP, SNA and Novell Netware. The planned future evolution of the C.M.S. will involve the replacement of the special purpose files described above by suitable database products to provide a more secure information management platform as discussed later in the thesis.

7.2.2 Information Distribution Architecture

At this level the interfaces between the devices involved are either Local Area Network connections or point to point links. The user PCs are linked to the cell system file server (and to each other) using RG62 coaxial cable in the Arcnet [Conner 1988] networking topology using Novell network protocols. The foremen's PC is linked to the mainframe via a standard IBM 3274 controller with RG62 coaxial cable using IBM 3270 synchronous protocols.

This link is based on the use of the foremen's PC in mainframe terminal emulation mode acting as a gateway between the C.M.S. and F.M.S. levels in a similar way to the link in the DNC system. However the Tempus Link file transfer mechanism is used as well as the raw IRMA interface. The data extraction programs are also run from Novell menus [Netware], see below, at the foremen's PC and continue to initiate mainframe transactions as necessary to extract data from the mainframe files. However this data is then stored in a transient form in the Tempus Link virtual disk system before being transferred down to the PC via the Tempus Link file transfer utility as illustrated in Figure 7.3. This is discussed in more detail in Appendix D.

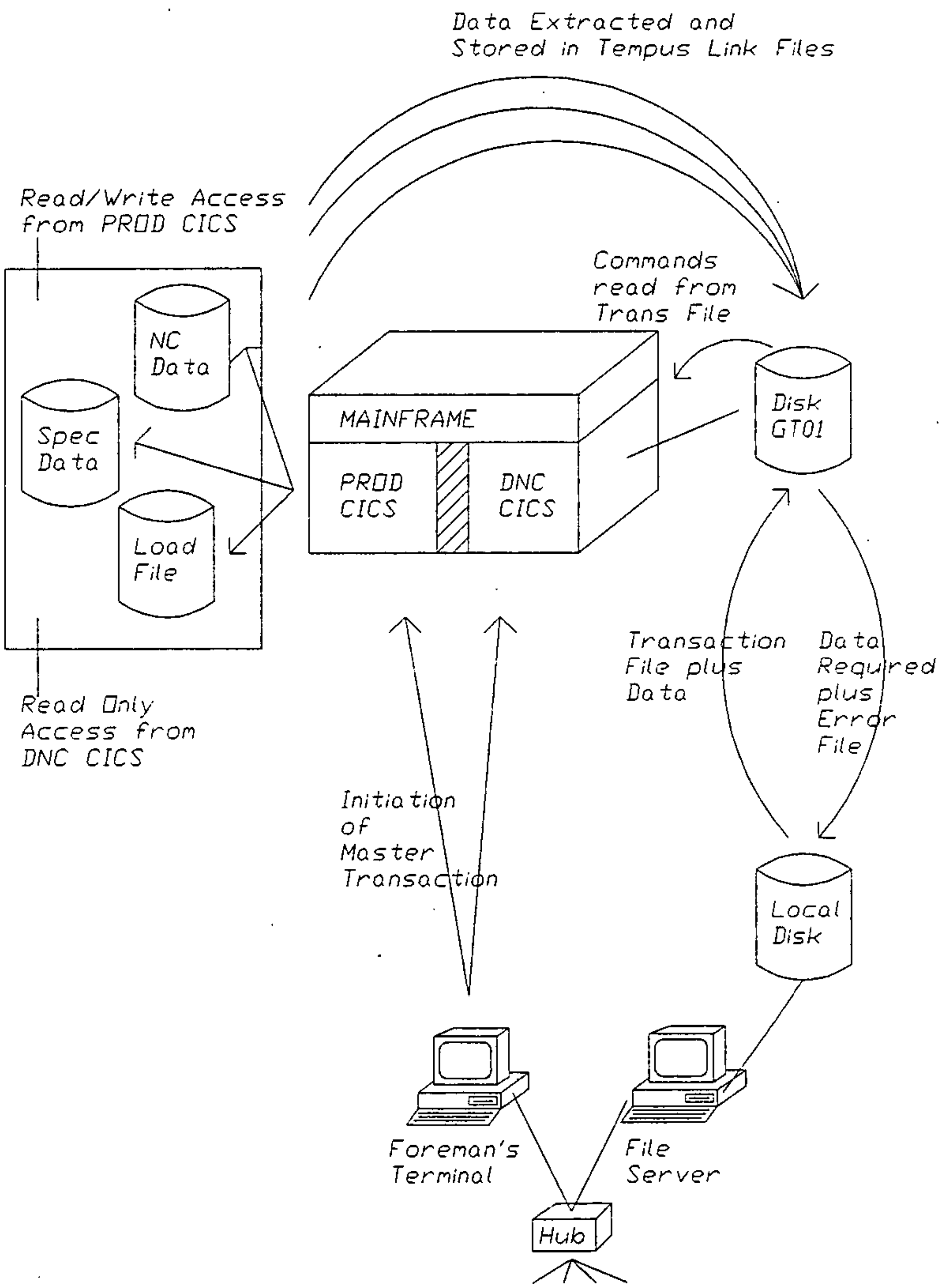
The PC interfaces to the CNC units of the machines have not changed from the DNC system implementation and remain standard RS232 cable using character oriented asynchronous data transfer.

Alternative information distribution tools could again have been used. In Rockwell PMC other specific file transfer products could have been used between the PC and the mainframe [Finkelstein 1988]. In addition communications products available for the PC and some minicomputer systems which conform to the ISO/OSI and MAP/TOP reference models are becoming available [Paranuk 1988]. The FTAM [Stuckey 1988] and MMS [EIA 1987] services described in Chapter 2 may also be of benefit in future applications. IBM have announced MAP Version 3.0 MMS products for Mainframe VM and PC OS/2 compatible computers which are due to be released during 1990 [IBM 1989]. The routines used to transfer information from the mainframe to the C.M.S. have been written wherever possible to allow for their replacement by the accepted standard functions at a later stage as discussed below.

7.2.3 Applications Architecture

The implementation of the C.M.S. in the Shaft Line involved the creation of suitable application programs for the machine operators and the foremen which operate at the M.M.S. and C.M.S levels of the Rockwell PMC hierarchy respectively. The programs have been written in Basic or Pascal as appropriate to the functionality required. However the programs have all been compiled independently of each other and are run from Novell menus rather than as the

Figure 7.3 Initiation of Mainframe Transactions via Tempus Link



interlinked routines used in the DNC system. This allows for easier reconfiguration of the applications level e.g. insertion of appropriate external vendor routines as well as in house upgrades and modifications.

The author remained responsible for specifying the functionality of all application routines used in the system. In addition many of the routines used at the PC level were designed and written by the author. After initial implementation a member of Rockwell PMC's Computer Aided Engineering department assumed the responsibility for the detail design and programming of further routines for the foremen as described below. The routines used at the Mainframe level were designed and written by members of the computer department.

The C.M.S. application programs are run independently at either the user PC or mainframe levels. As with the DNC system the link between the two levels is based on the use of a PC in mainframe terminal emulation mode but using the Tempus Link file transfer mechanism as well as the raw IRMA interface. Again the PC is the initiator of each applications program on the appropriate computer system as described above.

Figure 7.4 shows the menu used by the cell foremen. This menu provides the necessary functionality for the control of the total cell operation including routines to download information from the F.M.S. to the C.M.S. level and to control the flow of work around the cell by changing the status of job operations as required in addition to several other routines geared to specific functions. A 'second level' help menu is available as shown in Figure 7.5. Choosing any of the routines from this menu provides the foremen with textual instructions describing the functionality and use of each of the master menu options. Figures 7.6, 7.7 and 7.8. illustrate how the Cell Data Status program can be used to display the current status of operations on any of the machines within the shaft line as well by selecting the appropriate machine. Selecting Machine 00, WCen GT01 and then (T)otal work on Figure 7.7 provides a display involving all the workcentres within the cell as shown in Figure 7.8. By choosing the status value required on the screen shown in Figure 7.7 a selective display, e.g. of completed work only, will be created. Figure 7.9 shows an example of the display produced by the Create Projected Schedules option on the Foremen's menu. This illustrates the projected machine loading based on the job operation statuses current in the cell files. Each job is shown as a different letter of the alphabet in the figure. However these are shown as coloured symbols on the actual display produced helping the foremen to

Figure 7.4 Cell Foremen's Applications Menu

```
Novell Menu System  V1.22                      Wednesday  7 March 1990  8:30 am

        Rockwell PMC Cell Management System

   ..  Auto Updates & Deletions
   01. Transfer Cell Data from Mainframe
   02. Mainframe Live Load Op Completions
   03. Delete Completed Jobs from Cell Files
   04. Cell Data Status
   05. Set Holds On NC Part Programs
   06. Clear Holds On NC Part Programs
   07. Download New NC Part Programs
   08. Download Via Contract Number
   09. Create New Contracts (Yellow Peril)
   10. Create Projected Schedules
   11. View Machine Events
   12. View Machine Status
   13. Help Menu (F1 key for menu system help)
   [Press the two Shift Keys for Mainframe Mode]
```

Figure 7.5 Cell Foremen's Help Menu

```
Novell Menu System  V1.22                      Wednesday  7 March 1990  8:30 am

        Rockwell PMC Cell Manag
                                               CMS Help Menu
   ..  Auto Updates & Deletion
   01. Transfer Cell Data from  01. Data Extraction
   02. Mainframe Live Load Op   02. Live Load
   03. Delete Completed Jobs f  03. Data Deletion
   04. Cell Data Status         04. Cell Data Status
   05. Set Holds On NC Part Pr  05. Set Holds
   06. Clear Holds On NC Part   06. Clear Holds
   07. Download New NC Part Pr  07. NC Replacement
   08. Download Via Contract N  08. Download Via Contract Number
   09. Create New Contracts (Y  09. Create New Contracts (Yellow Peril)
   10. Create Projected Schedu  10. Scheduling
   11. View Machine Events      11. Machine Events
   12. View Machine Status      12. Machine Status
   13. Help Menu (F1 key for m  13. Overall Cell System
   [Press the two Shift Keys f
```

Figure 7.6 Cell Data Status: Entry Screen

ROCKWELL PMC CELL MANAGEMENT SYSTEM

Machine: | WCen: | Operator:

Cell Data Status Display

M/c No	WCen	Machine Description	Current Operator
00	GT01	Shaft Line	Dave Chambers
01	F10Q	Face and Centre	
02	F11Q	Straightener	
03	F13	Ramo Lathe	Gary Clarke
04	F15	Heid Lathe.	Ian Fowler
05	F16	Heid Lathe.	Roger Boon
06	F18	External Grinder	Derrick Sugden
07	F19	Vertical Mill	Jack Taylor
08	F20	Radial Drill	
09	F21	Deburr Identify Pr	

Status | Choose Machine using Cursor Pad Keys, (S)elect or (E)nd.

Figure 7.7 Cell Data Status: Choose Status Screen

ROCKWELL PMC CELL MANAGEMENT SYSTEM

Machine: 00 Shaft Line | WCen: GT01 | Operator: Dave Chambers

Cell Data Status Display

Status | (T)otal, (Q)ueued, (L)oaded, (A)ctive, (C)ompleted Work or (E)nd

Figure 7.8 Cell Data Status: Total Status Screen

```
                    | ROCKWELL PMC CELL MANAGEMENT SYSTEM |
| Machine: 00 Shaft Line          | WCen: GT01 | Operator: Dave Chambers    |
                    |    ALL Work: Total Cell Jobs =  62  |

 Job PWC No  Prty  Qty Part Number   Part Descr      OpNo WCen Tot Time Status
▲
   1 M 70844  1487  2       753718 HARMONIC GEAR S  20  F16B    0.78  complt
                                                    30  F11Q    0.00  complt
                                                    40  F18     0.93  active
                                                    50  F13     0.78  loaded
                                                    60  F19     1.21  loaded
                                                    70  F21     0.13  loaded
   2 X338819  1475  3       757999 SHAFT            10  F13     0.97  queued
                                                    20  F19     1.17  queued
                                                    30  F21     0.32  queued
   3 M 61450  1473  2       751037 NIP ROLLER       50  F15     1.85  loaded
▼
                         Hours Available: 171.96     Hours Selected: 0.00

| Status | Use Cursor Pad: (P)rint, (C)omplete, (D)elete ALL OPS :-> more     |
```

Figure 7.9 Cell Jobs Gaunt Chart Display

```
      Projected Schedules for  61 Jobs on 11 Machines
  1 |                     ----            ----   | Plot Start:    8.30 |
F10|                                             | ( 8.30 min) (hh.mm)|
  2 |                     ----            ----   | (56.30 max)         |
F11|                                             | Plot Scale:   10    |
  3 |AAAAAJJJJKKKKBBBBBBBB----BBBBBBBBBBBBBBBBBBB----  | (5,10,15,30,60mins)|
F13|                                             | First M/c :    1    |
  4 |CCCCCCCCCCCCCCCCCCCCC----DDDDDDDDDDDDDIIIII----   | (11 max)            |
F15|                                             |---------------------|
  5 |EEEEEEEEEEEEEEEEEEEEE----EEEEEEEEEEEEEEEEEE----   |                     |
F16|                                             |                     |
  6 |FFFFFFFFFFFFFFGGGGGGGG----GGGGGGGGGGGGGGGGGG----  |                     |
F18|                                             |                     |
  7 |GG    AAAAAAAAFFFFFFFF----FFFF            ----   |                     |
F19|                                             |                     |
  8 |                     ----            ----   |                     |
F20|                                             |                     |
  9 |         K           ----     H      ----   |                     |
F21|                                             |                     |
 10 |BBBBKKKKKKKJJJJJJJJJJJ----CCCCCHHHHHHHHHDDDDD----  |                     |
F23|                                             |---------------------|
   +++++++++++++++++++++++++++++++++++++++++++++ | some ops not shown  |
     9    10    11    12    13    14    15    16    17 | due to scale chosen|
  Day 1
1 Alloc 2 Scale 3  Job  4 % Use 5 Sdisp 6 Udisp                  10 Exit
```

easily follow the route taken through the cell by a given job's operations. The normal status change sequence for operations within the cell is described in Appendix D and illustrated in Figure 7.10.

Figure 7.11 shows the NC operator's menu. The options in the NC operators menu are based directly on those already available within the DNC system. The main changes involve the extraction of operation information from the C.M.S. files rather than the mainframe and the inclusion of operation status reporting routines as illustrated in Figure 7.12. The manual machine operators menu, Figure 7.13 contains a subset of the functions available to the NC operator including only those which serve useful purpose to these operators.

All of the routines are discussed in some detail in Appendix D.

7.2.4 Application of the C.M.S. in other Factories

The C.M.S. described here has been implemented to meet the specific requirements of the Rockwell PMC machine shop. However parts of the system could certainly be used without change by other factories within the Rockwell Corporation or indeed by other companies, although this would probably be limited to those factories operating similar machining facilities for the manufacture of discrete components.

The problems of transferability of the Rockwell PMC Cell Management solution to other factories are similar to those recognised for the DNC system previously. The main issues again involve the functionality available within the Information Distribution Architecture and its interaction with those aspects of the Information Management Architecture relating to the storage of the 'master' information. The basic PC network C.M.S. could be used with little change as the 'vehicle' for a cell control system in other discrete component manufacturing situations. As discussed in Chapter 5 the information distribution facilities used between the PC and the machine controllers for NC information transfers would probably have to be replaced by 'site specific' routines. However the provision of a suitable information distribution facility between the PC network and the master information store would obviously depend on the differences in the Information Management Architecture at the master store. In addition the specific applications routines made available to the foremen and operators at Rockwell PMC may not necessarily be appropriate for the way in which other companies operate their machining facilities. However the use of menus to initiate the

Figure 7.10 Job Operation Status Values

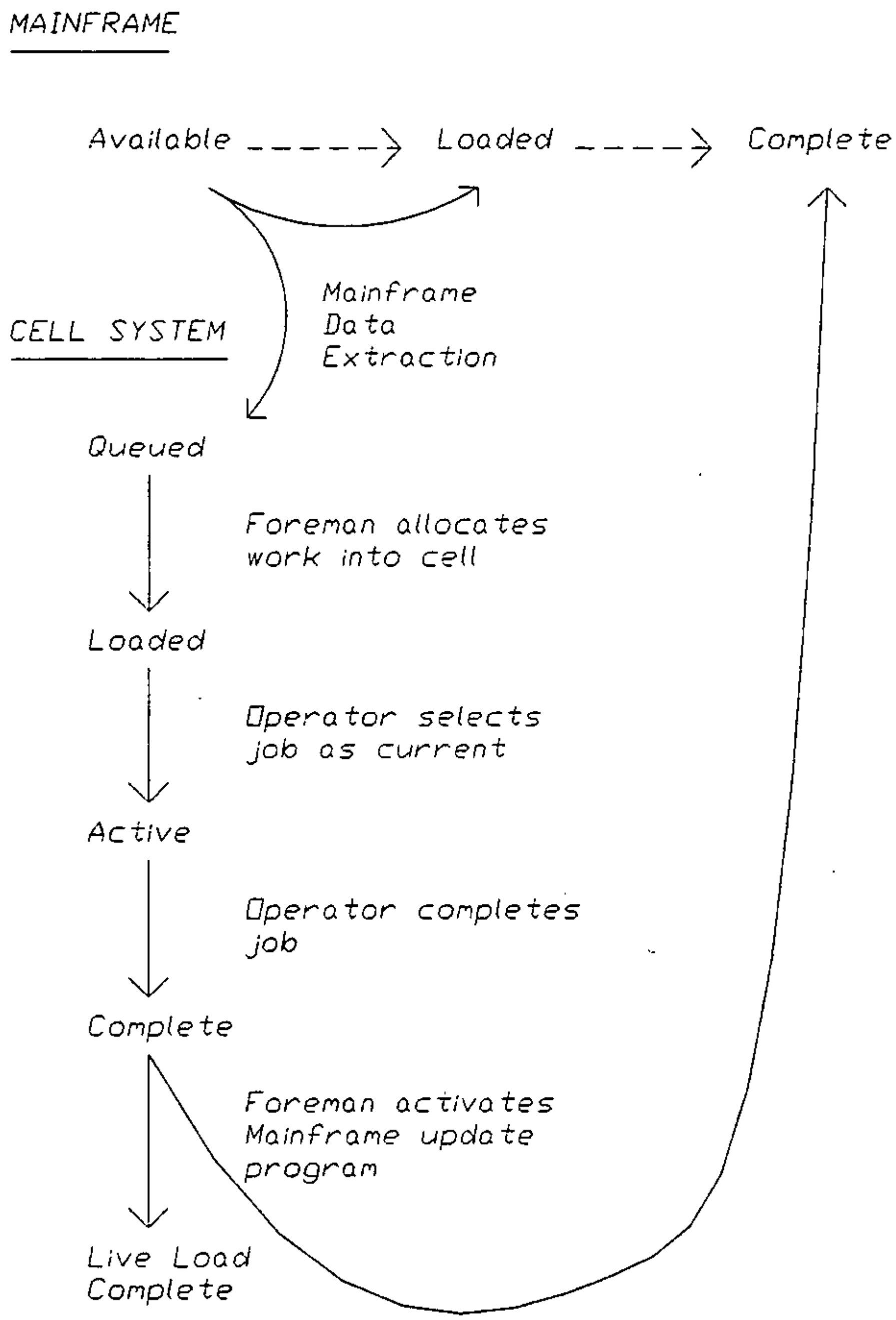


Figure 7.11 NC Machine Operator's Applications Menu

```
Novell Menu System  V1.22                    Wednesday  7 March 1990   8:30 am

          Rockwell PMC Machine Management System

          1. Transfer Cell Data into the Job Files
          2. Set the Status of a Job
          3. View Text Data in a Job File
          4. Clear Data from a Job File
          5. Edit/ Store a Message
          6. View Machine Events
          7. Transfer NC Data to the Machine Control
          8. Tooling Data Save/Restore
          9. Use the old DNC System
          H. Help Menu (F1 for menu system help)
```

Figure 7.12 NC Machine: Set Operation Status Screen

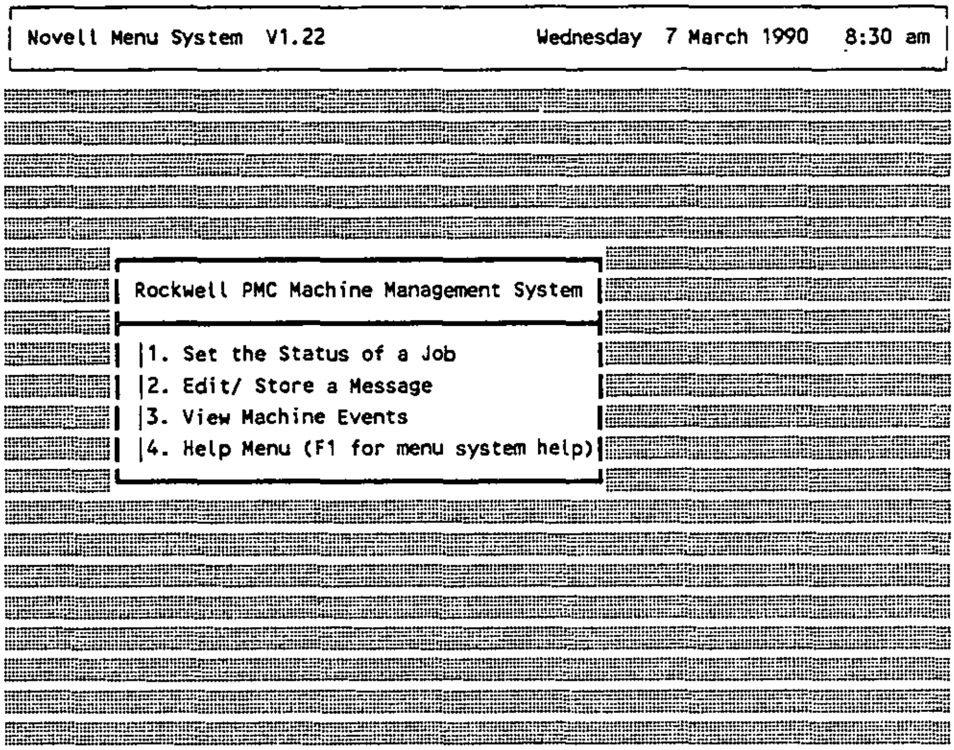
```
                ROCKWELL PMC MACHINE MANAGEMENT SYSTEM

Machine: 04 Heid Lathe.          WCen: F15    Operator: Roger Boon
```

File	PWC No	Priority	Part Number	Op No	Part Description	Total Time	Status
1	M 56411	716	39915873	10	STUB SHAFT	1.35	loaded
2	No data in file						
3	No data in file						
4	No data in file						
5	M 56166	203	6323359E	10	STUB SHAFT	1.90	active
6	No data in file						
7	No data in file						
8	No data in file						
9	No data in file						

```
Status | Select status to set: (A)ctive, (I)nactive, (C)omplete or (E)nd.
```

Figure 7.13 Manual Machine Operator's Applications Menu



application programs within the Rockwell PMC C.M.S. as described in this thesis would allow for appropriate newly written routines to replace or add to the functionality available with a reduced need for change to the base system.

7.3 Factors involved in C.M.S. Implementation

In accordance with the Rockwell Three Layer Systems Hierarchy approach described earlier the Factory (mainframe) and Cell (C.M.S.) levels have been considered separately as far as possible to ensure independence. The 'glue' between the two levels has been considered at the interface level. This ensures a degree of modularity in the design of the system which will allow for discrete changes to either system at one end of the interface to have less effect on the other system.

During the initial investigations into the evolution of the DNC system into a machine management system it became clear that the Rockwell three level system hierarchy was indeed the most suitable approach to machine shop management. Realistic cell management within Rockwell PMC, and any other company which works throughout the 24 hour day, requires a work in progress file which is available for update throughout this whole working period. The work in progress file used at the Factory level inevitably contains a large amount of information about the whole factory workload. By its very nature this amount of information requires regular housekeeping and, certainly at Rockwell, this involves a great deal of 'batch' update work during which the file is unavailable to interactive terminal users. The limitations enforced upon DNC CICS for data file access supported this view.

The advantages of this three level approach are that the autonomy of small groups gives improved local facilities and enables future specialised systems to be developed; distributed processing can lighten the load on each system and make them more reliable and easier to maintain and each area is also less dependent on another. Disadvantages are that redundant data / multiple data bases may result in out of step data across the levels and pose the problem of which 'data is real'. The application of truly distributed databases may overcome this problem in future implementations.

7.3.1 Choice of Cell Computer System Hardware

One of the first problems to be addressed in developing cell control was to choose an appropriate hardware strategy for cell systems which would provide the interactive, real time facilities required for data retrieval and status updating. In practice the choice of hardware for the C.M.S. boiled down to the use of either a small minicomputer with personal computers and/or standard terminals for operator interfaces or the use of a small network of personal computers with a central file server acting as the cell computer.

As indicated earlier the Company's Group Computer Manager had already issued guidelines on systems development which specified the mainframe and personal computers as the preferred choice of user machine rather than minicomputers, mainly because of existing in house expertise and the rapidly improving facilities offered at the personal computer level. Hence the use of a cell network of personal computers was chosen as the best option. It was also decided that one of the available standard PC networks [LAN Software 1985] should be used and that the possible implementation of any emerging standard networks, e.g. Manufacturing Automation Protocol [DTI 1986] [Beale 1988], would be considered if appropriate at a later date.

7.3.2 Choice of C.M.S. Network Software and Hardware

The rapid evolution in local area networking for personal computers made it somewhat difficult to decide which PC network route should be taken. In view of this a development network was set up in the computer department, chosen initially so as not to lock the system into any particular network strategy, which was used to evolve the cell control ideas and demonstrate the system software to shopfloor supervision and operators. Once this system had been fully demonstrated and the principles accepted the decision was made to continue with the same strategy for the first C.M.S. in the shaft line.

Novell Netware/86 was chosen for the PC network operating system software primarily because it had already become a market leader and 'de facto' industry standard and has been ported to over 30 hardware architectures [LAN Software 1985]. Arcnet was chosen as the network topology primarily because of its low cost and ease of configuration [Conner 1988]. In addition the cable used (RG62 coaxial) is the same as that used for the mainframe 3270 terminal installations and is particularly suitable for shop floor communications because of its immunity to noise.

The Novell operating system provides all the routines necessary for transfer of data over the network itself and so no software development has been necessary to provide this functionality. The intention was to use the network as a service and avoid having to produce specific software at this level. Apart from this the only features available through the network software which are used specifically are the file server subdirectory structure and trustee assignments which are used to restrict which facilities are available to each network user for security purposes, network logon and logoff facilities, menu facilities and the file and record locking features which are available through MSDOS 3.x, see Appendix D for more detail. However the standard Novell Netware operating system does not provide any particular information database facilities and relies on the file formats available with standard MSDOS although Btrieve record management software [Netware] is generally 'bundled' with Netware and can be used to develop suitable facilities. The onus is still on the network user to ensure secure data storage and retrieval by specific software or the use of Btrieve or other third party database products.

7.3.3 Use of Tempus Link for PC to Mainframe Communications

The Tempus Link file transfer software has been used for PC to Mainframe communications wherever possible rather than the specific 'screen oriented' software which was produced for the DNC system using the IRMA subroutines as described previously. Although the Tempus Link software itself relies on the basic IRMA screen oriented data transfer mechanisms, the user is buffered away from this functionality. This allows for a PC to Mainframe communications link which relies only on Tempus Link's ability to transfer files. Hence files created at the C.M.S. level which contain both execution instructions and data can be simply transferred to the mainframe for processing by a suitable CICS transaction. The approach taken has been to create a 'master' transaction which reads the supplied file to decide which execution program is required. The master transaction then starts the subordinate program necessary to read the data from the file and process it as required. The concept is illustrated in Figure 7.3.

The standards being accepted into the MAP/TOP 3.0 specification application layer, e.g. M.M.S. and FTAM (see Chapter 2), will provide a more open facility rather than the specific functionality currently available from particular vendors. The approach taken here should assist in a more straight forward migration to suitable OSI data transfer facilities as they become well established and available.

7.3.4 Applications Software

Appropriate software for the proposed cell system facilities was not available 'off the shelf', although some vendors have begun to produce software suitable for FMS cells [Siemens]. Rockwell PMC's C.M.S. needs fall short of a full FMS implementation and so there are few companies developing similar systems. The software routines have therefore been written in house to allow for an early implementation of the system on the shopfloor. However this software has been produced so that it is as portable as possible to other hardware structure implementations such that any subsequent change in the choice of network system will be unaffected. The main restriction on change is the fact that the software written for this implementation is based on the IBM PC as the 'compute engine'. Other vendors are now beginning to provide solutions which include some of the functions of the system described here and also some of the functions required in the future, e.g. local cell scheduling facilties [BAeCAM] [Coscom] [RWT]. It may be appropriate in the future to replace some or all of the Rockwell PMC 'bespoke' C.M.S. / M.M.S. systems by an external vendor's products in order to 'subcontract' the responsibility for continual maintenance and upgrade as situations change.

7.3.5 Implications of Emerging Network Standards

As the emerging OSI standards become established the standard hardware and software that these promote may well prove more appropriate to Rockwell's implementation strategy. The approach taken at present involving the use of 'off the shelf' hardware and software wherever possible allows for an early implementation of useful manufacturing management systems. However the application of a modular design approach for the evolving systems should allow for migration to the OSI standards at a suitable time with minimum effort.

7.4 Problems Encountered

The Cell Management System has worked well within the shaft line for the majority of contracts live within the cell. However there have been a number of problems with the feed of information from the mainframe which prevented the system from being used to best effect in controlling all the work in the cell. Changes to the mainframe and cell level applications programs were necessary which have much improved the situation. However the main problem encountered was that unavailability of certain mainframe systems, especially the work in progress 'Loadfile' update options, caused the 'systems view' of the shopfloor to differ from reality. In addition the way material (and components) are actually delivered to the shaft line area has made it difficult for the C.M.S. to control all the cell work. The current systems used, both computer based and manual, cause a mismatch between the material centre cutting sequences and the cell work to lists.

7.4.1 Loadfile Availability

Under normal circumstances the mainframe loadfile is unavailable for direct update throughout the night shift ('logging' of these updates, until the system is again available, is possible during part of this period) but available through the day shift. However any problems occuring in the MRPII runs can increase this unavailability. Use of the logging mode does not update the file until the overnight batch runs are completed. From a real time status enquiry point of view logging mode is therefore of little use.

7.4.2 Mismatches of Cell Contracts with Material Actually Available

The loadfile unavailability can also result in the inability to signal the completion of any previous operations quickly, especially cutting operations in the material centre. This prevents jobs from being released onto the Queued work to lists for shaft line workcentres which allows material/ components to arrive ready for loading and progressing within the cell before the job information is obtained from the mainframe files.

In addition to this contracts may be cut and delivered relating to work for machines which are already overloaded. This results in data being downloaded into the C.M.S. files too early while the material sits at the end of the cell thus 'clogging' up both the files and the buffer areas.

7.5 Solutions Implemented

A number of solutions have already been addressed in the short term by providing more flexibilty in the way the C.M.S. applications programs access information from the mainframe files. For the longer term the implications of the interaction between the shaft line C.M.S. and other cell systems including the material centre need to be considered and acted upon appropriately.

7.5.1 Short Term Solutions

The short term changes made to the C.M.S. applications programs allow the cell foremen to respond to the existing practical situation for job progressing based on material availability rather than restraining the system totally to the mainframe priority lists. The specific data download functions 07, 08 and 09 and associated routines 05 and 06 on the Foremen's applications menu, Figure 7.4, were produced to provide this flexibility.

7.5.2 Longer Term Solutions

The problems associated with the unavailability of interactive mainframe systems, e.g. the loadfile update routines, are caused by the need for batch update runs. These batch runs are necessary because of the vast amount of data that the mainframe 'Factory Management System' is required to handle. This situation is unlikely to change in the future, even with the improved facilities offered by the Cincom Shop Floor Control software, and mainframe system downtime seems therefore inevitable. The short term solutions proposed may help to relieve the situation but will not overcome the basic problem i.e. that mainframe unavailability causes the 'mainframe systems view' of the shopfloor to differ from reality.

Future development of manufacturing control as a whole, and not just the management of individual cells, will need to take this into account. If cell management is a realistic way to allow for the provision of localised data control and optimisation of production schedules then the cell management systems must be able to decouple themselves from the effects of 'mainframe system unavailability'. This may need to involve the evolution of the Rockwell PMC hierarchy into Four Levels with the inclusion of a 'Shop Floor System', corresponding to the Shop Control Level of the ISO hierarchy. Alternatively the individual cell systems could be allowed to communicate with each other independently of the mainframe when necessary by incorporating a hybrid hierarchical/heterarchical approach to the overall control system as discussed in Chapter 2.

7.6 Benefits of the C.M.S. Implementation

The installation of the Cell Management System (C.M.S.) in the shaft line is the second stage of a multistage implementation of shop floor and cell control systems as a part of Rockwell PMC's initiative for the creation of a 'Linked Business System'. The C.M.S., similarly to the DNC system as discussed previously in Chapter 5, can only be expected to impact on some of the many factors which can provide real benefits in line with the original business objective, although most of the benefits arising from this implementation are not easily quantified.

The implementation of C.M.S., which is considered to be a part of a strategic program for the Rockwell PMC CIM initiative, has coincided with the implementation of other systems, notably the introduction of Cincom's Control:Manufacturing MRPII software discussed in Chapter 3. The impact of the C.M.S. implementation has been limited to ten workstations in a single group technology cell which are not totally independent of over one hundred other workstations in the machine shop as a whole. The financial quantification of accrued benefits is therefore extremely difficult.

However there are some benefits which are apparent to the operation of the shaft line in isolation. The C.M.S./M.M.S. routines provide a consistent single interface for cell control for the foremen and machine operators alike. This control system is available 24 hours per day and therefore provides the necessary independence from the mainframe systems required by a manufacturing department. The operators' interface provides a simple means of reporting at source the changes in status of any given job operation. This ensures that the cell system has up to date information available at all times. The foremen's interface provides the information and control functions required to ensure effective and efficient running of the machines in the cell with much improved response times to manufacturing problems and associated quality levels. This interface integrates almost all of the interactions necessary with mainframe systems through the single C.M.S. interface.

There is also some indication that the number of jobs which need to be controlled by the foremen at any particular time has reduced even through the cell throughput has remained consistent. This indicates a reduced level of work in progress in the cell due to the improved control which the foremen can exercise with regard to loading to the operators only that work which can actually be progressed and preventing the delivery of material for jobs which cannot. This reduction in work in progress also has a beneficial effect on component lead times to the assembly areas by allowing focus on important work. The response to engineering design changes during the manufacturing cycle is also improved.

In the longer term when further implementations of C.M.S. are made in other group technology areas, appropriate communications methods will be implemented between these shopfloor systems and the factory level applications systems such as CAD, CAM and CAPE. The total system will provide for a single consistent interface for the machine shop as a whole which will amplify many times the improvements available to the single cell.

The major impact may be realised during the introduction of new products where engineering design changes are frequently made. The improved response to change brought about by the integration of the relevant systems will greatly reduce the problems which are encountered. The shop wide C.M.S. system interface is considered to be the 'gateway' where the 'Push' principles of the factory level MRPII systems are translated into the 'Pull' principles of the Just in Time control required for effective and efficient shopfloor operations.

7.7 Further Work

As envisaged the evolution of the DNC system into a Cell Management System has been made easier by using a modular approach and has involved extending the functionality already in place to encompass the 'Cell Control' concept.

Future work will involve the specific implementation of Cell Management Systems in other machining cells on the shop floor and appropriate service cells such as maintenance and tooling. However before the machining cells can be addressed the problems at the start of the chain, in material input management, must be solved. Therefore the first implementation planned is at the start of the component manufacturing chain, in the Material Centre. Once this is accomplished and a reliable communications mechanism is in place between the Material Centre and Shaft Line systems the other cell systems can be added with relative ease. These systems must also be further integrated with appropriate support systems such as NC programming and CADCAM at the appropriate time.

7.8 Summary

This chapter has described the implementation of a Cell Management System at Rockwell PMC. The C.M.S. has again been specific to the needs of the company with respect to the hardware and software used but nevertheless, as recognised for the core DNC system previously, offers a partial solution for similar implementations at other facilities concerned with the manufacture of discrete components. In particular changes would again need to allow for differences in the management functions of the main information storage system and the information distribution functions between this storage system, the PCs and any specific machine controllers used. Wherever possible 'off the shelf' products have been used in this implementation to simplify the solution subject to prevailing company constraints. In particular the system makes use of the Novell Netware network operating system software to provide the basic information distribution facilities with the C.M.S. and M.M.S. levels of the Rockwell PMC hierarchy. Alternative approaches have been discussed where appropriate. Due regard has been paid to the 'human aspects' of CIM implementation as on previous occasions by fully involving the foremen and operators in the design process and specification of the functionality required from their point of view.

The specific implementation work has led to the recognition of certain constraints which are generic in nature. These relate particularly to the information distribution facilities available for communication with machine controllers on the shopfloor and the central information storage system. The machine control manufacturers in particular do not appear to adhere to common standards for controller interfaces but to produce specific solutions. These specific solutions make the interface of DNC systems to the machine controls different in many cases and further complicate the application of CIM on the shopfloor.

The C.M.S. has provided real benefits. The system maintains a consistent single interface for cell control for the foremen and machine operators alike, which is available 24 hours per day, contains up to date information and provides the information and control functions required to ensure effective and efficient cell operation. Levels of work in progress within the cell have reduced resulting in improved component lead times and response to engineering design changes.

In the longer term the major impact of the system may be realised by the improved response to change needed during the introduction of new products. The shop wide C.M.S. system interface is considered to be the 'gateway' where the 'Push' principles of the factory level MRPII systems are translated into the 'Pull' principles of the Just in Time control required for effective and efficient shopfloor operations.

CHAPTER 8

Generic Considerations

8.1 Introduction

Previous chapters of this thesis have described the initial phases of the evolution of a computerised machine shop management system at Rockwell PMC. The work has involved the specific implementation of a Cell Management System (C.M.S.) in a group technology cell of machines producing 'shaft' components by building on the functionality of an initial single machine DNC system installed on a Heid Lathe within the cell. The Cell Management System offers the foremen and operators suitable decision making and information support facilities for the control of work flowing through any of the workstations within the cell including NC and manual machines. As described previously the implementation forms part of the company CIM strategy for the creation of a linked business system at Rockwell PMC.

The C.M.S. has been specific in as much as the needs of the company have constrained the particular choice of hardware and software used. However, wherever possible, 'off the shelf' products have been used to simplify the solution subject to these prevailing company constraints. The specific implementation work has led to the recognition of boundary conditions which are of a more generic nature. These constraints relate particularly to the information distribution facilities available for communication between machine controllers on the shopfloor and central information storage systems. Alternative approaches have been discussed where appropriate. The use of the three architecture model has also been shown to be valuable for the decomposition of systems into meaningful sub systems which can then be analysed and compared.

This chapter extends upon the previous discussions relating to the further applicability, at Rockwell PMC and at other companies, of the concepts evolved in the specific implementation described here and also the possible use of alternative approaches. Some of the important cost issues are also discussed. These considerations are made with particular reference to companies operating within the discrete engineering 'metal cutting' sector of the manufacturing industry and especially those involved in small batch manufacturing. The use of alternative methods and tools is considered from an industrial implementor's point of view with particular reference to emerging standards.

8.2 The Implications of Small Batch Manufacture

A recent ACME Directorate report [ACME 1989] highlights the challenge for industry to respond to the movement of high volume production from highly developed countries such as the UK and US to countries in the Pacific Basin. The report states that 'the UK manufacturing market sector will increasingly be that of small batch production, which will also contain a growing emphasis on product variants and, generally, a gradual reduction in product life'. This identifies the need for solutions involving flexible automation but incorporating the 'sensible application of computer science to the problems of manufacturing'. The report highlights particularly the use of robotics in Advanced Production Machines but nevertheless fully acknowledges the importance of information distribution as well as the physical aspects for the system integration needs of the future.

It is important that industrial companies such as Rockwell PMC concentrate on the issues which emphasise small batch production so that they are able to compete effectively in worldwide markets. Companies must address the needs for improved product quality, lower manufacturing cost for batches as small as one, shorter delivery lead times and, arguably the most important need, for increased responsiveness to the rapid changes expected in market demands by, for example, reducing the lead times involved in design and manufacture, reducing work in progress and increasing productivity. CIM is seen as the vehicle for providing the necessary changes required by 'tying together, via computer technology, all the various departments in an industrial company, so that they operate smoothly as a single, integrated business system' [CIM 1988]. Arguably the main goal of CIM systems integration for any company is to achieve real and lasting benefits in terms of increased competitive edge and therefore the ability to respond rapidly to change and subsequently to manage that change is the most important prerequisite for success.

As discussed earlier in Chapter 2, whilst many people can foresee the potential benefits which can be achieved from CIM systems integration, many of these benefits are not 'quantifiable by existing accounting methods nor are there proven new ways of evaluating them. At this point, the justification of CIM remains as much a strategic issue as a financial one' [O'Rourke 1990]. However, the problems which arise from specific CIM systems integration include the high cost of major changes which may be necessary to support new configurations or functionality of existing systems and to reproduce similar systems for other manufacturing situations. Arguably, therefore, companies must develop a strategic approach concentrating on appropriate successive system implementations which can provide real benefits but include the generic reconfigurability and flexibility needed to allow for rapid response to future changes with minimal cost penalty in the longer term.

8.3 The Need for Generic CIM Systems Integration

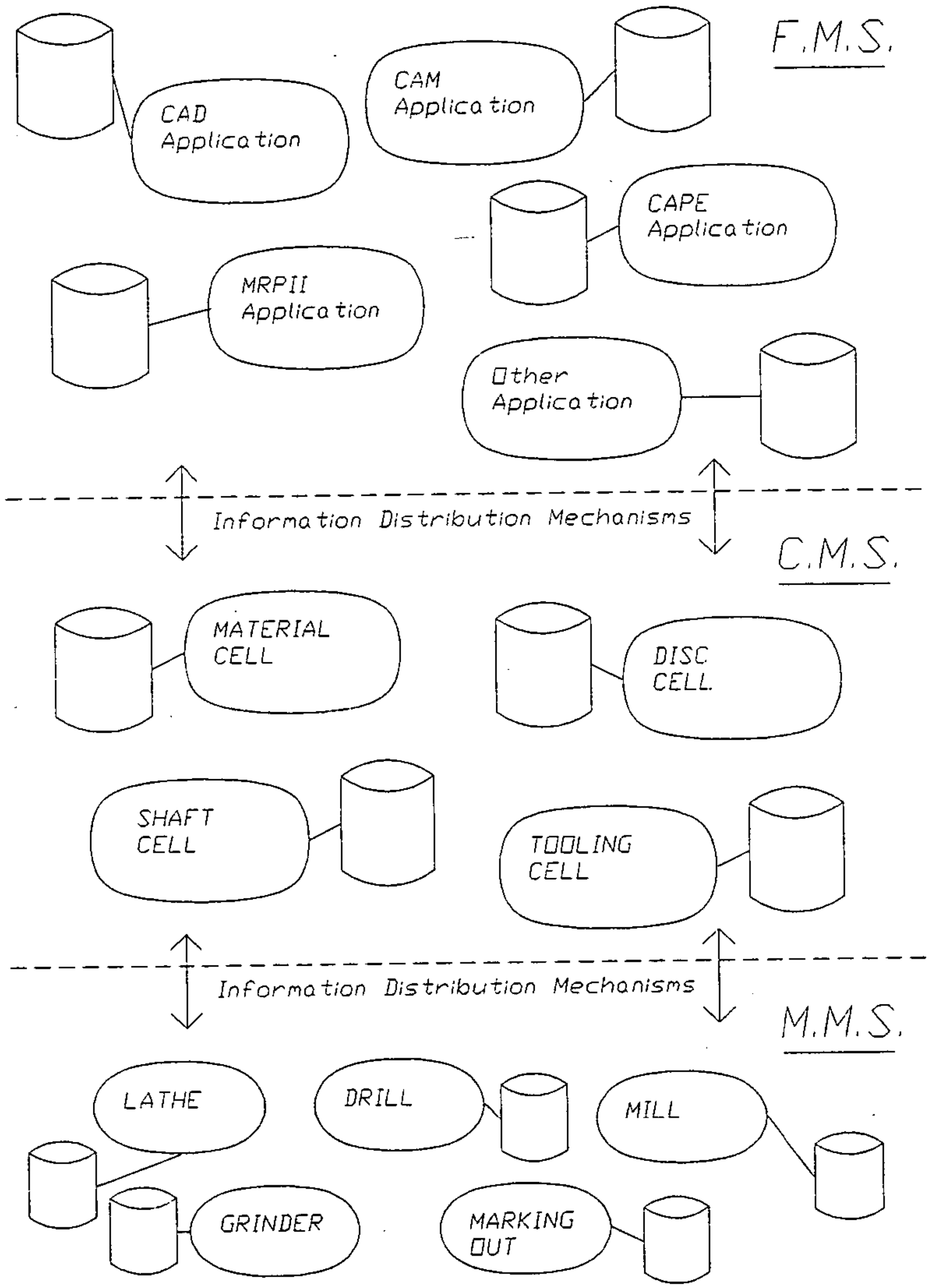
The concepts evolved in the work at Rockwell PMC, illustrated in Figure 8.1, relate to the implementation of suitable cell control systems which are able to integrate with existing and potential Factory level systems, including manufacturing control and the CADCAM interface, and with the equipment and personnel on the shopfloor in a cost effective manner. The concept involves a Factory (F.M.S.), Cell (C.M.S.) and Machine (M.M.S.) Management System hierarchy corresponding to the Facility, Cell and Workstation levels of the ISO hierarchy as described previously and forms a framework for the evolution of other localised control systems within the company. The Cell Management System, and integral DNC System, described in this thesis has been implemented to meet the specific requirements of one of the machining cells, the Shaft Line, in the Rockwell PMC machine shop. However as discussed previously the work described in this thesis has been prompted by the need for Rockwell PMC to operate within the limitations of small batch manufacture and therefore the author considers that the concepts evolved during this research will also be applicable to other companies operating within the same manufacturing sector.

8.3.1 At Rockwell PMC

As discussed in the previous chapter future work at Rockwell PMC will involve the specific implementation of a Cell Management System in the Material Centre followed by systems in other group technology machining cells on the shop floor together with appropriate links into support systems such as tooling, maintenance, NC programming and CADCAM. The real task faced by Rockwell PMC is to reconfigure the C.M.S. implemented in the shaft line in such a way that it can be implemented in these other cells at minimum cost but with maximum benefits.

Following on from the work reported in this thesis the author is in no doubt that the work involved in the reconfiguration of specific systems for application in new areas or for changes in functionality is not insignificant. The machining cells within the Rockwell PMC machine shop have been put together, following group

Figure 8.1 Rockwell PMC Hierarchical Control Concept



technology principles, to manufacture similar components within each cell but dissimilar components between cells. Although similar production machines are used, the actual control requirements of each cell may not be the same because of the different manufacturing methods needed. Therefore the cell control systems required for the machining cells at Rockwell PMC will have many similarities but also many differences and the specific implementations needed may be quite different. These differences are even more apparent when material centre, tooling or maintenance cells are considered. Here, for example, local databases of the stock holding of material, tools, jigs and fixtures or spares, interfaces to the Automatic Storage and Retrieval System in the material centre and to the tool setting machine in the tooling area, are necessary in addition to the details of how and when work should be completed.

Since it is not yet possible to buy CIM 'off the shelf', the costs involved in CIM systems integration, for both hardware and software, are not insignificant. The hardware required for cells containing the same levels of machines and/or workstations may be relatively similar. However this research work has indicated that software development costs can be of the same order or even higher. The implementation of the shaft line C.M.S., including the DNC system, at Rockwell PMC has involved several man years of systems analysis and software programming effort during an elapsed time of over three years. This is particularly significant when compared to the actual hardware installation costs incurred.

CIM systems integration which is specific to a given initial specification will incur the need to duplicate costs for each system implemented. For Rockwell PMC this would imply the need for many man years of systems effort over a considerable elapsed time period to install the number of Cell Management Systems proposed above. In view of this it is not difficult to understand that generic methodologies can provide the lowest cost route for CIM systems implementation. However, a totally generic approach to systems implementation will necessarily involve increased functionality compared to a specific approach so that the resulting systems are fully reconfigurable for new or changing requirements. Therefore the evolution of a totally generic approach to CIM systems integration is bound to be a difficult and costly exercise. In practice the author believes that manufacturing companies such as Rockwell PMC need to tackle the problem in a pragmatic way with due regard to their own internal needs and resources by using methodologies which make significant parts of the integration problem as generic as possible in real situations. This will ensure that companies such as Rockwell PMC can respond to changes in requirements which include for example changes in product variety and production techniques, in the enabling tools which are used in support functions such as CADCAM and also possible changes in management philosophy. These changes may typically occur over a number of years.

The author considers that the three architecture model approach proposed in this thesis for the decomposition of CIM systems integration provides not only a suitable means of comparison but also for the identification of manageable sub systems which can go a long way towards evolving a generic solution to the specific implementation problems involved. For Rockwell PMC the Cell Management Systems require similar core functionality although relatively different control mechanisms. In terms of the three architecture model the requirements for information distribution mechanisms between the cell systems and master data stores on the mainframe computer and certain aspects of the information management functionality can certainly be reused. The specific applications required for the support of certain cell control functions are potentially different but there are still several key applications for operators and foremen which are the same, for example the need for displays of operator information and updates of job operation status to provide the real time information needed by the foremen for control purposes.

The author believes that the methodology proposed here can provide a sufficiently generic approach to the integration problem such that it will reduce the cost of implementation of further Cell Management Systems at Rockwell PMC significantly. The author estimates that, although the hardware costs of consecutive systems implementations will be relatively similar to those incurred in the shaft line system implementation described in this thesis, the effort needed will be reduced to less than two man years, in terms of systems analysis and software programming, and an elapsed time of one year for the material centre and similar support cells and half this amount or less for the machining cells.

8.3.2 At Other Small Batch Manufacturing Companies

The problems of the possible transferability of the Rockwell PMC solution to other factories have been discussed in the previous chapters and it has been concluded that the basic PC network C.M.S., and integral DNC system, could be used with little change as the 'vehicle' for cell control systems in other discrete component manufacturing situations. The problems, which do exist, can also be classified with relation to the three architecture model. The specific problems identified previously relate to the functionality available within the Information Distribution Architecture, involving meaningful information transfers between the PCs and machine controllers and the PC network and master information stores, in addition to certain aspects of the Information Management Architecture at each level of the hierarchy relating to the way in which existing information is stored. In addition the specific functionality built into the Applications Architecture at Rockwell PMC for the foremen and operators may not be suitable 'as is' to other situations.

The author believes that the important issues to be considered in the transfer of the derived solutions to a wider CIM systems integration arena are largely common whether these cells are internal or external to Rockwell PMC. The issues discussed above are equally applicable and the methodologies used at Rockwell PMC can provide a sufficiently generic approach to the integration problem for the implementation of systems in other similar manufacturing companies. However in order to be totally transferable the current solution may need to evolve even further into one which is more easily reconfigurable for the application requirements of any new cell implementations. In addition the solution must also be flexible so that future changes in production procedures or processes, organisation or design practices can be accommodated after a system has been installed to a given specification. The solutions for the CIM implementations described in this thesis rely heavily on certain 'de facto standard' methods and tools for their supporting 'infrastructure'. The integration of emerging tools into the current system concepts, especially those which are being accepted into the ISO standards, is considered by the author as a prerequisite for the continuing future success of these solutions.

8.4 The Role of Emerging System Integration Methods and Tools

In the author's opinion the use of particular integration methods and tools in an industrial situation will continue to be limited, for the next few years, by specific constraints similar to those identified in this work. During this period CIM implementations will continue to include the integration of existing heterogeneous and non-standard systems. However, in order to avoid bespoke customised solutions to CIM integration problems in the longer term, accepted standard solutions to generic problems must be incorporated so that the solutions to specific problems can be produced by customising at the latest possible stage of an implementation with the least possible change to the underlying subsystems.

However the inclusion of standard methods and tools into the evolving solutions for CIM systems integration must be addressed both externally and internally to the manufacturing user. Companies within the manufacturing industry rely heavily on external suppliers for suitable support systems for their operations. Systems may be chosen from many different suppliers to suit different internal applications. In addition the company may still need to integrate these separate solutions using its own or other external resources. In some cases, as illustrated in the work described in this thesis, the company may need to produce its own solutions to specific problems where suitable external products are not available. The use of standard methods and tools by suppliers and user companies alike should help to minimise integration problems.

Decomposing the problems of CIM systems integration with reference to the three architecture model is again an appropriate means for focussing the discussion of the possible application of emerging methods and tools on specific areas. In view of the work reported here, which has illustrated some of the potential problems of CIM implementation in a live manufacturing situation, it is the author's opinion that the main focus for the industrial user is to provide appropriate functionality within the Applications Architecture for the required control mechanisms within the company. Functionality within the Information Management and Information Distribution Architectures is provided primarily to support this applications level. Therefore it appears that, in the future, the primary responsibility for applying standard methods and tools should lie with external suppliers and it may be possible to limit the use of these standards, internally to a user organisation, to the need to create specific functionality for certain applications. However the author fully recognises that this situation will take some time to accomplish and so user organisations must apply standards wherever possible to allow for system implementations carried out in the meantime to be fully integrated with future solutions.

8.4.1 Information Distribution Architecture

As explained earlier the Information Distribution Architecture used in this thesis as a basis for comparison deals not only with the transfer of data via a given cable configuration and data transfer mechanism but also with the commands, action or requirements statements at each end of the link to ensure meaningful information transfer. This model is used because of the limitations of the information management functions available for the specific implementations involved in the research described in this thesis. In particular the functionality apportioned to the information management architecture has been limited to the information storage facilities. It is the author's opinion that these limitations will apply to other CIM systems integration situations until such time as suitable Distributed Database Management Systems (see below) are readily available and accepted into user organisations. However the author acknowledges that some of the considerations made in this section could arguably be better discussed under the Information Management umbrella. Indeed the very form of the model used as a basis for this discussion allows for considerable interaction between the different architectures.

The specific problems identified in the work reported in this thesis relate to the functionality available for information transfers between the engineering office and business computer support systems, such as CADCAM and Manufacturing Control, and the shopfloor cell systems and, in addition, between the cell systems and machine tool controllers. Certain of the emerging standard methodologies may be particularly appropriate in these areas.

The author anticipates that the future acceptance of ISO supported network communication standards such as MAP and TOP, in view of the rapidly reducing cost of suitable interfaces [Bowman 1989b], will provide a standard interconnection method between multi-vendor computer based systems. However as discussed above these standards are of little use for flexible integration unless suitable standards supporting meaningful information flow are also made available. Currently ISO/OSI reference model application layer support functions are being evolved within the MAP/TOP initiative to provide for Network Management, File Transfer and Management (FTAM), Manufacturing Message Services (MMS) and Message Handling Services (MHS) as discussed previously in Chapter 2. The FTAM and MHS services may be considered appropriate to information transfers between the 'front office' support systems and the shopfloor whilst the MMS services may be particularly appropriate to information transfers between the shopfloor devices, although there may well be some overlap in certain circumstances [Dwyer 1989].

A. Information Distribution to Machine Tool Controllers

Many of the latest machine tools are designed primarily as stand alone production centres, retaining features of traditional manual machines. Each make of machine controller tends also to be proprietary to the manufacturer and the data supplied must be in specific formats to take full advantage of the controller's capabilities. Specialist machine tool builders currently bear the problems associated with this situation for machine interface level integration whereas the users need to overcome the problem at the systems integration level [Bowman 1990].

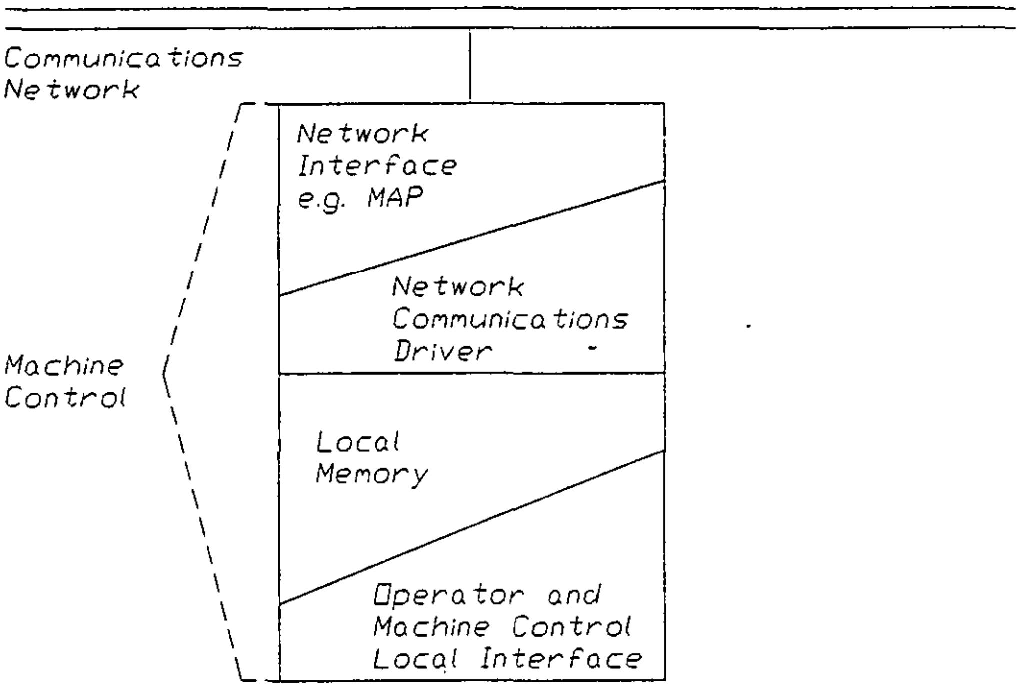
There are essentially two main choices for a machine interconnection mechanism: a 'backplane' solution where the manufacturer provides the appropriate standard communications facilities within the machine control and a 'gateway' solution where the controller is linked locally to another computer which provides common network communications functions, see Figure 8.2. As described in Chapter 4 this second approach has been used in the work reported in this thesis to provide a 'Two Layer Communications' strategy within an IBM PC for linking machine controllers into the cell systems at Rockwell PMC.

The former solution may take some considerable time to achieve given the effort, up to 100 man years, involved in producing a new machine controller [Weston 1989] and so the second approach may be more appropriate in the shorter term. However certain CNC, PLC and robot control manufacturers including Allen Bradley, Cincinnati Milacron, GEC, Modicon, Mitsubishi, GEFanuc and Siemens are indeed committed to the manufacture of MAP 3.0 conformant products [Bowman 1990].

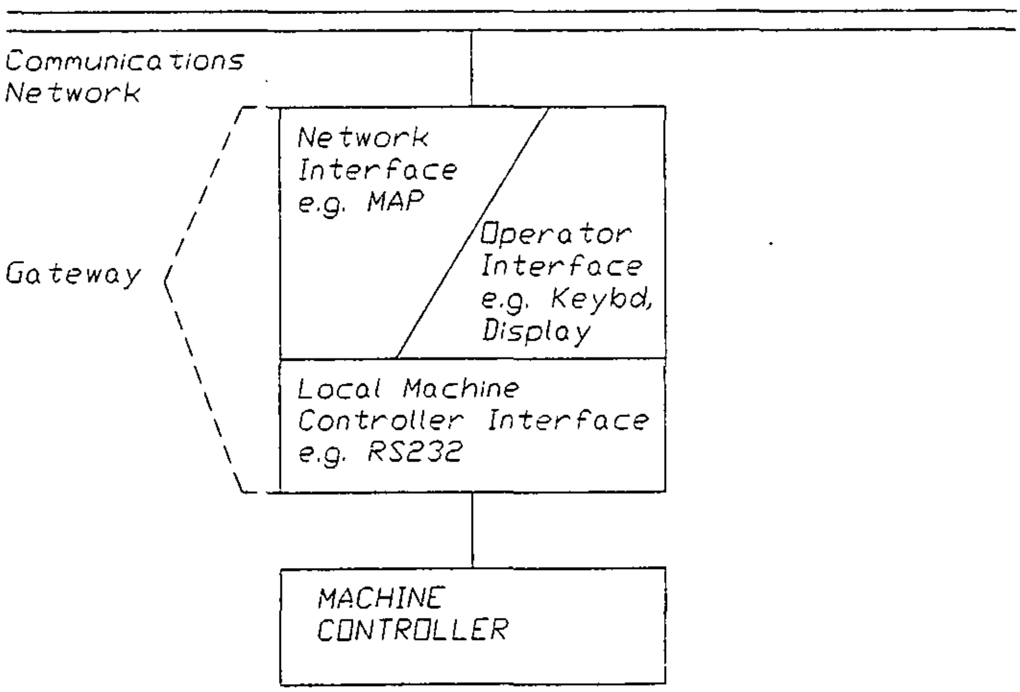
One attempt at a standardised gateway solution known as SERCOS (SErial Real-time COmmunication System) has been launched by a number of West German manufacturers including ABB, AEG, Bosch, Gildermeister, Heckler, Koch, Phillips and Siemens. This should allow for simplified interfacing of some CNC systems although the proprietary data handling characteristics of each product will still remain a problem [Bowman 1990]. The MAP Equaliser introduced by Reflex Manufacturing Systems, which provides a connection into a Carrierband MAP 3.0 network and four RS232 serial ports for connection to the controllers, is another available alternative. This product also includes a graphical programming tool to allow for quick configuration of the serial protocol needs of any connected machine control [Bowman 1989a].

However the application of standard messaging services to these communications solutions, such as MMS [EIA 1987], is key to achieving vendor independent interoperability between shopfloor devices. MMS's structure allows for, not only the transfer of messages between nodes on a MAP network, but also for the

Figure 8.2 Alternative Solutions to Machine Control Connection



(i) Backplane Solution



(ii) Gateway Solution

inclusion of commands which can initiate other functions at the receiving system as illustrated in Figure 8.3. Inclusion of MMS functionality by control manufacturers would be a major step forward for shopfloor communications [Dwyer 1989].

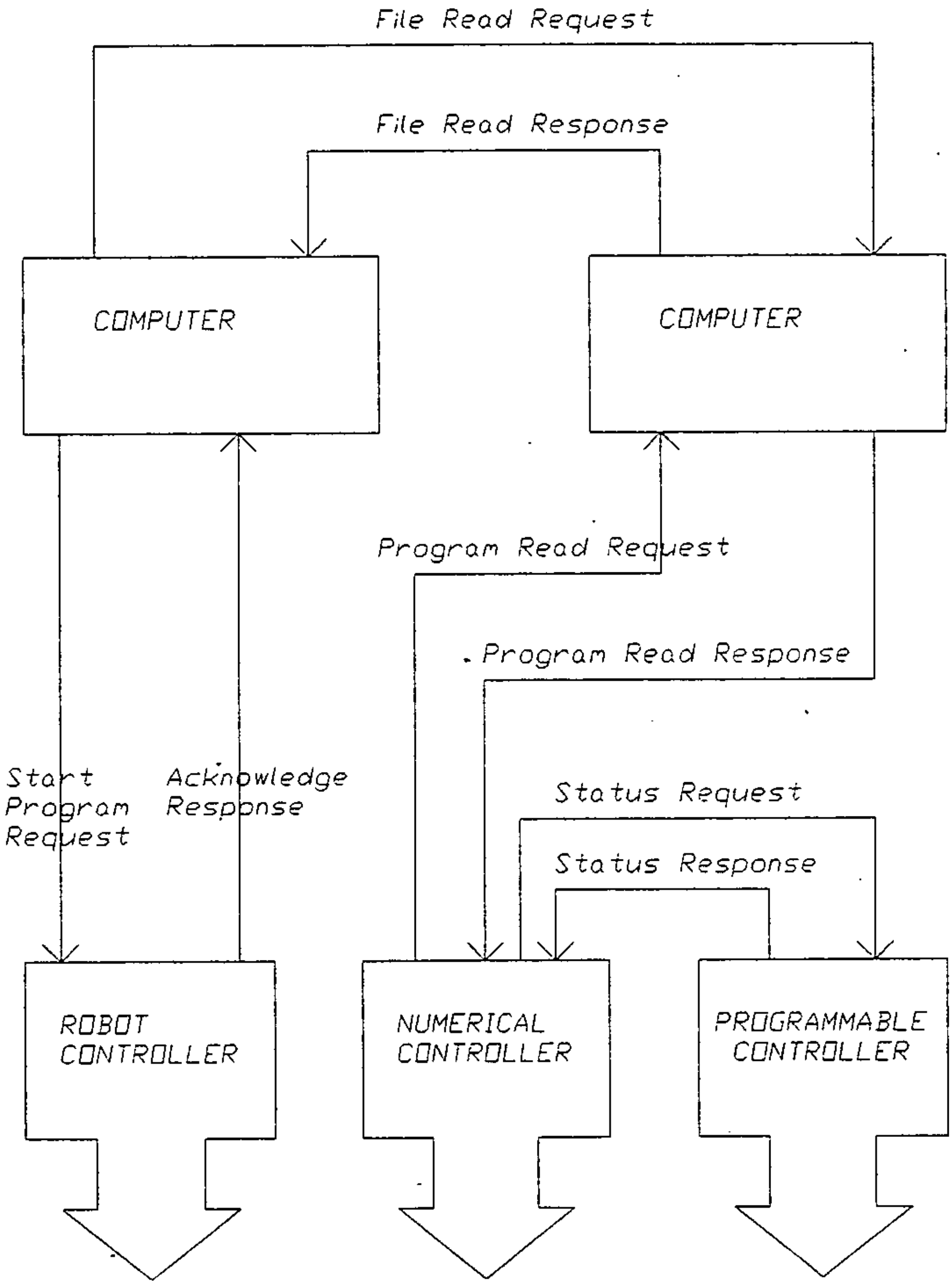
B. Information Distribution between Support Systems

As discussed above other problems relating to CIM systems integration involve the distribution of information between 'front office' support systems such as CAD, CAM, CAPE in addition to shopfloor cell systems. Suitable ISO supported communications interfaces provide the data transfer mechanism between these systems but again the meaningful transfer of information must be supported. The FTAM and MHS standards can go a long way to supporting data transfer functions. However, where suitable application system activation messages are necessary, MMS functions may provide a more effective vehicle. In addition to this the data modelling methodologies discussed in Chapter 2, such as IGES, PDES/STEP, GKS, ODA and Virtual Terminal, have an important part to play in future standardised methods for the meaningful transfer of information between systems in CIM integration. The commitment to OSI standards being shown by computer systems companies such as DEC [Commitment 1988], DG [Data General 1988], IBM [Laws 1987] and Novell [Walkenhorst 1989] will certainly help in this area.

8.4.2 Information Management Architecture

A number of constraints have been identified by the specific CIM system implementations described in this thesis which relate to the storage of information. In particular the problems encountered are a result of the proprietary nature of the storage mechanisms which have been 'built in to' applications by external vendors or in house by Rockwell PMC personnel. These include the hierarchical and relational database products used on the mainframe, the UGFM [UGFM] file management system used in the Unigraphics CADCAM system, the data storage facilities available on the various machine controllers and the simple text file based file management system produced during this research within the Rockwell PMC Cell Management System. Currently none of these facilities allow for common convenient interrogation methods. These circumstances are common to other small batch manufacturing companies [Weston 1989]. Certain of the emerging standard database methodologies will provide particularly appropriate solutions in these areas.

Figure 8.3 Manufacturing Message Services Functionality



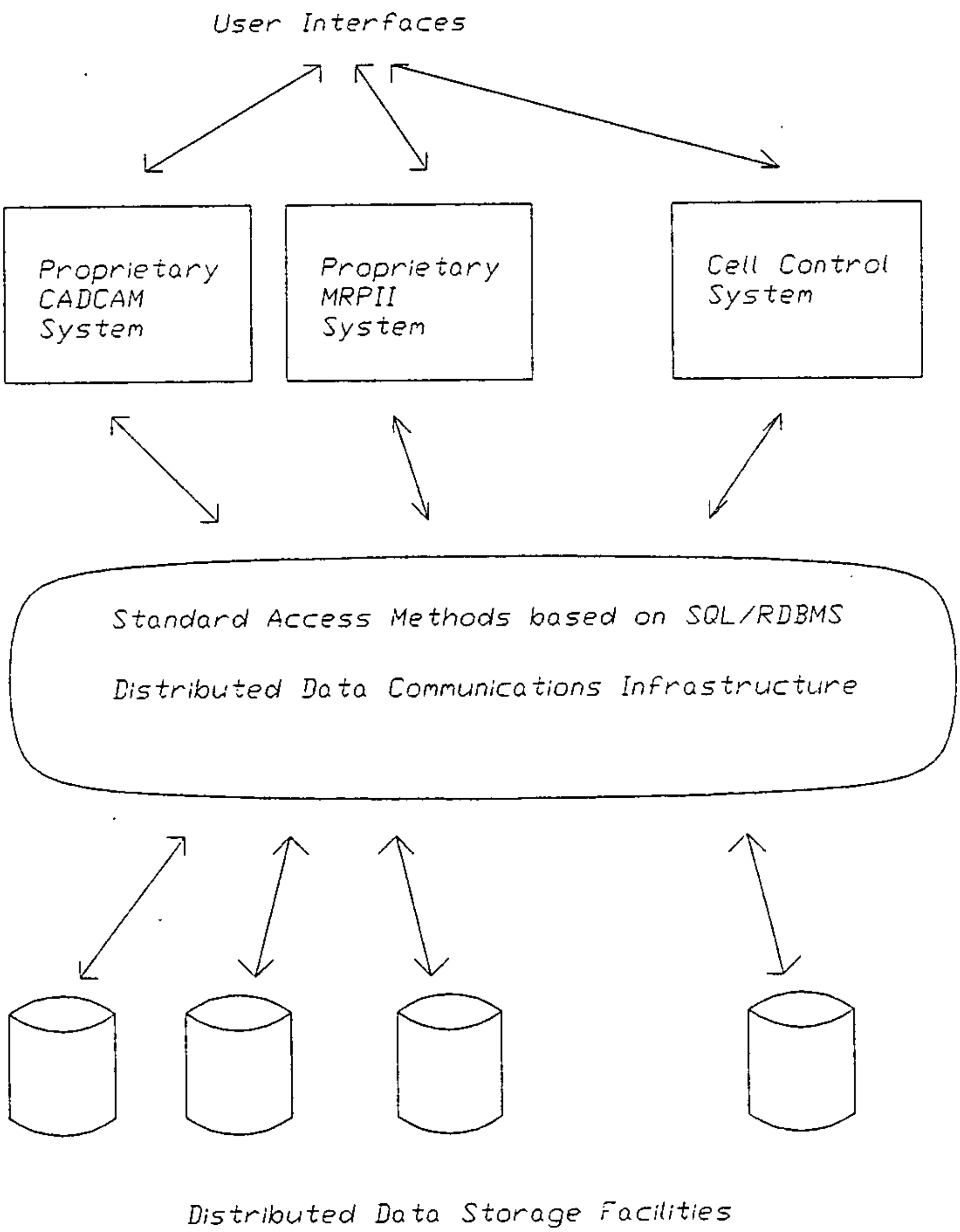
The Hierarchical Database Management Systems developed in the 1970's have been largely replaced by Relational Database Management Systems (RDBMS's), the latter accounting for 61% of the market in 1987, predicted 85% by 1992. These database products have gone a long way to providing applications programmers with more flexible approaches to the storage and retrieval of data. However the differences in the RDBMS products from various suppliers continue to make CIM systems integration difficult at present [Morris 1989].

RDBMS information storage and retrieval mechanisms such as those based on the Structured Query Language (SQL) originally developed by IBM [Barron 1989] [Morris 1989] provide more generic functionality for system integrators. These provide a common 'front end' to the underlying database for application programmers. However SQL products from different vendors may still be incompatible with each other to some extent [Morris 1989] and therefore SQL products conforming strictly to accepted standards such as ANSI/SQL [ANSI 1986] are more suitable for integration as CIM system implementation tools.

As discussed in Chapter 2 considerable work has also been done on the evolution of suitable Distributed Database Management Systems (DDBMS's) and the work carried out at USAAF on I^2S^2 [Althoff 1987] and NIST on IMDAS [Libes 1988] has illustrated that the concepts can be translated into specific areas for manufacturing organisations. However DDBMS products have only recently been made available to the end user, are still primitive [Rowe 1989] and pose difficult administration problems due to the additional complexity involved [Booty 1990].

Standard methods based on the RDBMS, SQL and DDBMS approaches, together with the emerging standard methodologies for data modelling as discussed in the previous section, will certainly be beneficial for CIM systems integration in the future where systems based on independent data storage facilities can be made accessible to any applications via standard mechanisms, see Figure 8.4. The author considers that as these standard methods become available, with particular reference to distributed information functionality, the Information Management Architecture will be able to encompass the functions for meaningful transfer of information between systems and the Information Distribution Architecture described in this thesis can 'revert back' to an Architecture providing 'basic communications backbone' functionality. However it may be some time before this is achieved since in the author's opinion products

Figure 8.4 Distributed Data Base Functionality



supporting accepted international standards must be delivered by the system vendors in order to be used by the manufacturing community.

In the interim period the SQL and RDBMS products which are currently available can be applied to CIM systems to provide some possibility for future system reconfiguration and flexibility. However these systems must also be combined with existing proprietary database products by providing suitable gateway facilities to allow for beneficial system integration in the short term.

8.4.3 Applications Architecture

The functionality available within the applications architecture is, as discussed above, the main focus for the industrial user. This must provide the required mechanisms for decision making and operations control to suit the organisational needs. Some of the many applications which come under this umbrella have already been referred to throughout this thesis. Most of these will be provided by external suppliers and thus, form an industrial user's point of view, it is the suppliers responsibility to provide solutions which can be integrated together in future CIM system implementations. The need for suppliers to adhere to internationally accepted standards in terms of the supporting information management and distribution functions has been discussed above but nevertheless the importance of this standardisation for suitable application evolution cannot be overstressed. However the industrial user may still need to produce solutions to specific applications problems and in addition may also need to integrate separate solutions using its own or other external resources as discussed above.

The evolution of suitable methodologies and tools for the support of application administration systems has received relatively little attention [Weston 1988]. There are few commercially available tools except for code development environments, many of which conform to ISO standards, which support the conversion of detailed logical designs into program code. These tools are mostly manual but with some support from windowing systems, interactive debuggers and incremental compilers. [Young 1989]. The activities related to the MAP/TOP MMS support functions has provided some standard functionality in this area as described previously. However a major research programme being undertaken by the Systems Integration Research Group at Loughborough University has been concerned with the specification and evolution of an AUTOMAtion Integration Language (AUTOMAIL) which functions as an application administration system. AUTOMAIL comprises a 'distributed system applications programming language and a set of configuration management, concurrent task management and debugging tools' [Weston 1988]. Currently the work has resulted in a system which is suitable for the programming of cell control applications [Weston 1989]. Once the evolution of AUTOMAIL and other such tools is completed and these tools become available to both system suppliers and industrial users a consistent and familiar approach to CIM systems integration will be available which will assist in the implementation of systems which have the required flexibility and reconfigurability necessary for the future.

8.5 Summary

This chapter has focussed on extending some of the previous discussions relating to the applicability, at Rockwell PMC and at other companies, of the concepts evolved in the specific system implementations described in this thesis and the possible use of alternative approaches. This focus has been made with particular reference to companies which operate in the small batch manufacturing sector of industry due to the increasing importance of this sector, involving increasing product variants and reducing product life, to highly developed countries such as the UK and US. Arguably the main goal of CIM systems integration for any company is to achieve real and lasting benefits in terms of increased competitive edge and therefore the ability to respond rapidly to change is the most important prerequisite for success. CIM systems integration is seen as a prerequisite for providing the necessary changes required to achieve this objective and these CIM systems integration solutions must be easily reconfigurable and flexible.

The work reported in this thesis has shown that the cost and effort involved in the reconfiguration of specific systems for application in new areas or for changing functionality is not insignificant. For Rockwell PMC many man years of systems effort over a considerable elapsed time period would be required to install the number of Cell Management Systems proposed. Therefore generic methodologies must be used to provide the lowest cost route for CIM systems implementation. However the methodology proposed here can provide a sufficiently generic approach to the integration problem such that it will reduce the cost of systems implementation to a large extent.

The solutions for the CIM implementations described in this thesis are shown to rely heavily on certain 'de facto standard' methods and tools for their supporting 'infrastructure' and, as this is potentially the case in other small batch manufacturing companies, the use of emerging tools, which conform to ISO standards, is arguably a prerequisite for the continuing future success of CIM systems integration. The available methods and tools which have been considered include such standards as MAP, TOP, FTAM, MHS and MMS for information distribution; IGES, STEP/PDES for data modelling; RDBMS, SQL and DDBMS for information management and solutions such as AUTOMAIL incorporating advances in messaging services for applications management.

The author considers that the main focus for the industrial user is to provide appropriate functionality for the required control mechanisms within the company and therefore the inclusion of standard methods and tools into the evolving solutions must be addressed by systems suppliers external to the company in addition to systems integrators within the company. Arguably, from the industrial implementor's point of view, the primary responsibility for applying standard methods and tools in the longer term should lie with external suppliers.

CHAPTER 9

Conclusions and Recommendations for Future Work

9.1 Introduction

The aim of this chapter is to consider the conclusions which can be drawn from the research work reported in this thesis. These conclusions are made with regard to the industrial implementor's viewpoint and the author believes that this will serve to offer certain contributions to the body of knowledge by complementing worldwide CIM systems integration research in terms of the following aspects:

(i) The problems encountered when implementing CIM systems;
(ii) The cost implications of CIM systems integration;
(iii) The advantages of using a Three Layer Hierarchy methodology;
(iv) The advantages of using a Three Architecture Model methodology;
(v) The assessment of the role of emerging standard methods and tools;
(vi) The use of Personal Computers in a shopfloor environment;
(vii) The importance of 'human integration' in CIM systems integration.

9.2 The Problems Encountered when Implementing CIM Systems

The specific implementation work reported in this thesis has led to the recognition of certain constraints which are generic in nature. The generic constraints faced during CIM systems integration in real industrial environments are concerned primarily with the management and distribution of information to those computer systems which provide application functionality to the users. The limited use of standards in existing systems forces real restrictions on the evolution of new applications since the system integrator must produce specific solutions thereby diverting valuable internal resources to enhancement of supporting systems rather than the important user applications themselves. The real problems faced by industrial CIM systems integrators involve not only the problems related to meaningful transfer of information between applications executed on different computer systems used for systems such as manufacturing control and CADCAM but also between computer systems and intelligent shopfloor devices such as the numerical controllers on machine tools, programmable logic controllers and robots. These shopfloor devices show a particularly wide range of proprietary solutions for information management and distribution. Machine control manufacturers in particular do not adhere to common standards for controller interfaces but produce specific solutions. These specific solutions make the interface to the machine controls different in many cases and complicate the application of CIM on the shopfloor.

9.3 The Cost Implications of CIM Systems Integration

Industrial companies such as Rockwell PMC must concentrate on the issues which relate to small batch production so that they can continue to compete effectively in worldwide markets. These companies must address the needs for improved product quality, lower manufacturing cost for batches as small as one, shorter delivery lead times and for increased responsiveness to the rapid changes expected in market demands. CIM systems integration is the appropriate vehicle for providing the necessary changes required and will allow for the achievement of real and lasting benefits in terms of increased competitive edge. However, the costs involved in CIM systems integration, for both hardware and software, are not insignificant. This research work has indicated that software development costs can be of the same order or even higher when compared with hardware costs. For example, the implementation of the shaft line C.M.S. at Rockwell PMC, as described in this thesis, has involved several man years of systems analysis and software programming effort during an elapsed time of over three years. The cost involved is significantly higher than the actual hardware installation costs incurred.

CIM systems integration which is specific to a given initial specification will also incur the need to duplicate costs for each system implemented. For Rockwell PMC this would imply the need for many man years of systems effort. It is therefore not difficult to understand that generic methodologies can provide the lowest cost route for CIM systems implementation. A totally generic approach to CIM systems integration is bound to be a difficult and costly exercise. However, generic integration methods must be derived since 'custom integrated' solutions can only produce more and more complex CIM systems. Arguably the responsibility for this lies with the vendors and associated research institutions. The author believes that manufacturing companies such as Rockwell PMC need to tackle the problem in a pragmatic way with due regard to their own internal needs and resources by using methodologies which make parts of the integration problem as generic as possible in real situations. The methodologies discussed below can provide a sufficiently generic approach to the integration problem such that the cost of implementation of CIM systems can be significantly reduced.

9.4 The Advantages of using a Three Layer Hierarchy Methodology

The implementation work carried out at Rockwell PMC has led to the proposal of a control model involving a three layer hierarchy of systems demonstrating many similarities to the ISO hierarchy. This hierarchy is formed from Factory, Cell and Machine Management Systems (F.M.S., C.M.S. and M.M.S.) respectively corresponding to the Facility, Cell and Workstation levels of the ISO six layer hierarchy. At Rockwell PMC the functionality required for the Factory Management System (F.M.S.) is already largely in place on the mainframe computer, in the form of many existing systems as described previously. There has been no necessity to change the basic functionality of these systems, although the use of particular functions has been amended. The research work has shown that suitable Cell and Machine Management Systems, which provide 'follow on' functionality to the evolving factory level MRPII systems, can be implemented thus providing extra functionality to the system as a whole. It has also been shown that the implementation of cell systems need not be restricted to machining cells alone but can be applied to other support functions such as material control, nc programming, tooling and maintenance. The three layer hierarchy approach has been shown to be a suitable model for the evolution of cell control systems in the small batch manufacturing situation at Rockwell PMC by the specific implementation of the cell and machine level systems. However as discussed previously there is some indication that heterarchical functionality may be appropriate within each of these hierarchical levels to provide certain communications facilities between manufacturing cell level systems for example. The author considers that this three layer hierarchy is applicable to other manufacturing companies in the same engineering sector and therefore provides a generic model for the evolution of similar systems in other companies.

9.5 The Advantages of using a Three Architecture Model Methodology

The author advocates the use of a Three Architecture Model as a suitable means for decomposing the CIM systems integration problem into manageable sub systems. The functional requirements of CIM systems in current small batch manufacturing situations can be considered with relation to this model which involves Applications; Information Management and Information Distribution Architectures. The applications architecture is responsible for supporting and coordinating the decision making actions and responses of the users. The information management architecture is responsible for providing the necessary information required by the user applications. The information distribution architecture is responsible for providing meaningful information transfer between the information management and the applications architectures and particularly between physically separate systems. This three architecture approach has resulted from the experience gained during the integration of existing with new systems and procedures in a real manufacturing situation using some of the technology currently available in the market place to industrial users. Systems available to the small batch manufacturing industry, particularly for the purpose of storing information used by specific applications programs, have been typically of a proprietary nature with a structure uniquely created by the applications designer. This requires that the CIM systems integrator is charged with extracting meaningful information via a 'gateway' mechanism and, arguably, this often involves transfer between remote systems.

The decomposition of CIM systems integration with reference to this three architecture model provides not only a suitable means of comparison but also for the identification of manageable sub systems. This also provides a particularly appropriate means for focussing on the potential application of emerging methods and tools in each of the specific areas. As implied above the major constraints found during the systems integration work undertaken during this research relate particularly to the lack of standards in the information management and information distribution architectures in a real manufacturing situation where 'green field site ideals' are inappropriate. The author considers that the main focus for the industrial user is to provide suitable functionality for the required control mechanisms within the company. Functionality in the information architectures is provided primarily to support this applications level. Therefore, in the author's opinion, the primary responsibility for applying emerging internationally accepted standard solutions lies with system suppliers external to the user companies resulting from a combination of initiatives funded by the Government and work undertaken by the suppliers and at other research organisations.

The author believes that this methodology can help to evolve sufficiently generic solutions to the specific implementation problems faced such that the costs involved in CIM systems integration can be significantly reduced.

9.6 The Assessment of the Role of Emerging Standard Methods and Tools

The author has also aimed to assess the role of some of the emerging standards, such as MAP/TOP and the services available in the application layer including MMS, MHS and FTAM together with the data modelling tools such as IGES and

PDES/STEP. Arguably the provision of suitable information management systems is the key to solving many of the problems involved in CIM systems integration and providing for the successful evolution of generic methods. The author considers that the application of Distributed Database Management Systems (DDBMSs) solutions based on emerging standards by the external system suppliers is a prerequisite for the success of CIM systems integration by the industrial user. DDBMSs will enable the combination of those subsets of the information management and information distribution architectures proposed here which deal with the distribution of meaningful information. This will allow the information distribution architecture to take on the role of a transparent connection between devices for the secure transfer of data allowing it to provide for a standard service in the same way as, for example, the telephone wire does now. The use of a standard Structured Query Language (SQL) will also provide a 'front end' for the industrial user which will greatly simplify or even eliminate the problems faced when integrating differing suppliers products for the evolution of improved manufacturing applications. The author suggests that the standardisation by suppliers of information distribution methods based on the emerging MAP manufacturing message services (MMS) functions will provide increasingly more suitable integration methods particularly for shopfloor devices, again assisting the evolution towards generic systems integration solutions.

There is little doubt that these standards will provide an improved platform for CIM systems integration in the longer term. However for the industrial user the integration problem for the foreseeable future will necessarily involve existing systems which do not conform to these standards so indicating that the generic constraints faced now will affect systems integration in industry for some time to come and emphasising the role external systems suppliers must adopt. In the interim period the industrial user must either 'stagnate' and risk loss of competitive edge or choose a 'player' to follow which, hopefully, is fully committed to international standards in the longer term. The need for short term solutions to real specific application requirements leaves companies such as Rockwell PMC no option but to choose from available non standard methods and products in order to integrate as far as possible the existing heterogeneous systems. The commitment to standards is fundamentally important and appropriate analysis of the requirements at an early stage, before any integration is considered, can help to produce solutions which may be partially reconfigurable as circumstances change. The specific implementation work reported here has, as far as possible, taken this approach and alternative solutions have been considered. However the research undertaken here has left the author in no doubt that the work involved in the reconfiguration of non generic solutions to incorporate changing needs will not be insignificant.

9.7 The Use of Personal Computers in a Shopfloor Environment

The specific implementation work described has illustrated the suitability of generally available low cost IBM PC compatible microcomputers for use as intelligent terminals on the shopfloor. The use of 'off the shelf' local area PC networking technology, which provides a suitable communications mechanism, can also provide low cost distributed computer systems which serve as excellent platforms for information and control systems supporting machining cell operations. This has been admirably demonstrated by the use of PC technology in both the DNC and C.M.S. implementations. These systems provide significant enhancements in functionality for the operators and foremen by supplying information on demand in real time on the factory floor. As discussed previously this increased functionality results in significant productivity improvements in component manufacture. These computer systems and the functionality they provide are particularly suitable for the shopfloor display of not only textual but also graphical information for the foremen and operators. The provision of shopfloor graphics is arguably a prerequisite for CIM systems integration on the factory floor by providing the means to eliminate the problems caused by the large quantities of shop paperwork required by existing manufacturing procedures.

9.8 The Importance of 'Human Integration' in CIM Systems Integration

The research carried out has reinforced the view that it may not be inappropriate to replace the term CIM with CHIM, Computer and Human Integrated Manufacturing. In the specific implementation work undertaken as a part of this research success or failure has been dependent on the full cooperation of the foremen and operators on the shopfloor from the initial conception of the functionality required down to the detailed design of the necessary user interface characteristics. In the author's opinion it cannot be overstressed that the aim of CIM systems integration is to provide useful applications for the user community and that the underlying technology only serves to support these applications.

9.9 Recommendations

From the industrial implementor's point of view the author considers that the future availability of suitable manufacturing control systems which are generically reconfigurable and flexible is dependent upon the rapidly increasing availability of products which incorporate mechanisms conforming to internationally accepted standard methods and tools. The primary responsibility for the integration of these standards lies with the systems supplier community external to the manufacturing users. Therefore the author recommends that the activities of the external hardware and systems suppliers concerned with the evolution of products which are involved in CIM systems integration are rapidly standardised according to the advances being made in information management and distribution by the database community. The integration of DDBMS technology into suppliers products together with suitably common 'front end' SQL functionality must be pursued to enable CIM systems integration to provide the required generic capabilities.

However it is fully recognised that the timescale for the availability of these improved products is too long for companies such as Rockwell PMC to just 'sit and wait'. Therefore CIM systems integration initiatives must continue using currently available non standard products. The methodologies described in this thesis should be used to provide suitable vehicles for this systems integration work. However, in order to ensure that it is possible to fully integrate the solutions being implemented in the short term into future systems, the author recommends that the industrial CIM system integrator chooses to work with a limited number of suppliers which have clearly defined and widely published commitment to the migration of their products to conform with international standards. In addition the author recommends that as far as possible the systems which are implemented are 'implemented as supplied' with the minimal amount of bespoke customisation and that the bespoke development of systems within a small batch manufacturing company is limited to the evolution of suitable applications functionality for the users. For Rockwell PMC this implies that the proposed implementation of further Cell Management Systems on the shopfloor and the interfaces into the Factory level management control systems and the CAD/CAM/CAPE interface should proceed wherever possible in collaboration with suitable external suppliers with the necessary commitment to international standards.

REFERENCES

Ablett, S., Coming up with the OSI goods, Network, February, p28, 1987.

ACME, Advanced Production Machines Research Review, The ACME Directorate, Science and Engineering Research Council, Polaris House, North Star Avenue, Swindon, September 1989.

Altoff, J.L., Integrated Information Support System: Common Data Model Subsystem, Autofact '87 Conference Proceedings, Detroit, Michigan, 1987.

AM&AM, Putting MAP to Work, American Machinist & Automated Manufacturing, January, p75 ,1985.

American Machinist, Computers in Manufacturing, American Machinist, April, SR-2, 1978.

Announcements Overview and Summary, Letter C88-22, IBM United Kingdom Ltd., November, 1988.

Anstiss, P., The Implementation and Control of Advanced Manufacturing Systems, Aerospace Dynamics, No 21, 1988.

AOS/VS, Master Reference Library, TDP3016, Data General Corporation.

AS/RS are expected to rise by 500% by 1994, Journal of Industrial Engineering, Vol 18, No 7, p6, 1986.

Astrop, A., DNC: The final link in the high tech chain, Engineering Computers, March, p19, 1983.

Banerjee, S.K., Application of structured design techniques in advanced manufacturing technology, 2nd Int. Conf. on Computer-Aided Production Engineering, Edinburgh, Mechanical Engineering Publications Ltd., 1987.

Batchelor, A.T., EIA and ISO numerical control standards for automated manufacturing systems, in Gardener, L.B., (ed.), Automated Manufacturing, ASTM Special Technical Pub. 862 ASTM, 1916 Race Street, Philedelphia, PA, USA, April, p21, 1985.

Banerjee , S.K., and Al-Maliki, I., A structured approach to FMS modelling, Int. J. Computer Integrated Manufacturing, Vol 1, No 2, p77, 1988.

Barkmeyer, E.J., Some Interactions of Information and Control in Integrated Automation Systems, Advanced Information Technologies for Industrial Material Flow Systems, Springer-Verlag, 1989.

Barron, D., Novell's SQL products, Lan Times, November, p64, 1989.

Beale, N.C.L., The MAP/TOP Initiative, Networks for the 1990s, Online, 1988.

Beck, L., Bar Codes Streamline Materials Tracking, Modern Materials Handling, Vol 41, No 5, 1986.

Becker, F.J., Improving Production Engineering with CAD/CAM, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Besant, C.B., Computer Aided Design and Manufacturing, 2nd ed., Ellis Horwood, 1983.

Besant, C.B., Computer Aided Design and Manufacturing, 3rd Edition, Ellis-Horwood, 1986.

Bessant, J. and Hayward, W., FMS in Britain - good and bad news, The FMS Magazine, January, p 35, 1986.

Bilalis, N.G. and Mamalis, A.G., The Flexible Manufacturing Systems (FMS) in Metal Removal Processing: An Overview, J. Applied Metalworking, Vol 3, No 4, p400, 1985.

Birchfield, E.B. and King, H.H., Product Definition Data Interface (PPDI), Proceedings of the 1985 United States Air Force CIM Industry Days Conference, April, 1985.

Black, I. and Murray, J.L., Conceptualisation and computer aided design- an applications perspective, Proceedings of the IMechE Conference, Effective CADCAM '87, Mechanical Engineering Publications Ltd, 1987.

Boeing Technical and Office Protocols Specifications Version 1.0, obtainable from the EMUG Secretariat, UK, 1985.

Bonnetto, R., Flexible Manufacturing Systems in Practice, North Oxford Academic Publishers Ltd., 1988.

Bonney, M. and Head, M., A framework to link theory to practice in computer aided production management, ACME Directorate 1987 Research Conference,University of Cambridge, 1987.

Booty, F., Still too many queries on distributed databases, Manufacturing Systems, February, p31, 1990.

Bourne, D. A. and Fox, M. S., Autonomous Manufacturing: Automating the Job Shop, IEEE Computer, Vol 19 , No 9, p76, September, 1984.

Bowman, D.J., CAD/CAM Primer, Sams, 1984.

Bowman, I., Red in Tooth and Claw, Manufacturing Systems, June, p15, 1989.

Bowman, I., Communications Costs does the message get through, Manufacturing Systems,June, p23, 1989.

Bowman, I., AMT- putting the bits in place, Manufacturing Systems, February, p12, 1990.

Broadhead, S., LAN Wars, Network, November, p109, 1989.

Brodner, P., Options for CIM: 'Unmanned Factory' Versus Skilled-base Manufacturing, Journal of Computer-Integrated Manufacturing Systems, Vol 1, No 2, p67, 1988.

Browne, J., Dubois, D., Rathmill, K., Sethi, S.P. and Stecke, K.E., Classification of flexible manufacturing systems, The FMS Magazine, April, p114, 1984.

Browne, M., How a control system links a 'high-tech' company, Production Engineer, June, p 39, 1985.

Buckley, C.P., DNC: The First Step Towards Factory Floor Data, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Bunce, P., Planning for CIM, The Production Engineer, 64, (2), Feb, p 21, 1985.

BURNYIV CNC, Programming and Operation / Installation and Setup Manuals, Cleveland Machine Controls Inc., 7550 Hub Parkway, Cleveland, Ohio.

Buyers Guide, Integrated CADCAM platforms, Industrial Computing, February, p47, 1989.

Callihan, H.D. and Loyacona, P.J., From Forms-Featured Solids Modelling to Production, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

CAM-I Standards Committee, A discrete parts manufacturing model (DPMM), R-86-SC-01, draft issue, 1983.

Capes, P., Putting Compatibility on the Factory MAP, Metalworking Production, May, p120, 1985.

Carrie, A., Simulation of Manufacturing Systems, John Wiley & Sons, 1988.

Case, K., Acar, B.S. and Hart, N.M., Computer Aided Production Engineering linking CAD, Process Planning and Tool Design, ACME Directorate 1987 Research Conference, University of Cambridge, 1987.

Casey, P.,The problems and benefits of CIM, Production Engineer, November, p25, 1986.

St. Charles, D.P., Simultaneous Engineering, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Chater, R., E. and Scott, P.B., New approach to costing and implementation, The FMS Magazine, October, p199, 1986.

Chorafas, D.N. and Legg, S.J., The Engineering Database, , 218-232, 1988.

CICS, General Information Manual, GC33-0155, International Business Machines Corporation.

CIM, Computer Integrated Manufacturing: the IBM Experience, Findlay Publications for IBM UK Ltd., Engineering, Scientific and Industrial Centre, Birmingham Road, Warwick CV34 5JL, 1988.

Cincom Systems (UK) Ltd., The Cincom Building, 99 King St., Maidenhead, Berks., SL6 1DP.

Clancy, G.J. Jnr., A status report on the IEEE project 802 local area network standard, Local Network No 81, p263, 1981.

Clare, D., Up against the ropes, Settling the differences between Ethernet and IEEE 802.3, LAN Times, October, p112, 1988.

Clarke, D.D., Pogran, K.T. and Reed, D.P., An Introduction to Local Area Networks, Proceedings of IEEE, Vol 66, No 11, p1497, 1978.

Clarke, M.J., On the problems involved in turning a computer aided draughting package into a computer aided design system, Proceedings of the IMechE Conference, Effective CADCAM '87, Mechanical Engineering Publications Ltd, 1987.

Commitment to Standards, An OSI guide for management, EB 31339-42-88, Digital Equipment Corporation, 1988.

Computer Aided Design (International Conference), Institution of Electrical Engineers, Southampton, 1969.

Computer Aided Design (International Conference), 1972, Einhoven, North-Holland 1974.

Computer Aided Design (International Conference), Institution of Electrical Engineers, Southampton, 1974.

Computer Aided Design (conference), National Engineering Laboratory, Glasgow, 1978.

Computer Aided Design, Manufacturing and Operation in the Automotive Industry (Conference), Geneva, Springer, 1987.

Conner, D., The deterministic character of Arcnet proves ideal for the factory floor, EDN, September, p101, 1988.

Costa, A., Garetti, M., Design of a Control System for a Flexible Manufacturing Cell, Journal of Manufacturing Systems, Vol 4, No 1, p65, 1985.

Cotter, S.L., IMPACT-An Integration Framework for Planning and NC Manufacturing,Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Crossley, T.R. and McCartney, D., A Decade of Direct Numerical Control, Annals of the CIRP, 27, No 1, p405, 1978.

Date, C.J., An introduction to database systems volume 1, Addison-Wesley Publishing Company, Inc, 1986.

Day, J.D., and Zimmermann, H., The OSI reference model, Proc of the IEEE, Vol 71, No 12, p173, 1983.

Deadman, R., Everything You Always Wanted to Know about MAP, Industrial Computing, November, p29, 1986.

Dept. of Trade and Industry, UK, Through MAP to CIM, Moore & Matthes Ltd., 1987.

Dorf, R.C., Robotics and Automated Manufacturing, Reston, 1983.

DOS/VSE, International Business Machines Corporation.

Duffie, N.A., Piper, R.S., Humphrey, B.J. and Hartwick Jr., J.P., Hierarchical and Non-hierarchical Manufacturing Cell Control with Dynamic Part-oriented

Scheduling, Proceedings of NAMRC-XIV, Minneapolis, Minnesota, 28-30 May, 1986.

Duncan, M.E., Emerton, G.F., CADCAM for mechanical parts in the electronics industry, C163/83 IMechE, 1983.

Dunn, J., Adding up the real costs of industrial automation, The Engineer, April, p28, 1986.

Dwyer, J., A standard stuck in the mud, Automation, March, p29, 1986.

Dwyer, J., CIMAP - the Verdict, Automation, January, p16, 1987.

Dwyer, J., MMS ignores the arguments, Manufacturing Systems, December, p18, 1989.

Eastwood, R., Maximum control from real-time feedback, Engineering Computers, p17, July 1989.

EIA Project 1393A Draft 6, Manufacturing Message Specification, Part 1: Service Specifictaion, May, 1987.

Elavia, J.D., Where Do I Start with CIM?, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Endelberger, J.F., Robotics in Practice: Management and Applications of Industrial Robots, Kogen Page, 1980.

Engineering Workstations, Industrial Computing, February, 1989.

Epson LX-80 Printer Operating Manual, Y56099102003, Epson Corporation.

Ethernet, The Ethernet - A Local Area Network, Data Link and Physical Layer Specifications, Version 1.0, September, 1980.

ESPRIT Project No 688, CIM OSA strategic management and design issues, CIM-OSA/AMICE. 489 Ave. Louise, B14-B-1050, Belgium, 1988.

Evans, S., Sackett, P.J., Realised performance in a novel approach to computer aided process planning, IEE International Conference on Computer Aided Engineering, University of Warwick, Coventry, UK, 1984.

Farish, M., Finding the way without MAP, The Engineer, November, p37, 1989.

Finkelstein, D., The road to peer-to-peer, Micro-Mainframe Links Survey, Network, September, 1988.

Finkelstein, R., In whom they serve, PC Tech Journal, May,p32, 1989.

Folkman, J., DNC: What is it?, Tooling and Production, January, p70, 1982.

Foreman, J.W., Gaining Competitive Advantage by Using Simultaneous Engineering to Integrate Your Engineering, Design, and Manufacturing Resources, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Fox, K.A., MRP II providing a natural 'hub' for computer integrated manufacturing systems, Industrial Engineering, Vol 16, p44, 1984.

Fritsch, C.A., Information Dynamics for Computer Integrated Product Realisation, Advanced Information Technologies for Industrial Material Flow Systems, Springer-Verlag, 1989.

FUSION, Network Research Corporation, including: Fusion Network Administrator's Manual; VMS Users Guide.

Gane, C. and Sarson, T., Structured systems analysis: tools and techniques, Prentice Hall, 1982.

Genord, D.C., Welsh, M.G., Houser, R.V. and Wyttenbach, L., An Automatic NC Processor: Harnessing the Technology of Form-Feature Based Solids Modelling, Autofact '88 Conference Proceedings, Detroit, Michigan, 1988.

Gershwin, S.B., Hildebrant, R.R., Suri, R. and Mitter, S.K., A Control Perspective on Recent Trends in Manufacturing Systems, IEEE Control Systems Magazine, April 1986.

Graves, G.R., Production Planning for GT Manufacturing, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Graves, G.R., Yelamanchili, B. and Parks, C.M., An interface architecture for CAD/CAPP integration using knowledge-based systems and feature recognition algorithms, Int. J. Computer Integrated Manufacturing, Vol 1, No 2, p89, 1987.

Green, T., Buyers Guide, Databases and Text Retrieval, PC User, February, p119, 1990.

Greenwood, N.R., Implementing Flexible Manufacturing Systems, Macmillan Education Ltd., 1988.

Gregory, J.G., Rule-Based Methods for Composite/Plastics Design and Tooling: Tools that Design Themselves, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

GRIP Programmers Manual, Vols I & II, UG V6.0, McDonnell Douglas Corporation.

Groover, M.P. and Zimmer, E.W., CAD/CAM, Prentice-Hall, p66, 1984.

Groover, M.P., Automation, Production Systems, and Computer Integrated Manufacturing, Prentice-Hall International Editions, p707, 1987.

Hampshire, N, The intelligent amendment, Workstation Magazine, November, p27, 1988.

Harhalakis, G., et al., An integration of manufacturing resource planning (MRP II) systems and computer aided design (CAD) based on update dependencies, International conference on Data Knowledge Systems for Manufacturing and Engineering, Hartford, Connecticut, USA, 1987.

Harhalakis, G., SSemakula, M.E. and Johri, A., Fuctional design of an integrated CIM system at the facility level, Int. J. Computer Integrated Manufacturing, Vol 1, No 4, p245, 1988.

Harrison, D.K. and Leonard, R., Optimising CAD usage in small manufacturing companies by parametric programming, Computer-Aided Engineering Journal, December, p229, 1986.

Hatvany, J., Intelligence and Cooperation in Heterarchic Manufacturing Systems, Robotics and Computer Integrated Manufacturing, Vol 2 No 2, p101, 1985.

Hatvany, J., Ed., World Survey of CAM, Butterworths & Co. (Publishers) Ltd, 1983.

Hawkes, B.R., The CADCAM Process, Pitman, 1988.

Herrin, G.E., What MAP means to you, Modern Machine Shop, April, p58, 1986.

Hess, G.J., Computer Integrated Flexible Manufacturing - 1985 (CIFM-85), A Program Guide for CIM Implementation, American Technical Publishers Ltd., p105, 1985.

Hill, J.M., Computers and AS/RS Revolutionize Warehousing, Industrial Engineering,Vol 12, No 6, p34, 1980.

Hillawi, J.I., and Bennett, K.R., EDIF- An Overview, Computer Aided Eng Journal, Vol 3, No 3, p102, 1987.

Hollingum, J., The MAP Report (Bedford:IFS (Publications) Ltd.), 1986.

Hordeski, M.F., CAD/CAM Techniques, Reston, 1986.

Hsu, C. and Skevington, C., Integration of data and knowledge in manufacturing enterprises: A conceptual framework, Journal of Manufacturing Systems, Vol 6, No 6, p277, 1987.

Hubbard, S.W., CAD/CAM Applications for Business, Oryx, 1985.

Huggins, T., IBM's ring arrives, Network, March, p4, 1986.

Huggins, T., LANs - getting the message across, (LANs Survey), Network, November/December, p55, 1985.

Hurwitz, D.R., Data Capture for MRP-II Systems, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Husband, T.M., Ed., International Trends in Manufacturing Technology, Education and Training in Robotics, IFS (Publications) Ltd, UK, 1989.

Hyer, N.L. and Wemmerlov, U., Group Technology in the US manufacturing industry: a survey of current practices, Int. J. Prod. Res., Vol 27, No 8, p1287, 1989.

IBM, Industrial Solutions Announcements Summary, CIM Architecture, Form No GU20-9899, October, 1989.

ICAM Project Computer Program Development Specification (DS) for ICAM Integrated Support System (IISS) Configuration Item: Prepared by Control Data Corporation and D. Appleton Company USA, 1983.

Ingersoll Engineers, Integrated Manufacturing, IFS(Publications) Ltd., UK, 1985.

IRMA, Domestic User's Manual,Digital Communications Associates Inc., 1989.

ISO, The Ottowa Report on Reference Models for Manufacturing Standards. ISO TC 184/SC5/WG1 N51, Version 1.1, 1986.

Ito, Y., Shinno, H. and Saito, H., A proposal for CAD/CAM interface with expert systems, Robotics and Computer-Integrated Manufacturing, Vol 4, No, 3/4, 1988.

Jablonowski, J., Reexamining FMSs, American Machinist Special Report 774, March, p125, 1985.

Jackson, R.H. and Eldred, A.H., Baker Perkins - six years experience with CAD/CAM, Production Engineering, May, p36, 1983.

Jackson, R.H., Achieving effective CADCAM: Ten years of experience at Baker Perkins, Proceedings of the IMechE Conference, Effective CADCAM '87, Mechanical Engineering Publications Ltd, 1987.

Johannesson, G., Programmable Control Systems: an Introduction, Chartwell-Bratt, 1985.

Jones, A.T., and McLeàn, C.R., A proposed hierarchical control model for automated manufacturing systems, Journal of Manufacturing Systems, Vol 19, p15, 1986.

Jones, A.T. and McLean, C.R., A Cell Control System for the AMRF, Computers in Engineering, 2. The American Society of Mechanical Engineers, p353, 1984.

Jones, R., Spreading Expertise, Network, December, p76, 1988.

Kelly, T., Forward Planning for the LAN User, (LANs Survey), Network, November, p90, 1987.

Kellock, B., Simulation scores on the shopfloor, Engineering Computers, May, p15, 1989.

Kemp, N.J., Clegg, C.W. and Wall, T.D., Human aspects of computer-aided manufacturing, IEE International Conference on Computer Aided Engineering, University of Warwick, Coventry, UK, 1984.

Kim, W., Relational database systems, ACM Comp. Surv., Vol 11, No 3, 1979.

Kimura, O, and Terada, H., Design and analysis of pull system, a method of multi-stage production control, International Journal of Operations & Production Management, Vol 19, No 3, p241, 1981.

Kleeman, M.W., Feature Based Parametric Solids Modelling for Improving Mechanical Engineering Design, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Knight, K.A., Socio-Technical Engineering: An Approach to Technology Integration,Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Klopp, R.L. and Smith, J.D., Application of Group Technology to Factory Design, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Kochan, A., FMS is for the big boys - in the US, The FMS Magazine, July, p 134, 1985.

Kochan, A., United Nations examines recent trends in FMS, The FMS Magazine, April, p77, 1986.

Koff, G.A., Automatic Guided Vehicle Systems: Applications, Controls and Planning, Material Flow, Vol 4, p3, 1987.

Kramer, W., Object Oriented NC Programming with CAD/CAM, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Krisnamurthy,V., Su, S.Y.W., Lam, H. and Barkmeyer, E., A Distributed Database Architecture for an Integrated Manufacturing Facility, National Bureau of Standards, Washington, D.C., 1987.

Kurland, R., Leading Edge CAD/CAM/CAE Technologies and Predictions for Their Success, Industrial Computing, February, 1989.

Kutcher, M., Data Driven Automation, IEEE Spectrum, May, 1983.

LaMarsh, J., Manufacturing Strategies and Change Management, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

LAN Software Report, Second Printing May, Novell Inc. Orem. Utah, 1985.

Lawrence, A., The CADCAM connection, Industrial Computing, March, p31, 1989.

Lawrence, A., A better scheduling option?, Industrial Computing, June, p28, 1989.

Laws, M., Living up to the OSI promise, Network, January, p27, 1987.

Lee, L. C., A comparative study of the push and pull production systems, International Journal of Operations & Production Management, Vol 9, No 4, p5, 1989.

Lefkon, R., A LAN Primer, Byte, July, p 146, 1987.

Libes, D., and Barkmeyer, E., The integrated manufacturing data adminstration system (IMDAS) - an overview, International Journal of Computer Integrated Manufacturing, Vol 1, p44, 1988.

Liewald, M.H., Initial graphic exchange specification: success and evolution. Computers and Graphics, Vol 9, No 1, p47, 1985.

Lillehagen, F., The product information system and data bases in mechanical CAE, Robotics & Computer Integrated Manufacturing, Vol 1, No 3/4, p255, 1984.

Maley, J.G. and Solberg, J.J., Part Flow Orchestration in CIM, Proceedings of the 9th International Conference of Production Research, Cincinatti, Ohio, 17-20 August, 1987.

Marca, D.A. and McGowan, C.L., SADT- Structured Analysis and Design Technique, McGraw-Hill, 1988.

Majchrzak, A., Effects of Computerized Integration on Shop Floor Human Resources and Structure, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Majchrzak, A., The Human Infrastructure Impact Statement (HIIS): A tool for managing the effective implementation of advanced manufacturing technology, Journal of Computer-Integrated Manufacturing Systems, Vol 1, No 2, p95, 1988.

Marks, P.C., Expert System-Based Generative Process Planning, Autofact '87 Conference Proceedings, Detroit, Michigan, 1987.

Major, F. and Grottke, W., Knowledge engineering within integrated process planning systems, Robotics & Computer-Integrated Manufacturing, Vol 3, No 2, p209, 1987.

Malley, J.C. and Ray, R., Informational and organizational impacts of implementing a JIT system, Production and Inventory Management, Second Quarter, p66, 1988.

Manoochehri, G.H., Improving Productivity with the Just-in-Time System, Journal of Systems Management, 36, January, p23, 1985.

MAP Specification Version 3.0, General Motors, obtainable from the EMUG Secretariat, UK, 1987.

Mather, H., MRP 2 won't schedule the factory of the future, Materials Management, Fall, 1989.

Maxwell, W.L. and Muckstadt, J.A., Design of Automatic Guided Vehicle Systems, IIE Transactions, Vol 4, No 2, p114, 1982.

Mayer, R.J., IGES one answer to the problems of CAD database exchange, Byte, June, p209, 1987.

McDonnell Douglas Information Systems Ltd., Wells Court, Albert Drive, Sheerwater, Woking, Surrey GU21 5RN.

McGinnis, L.F., Some Issues in Controlling Integrated WIP Material Handling Systems, Advanced Information Technologies for Industrial Material Flow Systems, Springer-Verlag, 1989.

McLean, C.R., an architecture for intelligent manufacturing control, Proceedings of the ASME Internal Conference on Computers in Mechanical Engineering, August, 1985.

McLean, C., Mitchell, M., Barkmeyer, E., A computing architecture for small batch manufacturing, IEEE Spectrum, May, 1983.

Mesarovic, M.D., Macko, D. and Takahara, Y., Theory of hierarchical, multilevel systems, Academic Press, 1970.

Melkanoff, J., The CIMS database: goals, problems, case studies, and proposed approaches outlined, Industrial Engineering, 16, p78, 1984.

Metcalfe, R.M. and Boggs, D.R., Ethernet: Distributed Packet Switching for Local Computer Networks, Communications of the ACM, Vol 19, No 7, p395, 1976.

Meyer, W., et al, Knowledge-based Factory Supervision - the CIM shell, International Journal of Computer Integrated Manufacturing, Vol 1, No 1, 1988.

Micro-Mini Links Survey, Closing the gap, Network, December, 1988.

Microsoft Limited, Excel House, 49 De Montfort Road, Reading, Berks, RG18LP.

Mizlo, J., LAN Tightens Factory Floor Control, Mini-Micro Systems, December, p53, 1985.

Moller, C., Applying Local Area Networks Effectively, Networks '85, Online Publications, 1985.

Morris, L., I want my DBMS! Enterprise-wide database management, Lan Times, Nov, p58, 1989.

MS-DOS Operating System Version 3.30, 41063001-330-R09-0787, Microsoft Corporation, 1987.

Mullins, P., JIT's competitive edge, Production, July, p62, 1989.

Musolf, J.V., Resource Management: The Long Range Goal of Just-In-Time, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Naylor, A.W. and Volz, R.A., Integration and Flexibility of Software for Integrated Manufacturing Systems, Design and Analysis of Integrated Manufacturing System, National Academy Press, 1988.

Nelleman, D.O., World Class Cost Management and CIM Justification: The Way of the 90s, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Netware, Advanced Netware 286 V2.15, Novell Inc., including: Btrieve Record Manager,100-000387; Command Lin Utilities, 100-000423; Menu Utilities, 100-000424; Supervisor Reference,100-000426; User's Guide, 100-000422, 1989.

Networks and Communications Buyer's Guide, Digital Equipment Corporation, 1989.

Norwood, D.L., ICAM Factory of the Future Concept, CASA/SME Autofact 5 Conference. Nov. 1984.

Oliva, L.M., Why Standards are so Important to CIM, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

O'Rourke, T., Accounting for CIM, Industrial Computing, March, p21, 1990.

Owen, J., and Bloor, M.S., Neutral formats for product data exchange: the current situation, Computer Aided Design, Vol 19, p436, 1987.

Parunak, H.V.D., Chapter 5: Factory Communication System, in Artificial Intelligence: Implications for CIM, IFS(Publications) Ltd./Springer-Verlag, 1988.

Personal Computers, What to buy for Business, A complete guide to buying a PC, No.98, May, What to Buy Plc., Kings Road, London, 1989.

Pressman, R.S., Numerical Control in Computer Aided Manufacturing, Wiley, 1977.

Plenert, G. and Best, T.D., MRP, JIT, OPT; What's 'best?, Production and Inventory Management, Vol 27, No 2, p22, 1986.

PC Weekly, Choosing between Ethernet and the Big Blue safety net, PC Weekly, May, 1988.

Pearson, M., Implementing MAP/EPA in the Manufacturing Cell, The FMS Magazine, January, p15, 1987.

Piciacchia, F.R., Plant Operations Control: A Vital Necessity for Executing the JIT Schedule in a CIM Plant, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

PL1 Optimising Compiler Language Reference Manual, SC33-0005, International Business Machines Corporation.

Primrose, P.L. and Leonard, R., The development and application of a computer based appraisal technique for the structured evaluation of machine tool purchases, Proc Instn Mech Engrs Vol 198B No 10, p141, 1984a.

Primrose, P.L. and Leonard, R., Optimizing the financial advantage of using CNC machine tools by use of an integrated suite of programs, Proc Instn Mech Engrs Vol 198B No 10, p147, 1984b.

Primrose, P.L. and Leonard, R., The use of a conceptual model to evaluate financially flexible manufacturing system projects, Proc Instn Mech Engrs Vol 199 No B1, p15, 1985a.

Primrose, P.L. and Leonard, R., Evaluating the 'intangible' benefits of flexible manufacturing systems by use of discounted cash flow algorithms within a comprehensive computer program, Proc Instn Mech Engrs Vol 199 No B1, p23, 1985b.

Purdue, R., Open Session, Communique, June, p13, Published by ComCentre, 1989.

Pustzai, J., Computer Numerical Control, Reston, 1983.

Rahman, M. and Narayanan, V., An expert system for process planning, Robotics & Computer-Integrated Manufacturing, Vol 3, No 3, 1987.

Ranky, P.G., Computer Integrated Manufacturing - an Introduction with Case Studies, Prentice-Hall, 1986.

Rathmill, K., Robotic Assembly (industrial trends in manufacturing technology), IFS (Publications) UK, 1985.

Rational Data Systems, Report on PC Integration, First Edition, July, Rational Data Systems Inc, 1988.

Reference Model of Production Systems, Version 1.0, Digital Equipment Corporation and Nederlandse Philips Bedrijven BV, 1987.

RJE, Remote Job Entry User's Guide, SH12-5328-05, International Business Machines Corporation, 1987.

RJE80 Control Program (RJE80) User's Manual (AOS & AOS/VS), 093-157, Data General Corporation.

Roberts, L.G. and Wessler, B.D., Computer network development to achieve resource sharing, Proc. SJCC, p543, 1970.

Round Table, Measuring MAP's Progress, Network, January, 1987.

Rouse, N.E., Developing Network Standards, Machine Design, December, 1985.

Saxe, K., MRP-II Into CIM: The Interface Phase, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Schnur, J.A., Can there be CIM without MRPII?, CIM Review, Vol 3, No 4, 1987.

Seyer, M.D., RS232 made easy, Prentice Hall Inc,1986.

Strole, N.C., A local communications network based on interconnecting Token-Access Rings, IBM Journal Res Develop, Vol 27, No 5, 1983.

Shaw, M.J., A distributed scheduling method for computer integrated manufacturing: the use of local area networks in cellular systems, International Journal of Production Research, Vol 25, No 9 p1285, September 1987.

Simpson, J., Hocken, R., Albus, J., The Automated Manufacturing Research Facility of the National Bureau of Standards, Journal of Manufacturing Systems, Vol 1, No 1, p17, 1982.

Singh, M.G., Dynamic Hierachical Control, North-Holland, 1980.

Snodgrass, B,N., Applications of Systems Engineering Tools and Techniques, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Sumpter, C.M., Weston, R.H. and Gascoigne, J.D., Computer integration in Flexible Assembly Systems, Int. J. Robotics Res., Vol 10, July, p43, 1987.

Suzuki, H., Inui, M., Kimura, F. and Sata, T., A product modelling system for constructing intelligent CAD and CAM systems, Robotics and Computer-Integrated Manufacturing, Vol 4, No, 3/4, 1988.

Schwartz, M., Telecommunication networks: protocols, modelling and analysis, Addison-Wesley Publishing Company, 1987.

Salzman, R.M., Engineering/Manufacturing Databases: The New Generation of Computer-Integrated Manufacturing Systems, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Santalla, R.W., Smart CAD Builds Large Plants, Computer-Aided Engineering, June, 1988.

Savage, E. and Mikurak, M., The Integration of a Finite Scheduling System into Manufacturing Resource Planning, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Schaffer, G., Stepping up to CAM, American Machinist, November, p87, 1978.

Schaffer, G., Non-real-time DNC, American Machinist, March, p103, 1979.

Sharpe, R., OS/2 under scrutiny, Network, January, p43, 1988.

Shapiro, S.F., ILANs Critical to CIM Success, Computer Design, April, 1988.

Siemens Sinumerik 810/850, Planning Instructions, Universal Interface, E80210-T77-X-A2-7600, Siemens AG.

Skinner, J., Theory into practice, Manufacturing Systems, June, p47, 1989.

Smith, G.W., Integrating humans and computers in manufacturing (CHIM), Journal of Computer-Integrated Manufacturing Systems, Vol 1, No 2, p66, 1988.

Solberg, J.J. and Heim, J.A., Managing Information Complexity in Material Flow Systems, Advanced Information Technologies for Industrial Material Flow Systems, Springer-Verlag, 1989.

SQL Server, Accessing the Data, PC Business World, January, p17, 1990.

Ssemakula, M.E., The role of process planning in the integration of CAD/CAM systems, Proceedings, Fourth European Conference on Automated Manufacturing (AUTOMAN 4), Birmingham, U.K., 1987.

Stauffer, R.N., IGES and Beyond, CIM Technology, Vol.4, No 2, 1985.

Stevenson, D.R., Applications of Microcomputers in Manufacturing Management, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Strom, J., Matter of Protocols, Systems International, December, p41, 1988.

Stuckey, R.J. and Pennington, R.A., MAP and TOP, Artificial Intelligence Implications for CIM, IFS Publications Ltd., 1988.

Survey Supplement, The British Industrial Computing Survey, Industrial Computing, October, p37, 1988.

System Selector, Production Management Systems, Industrial Computing, January, p31, 1987.

Swindle, R., Financial Justification of Capital Projects, Autofact '85 Conference Proceedings, Detroit, Michigan, 1985.

Talvalage, J.J. and Hannam, R.G., Flexible Manufacturing Systems in Practice: Applications, Design and Simulation, Marcel Dekker, 1988.

Tanenbaum, A.S., Computer Networks, Prentice-Hall, 1981.

Taylor, R., Common Connections, Systems International, August, p52, 1988.

TCP, Data General Corporation, including: Using AOS/VS TCP (TCP), 093-000398; Using AOS/VS Internet (Telnet), 093-000399; Installing & Administering DG TCP/IP (AOS/VS), 093-701027.

The Data General Communications Strategy, 012-3346, Data General Corporation, 1988.

TI Matrix, Personal Communication, 1985.

Tsatsoulis, C. and Kashyap, R.L., A case-based system for process planning, Robotics and Computer-Integrated Manufacturing, Vol 4, No, 3/4, 1988.

Tucker, W.W., The Linits of Automation: Sociotechnical Engineering in Manufacturing Assembly, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

UGFM, Unigraphics File Management, UGII V6.0, McDonnell Douglas Corporation.

UGNET, Unigraphics Resource Sharing Network, UGII V6.0, McDonnell Douglas Corporation.

UGPLOT, Unigraphics Plotter Management, UGII V6.0, McDonnell Douglas Corporation.

Urwick, Local Networks, A Product Review, Urwick Nexos Ltd., 1981.

Van Dyke Parunak, H., and White, J.F., A Synthesis of Factory Reference Models ITI TR-87-29, Industrial Technology Institute, PO Box 1485 Ann Arbor, Michigan, USA, 1987.

Vamos, T., Cooperative Systems- An Evolutionary Perspective, IEEE Control Systems Magazine, p9, August, 1983.

VAX/VMS Version 5.2, User Documentation, Media Kit QA-001AA-H5, Digital Equipment Corporation.

Virtual Machine/System Product Introduction, GC19-6200-4, International Business Machines Corporation, 1986.

Vizard, M., Networking: TCP/IP holds centre stage, Digital Review, March, p14, 1988.

VM, Virtual Machine/System Product, Introduction, GC19-6200, International Business Machines Corporation.

VSAM General Information Manual, GC24-5143, International Business Machines Corporation.

VSE/POWER Shared Spooling Users Guide, SH12-5330, International Business Machines Corporation.

VTAM Reference Summary, LY30-5600, International Business Machines Corporation.

Walkenhorst, S., Portable Netware offers host connectivity, LAN Times, IV, (IV), April, 1989.

Wang, M. and Smith, G.W., Modelling CIM systems Part 1: Methodologies, Journal of Computer-Integrated Manufacturing Systems, Vol 1, No 1, 1988.

Warnecke, H.J., Ed, Proceedings of the 3rd International Conference on Flexible Manufacturing Systems, Boeblingen, West Germany, IFS (Publications) Ltd. and North-Holland, 1984.

Warner, E., Steaming, High Technology Business, September, 1988.

Weber, D.M. and Moodie, C.L., Information management in automated and integrated manufacturing, Robotics & Computer Integrated Manufacturing, Vol 4, No 3/4, p601, 1988.

Weber, D.M. and Moodie, C.L., Distributed, intelligent information system for automated, integrated manufacturing systems, Advanced Information Technologies for Industrial Material Flow Systems, Springer-Verlag, 1989.

Weill, R., Spur, G., Eversheim, W., Survey of Computer-Aided Process Planning Systems, Annals of the CIRP, Vol 31, No 2, p539, 1982.

Weinberg, J.C., Linking the CIM Plan with Operations Strategy, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Wejman, J.M., The New Generation of Manufacturing Systems, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Weston, R.H., Sumpter, C.M. and Gascoigne, J.D., Distributed manufacturing systems, Robotica, Vol 4, p15, 1986.

Weston, R H, Sumpter C M and Gascoigne J D, Industrial computer networks and the role of MAP - Part 1, Microprocessors and Microsystems Vol 10, No 7, September, p363, 1986.

Weston, R H, Sumpter C M and Gascoigne J D, Industrial computer networks and the role of MAP - Part 2, Microprocessors and Microsystems Vol 11, No 1, January, p21, 1987.

Weston, R.H., Gascoigne, J.D., Rui, A., Hodgson, A., Sumpter, C.M. and Coutts, I., Steps towards information integration in manufacturing, Int. J. Computer Integrated Manufacturing, Vol 1, No 3, p140, 1988.

Weston, R.H., Gascoigne, J.D., Sumpter, C.M., and Hodgson, A., The need for a generic framework for systems integration, Advanced Information Technologies for Industrial Material Flow Systems, Springer-Verlag, 1989.

What Personal Computer?, PC User Special Issue, February, 1989.

Wild, K., Production and Operations Management: Principles and Techniques, 3rd ed., Holt Rinehart and Wilson, 1984.

Wildish, M., Computer nesting is key to success, Machinery and Production Engineering, November, p18, 1986.

Williams, T.J., Computer Control Technology - past, present and probable future, Trans Inst M C, Vol 5, No 1, p7, 1983.

Wilson, P.R., Interfaces for Data Transfer Between Solid Modelling Systems, IEEE Computer Graphics and Applications, Vol. 5, No 1, 1985.

Woodgate, H.S., MRP III-Material Flow Control in JIT Manufacturing, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Wright, O., Manufacturing Resource Planning: MRPII, Oliver Wright Ltd., 1984.

Xephon, The 3270 Handbook, Xephon Technology Transfer Ltd., 1988.

XODIAC Documentation Package, TDP0052, Data General Corporation, including: XODIAC Guide for Operators & Network Managers, 093-260; XODIAC Metwork Management System User's Manual, 093-178; Programming with XODIAC Management System (AOS & AOS/VS).

Yeomans, P.H., Improving quality and productivity in systems modelling using the IDEF methodologies, Micromatch Ltd, 1985.

Yeomans, R.W., Choudry, A. and ten Hagen, P.J.W., Editors, Design Rules for CIM, North Holland ,1986.

Young, A., CIM: The Social Impact, Autofact '89 Conference Proceedings, Detroit, Michigan, 1989.

Young, R.E., CIM System Development for Small to Medium Size Discrete-Parts Manufacturing Companies, Advanced Information Technologies for Industrial Material Flow Systems, Springer-Verlag, 1989.

Zimmermann, H., OSI Reference Model - the OSI Model of Architecture for Open Systems Interconnection, IEEE Trans Communication, Vol COM 28, p425, 1980.

Zorpette, G., The Main Event: Graphics Supercomputers, IEEE Spectrum, January, 1989.

APPENDIX A

April 1984
A.N. Walton

1. The Machine Shop Control System

1.1 Background

The computer based Machine Shop Control system will form part of the overall Factory Management System being developed at Baker Perkins Limited in order to improve its manufacturing efficiency.

The central computer system will provide information and management instructions to the various departments and receive data from them about work progress. The separate sections of the factory may each be controlled by their own computer system.

The Machine shop in particular is being split up into a number of manufacturing cells on group technology principles e.g. shaft, disc, gear cells. The machine shop control system will be responsible for the control of work through these cells and the machines in them.

1.2 The Machine Shop Control System Configuration

The control system is shown schematically in Figure 1. It will be based on a hierarchy of control systems.

Each machine, whether CNC, NC or manual, will be controlled by a Machine Management System (MMS). Each group of machines forming a machining cell and their MMS's will be controlled by a Cell Management System (CMS). These cell systems will report to the overall Factory Management System (FMS) together with other Management Systems e.g. tooling, maintenance, as they are developed.

A possible configuration is shown in Figure 2.

1.3 The Existing Factory Management System

The Factory Management System is already largely developed and installed. It is centred on a Hitachi Mainframe configured as an IBM 'lookalike'.

Figure 1 **Machine Shop Control System Configuration**

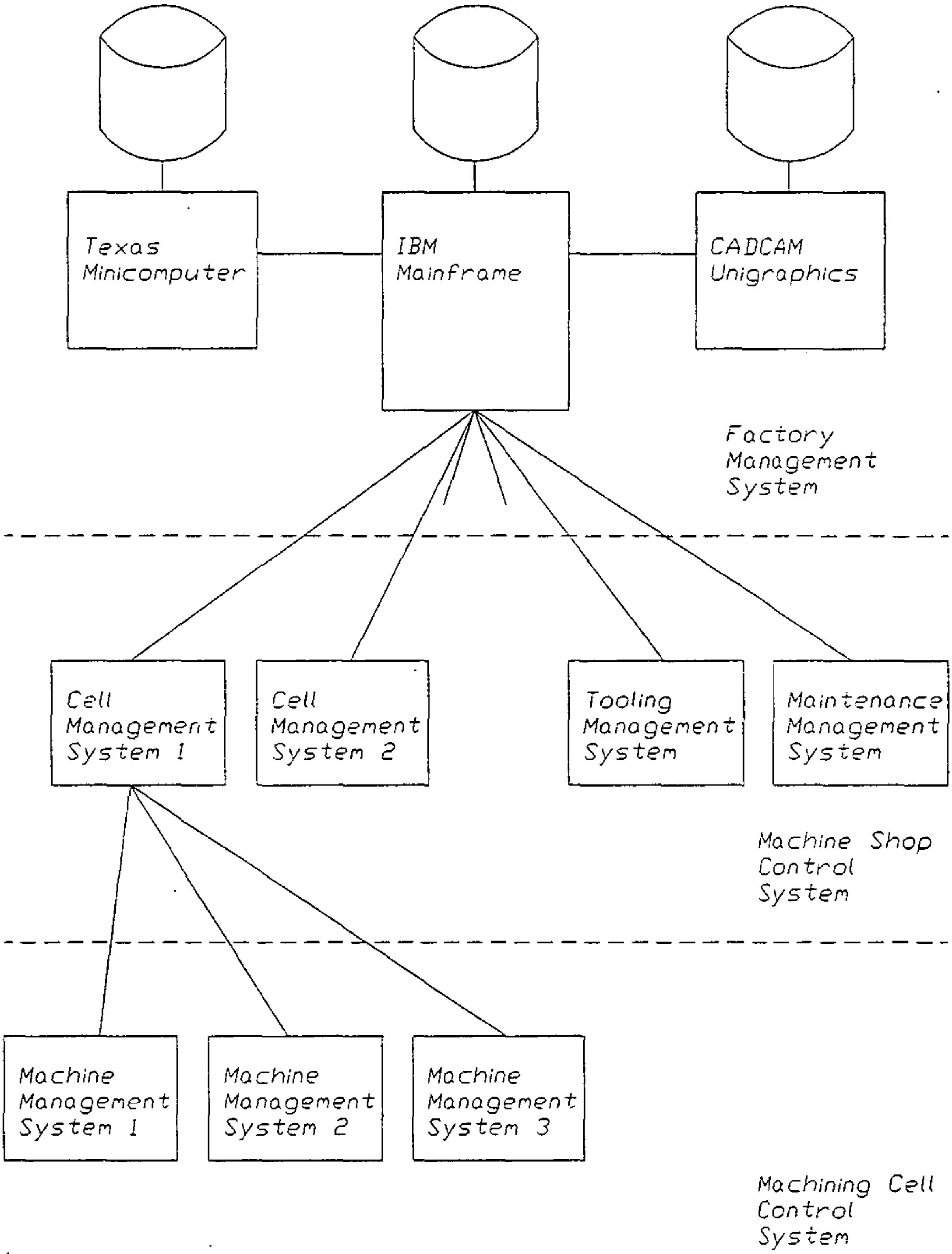
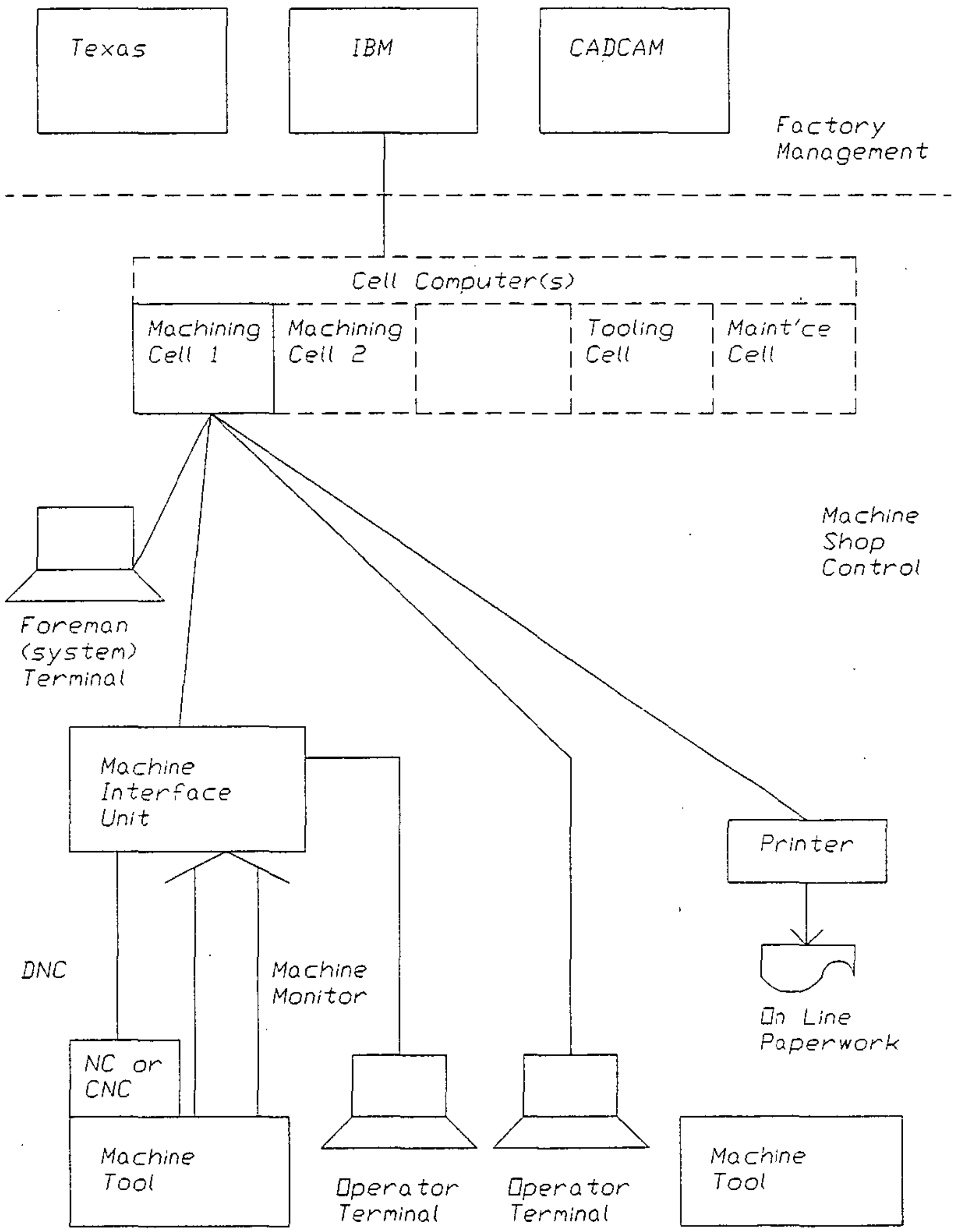


Figure 2 **Machine Shop Control System**



1.3.1 IBM Mainframe

The company has developed an extensive production control system which runs 'on line' from the mainframe. The more important systems are:

a) RAPID - allows drawing office to completely specify part lists;
b) CAPR - manufacturing specifications, planning and ratefixing;
c) ROSI - requisitioning/ ordering for stock or customers;
d) CASC - shop control system providing work to lists based on due date priority;
e) NCTP - input of certain NC program data and setup information.

The mainframe database is generally updated daily from 'holding files' resulting in parts of the system being 'offline' for short periods.

When on line numerous terminals throughout the factory can be used to interrogate the system.

The mainframe produces all manufacturing paperwork as required including operation tickets, material issue notes and NC program paper tapes on a batch printing basis.

1.3.2 Unigraphics CAD/ CAM

All new design work is done using the CAD system to detail the key plan for a given customer order so that many of the part drawings are available direct from CAD. However there are still a large number of drawings held in the archives which would not be readily available through the computer system.

A number of the CNC machines are now programmed using the CAD/CAM system and not the mainframe - paper tapes being produced from the system when needed.

At present there is no link between the mainframe and CAD/CAM so that there are two separate stores of NC programs. A link is being developed which will allow all NC programs data to be stored on the mainframe database.

1.3.3 Texas 990

The Texas minicomputer is currently used to run the company accounting system dealing with all details of purchasing, sales and marketing independently of the mainframe.

A full plant maintenance system covering plant records and costings is also available. The system provides a monthly printout of the scheduled maintenance to be carried out. These schedules are set up for each plant item when it is installed and can be altered as running experience is gained.

The Texas is currently linked to the IBM mainframe and terminals on the Texas can be used as though they were connected directly to the mainframe.

2. Machine Management System

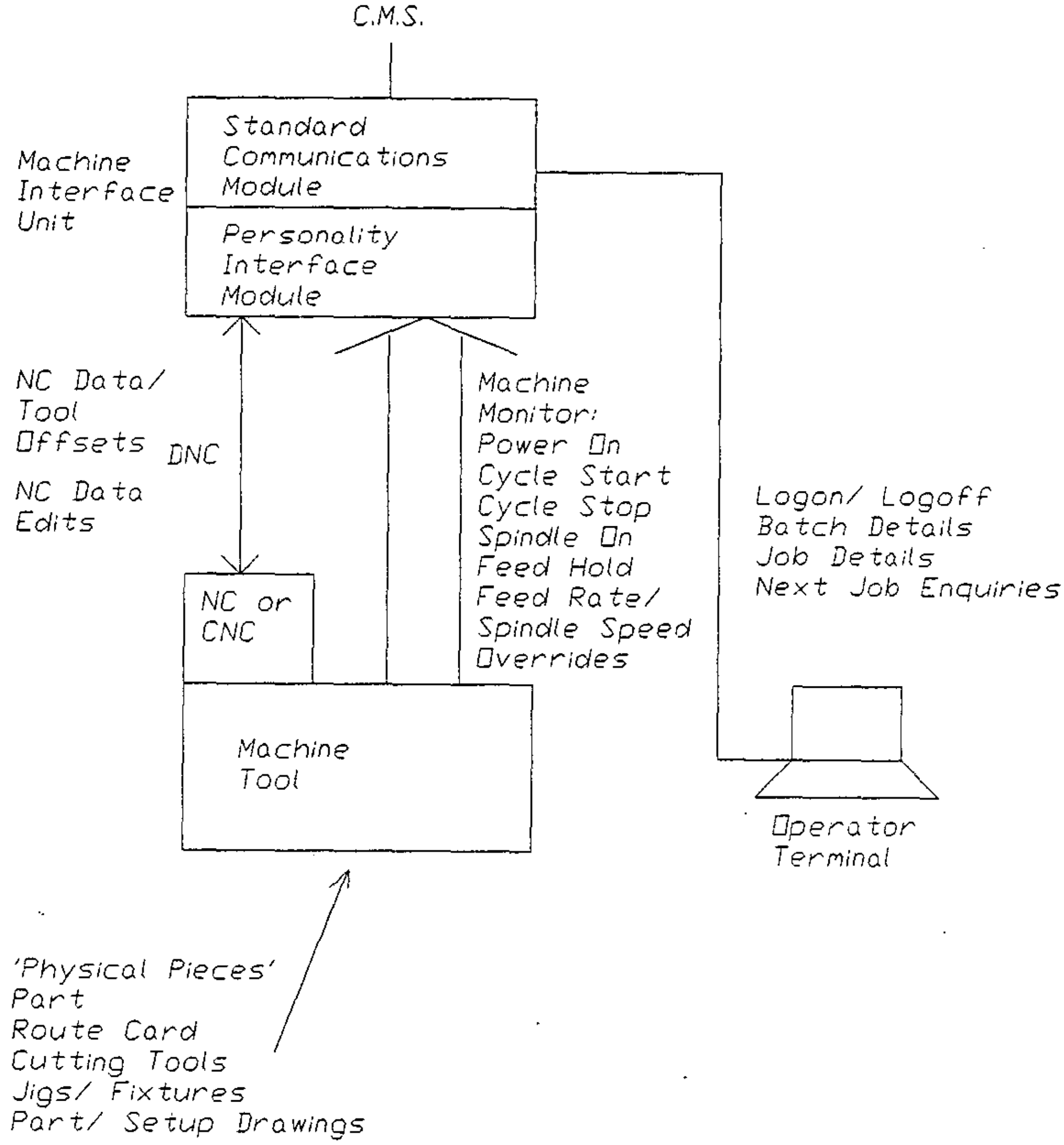
2.1 Envisaged System Configuration (Figure 3)

The MMS will be responsible for controlling the work at its machine by providing the operator with the information he needs to do each job. The MMS may also be linked to the machine by a DNC link, a machine monitor link or both.

Since the Westwood machine shop contains a wide range of different machine tools - NC, CNC and manual, the actual configuration at each machine may be unique e.g. depending on the type of numerical controller or the usefulness of particular information. The configuration will need to be tailored to each machine as it is linked into the overall system. Provision must be made so that any of the possible system links can be set up easily. However all of the NC and CNC machines will include a DNC link. Table I shows the NC machines being used.

Using a machine interface unit with a two layer communications strategy as shown will allow further machines to be integrated into the system without affecting existing machines. The personality interface module can be configured before the unit is connected to the cell system using the standard communications module.

Figure 3 **Machine Management System Configuration**



2.1.1 Machine Interface Terminal

The machine interface terminal will allow the operator to interact with the MMS. The MMS will tell the operator which job he should do next and provide him with the information he needs to do it. The operator will provide the MMS with the information it needs to control work flow.

Table 1

NC, CNC Machines in use at Westwood Works

Machine		Controller Type	No.off
NC:	Richmond Drill	ABNC 1100	2
	Numerimite Drill	Cincinatti Acramatic 8D	2
	Numerimite Drill	Giddings and Lewis	1
	Cintimatic Drill	Cincinatti Acramatic 8A	1
	Burkhardt Borer	Sperry Umac 5 (modified)	1
	Boehringer Lathe	GE Mark Century 7542	1
CNC:	Batchmatic Lathe	Herbert	3
	Bostomatic Mill	Boston Digital	1
	Asquith Mill	AB 8200	1
	Scharmann M/ctr	Siemens Sinumerik 7M	1
	Heid Lathe	GE Mark Century 1050 HLX	3
	Mandelli M/ctr	Mandelli Plasma NC	2
	Pfauter Gearcutter	Siemens Sinumerik 3	1

Machines on Order:

Heid Lathe	GE Mark Century 1050 HLX	1
Pfauter Gearcutter	Siemens Sinumerik 3	1

In particular:

a) The operator will log onto the MMS with his name or operator number at the start of his shift and log off at the end of the shift or when he is moved to another machine;.

b) The operator will then be logged onto and off from each job as it is presented by the MMS;

c) The inspector / foreman will record batch changes due to items needing repair or being scrapped;

d) The operator will record downtime reason codes whenever the machine is idle - provision should be made for each of the codes in Table 2;

e) The operator will request information as he needs it;

f) The operator will request the download of NC program data, including offset data if necessary, into his machine controller;

g) The operator may request the upload of NC program data from his machine controller when he has needed to edit the program;

h) The machine interface terminal will display 'system messages' to let the operator know what the MMS is doing at any time e.g. 'Downloading NC Program'.

2.1.2 Distributed Numerical Control Link

All of the NC and CNC machines will have a DNC link. The nature of this link will depend upon the particular NC controller type. Each DNC link will allow for the download of NC program data and in some cases, e.g. Scharmann Machining Centre, of tool offset data as well. The DNC link will also allow the upload of program data if editing facilities are available to the operator e.g. all CNC machines. Some CNC controllers are also able to provide certain machine status information via the DNC link.

a) NC Machines

Currently there are 8 NC machines within the Westwood machine shop and all of these would need a Behind the Tape Reader interface to allow program download. Two of these machines, the Burkhardt Borer and Boehringer Lathe, would benefit from CNC type editing facilities. These facilities could be provided by either updating the NC controller, adding an extra CNC interface unit or including them as an extra program module in the MMS. Hence program uploading would be useful for these machines but not for the other six.

Table 2

Possible Downtime Reason Codes

1. Machine Breakdown:
   a) waiting repair
   b) under repair.

2. Waiting for:
   a) material.
   b) transport.
   c) tooling.
   d) inspection.
   e) foreman.

3. No work allocated.

4. Cleaning Machine.

5. Setting up.

6 Meal break.

b) CNC Machines

There are 13 CNC at Westwood (with others on order) and all of these will need program data download and upload. However several different types of controller are involved using either integral or external paper tape readers and external paper tape punches. Therefore the actual DNC input and output links will need to be configured for each controller type.

For example: the Batchmatic Lathe and Herbert CNC will need a BTRI to suit the integral tape reader and an RS232 line to emulate the tape punch; the Heid lathe and GE 1050 HLX CNC can provide an extra communications interface independent of the tape reader punch which allows input and output down the same serial line.

c) Status Information

The more advanced CNC controllers enable machine status information e.g. cycle on, spindle on to be uploaded via the DNC link e.g. the Heid Lathe GE 1050 HLX CNC using the extra communications interface. The DNC/machine monitor links will need to be configured to obtain the best compromise.

2.1.3 Machine Monitor Interface LInk

The usefulness of a machine monitor interface link will need to be assessed for each machine as it is included in the system. However it is possible that a record of power on spindle running would be needed for each machine to provide information for maintenance procedures and performance uptime/downtime measurement.

2.2 Information Flow between the MMS, Operator and Machine

2.2.1 Information Needed by the Operator

The MMS will tell the operator which job he is to do next and provide him with most of the information he needs to do it. It will also allow him to look at the details of his next job while the current job is being machined so that he can prepare for it.

Only textual information will be provided on the machine information terminal. Any graphical information will be provided 'on paper' including any part drawings and setup drawings. A printer will be available to provide a hardcopy of any information shown on the terminal.

a) Work to List

The 'work to list'shown to the operator on the terminal will include details for only the current and the next job.

b) Batch Details

The operator needs the following details about the batch:

i) Works Order Number;

ii) Piece Work Contract Number;

iii) Part (Drawing) Number;

iv) Part Description;

v) Batch Quantity;

vi) Time allowed - set, operation, total for batch.

c) Job Details

The operator needs the following details about the job itself:

i) Operator description;

ii) Tool list;

iii) Tool offset list (if needed);

iv) Textual setup details.

d) NC Part Program

The operator needs a terminal listing of the part program object code for the current job.

2.2.2 Information Needed by the MMS

The MMS may collect information about machine status and performance from the machine monitor link and the operator input to the machine interface terminal. This information may vary from machine to machine and will need to be assessed separately.

a) Performance Measurement - Machine

The machine monitor link (including DNC link) should be able to measure as necessary:

i) Power on/off;

ii) Cycle start/stop;

iii) Spindle on/off;

iv) Spindle speed override;

v) Feed rate override;

to provide information on machine uptime, downtime and utilisation. Whenever the machine is idle the operator should be prompted to input a downtime reason code so that further analysis can be made, e.g. Setting up, waiting for (service), breakdown under repair etc..

b) Machine/Tool Condition Monitoring
In the case of certain machines tools it may be useful to measure machine and/or tool conditions to provide alarms to the operator or service departments and maybe adaptive control of the machine or tool. For example: lubricating oil level, hydraulic oil level, overheating, spindle power/torque.

c) Maintenance Information
The machine performance and machine condition monitoring information can be recorded in a machine maintenance file in the CMS database for use by the Maintenance Management system. Data would include:

i) Machine running hours;
ii) Machine failure - reason codes;
iii) Action taken;
iv) Waiting time;
v) Repair time.

This may allow improved machine and cell maintenance plans to be developed to improve machine availability and performance.

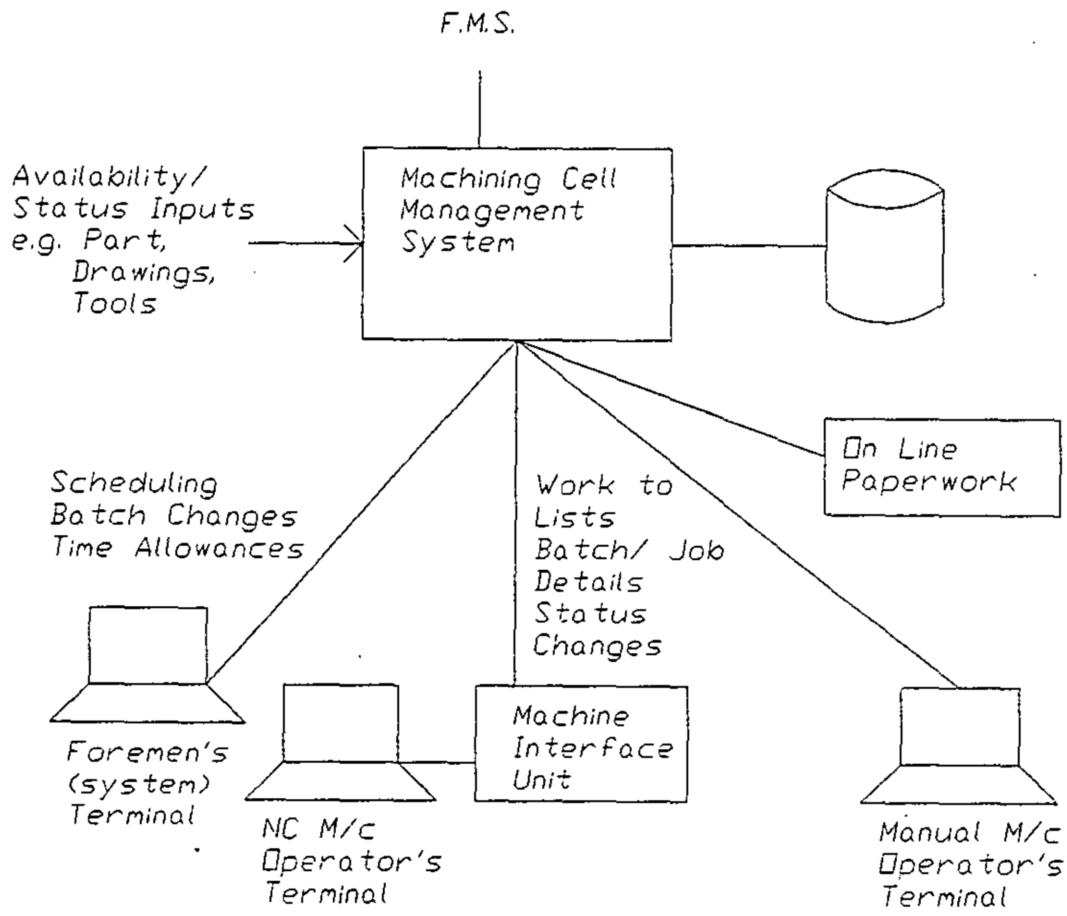
3. Cell Management System.

3.1 Cell System Configuration (Figure 4)

The CMS will be responsible for controlling the flow of work through the machines in its cell. It will need to be a stand alone system with its own database to cater for the times when the mainframe FMS is taken off line for batch updating.

The database will hold the data for all the work available to the cell machines including NC programs, set up details, operation details; and also about the machines in the form of performance, status and maintenance information. The FMS and CMS databases will need to be updated at specified periods to ensure compatibility.

Figure 4 **Cell Management System Configuration**



The machining cell will need a printer to provide hard copy information on request.

3.2 Cell System Responsibilities

3.2.1 Control of Work Flow

At the start of each shift (day and night) the FMS will provide to each CMS a total list of the work available to the machines in its cell in the form of a work to list giving job priorities. For each of these jobs the relevant information will be transferred into the CMS database. This will provide base information for the cell system so that a cell work schedule can be produced.

a) Item Availability

The system will include availability flags for all the items needed for each job. The CMS will check these flags to ensure that a given job can be done i.e. the part is available in the cell buffer system,. all files are complete in the database, and that special tooling is available from the tool setter. The CMS will then be able to produce a 'possible' work to list for each machine for the start of the shift.

b) Job Scheduling

The CMS will use the possible work to lists to help the foreman schedule work through the cell according to a set of rules. The CMS will need to display a 'Gannt Type' chart showing machine loading vs. time to let the foreman see the effect of any particular loading strategy on job exit times from the cell. This chart will need to be real time in the sense that it shows the real effects on machine loading as jobs are logged on and off.

The CMS will then be able to set up work to lists for each machine so that it can channel work to each MMS.

c) Loadfile Updating

The mainframe loadfile currently shows how a contract is progressing through the machines on the route. The equivalent file in the CMS would need to be updated as each job is aacepted by an MMS - to show job loaded and when completed - to show job complete.

3.2.2 Interaction with other Systems

The CMS will need to pass information to and request service from other management systems. These will include tool and maintenance management initially but could also involve such departments as part programming and planning.

a) Tool Management System

The CMS will need to make a request for tooling when a contract enters the cell input buffer. The CMS will be able to calculate the time when a contract will be loaded onto a machine and so it can tell the tool system when tooling will be needed. The tool system will thus be able to build up a schedule for the tool setter. Interaction between the tool and cell systems will ensure that any changes in priority are recognised quickly.

b) Maintenance Management System

The CMS will be able to generate requests for service from the Maintenance Department should any machine breakdown be reported by the MMS. It will also be possible for the CMS to report on machine running hours and conditions to signal the need for planned maintenance.

3.2.3 Information Flow

a) Data Base Management

The CMS will be responsible for controlling the data files for each machine, MMS and contract in the cell. The files will include information about:

1. Batch;
2. Job;
3. Machine;
4. Operator.

as shown in Table 3.

b) Hard Copy Reports

The CMS will be responsible for producing hard copy reports on a regular or on demand basis. These reports may include:

1. Machine performance;
2 Operator performance;
3. Jobs progressed by the cell;
4. Machine breakdown data.

ANW/DB
13.4.84

Table 3

Basic CMS Data Basic Details

1. Details for each Job/Contract

1. Piece work contract number	)	
2. Works Order No.	)	
3. Part No.	)	Batch Details
4. Part Description.	)	
5. Time Allowed Set, Op, Total.	)	
6. Batch Quantity.	)	
7. CASC Priority.	)	
8. Routing	)	
For all machines en route (in cell)	)	
9. Workcentre.	)	
10. Operation No.	)	
11. Complete parts.	)	
12. Scrap Parts.	)	
13 Job Status.	)	
14. Scratch Pad.	)	
15. Operation Description	)	
16. Set Up Text.	)	
17. Tool List.	)	Job Details
18. Tool Offset List.	)	
19 NC Program(s).	)	

Table 3 cont.

2. Details for each Machine
    1. Power On Time.
    2. Cycle On Time.
    3. Spindle On Time.
    4. Machine Breakdown Details:
       running hours, failure codes, action taken,
       waiting time, repair time,
    5. Machine Downtime Details:
       Hours to each reason code.
    6. Tool Usage Times.
    7. Override Changes.

3. Details for Each Operator
    1. Hours available at machine
    2. Specified Work Hours.
    3. Recoverable Hours.
    4. Gross Hours.

APPENDIX B

DNC System Configuration

1. Introduction

The DNC system forms the first stage of a multistage introduction of a Machine Management System in the Rockwell PMC machine shop. The system allows for the core functions required by the machine operator for any particular job operation by allowing operation, part program and tooling / setup information to be extracted from the mainframe data base files and used locally by the operator via a terminal at his machine.

2. System Hardware Configuration

The DNC system consists of a PC linked into a mainframe enquiry system which acts as a terminal for the operator at his machine. The PC is also linked to the computer numerical control (CNC) of the machine for the transfer of NC part program data. The system configuration is illustrated in Figure 1.

2.1 Mainframe System

The Mainframe is a Comparex 7/78 (IBM 3083 plug compatible) computer with 16MB of main memory. The operating environment consists of a hierarchy of logical operating systems, see Figure 2. It is configured as a number of logically seperate computers each controlled by its own DOS/VSE operating system [DOS/VSE]. These DOS/VSE machines are in turn supervised by the Virtual Machine (VM) 'hypervisor' software [VM]. Within each DOS/VSE machine there can be upto 9 partitions in each of which a further level of 'operating system' can be run. For on line users the operating environment used is the Customer Information Control System (CICS) [CICS]. Any batch routines are run in one of the many batch partitions as appropriate. The (POWER) system [VSE/POWER] marshalls the use of each batch partition available as necessary. The Virtual Telecommunications Access Method (VTAM) [VTAM] partition is needed to provide SNA [Tanenbaum 1981] level communications functions between the different DOS machines.

2.1.1 DNC CICS

In view of the downtime associated with the generally used Production enquiry system 'PMC CICS' because of the need for batch update procedures, a separate CICS has been installed for the DNC system use. 'DNC CICS' has read only

Figure 1 DNC System Configuration

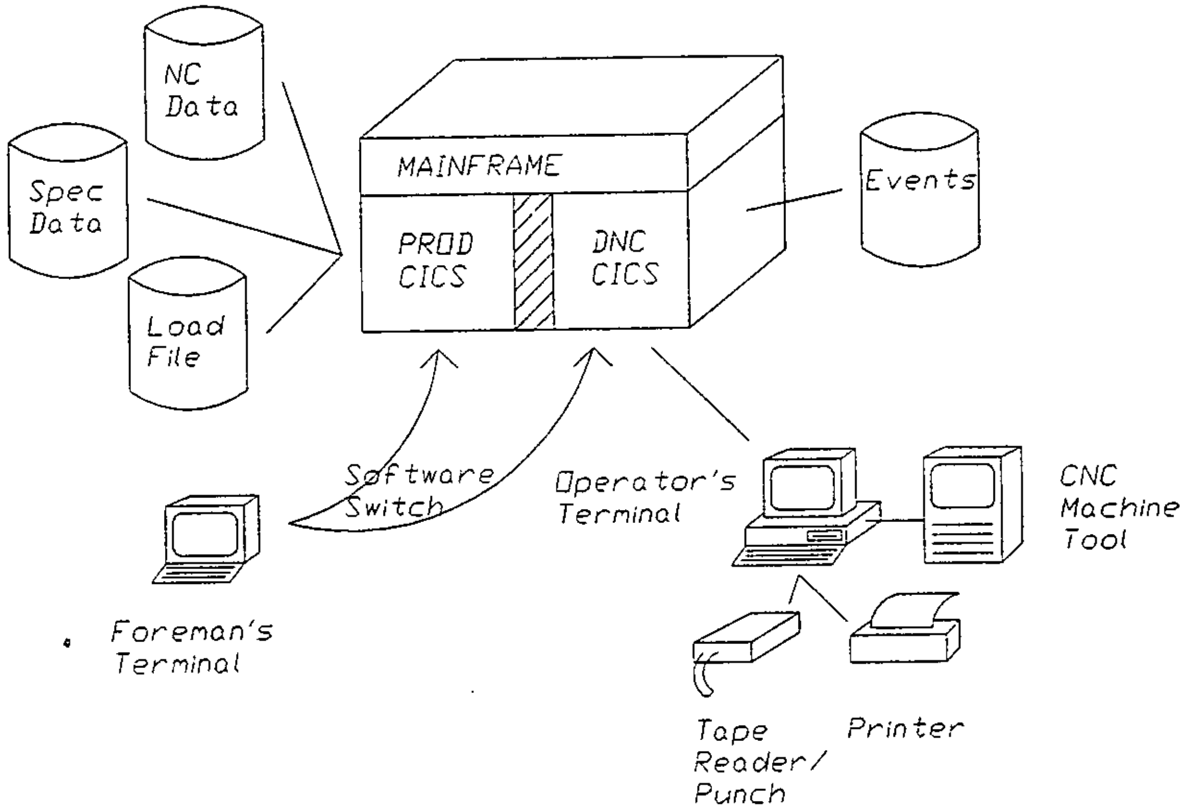
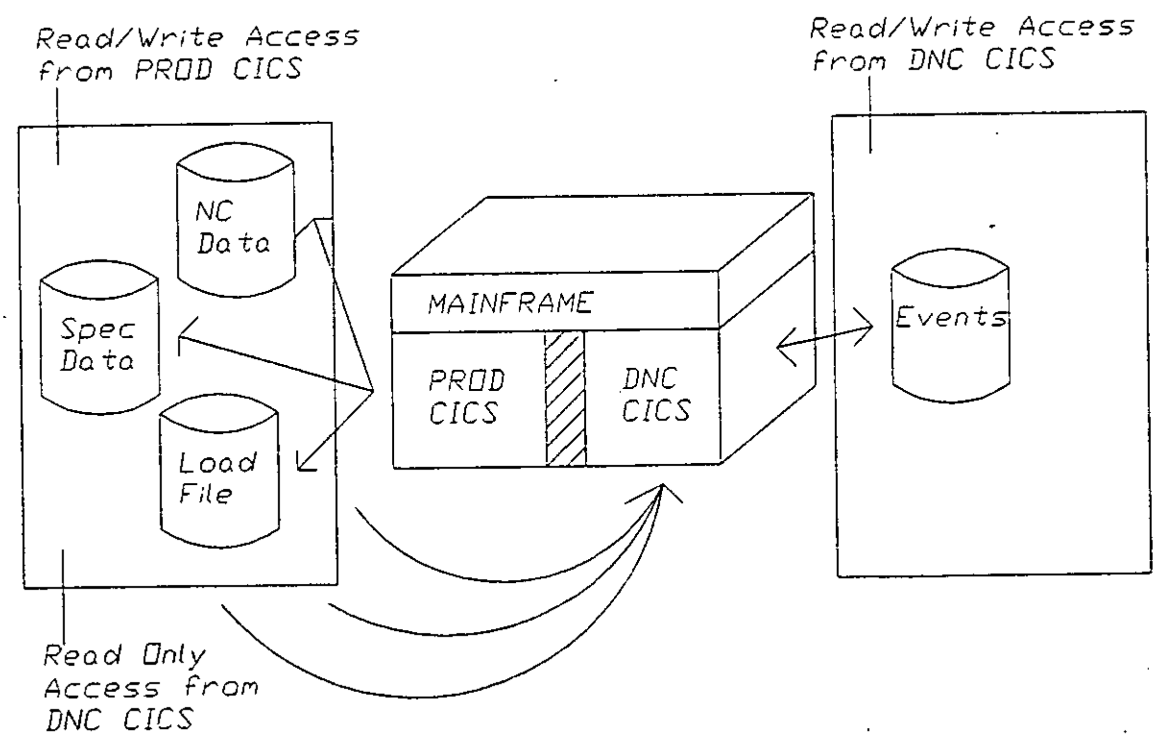


Figure 2 Mainframe Computer Configuration



access into the specification or bill of materials, NC and work in progress files which are 'owned' by PMC CICS. The only file updated by DNC CICS is the events file used to log use of the system by the operator. Because of this limited access situation DNC CICS can be run almost 24 hours each day. The only downtime involves the daily update of a local index into the production work in progress file. Hence DNC CICS provides a round the clock service to the shopfloor PCs for mainframe data extraction.

2.1.2 CICS 'Switch'

A 'software switch' can be made available to mainframe terminal users which allows the selection of the system required to be active at the terminal. This facility allows the user to switch between different CICS as necessary.

2.1.3 Terminal Connections

All user terminals are linked to the mainframe systems using 3270 coaxial cable from IBM 3274 terminal controllers. The IBM PCs are also attached in this way.

2.2 Operator Terminal

The operator terminal consists of an IBM compatible PC with at least 256KB memory, monochrome screen, a hard disk or bubble memory card for local data storage, two RS232 ports, parallel printer port and IRMA [IRMA] interface card. Bubble memory or hard disk is used since floppy disk has been considered to be unsuitable for the shop floor.

The two RS232 ports are used for connection to the machine controller and optional paper tape unit. The IRMA interface allows the PC to emulate a standard mainframe 3270 terminal by connection to a 3274 controller.

3. DNC System Functionality

The DNC terminal software allows the machine operator to obtain job information from the mainframe data base and store this in local files for use as required. The system involves a number of programs at each end of the link, on both the Mainframe and the PC. Data is passed between these programs using the emulated mainframe terminal screen of the PC.

3.1 Mainframe Programs.

The mainframe programs have been written in the PL1 programming language as a part of the Rockwell PMC Ltd. 'NCxx' series and are activated using standard 'NCxx' transactions which are called via the IRMA subroutine software from the PC level programs. The programs written for this application also use modules created for the retrieval of NC tape data within the NC editing and specification systems. The programs involved are:

(i) NC35 NC, tooling and specification data extraction, extracts data from mainframe files and creates pages for display;

(ii) NC24 Data page retrieval, displays pages of extracted data for storage in local data files;

(iii) NC36 NC data only extraction, extracts data from mainframe files and creates pages for display;

(iv) NC38 Data page retrieval, displays pages of extracted data for storage in local data files;

(v) NC25 Status data storage, Status codes are sent to the mainframe computer whenever a 'significant event' occurs and stored in a VSAM file.

3.2 IBM PC Programs.

The IBM PC programs have been written in Microsoft Quickbasic and compiled to produce executable files. They have been developed to form an interlinked set of routines which chain into each other using a built in menu system. The system functionality is illustrated in Figure 3.

3.2.1 DNC System

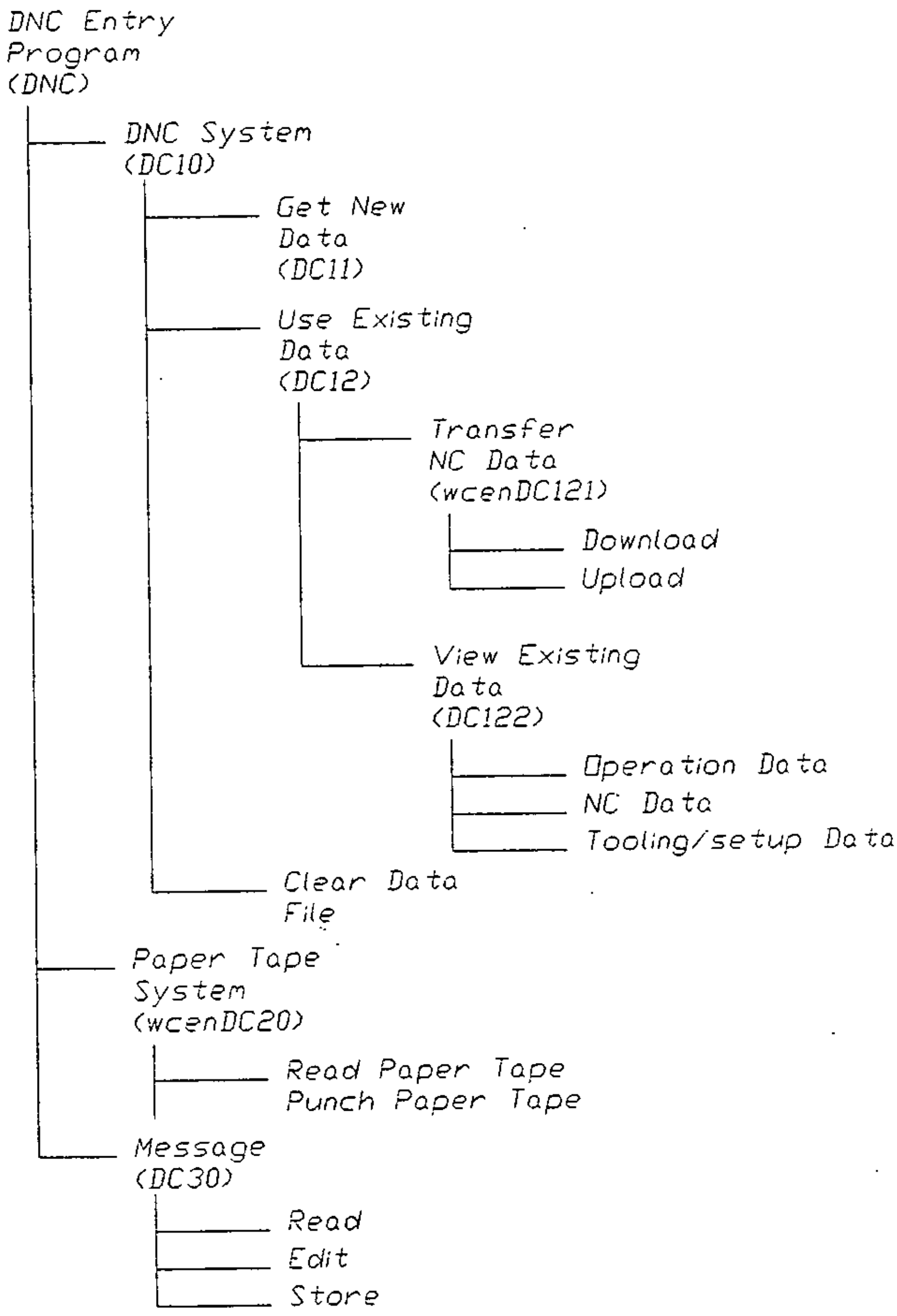
These routines form the basic system for the operator.

A Get New Data

This option allows the operator to download information from the mainframe data base and store this locally in any one of 10 available job files. The information extracted includes operation description, part program, tooling and setup details.

The extraction routine makes use of basic subroutines supplied with the IRMA interface card. These subroutines allow for the generation of keystrokes, as well as the reading and writing of screens from within the user program. The screen buffer used is of the same form as that for a standard mainframe terminal i.e. any routine a user can perform on a standard terminal can be mimicked by the use of

Figure 3 DNC System Functionality



these subroutines. The data transfer routines work by initiating a mainframe CICS transaction in the screen buffer which then causes a mainframe program to extract the data required. This data is transferred to the PC one screen at a time in a specifically designed format and the PC routine reads the data from each screen page and stores the data in the local files. The mechanism is illustrated in Figure 4. If the data is unavailable a reason code is returned in the screen buffer.

B Use Existing Data

The operator can then use the data in the local files independently of the mainframe system. The functions available are:

(i) View Data allows the operator to display any of the information available on the PC screen, page through it and print off a copy of any file as required;

(ii) Transfer NC Data allows the operator to transfer any of the stored part programs from the PC to the machine control. The operation of the machine control remains unchanged. A different program is needed for each controller type for the actual NC program transfers, as well as the reader/ punch backup routines, since the NC tape formats vary for the different machine controllers.

3.2.2 Paper Tape Backup System

These routines for punching and reading paper tapes are intended for use when the required part programs are unavailable from the mainframe files but do exist as paper tapes. This could occur if the mainframe is off line for any reason. In practice none of the DNC systems use this facility since reliability of the system has proven to be excellent.

3.2.3 Store Message

The store message routine allows the machine operator to create a free format message on the PC screen which can be stored on disk. The operator can use this routine to pass on relevent information from one shift to the next.

3.3 Event Reporting

An event reporting function is included in the DNC system. When a 'significant event' occurs an event code is transmitted to the mainframe by an IRMA initiated transaction together with the date, time, part number and operation number of the job in use. These codes are stored in a file on the mainframe and used to report system performance. The events logged are shown in Figure 5 and an example of the event report in Figure 6.

Figure 4 **IRMA Communications Mechanism**

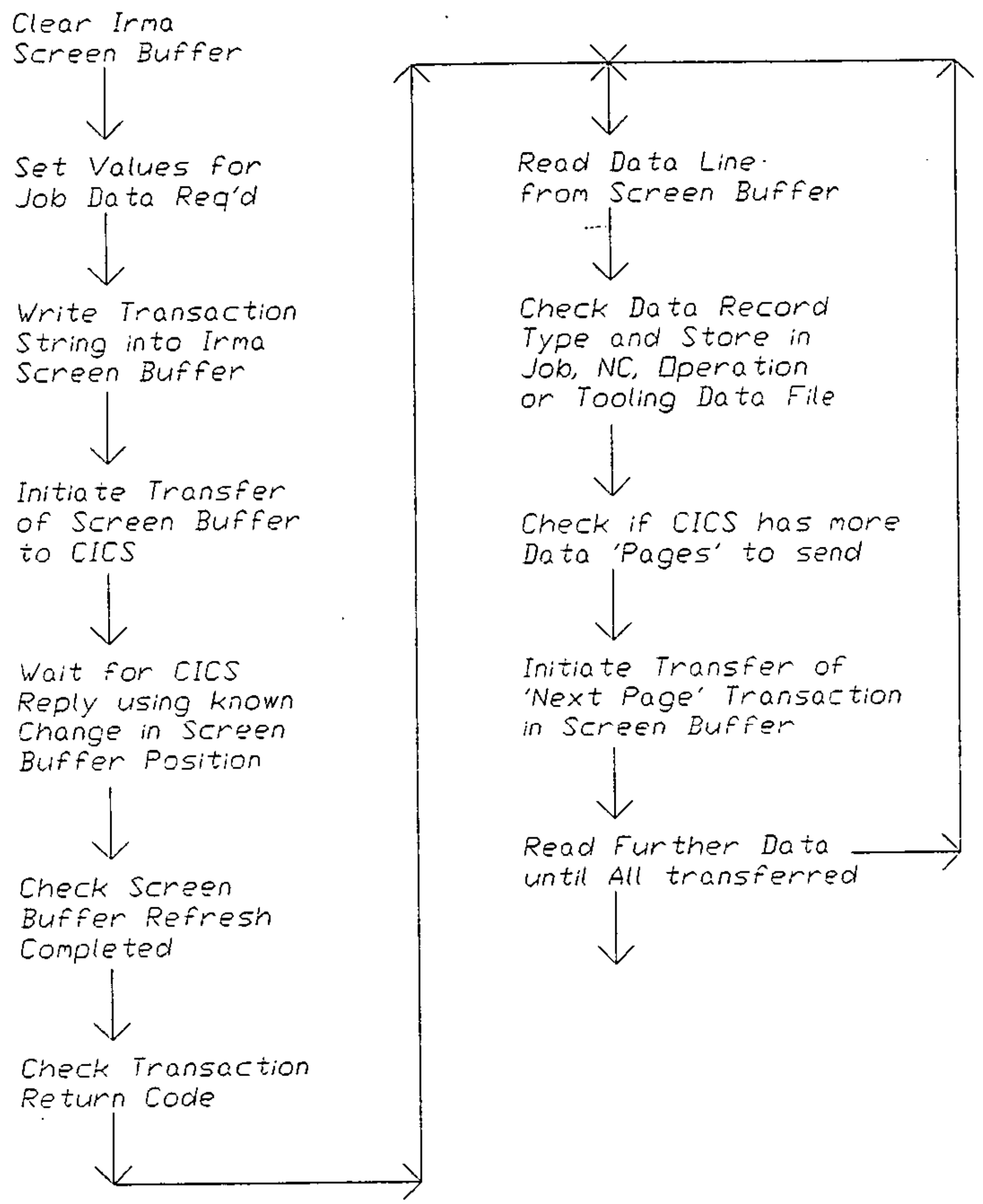


Figure 5 **DNC Status Events Logged**

1. Data Unavailable from mainframe computer:

    Tape Stopped.

    No Tape on File.

    No Specification.

    Tape Number/ Specification Mismatch.

2. Data Available from mainframe computer.

    Unproven Tape Transferred.

    Being Proven Tape Transferred.

    Proven Tape Transferred.

3. Reader/ Punch unit used.

    Paper Tape Read.

    Paper Tape Punched.

4. Mainframe Computer off line.

Four counters are stored by the personal computer and sent to the mainframe computer when it comes back on line.

1. DNC Tape passed to CNC from personal computer.
2. READR Paper Tape Read.
3. PUNCH Paper Tape Punched.
4. MISC Download from mainframe attempted.

3.4 CICS Enquiries

The operator can use the PC as a normal mainframe terminal by simply pressing the two shift keys simultaneously. This cause the PC function to be suspended and the display to show the contents of the mainframe screen buffer. The operator can then key in any of the available DNC CICS transaction as required. The display can be alternated between mainframe and PC mode by this method.

__Figure 6__ __DNC Events Enquiry__

```
           D.N.C. EVENTS ENQUIRY FOR F23              PAGE   1 OF  2
 PLEASE SELECT NEXT ACTION
DATE  HH MM SS  TAPE NUMBER         EVENT DESCRIPTION  DNC READR PUNCH MISC


870430 11 14 48     6435851LF23 0402 PROVEN TAPE
870430 11 14 48     6435851LF23 0401 PROVEN TAPE
870430 05 55 35     6435863DF23 0301 NO MATCHING W/C OP
870430 05 54 04       754927F23 0501 PROVEN TAPE
870430 05 51 48     63119160F23 0451 PROVEN TAPE
870430 05 41 41                      CICS DOWN          1
870430 05 49 23     6411749AF23 0301 PROVEN TAPE
870430 01 17 16     6435851LF23 0401 TAPE PASSED TO CNC
870429 23 21 28       754237F23 0502 TAPE PASSED TO CNC
870429 22 17 28     6435851LF23 0401 PROVEN TAPE
870429 22 17 28     6435851LF23 0402 PROVEN TAPE
870429 21 44 14     6440596JF23 0401 PROVEN TAPE
870429 21 44 14     6440596JF23 0402 PROVEN TAPE
870429 04 30 41       753238F23 0601 TAPE PASSED TO CNC
870429 03 37 21                      CICS DOWN          2                1
870429 03 37 21       753238F23 0601 PROVEN TAPE
870429 03 25 37     39915152F23 0401 TAPE PASSED TO CNC
870429 02 48 50     6374134EF23 0801 TAPE PASSED TO CNC
NEXT ACTION:    PAGE      (1) EXIT
```

3.5 IBM PC Data Storage.

The PC files used by the DNC system programs are stored on the local hard storage media. A number of data files are involved:

(i) PARAMS: contains details about the workcentre, machine name and whether reader/ punch backup is used;

(ii) JOBS: holds job details for up to 10 'local files' together with the number of operation, tooling and nc program files and pointers to nc, tooling and operation data files created at the pc;

(iii) OPn: holds the operation details for job file number 'n';

(iv) TLn.m: holds the 'm'th tooling details for job file number 'n';

(v) NCn.m: holds the 'm'th nc program for job file number 'n';

(vi) MESSAGE: holds a free format message;

(vii) EVENTS: holds details of 'events' reported to mainframe.

APPENDIX C

Unigraphics Plot File Format

Character Values		Operation
Byte	Hex	
00000001	01	Start of plot record. Concatenated plots in a plot file will have a plot start byte at the beginning of each plot, followed by: Plot Number 2 bytes Steps per Inch 2 Bytes X minimum 2 Bytes X maximum 2 Bytes Y minimum 2 Bytes Y maximum 2 Bytes N.B. All X and Y size values are in inches relative to the plot origin.
00000010	02	Lower Pen.
00000011	03	Raise Pen.
00000100	04	Change to Pen Number in following byte.
00000101	05	Flash Exposure in Photo mode or a cross (+) in Pen mode. Ignored by all but photo plotters.
00001111	0F	End of plot record. Concatenated plots in the same plot file will have an end-of-plot byte after each plot.

0001XXYY	1xy	Move pen. Followed by one to four bytes which comprise the X and Y deltas in two's complement.

XX is the number of bytes that immediately follow for X.
YY is the number of bytes that immediately follow for Y.

00100000	20	Arc primitive followed by 16 bytes of data as follows:

Start angle	(angle in radians)*1000000
End angle	(angle in radians)*1000000
Radiuslength	in plotter steps
Chords	number of chords

N.B. Each of the above are 4-byte long integers.

The pen is positioned at the center of the arc in an up position before completing the arc primitive. After completing the arc, the pen is restored to the up position at the center of the arc by the despooler.

The start angle is between -2pi and 2pi. The end angle is between (start angle - 2pi) and (start angle + 2pi). If the ending angle is greater than the start angle, the arc is drawn counterclockwise, otherwise it is clockwise. The number of chords to use to generate the arc, if no hardware arc capability is available, is the value of the last parameter.

11111111	FF	End of plot file. Further data is ignored.

[UGPLOT]

APPENDIX D

Cell Management System Configuration

1. Introduction

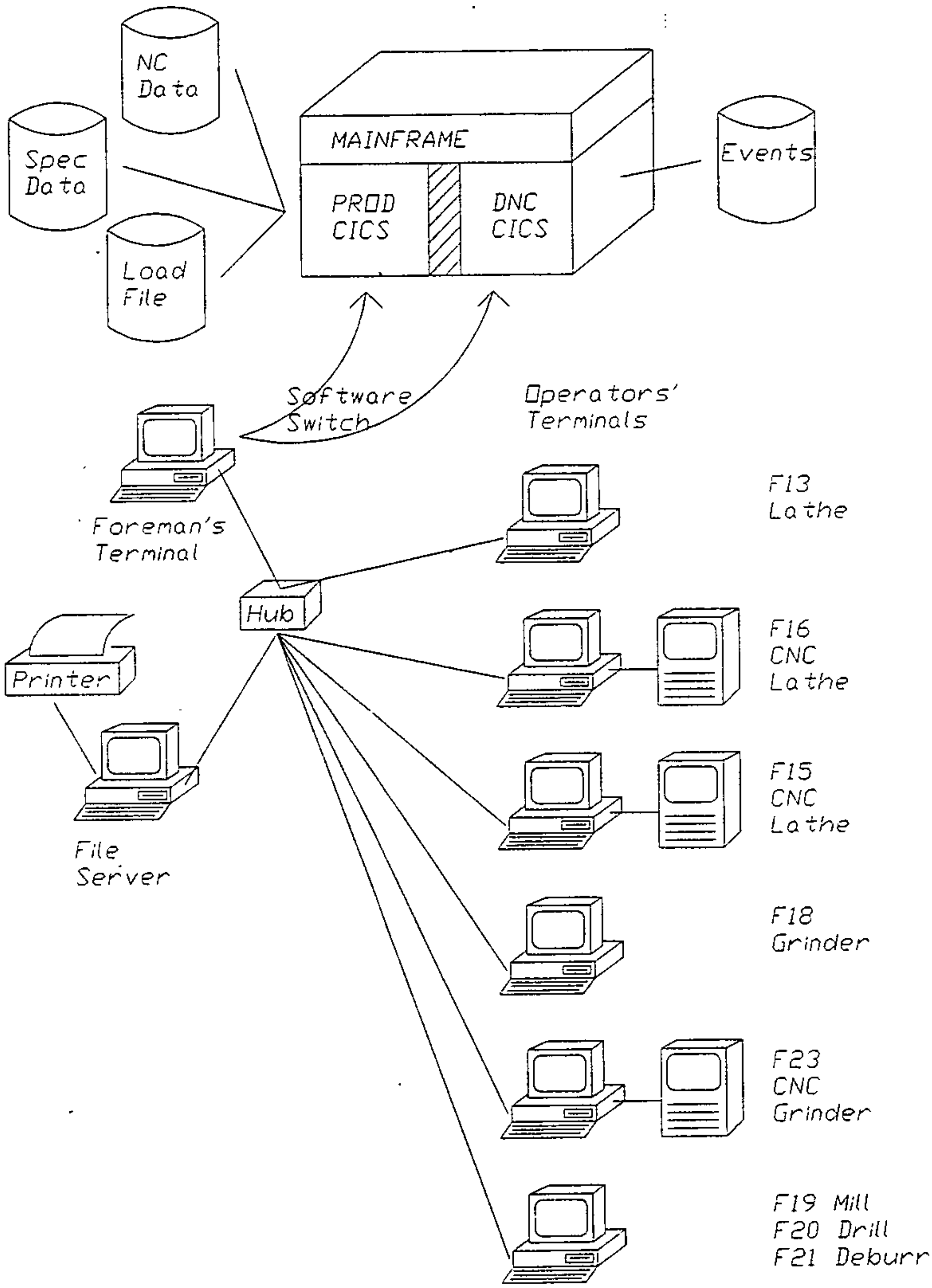
The Cell Management System forms the second stage in the introduction of a Factory Management System hierarchy in the Rockwell PMC machine shop. The system provides for the control of work flow through a single manufacturing group technology cell over limited periods of time independently of the mainframe manufacturing computing systems used for the machine shop as a whole. It builds on the work already done in the implementation of the DNC system and in particular extends the original facilities rather than replacing them.

The system allows for the transfer of job contract information, together with associated operational information and NC data, from the mainframe computer data base into a local store within the cell. This information can then be used by the foremen and operators independently of the mainframe for the period during which a contract is 'live' within the cell. Status information is updated in real time at the cell level during this period and the relevent data is tranferred back into the master mainframe work in progress data files as appropriate. Once any contract has left the cell area the information for that contract, which has been held within the cell level system, can be discarded to make way for further live information.

2. System Hardware Configuration

The Cell Management System configuration is illustrated in Figure 1. It consists of 7 IBM compatible PCs linked together in a local area network. One of these PCs acts as a File and Print Server to the other 'user workstations'. One 'user' PC is located in the foremen's office and six other PCs are situated as necessary near to the machines within the cell. Each PC acts as an intelligent terminal running application routines which are appropriate for the user concerned. The foremen's PC is also attached to the mainframe and therefore acts as a replacement for the normal dedicated mainframe terminal as well as being able to run the cell level applications. The applications available to the foremen also allow this PC to act as the gateway for information transfer between cell and mainframe level data bases.

Figure 1 Cell Management System Configuration



2.1 Mainframe System

The Mainframe system configuration described previously in Appendix B is equally applicable to the implementation of cell management. The system hardware aspects have not been affected, those already set up for the DNC system continue to be used. These include the interfaces already used to link PCs with 'PMC and DNC CICS' and including the 'software switch' facility available to the standard mainframe terminals used by the foremen. This functions equally well in a PC with an IRMA interface.

2.2 Network System and File Server

The Local Area Network used for the connection of the cell PCs uses the Arcnet topology [Conner 1988]. Each PC is linked to an 'active hub' using RG62 coaxial cable (the same cable as used for existing IBM 3270 terminal connections). This hub acts as a repeater unit for the transmission of network data packets between PCs on the network.

Each PC on the network contains an Arcnet interface card which incorporates a unique network 'address'. In order to allow for a consistant expansion path for any future systems the network node addressing scheme shown in Figure 2 has been adhered to.

Figure 2 **Arcnet Network Node Addressing Scheme**

Workstation Type	Cell Number	Node Address
Fileservers		01 through 10
Systems Development		11 through 19
Cell Management:	1	20 through 39
	2	40 through 59
	through	
	11	220 through 239

N.B. Arcnet allows for up to 255 PC workstations on a single network.

The File Server system consists of an IBM compatible PC with 1MB memory, monochrome screen, 20MB hard disk unit, parallel printer port and Arcnet interface card, with network node address 02 (the server used for system programming has been allocated address 01). An Epson FX80 printer is attached to allow for output generated by user PCs to be printed in a shared central location.

2.3 User Workstations

The foremen's workstation consists of an IBM compatible PC with 640KB memory, colour screen, 20MB hard disk, IRMA and Arcnet interface cards.

The workstations used by the machine operators consist of IBM compatible PCs with 640KB memory, monochrome screen and an Arcnet interface card incorporating a Remote Reset ROM, which allows the PC to load 'boot' routines from the network file server disk rather than from local disk.

The PCs used on the NC machines also include two RS232 ports for connection to the machine controller and an optional paper tape unit. The major change made to these particular PCs, involved in the migration from the DNC system to CMS, is the use of a cell level network interface as the primary communications mechanism rather than the mainframe level IRMA [IRMA] interface. However the links already existing between the mainframe and the IRMA interface in the PCs on the Heid Lathe and the Matrix Grinder were left in place to allow for the DNC system to be used as a backup for the new CMS on these machines if necessary.

The network set up for the shaft line system is shown in Figure 3.

3.0 Cell Management System Functionality

The functionality available from the software used in the cell system can be considered at two levels:

(i) functions available within the existing mainframe interface and network operating system software;

(ii) functions available from software created specifically for cell system users.

Figure 3 **Shaft Line CMS Organisation**

M/c No	Wcen Code	Machine Type	PC No.	Node Address
MC00	GT01	Shaft Line	01	14 hex
MC01	F10Q	Face and Centre		
MC02	F11Q	Straightening		
MC03	F13	Ramo Lathe	02	18 hex
MC04	F15	Heid Lathe	03	1A hex
MC05	F16	Heid Lathe	04	1B hex
MC06	F18	Grinder	05	1D hex
MC07	F19	Vertical Mill	06	1E hex
MC08	F20	Radial Drill	06	
MC09	F21	Deburr etc.	06	
MC10	F23	Matrix Grinder	07	22 hex

N.B. The 'queued' workcentres F10 and F11 have not been included in the system at present because they are treated as 'service' workcentres and are therefore not directly important in job sequencing decisions. The machine operators on workcentres F18, F19 and F20 share a single PC workstation.

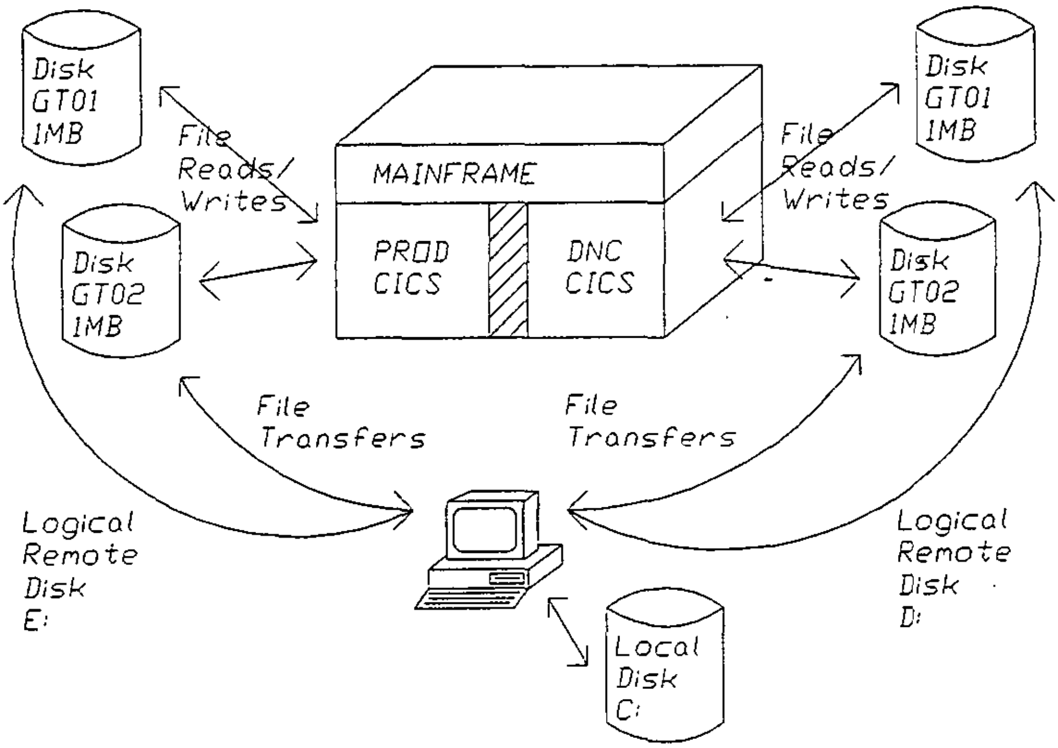
3.1 Mainframe Interface Software Functionality

The Cell Management System continues to use the IRMA interface software already available within the functionality of the DNC system but also includes the use of Tempus Link interface software [Tempus Link].

3.1.1 Tempus Link Virtual File Software

Tempus Link is a software product based on the virtual disk concept which, working through the standard IRMA interface, allows a PC to access a disk on a mainframe computer as though it were physically attached to the PC. Thus PC applications can access the mainframe disk through this software in the same way as a local disk. The Tempus Link product also includes a Host application programming interface mainframe so that applications can also access these virtual disk areas directly. Hence this provides a suitable communications mechanism between the PC and Host application programs.

Figure 4 Tempus Link Functionality



The software is used in the CMS to provide a virtual disk, logically attached to drive D: of the foremen's PC, which can be used to transfer job information and status information between the mainframe and the PC cell system file server as illustrated in Figure 4.

3.2 Network Operating System Software Functionality

Novell Netware/86 [LAN Software 1985] is used for the PC network operating system software. This software provides the basic functionality of the cell system network. The network file server acts as the 'heart' of the network. It manages the sharing of data files and system security, coordinates inter-workstation communications and controls the use of printers through a spooling service.

3.2.1 File Server Subdirectory Structure

The network software provides a 'virtual file service' for any of the networked user PC workstations. This allows any subdirectory on any of the disk units attached to the file server, and their contained files, to be used by the networked

Figure 5 **Shaft Line CMS File Server Subdirectory Structure**

```
FLINECMS/SYS:
            IBM_PC
              MSDOS
                      3.30          PC operating System Files
            LOGIN                   Netware Login Routines
            PUBLIC                  Netware Utilities
            UTILCELL                CMS Utilities
            UTILCMS                 Foremen Applications
            UTILMMS                 Operator Applications
            SYSTEM                  Netware System Utilities
            UDD                     User Directories
              GT01                  Shaft Line CMS Data Files
                      MC01          Machine No.1 CMS Data Files
                      MC02          etc.
                      MC03
                      MC04
                        DNC         Machine No.4 DNC Data Files
                      MC05
                        DNC         etc.
                      MC06
                      MC07
                      MC08
                      MC09
                      MC10
                        DNC
```

workstations as though they were part of the local storage capacity of the PC. The subdirectory structure of the file server has been set up to allow for the coordination of contracts flowing through the shaft line by providing suitable data files which can be used at both the cell and machine levels as appropriate. This directory structure is shown in Figure 5.

Each of the CMS user directories, under UDD, contain the files appropriate to that user. The GT01 directory contains the cell master files created when information is extracted from the mainframe data base. The machine subdirectories MCxx contain the transitory job information files used by the machine operators as each job is in progress on their machine. These files are of the same form as the data files used in the original DNC system. The DNC subdirectories are used to hold the DNC system files described in Appendix C for use whenever the backup system is needed.

A. CMS Cell Data Files

CELLPARS: the cell parameters file holds details about the machine numbers, workcentre codes, operator numbers, machine descriptions and operator names for all the cell machines;

JICGT01: the Jobs in Cell file holds a list of contract numbers in priority order for all jobs live to the cell and an index into the cell loadfile;

LFGT01: the Load File, or cell work in progress file, holds supplementary information about each cell job and its cell routing including operation numbers, workcentre codes, operation times and statuses together with indexes into each cell job Jobdata file for each operation on the cell route;

JOBDATA.nnn: the Job Data files for job number 'nnn' contains operation description, setup and NC program information for each operation on the cell routing;

SHIFTPAT.nn: the Shift working Pattern file for machine number 'nn' contains the times of each working period during a seven day cycle for each cell machine.

EVENTS: holds details of cell 'events' reported to the cell system.

B. CMS Machine Data Files

PARAMS: holds details about the machine number, workcentre code, operator number and machine description (a subset of cellpars);

JOBS: holds job details for up to 9 'local files' together with the number of operation, tooling and nc program files and pointers to nc, tooling and operation data files created at the pc;

OPn: holds the operation details for job file number 'n';

TLn.m: holds the 'm'th tooling details for job file number 'n';

NCn.m: holds the 'm'th nc program for job file number 'n';

MESSAGE: holds a free format message;

EVENTS: holds details of machine 'events' reported to the cell system.

3.2.2 Subdirectory Mapping

The Netware file server software provides the shared network file access functionality via a virtual file service for each PC workstation by allowing each user to 'map' [Netware] any server disk subdirectory to one of the drive letters A to Z available within the MSDOS PC operating system. In the MSDOS V3.30 operating system the PC drives A and B are allocated to local floppy drives; C,D and E to local hard disk drives leaving F through Z available for network drive mapping. The available subdirectories can be mapped to any drive as required. For example if drive F is mapped through to FLINECMS/SYS:PUBLIC then accessing a file on drive F will cause a network file access to be made into the file servers PUBLIC subdirectory. Drive mappings can also be set up which will allow for the searching for executable routines and data files in subdirectories other than the current directory. These 'search drives' [Netware] are mapped to drive letters Z back through to K as necessary.

3.2.3 Login Routines

In order to make use of the CMS network each user has been allocated an individual login username which gives the user access rights to use and update the files containing the information necessary for his work. A login script [Netware] is provided for each user which contains a set of commands which customise the user's network environment when the user logs in. This login script sets up the necessary file server drive mappings for the particular user, allocates the PC to a shared printer queue and then executes a menu program which allows the user to access the application routines in the appropriate file server subdirectory.

The login scripts are also used to check on the PC workstation network node address so that the users 'home' directory is mapped to the appropriate user directory on the file server. This ensures that each PC (e.g. for the foremen, manual and NC machines) can only access files which are allocated to that workstation and in the case of NC machines prevents NC programs from being used on the wrong machines.

A generalised login script has been provided which covers both the foremen and operator users. Figure 6 illustrates how this login script is set up. It is used to provide a 'safe' user environment which confines each user to the necessary CMS functions by mapping the directories and then executing a menu appropriate to the user's needs. When the user exits the menu he is automatically logged out of the CMS.

Figure 6 Generalised CMS Login Script

```
rem Set up search drive mappings and home directory
rem standard search drive mappings
map s1:=FLINECMS/SYS:PUBLIC                          ! Drive Z
map s2:=FLINECMS/SYS:IBM_PC:MSDOS:3.30               ! Drive Y
rem specific search drive mappings for machine PC
map s3:=FLINECMS/SYS:PUBLIC/UTILMMS                  ! Drive X
map s4:=FLINECMS/SYS:PUBLIC/UTILCELL                 ! Drive W
map s5:=FLINECMS/SYS:PUBLIC/UTILCMS                  ! Drive V
map s6:=FLINECMS/SYS:PUBLIC/UTILDNC                  ! Drive U
rem Check network node address to ensure logon as the correct machine
rem Station 24 / 18 hex: Machine 3: F13 Ramo Lathe
if p_station is "000000000018" then begin
        map *1:=FLINECMS/SYS:UDD/GT01/MC03           ! Drive F
        #menu manops                                 ! Home Drive
        #logout
end
rem Station 26 / 1A hex: Machine 4: F15 Siemens 850M cnc
if p_station is "00000000001A" then begin
        map *1:=FLINECMS/SYS:UDD/GT01/MC04           ! Drive F
        #menu ncops                                  ! Home Drive
        #logout
end
rem Check if foremen's PC and user is a foreman
if p_station is "000000000014", MEMBER of "foremen" then begin
        map s3:=FLINECMS/SYS:PUBLIC/UTILCMS
        map s4:=FLINECMS/SYS:PUBLIC/UTILCELL
        map s5:=FLINECMS/SYS:PUBLIC/UTILMMS
        map *1:=FLINECMS/SYS:UDD/GT01                ! Drive F
        #menu foremen                                ! Home Drive
        #logout
end
rem If login not allowable logout with message
write "This station (P_STATION) has not been allocated for CMS login"
logout
```

3.2.4 CMS Menus

The network operating software provides a standard menu mechanism which has been used to give users a customised menu allowing them to execute the appropriate applications programs. Four menus have been provided: one for the foremen, one for the NC machine operators; one for the manual machine operators and one for the operator's who use the shared PC allocated to F19, F20 and F21 workcentres.

3.2.5 Print Service

Any networked PC workstation can use the printer attached to the network file server as though it were directly attached to that PC. The file server maintains a queue of print requests which are passed onto the printer in the correct sequence.

3.3 Specific CMS Application Software

The applications software written for the Cell Management System consists of a set of independently executable routines which are selected from the menus created using the Novell menu system. A set of user routines have been written specifically for the foremen (which interact as required with mainframe CICS programs), nc operators and manual machine operators. These routines are based on and provide extra functions to the existing DNC system and have been programmed in the MSDOS batch, Microsoft Quickbasic or Microsoft Pascal [Microsoft] programming languages as appropriate.

3.2.1 Mainframe CICS Programs.

The new mainframe programs have been written in the PL1 and Cobol programming languages as a part of the Rockwell PMC Ltd. 'NCxx' series and are activated using standard 'NCxx' transactions which are called via the IRMA subroutine software from the PC level programs. For the status update routines the already existing mainframe 'Live Load' programs have been used. The programs written for this application also use modules created for the retrieval of NC tape data within the NC editing and specification systems. The programs involved are:

NC15 extracts job routing, operation, time and NC information from mainframe files for a chosen workcentre code. The information is selected in priority order from the workcentre's queued work to list in priority order. Active only in DNC CICS;

NC53 duplicates the NC15 procedure but also updates the relevant operation statuses to 'loaded' on the loadfile. Active only in PMC CICS;

NC60 extracts nc data only for a given part number, operation number;

NC61 creates a contract from the bill of materials file for a particular unprinted contract number providing the same information as NC15 above;

NC62 extracts information as NC15 above for given input contract and operation numbers;

NC64 activates NC61, NC62 as appropriate.

3.3.2 Foremen's Level Routine Menu

Figure 7 shows the menu options currently available to the shaft line cell foremen. Each option causes the appropriate applications program to execute on the foremen's PC. Where communication with the mainframe is involved the IRMA interface routines are used to execute programs in the selected mainframe CICS partition in the same way as the DNC system software. However as already indicated the Tempus Link virtual file service is used wherever possible to simplify communications.

A. ..Auto Updates and Deletions

This routine performs the functions in menu Update and Deletion options automatically and is run continuously as required by the foremen.

B. Transfer Cell Data from Mainframe

This program extracts job data from the mainframe master data files and assembles this data in files in the tempus link library. The data is then transferred to the cell system where it is 'merged in' with any existing data. Any contract data obtained which already exists in the cell is ignored. The job data is extracted from the mainframe files in priority order using the appropriate Queued Work to List to signify job availability. Any data relating to subsequent contract operations which will be done within the same cell are also considered for transfer. Job operations which are already Loaded or Complete are ignored, see Figure 9.

The program uses a CICS transaction which is run in either PMC CICS or DNC CICS as appropriate to extract the data from the shared mainframe data files. If run in PMC CICS the transaction not only creates the cell data files but also updates the production loadfile to set the status of all those operations extracted to 'loaded' so that subsequent downloads will not pick up the same data whereas

Figure 7 **Cell Foremen's Application Menu**

```
Novell Menu System  V1.22                Wednesday  7 March 1990  8:30 am

      Rockwell PMC Cell Management System

  |..  Auto Updates & Deletions
  |01. Transfer Cell Data from Mainframe
  |02. Mainframe Live Load Op Completions
  |03. Delete Completed Jobs from Cell Files
  |04. Cell Data Status
  |05. Set Holds On NC Part Programs
  |06. Clear Holds On NC Part Programs
  |07. Download New NC Part Programs
  |08. Download Via Contract Number
  |09. Create New Contracts (Yellow Peril)
  |10. Create Projected Schedules
  |11. View Machine Events
  |12. View Machine Status
  |13. Help Menu (F1 key for menu system help)
  |[Press the two Shift Keys for Mainframe Mode]
```

in DNC CICS the transaction does not update the loadfile because of the read only status of the files. The transaction is therefore run in DNC CICS only when the PMC system is unavailable and data is required urgently.

The success of the data merge and any mainframe data extraction errors are displayed in screen reports.

C. Mainframe Live Load Op Completions

This program uses the already existing Live Load Update transaction in PMC CICS via the IRMA subroutine functions to set the status of any job operations, which are shown as complete in the cell data files, to complete on the Mainframe Loadfile. It also updates the Loadfile to show any workcentre transfers which have been made within the cell.

The program automatically searches through the cell loadfile for completed job operations and workcentre transfers. If the updates are successful the cell loadfile is updated to reflect the new statuses. Any workcentre modification statuses are reset and any completed operations are set to Live Load Complete, see Figure 9.

A report is displayed which shows update success or otherwise for each contract considered.

D. Delete Completed Jobs from Cell Files

This program deletes any redundant data held in the cell data files. In order for a contract to be removed from the cell data files all operations on that contract need to be signified as 'live load complete' i.e. the operations have been signalled as complete in the cell system AND the liveload update program has been used to set mainframe loadfile status to complete. In any case operations completed 'today' are not deleted. It should always possible therefore to check on any contracts which have been completed during the current day.

The program automatically searches through the cell loadfile for suitable contracts and effectively deletes them by creating new temporary files and copying over the data that is to be kept into these. Once the copies are complete the old cell files are deleted and the new files renamed. A report is displayed which shows all the contracts currently in the cell loadfile and whether the data was restored or deleted successfully or an error occurred.

E. Cell Data Status

This program displays the status of jobs held in the cell data files, as illustrated in Figure 8. This status does not necessarily coincide with the status shown on the Mainframe Loadfile. Job data is displayed in priority order. Any data relating to subsequent operations within the cell is also shown. The status of any job operation can be changed subject to the 'rules' set within the program for logical changes. Job operations can also be transferred to alternative workcentres. When operations are transferred to another NC workcentre (or an NC program is amended for some reason see below) the existing data in the job data files will be incorrect for the new work centre. Therefore to stop existing data from being used the particular operation is also put on 'hold', until the data is replaced with new correct data.

The status data display can refer to any single workcentre within the cell (plus following ops) or to all cell workcentres if the 'cell workcentre code' is chosen. Jobs for the chosen workcentre are displayed according to the status value selected. The cell data status of each job operation, as illustrated in Figure 9, can be:

__Figure 8__ __Cell Data Status: Total Status Screen__

```
                    | ROCKWELL PMC CELL MANAGEMENT SYSTEM |

| Machine: 00 Shaft Line          | WCen: GT01 | Operator: Dave Chambers        |

                    |        ALL Work: Total Cell Jobs =  62 |

 Job PWC No   Prty  Qty Part Number   Part Descr       OpNo WCen Tot Time Status
▲
   1 M 70844  1487   2        753718 HARMONIC GEAR S  20   F16B     0.78  complt
                                                      30   F11Q     0.00  complt
                                                      40   F18      0.93  active
                                                      50   F13      0.78  loaded
                                                      60   F19      1.21  loaded
                                                      70   F21      0.13  loaded
   2 X338819  1475   3        757999 SHAFT            10   F13      0.97  queued
                                                      20   F19      1.17  queued
                                                      30   F21      0.32  queued
   3 M 61450  1473   2        751037 NIP ROLLER       50   F15      1.85  loaded
▼
                      Hours Available: 171.96     Hours Selected: 0.00

| Status | Use Cursor Pad: (P)rint, (C)omplete, (D)elete ALL OPS :-> more       |
```

(i) Queued: Contract not released to the cell. All ops should be the same status (includes newly transferred data);

(ii) Loaded: Contract released into the cell and available to the operator;

(iii) Active: Operation currently in progress. Only one op can be active on each contract at any time;

(iv) Complete: Operation completed;

(v) LLcomplete: Operation completed AND mainframe loadfile status set to complete using the Live Load update program.

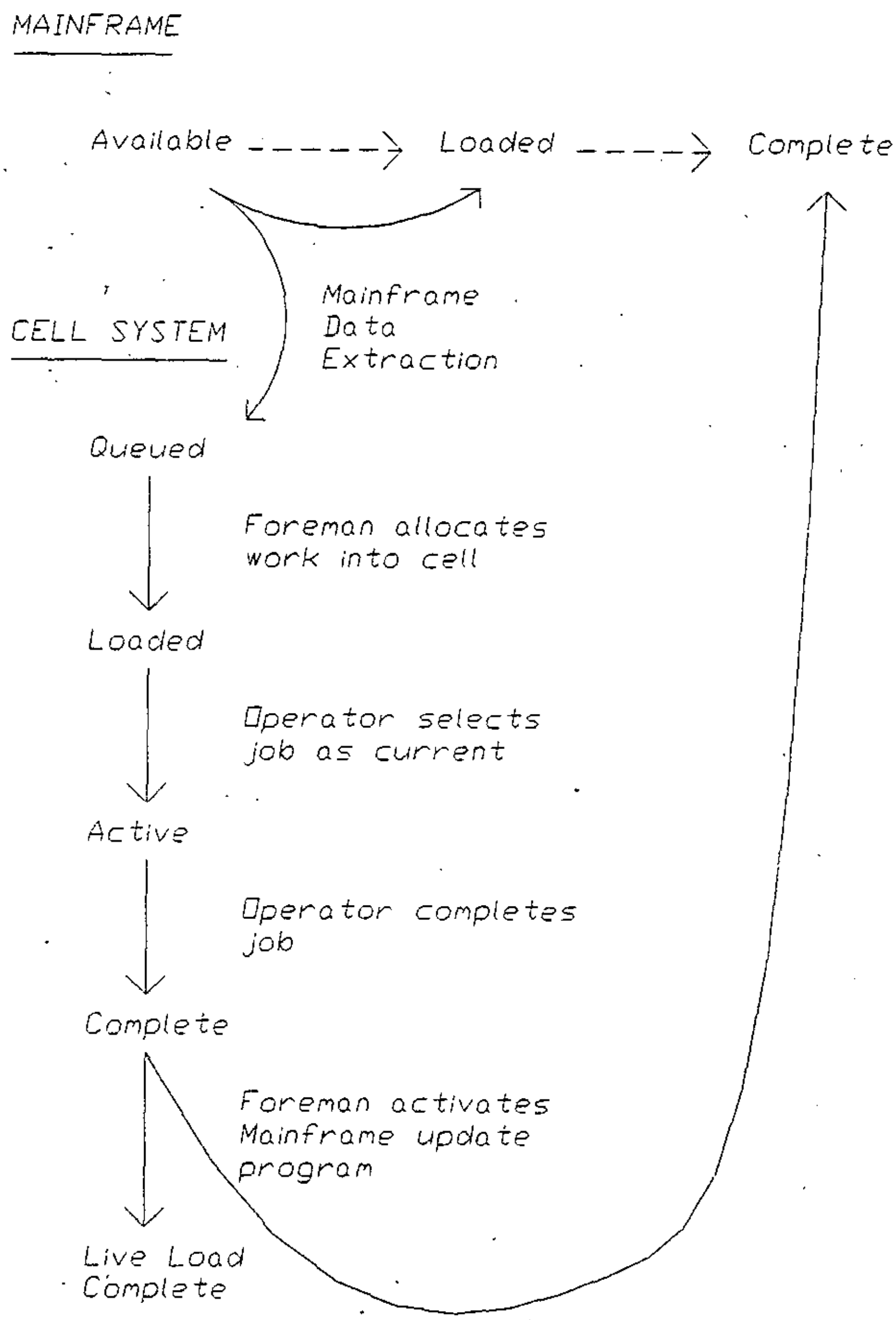
F. Set Holds on NC Part Programs

This program searches through the Cell loadfile for all the Operations matching a given input workcentre code and part number and sets the 'HOLD' flag. If any of the relevant NC programs exist in any of the operators' job files then a message indicating this is displayed. The foremen is responsible for ensuring that the operators delete this redundant data.

G. Clear Holds on NC Part Programs

This program searches through the Cell loadfile for all the Operations matching a given input workcentre code and part number and clears the 'HOLD' flag.

Figure 9 Job Operation Status Values



H. Download New NC Part Programs

This program searches the Cell data files for all Operations which are on Hold and activates a mainframe transaction in DNC CICS using the IRMA interface subroutines. This transaction retrieves new NC, Op and Tooling data for all Held operations and creates files in the Tempus Link library which are then transferred to the cell system. All the new data in these files is then merged into the Cell data files and any errors displayed. For all operations where the new data is successfully merged the 'HOLD' flags are cleared.

I. Download Via Contract Number

This program extracts job data from various mainframe master data files in the same way as the option described in section B above. However instead of using the Queued Work to List to select which jobs are transferred the job are selected via contract numbers / operation numbers entered by the user.

The program also uses a transaction in DNC CICS to extract the data (rather than PMC CICS) since mainframe loadfile update is not necessary. Using DNC CICS also allows the transaction to be used throughout the whole of both day and night shifts because of this systems increased availability.

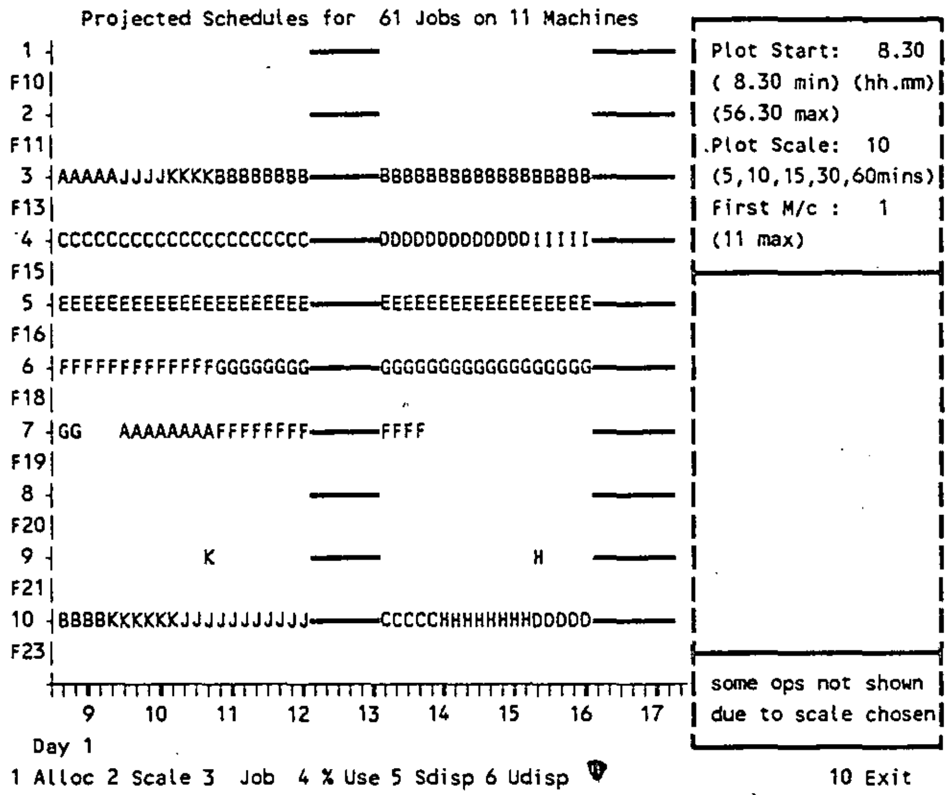
J. Create New Contracts

This program uses a mainframe transaction in DNC CICS in the same way as described in sections B and I above to extract data for new contracts which are not yet available on the Mainframe loadfile but for which the paperwork and materials are already available in the cell. This happens when contracts have been printed by the on line system and before the overnight mainframe batch routines have put the necessary information on the mainframe loadfile. These contracts are 'created' in advance according to a list of contract numbers, part numbers, quantities and operation numbers which are entered by the user. The data for these new contracts is merged with the CMS files and any errors reported.

K. Create Projected Schedules

This program displays in Gannt Chart Form a projected schedule of the loaded and active cell contracts, see Figure 10. The chart is intended to show the possible outcome of releasing contracts into the cell in terms of workcentre loading and contract completion times. The projected schedules take into account simplified shift patterns for each of the machines involved and also the allocation of

Figure 10 Cell Jobs Gannt Chart Display



operators. If any operator is shared between 2 or more machines the availability of the operator is then the deciding factor in scheduling. A number of user functions are also available once the Gannt Chart is displayed:

(i) Change Machine Allocations;
(ii) Change Chart Scale;
(iii) Identify Job Character;
(iv) Display % Utilisation of Machines or Operators;
(v) Display Machine or Operator Schedules;
(vi) Display List of Unscheduled Job Operations;

L. View Machine Events

This program displays a report of any significant events which have been logged against a selected machine. The data display can refer to the events logged against any single workcentre within the cell or to the cell workcentre itself.

M. View Machine Status

This program displays a report of the current status of each machine within the cell including the details of any active job.

N. Help Menu

The help menu option causes another level of menu to display. This menu provides a help facility for each of the first level menu options described above. Each help option causes the help file for the corresponding user program option to be displayed. This help file describes the function of the program and how it is used by the operator.

3.3.3 Operators' PC Level Routine Menu

The menu options currently available to the NC operators in the shaft line are shown in Figure 11 and those to the manual machine operators in Figure 12.

The options available to the NC machine operators are based directly on those already made available in DNC. The major changes involve the extraction of job information from the cell system files rather than from the mainframe database directly and the inclusion of a routine to allow for job operation status reporting into the cell level work in progress file. The menu also includes a second level DNC system menu which allows for the use of DNC as a backup to the Cell Management System wherever IRMA interface cards are still available in the PCs.

The manual machine operators' menu includes a subset of the functions available to the NC operators. The menu does not include any functions for viewing job information apart from operation status because at present this functionality is of no real use to the particular operators in the shaft line. The menu presented on the PC workstation shared by F18, F19 and F21 has the same options as the other manual machines however it works in a slightly different way. On selecting any option the operator is asked to also select the appropriate workcentre code and the 'home' drive is then mapped to the correct MCxx subdirectory before the program is executed.

A. Transfer Cell Data into the Job Files

This program allows the operator to access job information about all those contracts which are available for his machine i.e. where any previous operations have been signalled as complete. The data is transferred from the cell data files

Figure 11 NC Machine Operator's Applications Menu

```
Novell Menu System  V1.22                 Wednesday  7 March 1990   8:30 am

        Rockwell PMC Machine Management System

        1. Transfer Cell Data into the Job Files
        2. Set the Status of a Job
        3. View Text Data in a Job File
        4. Clear Data from a Job File
        5. Edit/ Store a Message
        6. View Machine Events
        7. Transfer NC Data to the Machine Control
        8. Tooling Data Save/Restore
        9. Use the old DNC System
        H. Help Menu (F1 for menu system help)
```

Figure 12 Manual Machine Operator's Applications Menu

```
Novell Menu System  V1.22                 Wednesday  7 March 1990   8:30 am

        Rockwell PMC Machine Management System

        1. Set the Status of a Job
        2. Edit/ Store a Message
        3. View Machine Events
        4. Help Menu (F1 for menu system help)
```

into the job files allocated to the given machine so that the operator can use / view the data independently of the central files.

The program displays a machine work to list from which jobs can be selected. Job data is displayed in priority order and any data relating to subsequent operations within the same cell is also shown. A number of job files can be transferred one after the other if appropriate. Each machine's job files can accomodate up to 9 jobs worth of information.

B. Set the Status of a Job

This program is used to change the status of any job held in the machine job data files. The program displays the contents of each of the 9 'slots' in the machine job files together with the current status of the operation as held in the cell data files. The status of any job operation in the machine data files can only be moved through the sequence of the Loaded, Active or Complete statuses described above, although an active job can be returned to loaded (or inactive) if required.

The status change facility for completion of a job operation also allows for the completed quantity to be entered (for subsequent transfer into the mainframe loadfile).

C. View Text Data in a Job File

This routine is based upon and is used in the same way as the corresponding DNC routine to allow for viewing of the operation description, NC and tooling/ setup information.

D. Clear Data from a Job File

This program allows the operator to discard any of the data in the machines home directory as long as the job operation has not been signalled as 'Active' on the machine.

E. Edit/Store a Message

This program allows the operator to create, edit and store on disk a free format message as in the original DNC system.

F. View Machine Events

This program displays a report of any significant events which have been logged against the operators machine.

G. Transfer NC Data to the Machine Control

This program allows for the transfer of any Active job from the machine data files to the machine controller as in the original DNC routine.

H. Tooling Data Save/Restore

This program, used on the Heid Lathes only, allows the operator to upload the machine controller tooling setup data into a file in the machine directory for backup. This file can then be re-downloaded as required.

I. Use the Old DNC System

This option causes a second level DNC System menu to be displayed from which the original DNC routines can be executed. However before the DNC program runs the machine home directory is changed to 'MCxx/DNC' to ensure access of the correct file data. When the program is exited the home directory is restored to 'MCxx'.

J. Help Menu

The help menu option causes another level of menu to display. This menu provides a help facility for each of the first level menu options described above. Each help option causes the help file for the corresponding user program option to be displayed. This help file describes the function of the program and how it is used by the operator.