MMPHIL Ø7

A Philosophy for the Implementation of C.A.E.

Andrew J Miller

A thesis submitted in partial fulfilment of the requirements of the Council for National Academic Awards

November 1991

Nottingham Polytechnic in collaboration with Boart UK Ltd

I would like to acknowledge and sincerely thank Bruce Foster and Brian James for providing me with such an opportunity. I would also like to express my gratitude to Roland Metcalfe for his support and advice throughout the duration of this project.

Summary

In 1987, Boart UK Ltd approached Nottingham Polytechnic with the objective of setting up a Teaching Company Scheme. Boart had decided that to meet its business goals for the future, successful exploitation of computer technology was necessary, specifically in the technical activities of the company.

The project started in August 1987 with the author being appointed as a Teaching Company Associate, and the first period of work was devoted to establishing what advantages and disadvantages the company would obtain from computer implementation.

Once it was established that potential gains existed in areas of design, design management and in effective application of the information captured and used during the design process, a preliminary assessment was undertaken of the computer marketplace.

An appreciable period of time was subsequently devoted to preparing suitable benchmark tests truly representative of the environment and manner in which the chosen system would have to function. Five vendors were subjected to these tests and a proposal from Cadlinc was ultimately accepted.

Once installed, a period of programming was undertaken, to take the system that had shown it had the greatest potential to fulfil the company's requirement, to a level that actually fulfilled that requirement. This was achieved by the creation of "DOMS", the Design Office Management System.

It is suggested that the benchmark was the key factor in the evaluation process, due mainly to the commercial nature of the computer marketplace. Whilst the buyer's requirement can be based on technical suitability, the vendors will be based on profitability. The benchmark was found to be necessary in pursuing technical satisfaction in a commercial environment.

Whether the system was implemented successfully or not, could not be determined without first taking into account the original requirements of the company. Measuring implementation was discussed as were the components that were necessary for its success. In this context, the implementation was deemed successful for Boart UK.

Contents

Glossary

Referred to in this thesis are the following

(a) Computing Acronyms and Abbreviations

AMT	Advanced Manufacturing Technology
CAD	Computer-Aided Design
CADD	Computer-Aided Design and Draughting
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CIM	Computer Integrated Manufacture
DAS	Design Analysis Software
DBMS	Database Management Software
DOMS	Drawing Office Management Software
DTP	Desktop Publishing
GRPS	Graphics Related Programming Software
kb	Kilobyte
macro	Macroinstruction - defined Page 24
Mb	Megabyte
MIS	Management Information System
NC	Numeric Control
PC	Personal Computer
PPS	Parametric Programming Software

(b) Computer Vendors and Companies

Applicon, Apollo, ATPL (Advanced Technology Products Limited), Autodesk, Care Business Solutions, Cadlinc (now Cimlinc), Compaq, Computervision, Datron Microcentres, DEC (Digital Equipment Corporation), Hewlett-Packard, IBM (International Business Systems), Intergraph, McDonnell Douglas, Microsoft, Oracle, Pafec, Sun Microsystems, Vistec Business Systems.

(c) Some Computer Vendors' Hardware and Software Packages

Adimens	Drawing management software from Hewlett-Packard
Autocad	2D based drawing software from Autodesk (through Distibutors)

Bravodraft	2D based drawing software from Applicon
CADDS4X	2D based drawing software from Computervision
Cimcad	2D based drawing software from Cadlinc
Empress	Relational database software from Care
Medusa	2D based drawing software from Computervision
MicroVax	Mini-computer from DEC
MS-DOS	Microsoft - Disk Operating System
NFS	Network File Software from Sun Microsystems
PC-DOS	Personal Computer - Disk Operating System from IBM
Unigraphics	2D based drawing software from McDonnell Douglas
UNIX	Multi-tasking, multi-user operating system from AT&T Bell Laboratories, available on some workstations
VMS	DEC proprietary operating system.

1. Introduction

1.1. The Basis of Work

The work on which this thesis is based, was carried out over a period of two years. The author was employed by Trent Polytechnic (now Nottingham Polytechnic), as a Teaching Company Associate, and was seconded full-time to an industrial partner.

The partner (from here on often referred to as the company) was Boart UK Ltd., designers and vendors of rock drills, drilling booms and many other products associated with the mining of hard rock.

1.2. Objectives

There were three main project objectives. They were as follows:-

(a) to select a computer-aided engineering (CAE) system, following a detailed analysis of the company and of the CAE system vendor market,

(b) to develop an implementation plan for the chosen system,

(c) to install and develop the CAE system in such a way that fulfils implementation, and the original requirement of the company.

1.3. The Company

1.3.1. The Boart International Group

Boart International is owned by Anglo American Industrial Corporation - a major division of the Anglo American Corporation of South Africa. The Boart Group has been in existence for more than fifty years and currently employs approximately 11,000 people in 80 countries.

The name of the company is derived from the low grade diamond, not usable as a gem stone and fit only for industrial uses, which accumulated from the early diamond mines in Zaire. The company built up its business using this low grade diamond (boart) in the manufacture of drill bits. As the mining industry worldwide grew, then so did the requirement for harder cutting materials for the actual mining of minerals, and subsequently the development of Tungsten Carbide drilling.

Boart International developed its cemented tungsten carbide products, primarily for the production of chisel rods for hard rock mining. The group is currently one of the leading manufacturers of rock drilling equipment in the world.

1.3.2. Boart UK Ltd.

In 1983 Boart International decided to enter the capital equipment market for underground mining, specifically mobile-drilling equipment for hard rock conditions. The development was undertaken at the site in Eckington, Sheffield.

At the commencement of the project the company employed 80 people. It was of conventional structure comprising Design, Manufacturing, Sales and Marketing, Quality Assurance and Finance departments.

Most of the company's business is from rock drill, drilling booms, hydraulic power packs, controls and carriers. These products are marketed separately, or built into mobile drilling rigs which typically weigh 18 tonnes, cost approximately £170,000, and work in tunnels with a cross-sectional area of between 25 and 50 square metres.

Sales for 1988 were £6M of which 32% was from the export market.

In 1987 the company formulated a five year plan with the objective of increasing its share of the worldwide market for mining equipment. The company strategy required

(a) more tenders submitted to potential customers,

(b) the number of design engineers to remain at seven,

(c) a broadening of the product range to include different sizes of drilling booms, carriers and mobile-drilling rigs,

(d) an extension of the product range to include surface as well as underground mining equipment,

(e) the enhancement of the product range to include computer-controlled mobile-drilling rigs.

Towards the end of the two year period, Boart UK acquired one of its largest manufacturing contractors. Based in Newcastle, this addition increased the number of employees to 96.

2. The Potential for Computer Implementation

" .. there are strong reasons to believe that the penetration of AMT will accelerate, and the question being asked in the industry is not whether to adopt this new technology, but how and when." [1].

2.1. Analysis of the Company

Throughout the 1980's the practicability of buying some form of CAE system has greatly increased for both small and medium size industries. Bertoline [2] reports a growth rate of 30% in the early 1980's for the worldwide computer graphics market, and by 1985 the growth rate in the market for CAE systems was calculated at 40% [1].

With the ever increasing viability of such systems, and with the five main goals to achieve, the company concluded that the introduction of some form of CAE system would significantly increase their chances of realising these goals.

To determine the true potential for such a system however, it was considered important to ascertain, in broad terms, a realistic path of implementation.

Nadler and Robinson [3] concur with this consideration and refer to the dangers of what they term the "snapshot myth". This is where the potential buyer forms an impression of their company before and after installation, but with little thought given to the finite stages that must be completed if the desired final outcome is to evolve.

The point is valid in this case, and potentially in any case where the snapshot concept is considered in isolation. It can however, serve as a strong starting point when considering the long term objectives of computer implementation. The snapshot can subsequently be divided up into smaller and achievable transition stages.

The company had defined a snapshot view. In their considerations they had included each internal department, their outside manufacturers and other members of the international group.

By the end of the main implementation phase, the company planned for the integration by computer, to some extent, of the majority of its departments.

Figure 2.1 shows the breakdown in snapshot form, of what the company intended to achieve. The contents of the table were gained from discussions with the company's management team.

Design or Practice	Before computer implementation	After computer implementation
conceptual design & draughting	manual creation on drawing boards	created and stored on computer
technical analysis of designs	hand calculations	"integrated" programmes for calculations on computer
technical documentation e.g. parts lists, build specifications	manual creation and compilation	information stored and reports created on computer
sales scheme drawings	manual creation and compilation	partly compiled from existing information on computer
sales and marketing documentation e.g. proposals, brochures	manual creation and compilation	compiled on computer, merged with sales schemes for proposals
general transfer of information within the company	verbal, written and drawings (paper)	verbal, written and drawings, also via technical database
general transfer of information within the group	mainly verbal and written (some paper drawings)	mainly verbal and written, some drawings - both paper and data
general transfer of information with manufacturers	some verbal and written - mainly drawings (paper)	verbal and written though mainly drawings*

Figure 2.1. The results of applying the "Snapshot myth" to Boart UK

* the potential for future transmission of manufacturing data with the company's contractors was a consideration borne in mind throughout the evaluation process.

The table in Figure 2.1. reflects the expectations of the company in implementing a CAE system. It was important at this stage however, before developing a path of implementation, to decide whether the expectations of the project concurred with the five company goals, and to determine whether investing in CAE was a practical method of achieving them.

The first of the company's goals was to increase the number of tenders submitted to potential customers. With many of the their new designs being modifications of existing ones, e.g. in a simplistic form, a mobile-drilling rig will always comprise a chassis, a boom (or booms), a feeder (or feeders), and a rock drill (or rock drills), then the company could see considerable time being wasted in drawing repetition (see Figure 2.2.).

With the implementation of a CAE system, the facility to collate existing information, both drawings and text, would reduce the time taken for the designer to generate a sales scheme. Consequently, the time taken to submit the tender would reduce, whilst the quality of the tender documentation would be enhanced.

The company employs seven design engineers and the second goal required that this number be maintained. The implications of an increase in the number of tenders however, should lead to a corresponding increase in the number of orders, which in turn leads to a requirement for a greater number of drawings per head.

Medland and Burnett [4] discuss whether a greater number of drawings produced from the design office, is a forward step. They conclude that although a drawing is the most tangible output of a traditional drawing office, the designer should generate more or better work while producing fewer drawings. A 1982 survey [5] recorded gains ranging from over 1700% in the design of integrated circuits, down to 140% in mechanical draughting. In the same year a similar survey [5] suggested that the expense involved in purchasing a medium-sized CAD system could not be justified unless a productivity increase of 200% was achieved (assuming single-shift utilisation). As there was little information in the form of technical or financial data communicated within the group, and as none of the company's sub-contract manufacturers used computers for their design or production activities, paper drawings would continue to be the output of the Boart design office.

Due to the fact that Boart UK used sub-contract manufacture and a high proportion of bought-in items, the destination of drawings was frequently different. Consequently, the detailing process of breaking down assemblies into sub-assemblies, and then down further to single items, would remain unchanged once on the computer, and therefore the same number of drawings for each design was envisaged. For Boart UK therefore, an increase in design output would involve a corresponding increase in the number of drawings generated.

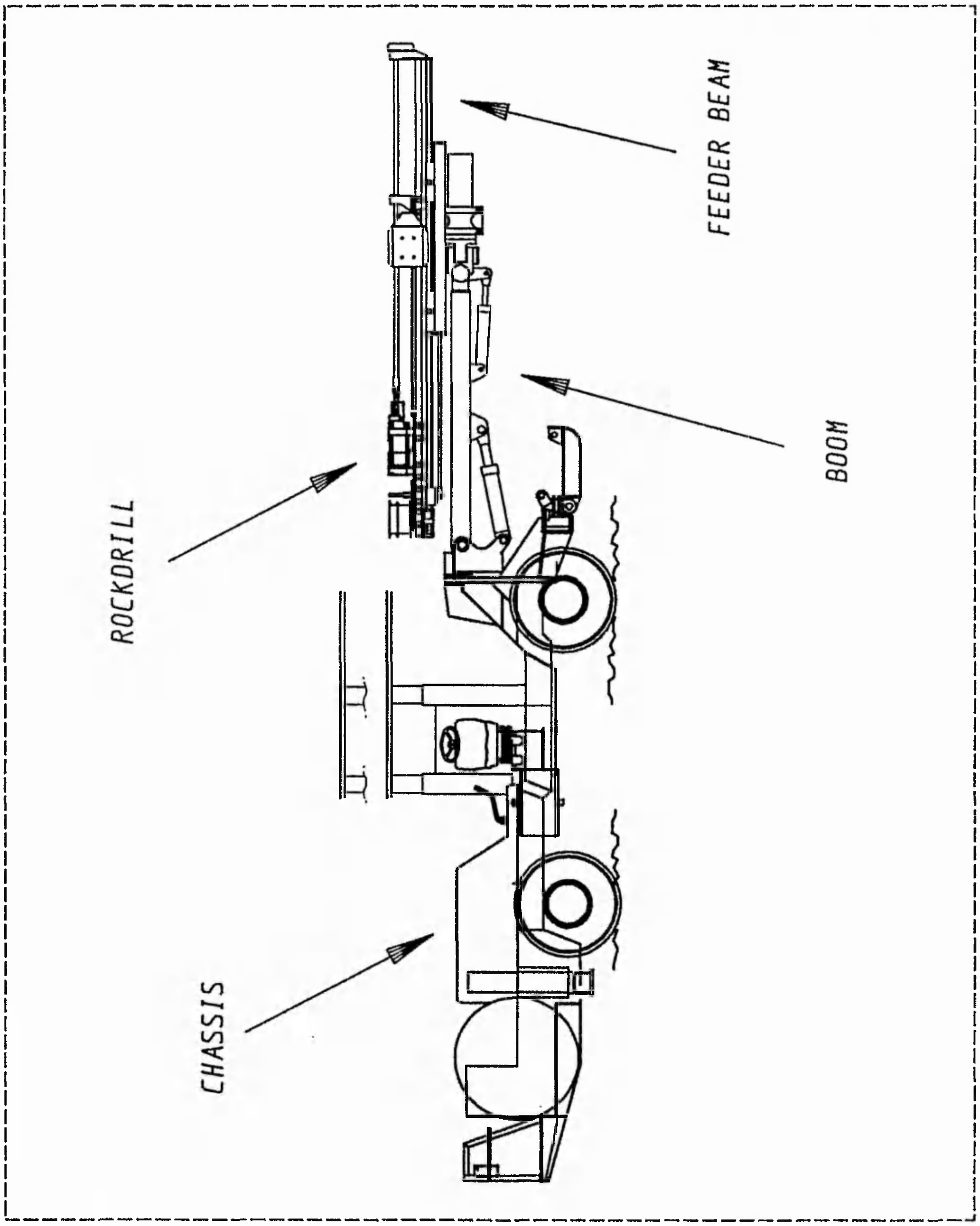


Figure 2.2. Boart UK Mobile Drilling Rig

Allowing for the inevitable problems caused by retraining and the debugging of an unfamiliar system, a study at Brunel University [5] indicated that existing rates of productivity would not be improved upon during the first year, and therefore an aggregate for the whole year would show a loss. The company's goals however were not short term and the study goes on to show that in the second year, the productivity ratio between the new methods and the old could rise from 1:1 to 2:1 with the figure finally stabilising at 3:1. Consequently the company should be able to increase its design productivity whilst maintaining the number of designers at seven.

The remaining three company goals all relate in some way to an enhancement of the product range. It was a perception of the company, that by implementing the computer system, the enabling technology would be in place for structured, long term development towards achieving this enhancement. This perception is considered below.

The source of conceptual input for a new design is the engineer. An enhanced and successful product range will therefore require that the designer uses the knowledge and information gained from work on equipment already proven, and applying it to perhaps similar, but nevertheless new products. As the computer system would not replace the conceptual design input, it must assist the engineer in carrying out his conceptual function.

CAD gives the designer the capability to manipulate the design, assess the changes he has made, and then return to the original design if he so wishes. "What-if" analysis as it is often called, is where the designer can determine **what** result he will get **if** he makes a certain change. This "iterative" approach to design optimization was never practically possible under manual drawing conditions, due to the excessive time and repetitive effort involved.

The "what-if" approach has been used in financial computing for a number of years. The commonest tool is the spreadsheet - a program that is dependent on the computer's ability to mass edit information. It has given the financial user the scope to alter a numerical value in his manufacturing cost of sales - January 1988 for example, and to witness the effects that this alteration has on his company's profitability for year-end 1989. In discussion with the commercial manager at Boart UK, it was noted that the spreadsheet had enabled greater analysis relating to forecasting and budgetary control, and iterative "what-if" calculations resulted in the optimization of the planning process.

An example of where CAD can optimize the design is given by Boeing [6]. The first prototype 747, designed traditionally, required several hundred metal shims to fill various gaps in its construction. The first 757 which was designed on a CAE system only required six.

With each of the five goals considered, the potential for successful computer implementation certainly existed. The path of implementation could now be considered.

From Figure 2.1 it can be seen that the company intended purchasing a CAE system that would ultimately serve a majority of the departments in some way. There are two different ways of achieving this final outcome.

The first method would be to attempt a fully integrated system in one phase, trying to fulfil the requirements of all departments. This way the company only enters one large stage of upheaval.

There are a number of overwhelming disadvantages related to one phase implementation however. One such disadvantage arises from the fact that it is very easy for the customer to purchase more hardware and software than is actually required. Medland [7] proposes that often when modest systems are installed, the company finds its own ways of developing the system in response to definite requirements that emerge from within the company. This response may ultimately involve a further investment, but the buyer by this stage will have considerable "hands-on" experience, which is more valuable than pre-sales assurances made by the vendor. Consequently, the second method would be to install a CAE system in a number of stages, seeing each stage implemented before considering the next.

A further consideration relates to the resources available with which to implement the computer system. With Boart UK expecting one person, the author, to implement whatever systems were selected, a one phase purchase would inevitably result in some areas being under-developed after a significant amount of time. This was considered financially unacceptable by the management team, and so a multi-phase implementation was chosen.

Due to the expenditure implications of the project, both in capital and employees' time, the implementation was divided up into stages of investment, with the technical systems being defined as the first and primary investment stage.

The idea of the primary investment implies a bias towards the technical aspects of the overall selection. This bias is in fact useful as it creates a starting point for evaluation, and naturally begins to breakdown what was a snapshot view of the overall selection, into two preliminary stages: firstly, the selection of a CAD system, and secondly, the development to fulfil the company's overall requirements. The snapshot can subsequently be divided up further into modular investment stages of expansion that may (or may not) include further purchases of hardware and software following the initial system purchase.

A general path of implementation can be prescribed. Figure 2.3 depicts the chronological stages that together result in the achievement of the "after" snapshot.

Before Implementation - Snapshot

|

Design Office/Technical Department Investment

|

Technical Publicity Department Investment

|

Sales & Marketing Department Investment

|

Investment for Departments requiring Database Access

|

After Implementation - Snapshot

Figure 2.3. - First Level Breakdown of the Snapshot applied to Boart UK

The first level breakdown can be broken down once more to give an explicit implementation plan. Before any investment can take place (whether in monetary terms or in development time), an operational analysis needs to be undertaken, to ascertain exactly what each level of investment involves. An analysis of how each department functions is therefore required.

This thesis concentrates on the operational analysis relating to the first stage of investment, that relating to the technical department. This can be seen in Chapter Three.

2.2. Existing Installations within the Boart International Group

Although Boart International has representation in eighty countries, only some of the larger plants have any form of CAE system installed. The majority of installations are discussed below.

2.2.1. Boart Hardmetals Europe

Boart Europe, situated in Shannon, Ireland, manufacture rock drilling tools and accessories of which over 95% are exported [8]. The company has a large manufacturing facility and its activities include forging, machining, heat treating, brazing, and finishing of taper socket bits and the grinding of tungsten carbide inserts.

The computer system chosen comprised Applicon software running on a Microvax central computer. Two workstations were implemented in the Design Office with a third situated in the production department specifically for the CAM related aspects of the product cycle.

2.2.2. Boart Hardmetals

Boart Hardmetals, BHM, situated in Springs, South Africa, have a similar operation to that in Ireland. The site at Springs however is significantly larger as it produces its own tungsten carbide which forms the basis of a wide range of consumables.

Employing approximately 1500 personnel, BHM also have an Applicon based engineering computer system.

2.2.3. The Steel Engineering Company

S.E.C.O., based at Roodepoort in South Africa is a rock drill based division of Boart International, and one of the largest employing approximately 2000 people. Unlike Boart UK who design hydraulic rock drills, SECO design pneumatic rock drills.

At the time of writing, SECO were using a microcomputer based CAD system in an attempt to become familiar with the capabilities of CAD.

2.2.4. Boart Research

Boart Research, also situated in South Africa, cover many major developments within the Boart Group. A large proportion of their resources are dedicated to improving the structure and brazing techniques of tungsten carbide. Also, alternative styles of rock drilling are developed by a staff of approximately 200.

Boart Research has installed Personal Designer from Computervision. Personal Designer runs on personal computers as the name of the package implies.

2.2.5. Boart Gmbh

Boart Gmbh is situated in Fernkop. The company manufactures a similar range of products to that in Ireland. The main difference however is that the Boart Gmbh consumables are aimed at the soft rock market whereas products from Ireland are also developed for hard rock drilling.

Boart Gmbh have Autocad software running on a number of microcomputers.

2.2.6. Boart Burlington

The operation at Burlington, near Toronto in Canada is similar to Boart UK. Autocad has been installed for draughting and CAD based applications, whilst Applicon software has been implemented on personal computers for NC programming.

Although all the companies referred to in this section are part of the Boart group, each company is highly autonomous and there is often little similarity in the products of one site and another.

SECO and Burlington share a similarity with Boart UK, but it was only Boart Europe in Ireland that had completed a significant CAE system evaluation process prior to the two year project on which this thesis is based.

The site at Shannon was visited to discuss matters relating to the selection of the Applicon system, and it was found that some of the evaluation principles and ideas that had been used in Ireland could be applied equally as effectively in the selection of the system for Boart UK. As the applications of the two sites are very different however then only a relatively small insight could be gained into the technical suitability of the Applicon system for Boart UK.

There is a possibility that if an evaluation process had been undertaken at either SECO or Burlington, resulting in the successful implementation of some form of CAE system, that Boart UK would have chosen the same system following only a very basic evaluation process.

Nadler and Robinson [9] discuss the merits of implementing a system on the grounds that it was successful at a similar site however. They describe a "cloning myth" which is defined as " .. *that what worked well in one setting is likely to work well in comparable settings.*". They propose that methodologies adopted at the first site may also be relevant for the second site, but often that the final outcome, after two in-depth evaluations, can be significantly different.

Following discussions within the Boart group it was decided that although Boart UK may need to transfer information to and from existing computer installations, the evaluation process should be carried out with data transfer as a consideration but not as an overriding factor.

3. Operational Analysis of the Company

" In particular, it can be fatal to look at the issue only in the context of design as an isolated function unrelated to the rest of the business." [10].

Before commencing any evaluation of the CAE system market, it is important to have an understanding of how the company operates, how the company would like to operate in the future, and to qualify specifically how the company can benefit from implementing a CAE system.

Section 3.2 will consider the majority of departments within the company, with the objective of considering some benefits of enabling access to the CAE system. It was reported in Section 2.1 however, that the CAD system was to be the primary investment, and as such, it was important that an operational analysis was undertaken to consider the functions and operations of the design office of Boart UK.

There were two main objectives of this analysis. Firstly, if a system was to be purchased that would fulfil the technical requirements of the company, then it was necessary for the author to become generally familiar with the activities of the designers at their place of work. Once familiar with the environment, the author could subsequently identify any unusual characteristics within the design office, and ensure that any system purchased would be able to manage such characteristics. The way in which this was actually ensured can be seen in Chapter Five.

Secondly, it was necessary to determine the general size of the system that was required. Chapter Four will consider "like" systems from £30,000 to £250,000. Collecting information relating to the number of seats, drawing turnover, complexity of the designs and the processes involved was therefore undertaken. It should be noted that it was not known at this stage of the project whether the system would be a minicomputer with slave or dumb terminals connected to it, workstations, microcomputers, or possibly some other configuration. Consequently, the word "seat" is used to denote the places from where the system can be used.

3.1. Requirements of the Technical Department

An initial consideration was to ascertain the number of seats required. Capital expenditure relating to hardware and software was initially prescribed at £128,000, or below. It was made known by the management team of Boart UK however, that the budgeted figure should not be the primary factor of system selection, and that if a CAE system was found that was better value for money than any other, the original figure of £128,000 would be reviewed.

It should be noted that the initial budget figure was purely to cover the implementation of the technical computer systems - with the capability of being expanded and integrated at a later date, but under a separate budget.

3.1.1. The Number of Seats

3.1.1.1. Number of Users

The number of potential system users is the most obvious influential factor in deciding the number of seats required. At Boart UK the number was 11. In addition to the 7 designers, were 2 technical authors and 2 systems people. It was therefore concluded that an upper limit of 11 seats was required.

3.1.1.2. Users' Job

This is a very significant factor as it indicates how long each user is likely to spend using the system. If the user is a draughtsman whose job requires the inputting of previously drawn information into the system, he may spend for example up to 90% of his time on the computer. Conversely however, if the user is a project engineer whose work on the system is confined to conceptual design, with the remainder of his time being spent away from the system progressing other aspects of his project, then he may spend for example, as little as 30% of his time on the computer. An argument exists therefore, that for an office of ten draughtsmen, nine seats would be required, whereas for an office of ten project engineers, only three seats would be needed.

A study of where designers time was spent, had already been completed by the technical manager of Boart UK. He had collected information over a twenty four week period. The results are summarised in Figure 3.1.

Activity	Time Taken (%)
conceptual and detail design	29
procurement, enquiries, telephone, firm visits, etc	10
housekeeping, records, drawing numbers, modifications, change notes	16
sales support, customer support	11
service support, technical problems	5
production assistance	11
holidays, illness, etc	18

Figure 3.1. - The Distribution of the Design Engineers' Time at Boart UK.

Before considering the proportion of time the designer was likely to spend on the computer system, it was necessary to determine whether or not the obtained variables under the manual system were in fact desirable. The results in Figure 3.1, indicate that a large proportion of the designers' time was involved in activities that are not directly productive, and highlights therefore one of the potential benefits of implementing a system, and that is the increase of the value-added activities of the department, at the cost of the non value-added activities.

The highest value-added activity of a designer is described in Figure 3.1. as "conceptual and detail design", within the non value-added tasks (excluding holidays and illness) being covered within the housekeeping category - an area which with appropriate software could be automated on a computer system (see section 3.3.). Consequently, the 16% of time released from this category, would then be made available for design related work - the highest value-added activity, resulting in 45% of the designers' time spent working on the system.

The minimum number of seats therefore, calculated as the product of the number of designers and their expected utilization is as follows

$$\text{Number of Seats} = 7 \times 0.45 = 3.15$$

Four seats was therefore the minimum number that would offer a suitable level of access to the designers.

The company also envisaged that the two technical authors would also benefit from the system. With the primary investment being CAD however, it would not have been meaningful to have calculated a numerical value relating to their usage. If during the evaluation process, appropriate software was found that enabled them to take advantage of the system, the company wanted them to do so.

Depending on whether or not the system is to be developed, by perhaps writing in-house programs or macros (see Chapter Eight), will determine whether or not resources have to be made available for extra users.

Developers require considerable access to the system, and it is feasible that they would use the system for longer periods than any other user, as their value-added activity is programming. Consequently, the very fact that a company decide to develop the computer system in-house, can lead to a requirement for an additional seat.

3.1.1.4. Locality of the Users

If the computer system has all of its seats in one location, then there is the potential to purchase fewer than if the system has its seats at a number of different locations, as resources in one location lend themselves to sharing.

Boart UK intended installing a system at one location.

3.1.1.5. Hours of Work

The number of seats required will reduce if the company adopt a shift style of working, wherein the number of seats could theoretically be reduced by two-thirds.

Boart UK work one shift, between 9am and 5pm, Monday to Friday.

3.1.1.6. Type of System Usage

The word "seat", denoted on Page 14, has thus far referred to a point of access to the system where graphics based work can be done. It is sometimes the case however when less expensive, alphanumeric seats would suffice, especially for the purpose of administration related tasks.

Providing that it was financially sensible, based on the discussion in this section, the company pursued a six seat system, nominally four on design, one on development and one on technical documentation activities.

The number of seats required for any installation gives an indication to the power of the system that is needed, but it is not a solitary figure on which the overall computer capacity can be based. It is important therefore to perform sufficient operational analyses within the relevant departments, so that all necessary facts are available, when the time comes to approach the system vendors.

This type of analysis was important at Boart UK as considerable work had previously been dedicated to the compilation of the Design Office Manual [11] which is the definitive document regarding design and drawing administration. Consequently, it was decided that a CAE system that could be tailored (if necessary) to acquiesce with the existing design office methods, would be far more appropriate than a system that required a different way of working for no additional benefits. It was decided that information representative of the existing design office practices should be collated.

3.1.2. Design Complexity

Due to the type of equipment developed by the company, many finished designs include several stages of assembly. Following an evaluation of the company's more complex designs, a representative hierarchical breakdown was developed depicting the number of drawings generated at each level. The results are shown in Figure 3.2. and it can be seen that seven levels of assembly are obtained.

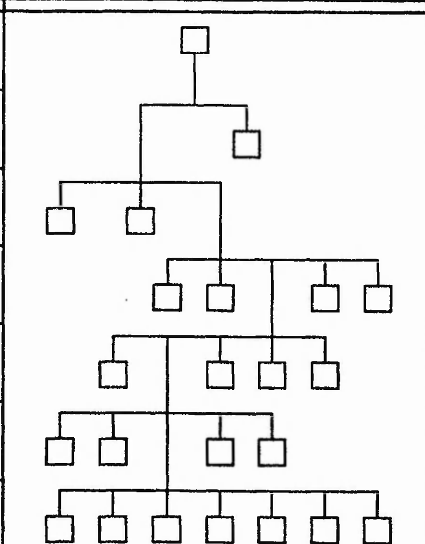
LEVEL	TREE	DESCRIPTION	No of Drgs.
7		Complete Assembly	1
6		Single Items & Sub Assemblies	30
5			166
4			34
3			53
2			26
1		Single Items	20

Figure 3.2. Typical Design Breakdown

3.1.3. Drawing Size and Turnover

An analysis was undertaken to ascertain the drawing sheet turnover, for various sizes of sheet. The results, seen in Figure 3.3, are exaggerated as there is no compensation for wastage, but were recorded as indicative figures, on which a good estimate regarding storage and output capacity of the system could be based.

It was also found that the designers would require immediate access to approximately 2,000 drawings. This figure also gives an indication of the on-line disk capacity that was required.

Paper Size	Consumption (sheets/year)
A0	170
A1	500
A2	1600
A3	0
A4	0

Figure 3.3. Annual Paper Consumption for the Design Office of Boart UK.

3.1.4. The Production Process

As existing design and production methods were to be adhered to, it was necessary to record the significant stages within the production process. A flowchart representing this process can be seen in Appendix A.

3.1.5. Nature of the Design Project

It was observed that designers often provided assistance for one another during some of the major design projects. Drawings, especially those that required dedicated attention, were often worked on by more than one person. In discussion with the design team, it was also noted that items used on one design, were often used (though sometimes after modification) on other designs. The sharing and traceability of information was as such an important requirement.

3.2. Inter-Departmental Integration

The objective of this section is to consider the broad requirements, of the company's departments only indirectly affected by the introduction of the CAE system. The company structure can be seen in Appendix B.

It has already been concluded that before making any decisions regarding engineering computer systems, the company should be considered as a whole, as well as considering those departments potentially most affected by computer implementation. It is possible however, that the evaluation can be too exhaustive regarding the analysis of the whole company, consequently neglecting to some extent those areas relating to the primary investment.

If an in-depth operational analysis was undertaken for each department, then the concept of the primary investment becomes increasingly insignificant, as all the desirable features of the system are raised by each department in turn. This potentially diminishes the importance attached to the original justification for purchasing the computer system.

A second consequence of over analysing all of the company's departments is the inappropriate allocation of resources, as time and inherent investment are dedicated to facets of the evaluation process that do not directly aid its progression.

In the case of Boart UK, the primary investment had been defined explicitly, and so the analysis of the non-technical departments was confined to obtaining their main aspirations in having access to the CAE system. From this analysis a "flow" of technical information was obtained and can be seen in Figure 3.4.

The general aims of the departments, other than the Design Office, regarding the computer installation are tabulated in Figure 3.5.

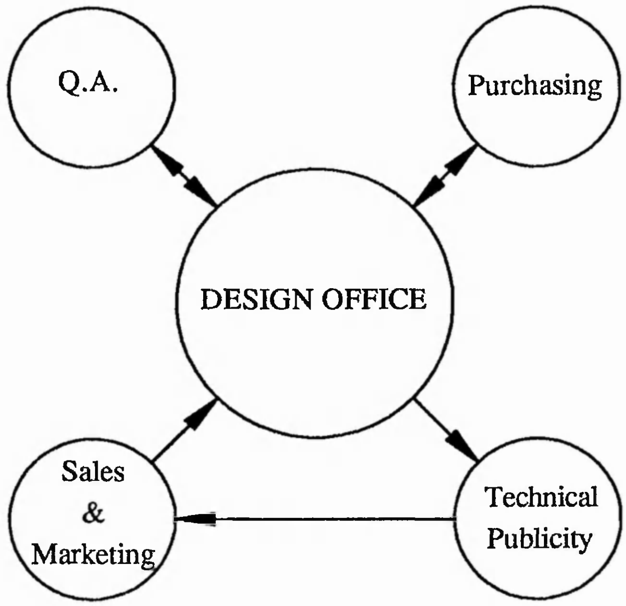


Figure 3.4 Flow of Technical Information around the Departments of Boart UK

DEPARTMENT	DEPARTMENTAL AIMS	
	Input to System	Output from System
Sales & Marketing	Customer requirement information	-
Technical Publicity	-	Sales schemes and proposal documentation. Customer support documentation
Purchasing	Cost and supplier information	Assembly and part information. Purchasing requirement information
Quality Assurance	Quality records and inspection	Assembly and part information. Quality assurance documentation

Figure 3.5 Reasons for Departmental Access to and from the CAE System at Boart UK

3.3. CAE System Specification

The term computer-aided engineering has been used throughout the first three chapters of this thesis, to represent the type of computer system required by Boart UK. As the evaluation process was based on the requirements of the company however, it was not possible in the early stages to be more explicit regarding the type of computer system required. Consequently, it was only after the analyses within the company had been completed, that a specific CAE requirement could be formulated.

The purpose of this section is to relate the company's expectations in purchasing an engineering computer system, to the types of software packages that could substantiate such expectations.

3.3.1. CAD Software

CAD software, potentially 2D or 3D, was required by Boart UK for all design, draughting and detail work.

3.3.2. Drawing Office Management Software (DOMS)

DOMS is sometimes marketed as an integral part of a CAD package and can facilitate the following:

(i) full generation of parts lists, build specifications, modification documentation, etc.,

(ii) full information integrity between parts lists, build specifications, modification documentation, etc.,

(iii) secure issue control,

(iv) security and privilege control regarding drawing access and information retrieval.

It can be seen in Figure 3.1. that a reduction in time spent on administration related tasks was a requirement, and it was concluded that a strong requirement for DOMS existed.

3.3.3. Database Management Software (DBMS)

DBMS can be considered as a 'neutral' piece of software as database systems have been available for many years for a wide range of computer applications. If a design office wishes to make further use of information that is generated therein during the design stage of the company's product, then DBMS can become a very significant factor in the success or failure of the overall system.

Medland [12] suggests that there are 6 basic advantages in adopting a design-based database system:

(i) redundancy can be reduced,
(ii) inconsistency can be avoided,
(iii) the data can be shared,
(iv) standards can be enforced,
(v) security restrictions can be applied, and
(vi) integrity can be maintained.

Boart UK had a requirement to use information created during the design of a product in mainly two other ways. Firstly, with the planned enhancement of the product range, and considering the nature of the design projects (section 3.1.5.), traceability of new and existing information was important.

Secondly, it was reported by the technical manager, that the lead time for a design was sometimes in excess of six months. During that period the designer would collect much information relating to such areas as purchasing and production. For example, he may require a specialist part which requires further manufacturing work. If this sourced item is an integral part of a sub-assembly, location positions and clearance dimensions would need to be known at an early stage.

It was envisaged that an integral database should enable the engineer to capture and control much information during the design stage. Consequently, DBMS was part of the overall CAE requirement.

3.3.4. Technical Publicity Software

More commonly known as desktop publishing software (DTP), this software facilitates the creation of high quality documentation using geometric information developed using the CAD software.

In the case of Boart UK, it was concluded that DTP software would be used primarily by the technical publicity department, with considerable work being undertaken on converting sales schemes developed by the designer on the CAD system, into presentable tender and proposal documentation for the sales department. With one seat nominally allocated to this function, DTP software was part of the overall requirement.

3.3.5. Graphics Related Programming Software (GRPS)

The majority of CAD systems have GRPS as either an integral part of the CAD package, or as a separate programming package. The inclusion of GRPS gives the buyer the facility to write macro routines.

The word macro is short for macroinstruction and defines any single instruction to the computer which initiates a group of instructions that together perform a specific task [13]. Macros can be used in a wide range of programming applications but always offer the buyer the facility to create in-house programs that customize the system to suit the applications, and the company's method of operation.

As Boart UK wanted to develop the computer system extensively, then it was important that the chosen system could be tailored appreciably, and as such this was to be a requirement that needed consideration from the outset of the evaluation.

3.3.6. Parametric Programming Software (PPS)

PPS is a form of macro which allows the user to define the dimensions of a part using labels as opposed to numerical values. When the program is run the user assigns values to the relevant labels, thereby prescribing the actual dimensions of the part which the system then generates. PPS is consequently most useful to companies who create a large amount of similar geometrical shapes. It should be noted however that PPS is severely limited by the complexity of the shape.

Boart UK had a modest requirement for PPS as a large number of repetitive drawings are created for fabrications. It was concluded therefore that PPS would be considered during the primary evaluation process.

3.3.7. Computer-Aided Manufacturing Software (CAM)

In the case of Boart UK, it was concluded that as all manufacture was contracted out at the time, there was no requirement for CAM software. The potential to expand in the future to include CAM software was to be a consideration however.

3.3.8. Other Software

CAE is representative of software areas that have not been discussed in this section, for example stock and production control. The nature of the company's business however, required far greater possible customization and therefore consideration, in the technical areas of the company regarding the need for a computer system that is fully compatible with the current methods of operation, than in the company's commercial departments. It should nevertheless be noted, that the requirement for a CAE system capable of considerable expansion was a significant factor throughout every stage of the evaluation process.

4. The Commercial Market

"All the big companies deliberately manufacture hardware that cannot interact with rival brands, and produce operating systems that drastically restrict the useable range of software." [14].

Once a specification has been fully defined, the buyer can begin to explore the commercial market in an attempt to find a system that fulfils his requirement. It is pertinent however to partly appraise the existing state-of-the-market hardware before approaching any system vendors, as the majority of computers suitable for CAE applications can be observed in many other environments. Consequently, it is possible to perform the early stages of analysis relatively objectively, without the involvement of numerous CAE vendors.

The same approach cannot be applied to the software however. A company that is often thought of as a CAE system vendor, hardware and software, is often in reality better described as a software house that develops its packages to run on one, or a number of different makes of computer. The range of software packages under evaluation were discussed in 3.3., and their appraisal can be seen in Chapters 5 and 6.

4.1. CAE - Existing Hardware Technology

The current rate of technological advance in the computer industry is such that the hardware platform offered by a vendor can change significantly from one month to the next. An accurate assessment of the technology is therefore an important factor in the successful evaluation process.

Both Linguard [15] and Lambert [16] stress the importance of completing an effective hardware evaluation, with a bias towards the computer's capacity for maintaining a consistent level of rapid response. Linguard states that *"inconsistency of response has been shown to be more harmful to productivity than consistently poor response"*, whilst tests by Lambert indicated that a reduction in the average system response time from 2.22 seconds to 0.84 seconds increased the productivity of software developers by 62%.

The system configuration i.e. the size, type and layout of the computers, is the primary factor in the evaluation of hardware. Medland [17] supports this reasoning and proposes *"The different kinds of display technology and various kinds of input and output devices are basically no more than a means of ensuring that the interaction between designer and computer should be as easy, efficient and effective as possible".*

Until as recently as 1987, central host systems appear to have been the only affordable way of providing substantial computing resources for an appreciable number of users. As prices decreased and computing power increased however, the sub-division of part, or all, of the processing resources became feasible and the buyer was given the option to choose from a wide range of computer arrangements. There are advantages and disadvantages associated with each type of configuration. These are considered below.

4.1.1. Central Host Computer Systems.

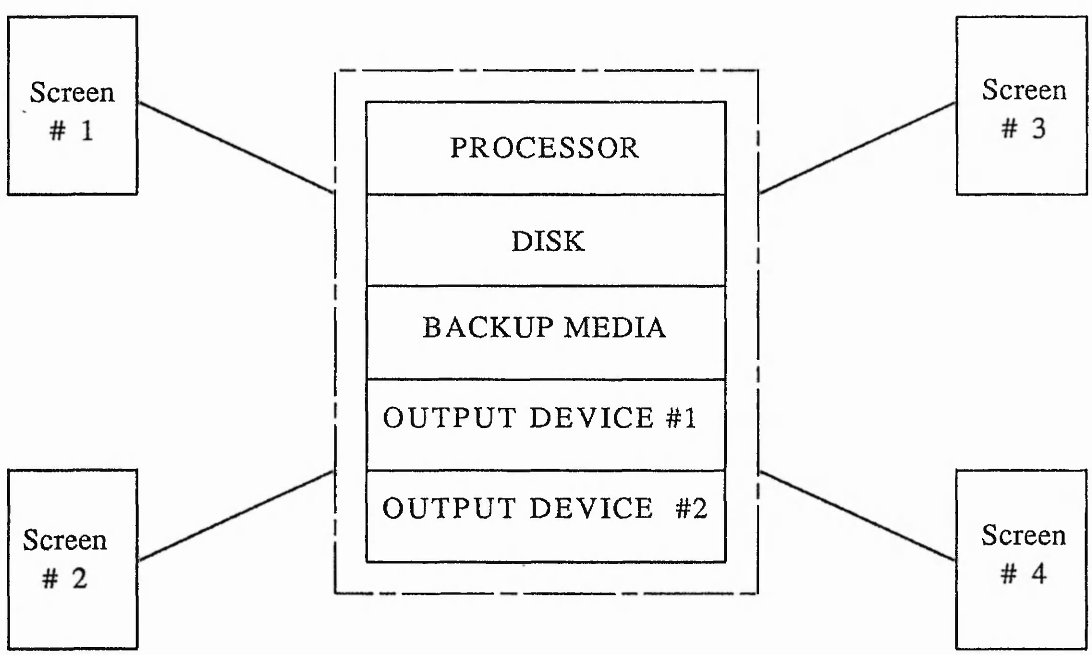


Figure 4.1. Central Host Computer System

Advantages:

(i) Information Management. All the information that is generated on a central host system is naturally stored at one location and is, security permitting, directly available to all the system users. This environment is ideal for database and library development.

(ii) Peripheral Access. Just as the central computer maintains all the screens, it also supports any additional peripherals. This facility gives each user access to all plotters and printers.

(iii) Manageability. As all the resources reside at one location, there is only one computer to manage. This feature makes data backup and other administrational areas straight forward.

Disadvantages:

(i) Consistency of Response. A central host computer system is based on a concept called "time-sharing" - a situation where processing time is divided amongst those using the system. Maintaining good response in a time-sharing environment is often difficult. To achieve acceptable response during peak periods would mean providing significant unused resources during off hours, which is financially wasteful. The result therefore is a system that is slow and susceptible to fluctuation during peak hours. Only at night or at other off peak hours will the system maintain truly satisfactory performance.

(ii) Vulnerability. As the central host computer system has all its resources at one location, it is susceptible to a complete shutdown even for minor problems or for routine maintenance. An all or nothing situation exists.

(iii) Expandability. Once a central host computer system is installed, expansion can take the form of additional screens without providing any further processing resources. This would happen because the cost of the computer is considerably greater than that of the screens. The resultant increase in load however progressively degrades the response of the system until a second computer is eventually purchased. The diagrams in Figure 4.2(a) are representative of host system expansion.

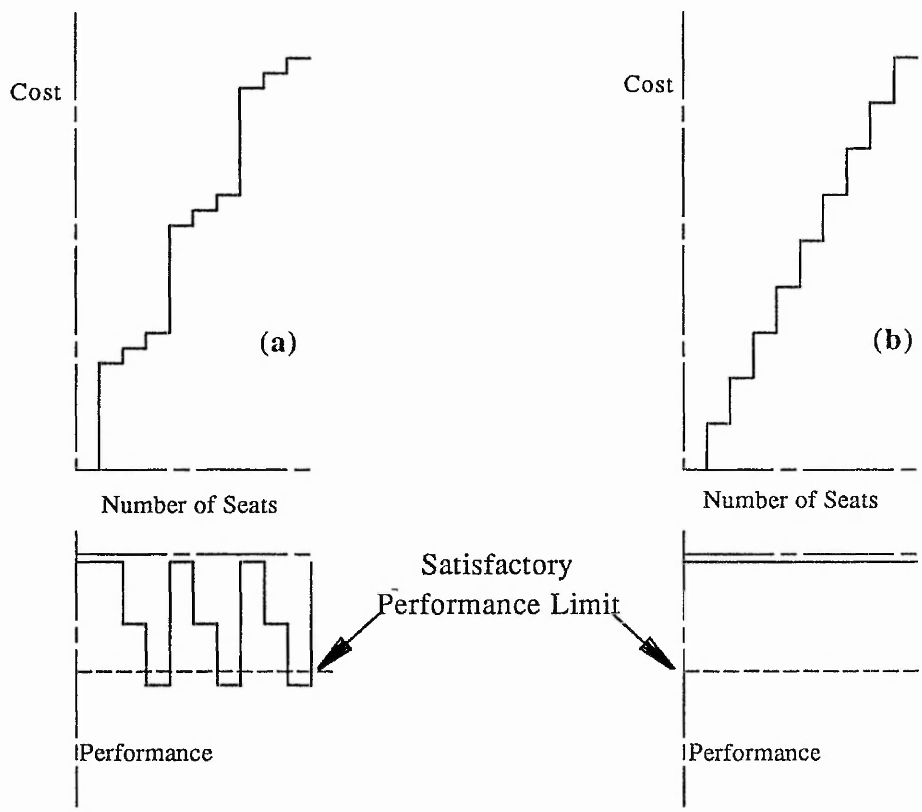


Figure 4.2. Cost & Performance Curves for Central Host (a) and Distributed (b) Computer Systems

4.1.2. Distributed Computer Systems.

Advantages:

(i) Consistency of Response. Distributed computer systems should provide users with steady response, the level of which will be determined at the time of purchase with the subsequent guarantee of consistent performance, since there are never competing tasks on the same system.

(ii) Controllability. A second advantage of the distributed computer is that each user gets the full resources of a machine regardless of what others are doing. This feature can be especially important when resource-demanding CAE applications are used. In time-sharing environments a user running a solid modelling package would considerably impair the response time of other users on the system.

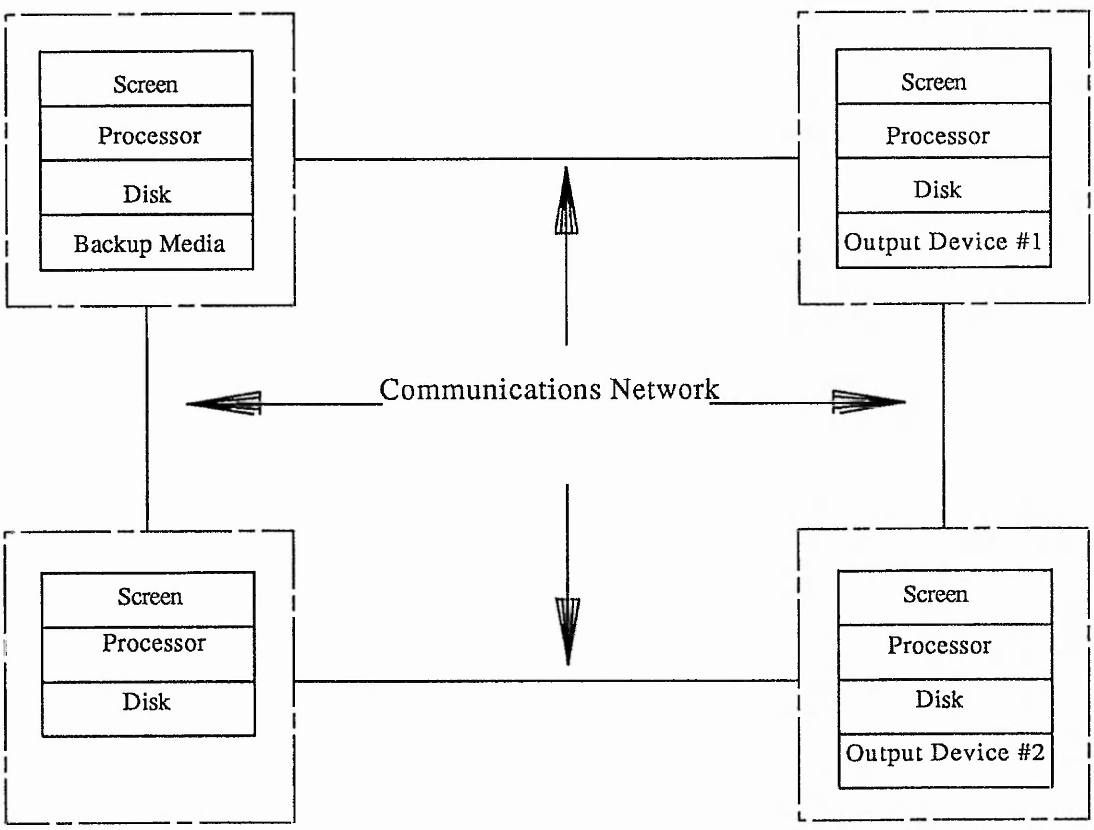


Figure 4.3. Distributed Computer System

(iii) Information Management. An historical failing of distributed systems emerged from the complexity of networking computers effectively. For a successful database or library development, it is important that all users can access the relevant location around the network and to subsequently perform the necessary operations on the information that is found.

With the advancement of networking however, it is now practical to link systems together and share the resources from around the network. The latest techniques in this area support a user interface that to the user bears a strong similarity to a mainframe environment. This results in an arrangement of individual computers, with no less resource-sharing potential than a central host computer system. Consequently, a common database and library can be developed for all system users to access.

(iv) System Reliability. A distributed system has an inherent reliability as a failure in any one machine does not affect the others. Critical resources such as permanent storage or output devices are often shared however, but providing alternatives can be made available, the system need never be completely shut down.

(v) Expandability. If the expansion of the distributed system is steady, then it follows that there will be no severe investment jumps (see Figure 4.2b). This gives the buyer a good deal of flexibility as he is never faced with a disproportionate spending requirement.

Disadvantages:

(i) System Complexity. There are appreciably more elements in a distributed system than in a central host system. This feature in conjunction with the fact that information can reside at a number of locations around the network, leads to a more complex system to manage than the central host configuration.

(ii) Network Integrity. The success of the system is dependent upon the quality of the network. This is not necessarily a disadvantage but it does add an extra consideration to the evaluation appraisal.

4.1.3. Stand-Alone Computer Systems

Advantages:

The basis of the stand-alone system, is the distributed configuration but with the communications network removed. It therefore has similar characteristics regarding consistency of response and expandability, but has a further advantage in portability, as the systems are truly independent and as such do not recognise "neighbours" however closely they are physically situated.

Disadvantages:

(i) Information Management. Stand-alone systems do not lend themselves easily to sharing information, and any information that does need to be shared must be physically copied between machines which inherently introduces an additional factor - the synchronisation of information between machines.

(ii) Duplication of Resources. It may be the case that users have no requirement to communicate information between systems. There are certain areas of efficient computing that are common to all users.

An example of this is data backup, and the situation exists where each stand-alone system requires its own facility for backup.

It was not the intention at this stage to determine which hardware configuration should be adopted at Boart, as this would have started to refine the field of vendors without a single software package being seen. There was one exception however. It was decided that a stand alone computer system would be unsuitable as Boart had a large requirement to share information and develop a database accessible to all users (see section 3.1.5.)

This chapter has thus far considered the types of configuration that were marketed at the time of evaluation. The computers used in these configurations also change with the industry's progression, and it was therefore important to become familiar with the types of system available.

The host computer system market generally had a Digital Equipment Corporation (DEC) Microvax II minicomputer as the resource for the configuration. The distributed system market however, is itself divided up into workstation and microcomputer based configurations. The differences between the two will be discussed in 4.3. Typical workstation makes were Sun, Apollo, DEC, Hewlett-Packard (HP). Microcomputers however were either IBM or compatible based machines.

4.2. System Vendors

There were arguably three levels of CAE system.

Level One. At the top end of the monetary scale were vendors who marketed minicomputer based or powerful distributed computer systems. These systems were traditionally expensive and a six seat system would typically cost £200,000-£300,000. The selected vendors were Intergraph, McDonnell Douglas and Applicon.

Level Two. This level comprised networked workstations. The software was still considered powerful and each vendor could often meet the requirements of both large and small companies. A system comprising six seats would typically cost £140,000-£200,000. The selected vendors were Computervision, Hewlett-Packard, Pafec and Cadlinc.

Level Three. At the lowest investment end of the scale were the microcomputer based configurations. At this investment level the market was very crowded with the numerous 2-D packages available. A system comprising six seats would typically cost £60,000-£100,000. The selected vendors were Datron Microcentres (Autocad), Vistec Business Systems (Autocad) and Advanced Technology Products (Robocad).

Key reasons for the selection of each vendor are given below.

Intergraph had a reputation of marketing very powerful and expensive systems, out of the investment range of Boart UK. It was decided however, that as the price of hardware was falling, there was a possibility that a cost effective solution could be offered.

As with Intergraph, McDonnell Douglas had the reputation of being good but expensive. Their strength was in CAM and numerical control (NC) software, and their CAD range was developed partly as a front end to their manufacturing based packages.

Trent Polytechnic had a studio of 8 Unigraphics seats, and discussions revealed that a successful relationship had been achieved between Trent and McDonnell Douglas. Consequently they were selected for this reason and also because they were making a move towards packages for medium sized companies.

As with McDonnell Douglas, Applicon had built their reputation throughout the CAM industry and have subsequently progressed to develop their CAD software, Bravo! and more recently Bravodraft.

Boart International have Applicon systems in both South Africa and Ireland where manufacturing is of high priority. In installing these systems Applicon have proven to be both reliable and professional in their approach, implementing both systems successfully.

Computervision had generally a sound reputation for covering a wide range of engineering software. Their three main packages are Medusa, Cadds 4X and Personal Designer.

Hewlett-Packard, although traditionally expensive, had created a reputation for high quality. A true turnkey vendor with the potential to offer a system within the set budget.

As with Applicon and McDonnell Douglas, Pafec had created a CAD package as a front end to other software. Their DOGS software was developed as the necessity to create a front end for their Finite Element Analysis software increased. The resulting software was nevertheless very successful and Pafec were chosen as they had the potential to offer a practical solution.

Although by comparison small in the UK (£5M turnover, 50 existing users), Cadlinc software appeared to be technically sound. The company was also local. Further investigation confirmed that their parent in the USA, Cimlinc, had a substantial user base in significant operations such as Boeing, John Deere and General Motors, and that they were an operation of considerable substance.

Autocad held over 50% of the UK microbased market. It is installed in Boart Germany and also in Canada (Rockdrill Division) and as a 2D draughting system, Autocad had a good reputation even against the software packages associated with larger configurations.

Autodesk, the proprietors of Autocad, have many distributors throughout the UK. Two local vendors, were selected to investigate not only the merits of Autocad, but also the relative merits of the system distributors.

Research in computing journals had revealed that the CAD package Robocad had some features that were lacking in Autocad. Robocad was distributed through a local vendor.

4.3. Initial Evaluation

The objective of an initial evaluation was to form a shortlist of vendors who, during the discussions and demonstrations, had shown a potential to fulfil the requirements of Boart UK. The shortlisted vendors were Applicon, Cadlinc Computervision, Hewlett-Packard and Pafec. The reasons for their selection, and the rejection of the remaining vendors are given below.

4.3.1. Intergraph

Intergraph proved to be too expensive (£250,000). In addition to this, they generated little confidence in their systems. This was due mainly to many inconsistent statements made by Intergraph personnel in trying to propose a configuration that was financially acceptable to Boart UK. The impression was formed that if there had been substantially greater investment planned, Intergraph could offer a solution, but in the region of £150,000 they could not compete with those vendors in the Level Two category. Consequently it was decided not to include Intergraph on the shortlist.

4.3.2. McDonnell Douglas

McDonnell Douglas were approached and given an opportunity to submit a quotation - an opportunity to which they did not respond.

4.3.3. Applicon

Applicon were approached and they proposed a central host based configuration. Their personnel made it known that they were moving towards distributed computer solutions, but they still had to modify all of the proposed software to run on workstations. Its was felt however, that as systems had been successfully implemented in South Africa and Ireland then Applicon should be included on the shortlist.

4.3.4. Computervision

Computervision submitted quotations for their Medusa software on both DEC and SUN equipment. The demonstrations of Medusa and related packages was impressive and so Computervision were included on the shortlist.

4.3.5. Hewlett-Packard

A range of software packages in their Mechanical Engineering series were demonstrated and appeared effective. Consequently Hewlett-Packard were included on the shortlist.

4.3.6. Pafec

The Pafec DOGS software was used widely in academic institutions, and they also offered the Oracle database package which they were in a position to relicense. The demonstration was impressive and Pafec were therefore included on the shortlist.

4.3.7. Cadlinc

The demonstration by Cadlinc indicated that the software had been well developed with user interaction of high priority. On first viewing it appeared that the system had capabilities that were unavailable on the other systems and so it was for this reason that Cadlinc were included on the shortlist.

4.3.8. The Microcomputer-Based Systems

Demonstrations were given by Datron (Autocad), Vistec (Autocad) and ATPL (Robocad). All three distributors highlighted many useful functions that their software could perform, and as a basic 2D draughting system both Autocad and Robocad could have been appropriate, especially Autocad as it was effectively "Industry Standard" within the micro-based environment.

Boart UK required more than just a draughting system however. As already discussed, the capability to create a database that could be accessed frequently was of high priority to ensure that the full potential of the system was obtained. Highest productivity can always be obtained when the greatest number of appropriate packages are implemented. For Boart UK these were potentially

(i) 2D draughting software,
(ii) functional 3D software,
(iii) desktop publishing software,
(iv) drawing office management software,
(v) database management software and
(vi) parametrics software.

It is not always appreciated that to have Autocad software implies having a CAD system whereas for Boart UK it would in reality, be having only one out of six parts of a CAD system. To obtain the ultimate system many vendors must be approached and a possible 5 further parties could be involved. Conversely, when purchasing through a turnkey vendor, although a bigger step is being taken at the outset, one vendor is responsible for the complete system and any problems following purchase can all be directed through one channel. Orr [18] in referring to turnkey solutions suggests that it is often the easiest way to implement CAD/CAM. Kochan and Cowan [19] state that it is essential to go to one vendor and buy a turnkey system.

Microcomputers were not appropriate if a central facility, such as a database was required. The only way to overcome this when configuring a microcomputer based system was to create a library of floppy disks, since advantages of networking to enable file transfer were outweighed by the disadvantages. It should be noted that there were generally no prohibitives to stop micro-based software being run on workstations. The investment however was then approaching 80% of that incurred by implementing traditional workstation software.

A major difference between a microcomputer and a workstation was the Operating System which governs the running of the hardware and software. Microcomputers used a Disk Operating System (DOS). The operating system had significant restrictions which are considered below.

DOS is a single user and single tasking. The implication of this is that only one user can run one process at one time. Therefore, if the user was plotting a drawing, larger than the memory capacity of the plotting device, the computer would be "locked" whilst the information was being plotted.

Conversely, due to the multi-tasking capability of the workstation, numerous separate operations can be undertaken concurrently without having to exit from the graphics software. This feature is especially useful when interacting between graphics and database software.

A further limitation of DOS based microcomputers, was that the operating system required separate software to facilitate the addressable memory of the computer to 640Kb, so a microcomputer with 3Mb of system memory would still be considerably slower than a workstation of similar capacity, as the hard disk of the microcomputer would be paged far more often. The type of operating system of the workstation was the same as that used on minicomputers, and facilitated a multi-user and multi-tasking operating environment.

The final reason why a micrcomputer based system was unsuitable, was that none had been proposed that could fulfil the database requirements of the company. It was therefore decided not to include the micro-based system vendors on the shortlist.

5. Technical Evaluation

"One of the most expensive things a company can do, is invest in a CAD system and start to develop it, only to find that, as they gain experience of CAD, there are major benefits which their system is incapable of achieving." [20].

5.1. Introduction

At this stage of the evaluation process, those involved were generally familiar with what was commercially available. To choose the most appropriate system however requires a more thorough evaluation, mainly to determine how closely each proposed system matches the requirements of the buyer.

Discussions were held with each of the five remaining vendors. All expected that a buyer with requirements akin to those of Boart, to test their system with exercises predominantly based on geometry manipulation. It is suggested that this type of testing originated when CAD became available to all but small engineering companies, but was nevertheless surrounded by scepticism as to whether or not a computer could truly replace a drawing board. Further discussions with the five vendors supported this idea, as all had been party to tests wherein the buyer attempted to demonstrate that his 2D draughting requirement was outside the capability of the vendor's system.

Today however, CAD systems generally overcome the majority of the scepticism on which those tests or benchmarks (as they are commonly called) were based, and it is increasingly important to set a benchmark that is a direct derivation of the company's requirement, one that covers all significant areas of the buyer's specification - not solely those relating to the primary investment.

5.2. Evaluation Philosophy

Following the visits and demonstrations that had been completed by this stage, it was noted that each person involved had to some extent, a different expectation of the ultimate CAE system. Whilst the process of evaluation had been objective based on research and collective decisions, it became apparent that each saw different features with a different perspective. This expectation of the buyer was termed the "expected result".

This expected result arose due to the additional features the vendors had demonstrated, over and above the requirements as defined by Boart UK. As these features often highlighted how the vendor was at the forefront of the technology, it left the visitor with a very high impression of the vendor and arguably the opinion that if the vendor was so competent in the new areas of technology, it follows that he would be competent in all areas in which he was associated.

It was known by this stage, that the computer marketplace was aggressive, and it is suggested that in any such environment, the capability of the marketing function of the companies therein, is vital to their success. A consequence of this situation is that companies in areas of high technology must be seen to be ahead, or at least alongside their competition. Therefore for this requirement to always be fulfilled, financial resources will always be allocated to such sales-oriented areas of software development at, in some cases, the cost of less attractive, but nevertheless equally important areas of development to the buyer, if his specification is to be fulfilled.

A requirement of the benchmark therefore was to test all the necessary features of the proposed system and not just the most difficult or conspicuous ones.

By their very nature, benchmark tests vary with each requirement. During their compilation, the benchmark designer will decide (often unknowingly) whether to set specific application program tests where the final result is all important, or conversely tests made up of the processes involved in designing on a CAD system. Both types of test have a place in the effective benchmark. They are discussed briefly below.

5.2.1. Final Result Tests

All buyers have some specific requirements. A few will have some unique ones, and as such should aim to highlight these to enable their evaluation during the execution of the benchmark. It is often the case that the buyer requires assurance that the proposed system can substantiate the salesman's claims. Under these circumstances the buyer is more interested in achieving the final result than in the manner by which it is achieved.

5.2.2. Process Tests

The buyer often has the intention of moving existing manual processes completely onto the computer system. It is necessary in this case for the benchmark designer to base the tests on the processes that will be involved once the system is put into place. A process test is therefore compiled.

Such a test can often comprise a number of packages. Unlike the Final Result tests which can often be executed within one application program, the process tests may often include the flow of information from one application to another. Consequently, any buyer contemplating the purchase of a number of packages will obtain an insight into how well the packages are, or could be integrated together. It is sometimes the case that the software modules, although adequate individually, integrate poorly. This will be considered in greater depth in Chapter Nine.

Vendors reported that the testing of hardware is a feature that many buyers often incorporate in a benchmark. This testing can serve a purpose if, for example, the application software requires considerable computer processing time. When this is not the case however, little time should be dedicated to evaluating the system response, as the hardware performance will vary once a wealth of data has been created within the company, and the system is fully loaded.

There are many factors that can influence hardware response. The most obvious and often quoted relate to the capacity of the machine. This computer however may be part of a network. If this is the case then the network communication will influence the overall system's performance. Consequently, to maximize the effectiveness of the benchmark in areas relating to the software, it was decided just to add a requirement to the benchmark specification, to ensure that the hardware used during the tests is identical to that under proposal. Kochan and Cowan [19] suggest that software is the only criterion on which to base the suitability of a CAD system.

The software investment appropriate for Boart UK was considered in Chapter 3, and as a result, it became necessary that the benchmark had to represent a range of software application programs, and so the requirement for a process test was highlighted.

Although there is no general time limit to benchmark testing, the tests had to be concise if they were to gain sufficient management commitment. With this in mind, the benchmark package was designed to last for no more than one day.

With the primary investment being the engineering drawing software, it was appropriate for this application area to figure as a starting point for the benchmark tests. Although the designs of the company are complex once assembled, parts on an individual basis are seldomly so, with a significant amount of design work related to fabrication drawings and straight line geometry. It was therefore sensible to compile a benchmark that even within the 2D environment, would only spend a relatively small amount of time dedicated to geometry creation and manipulation. In preference, the tests were designed to probe into the flexibility with which 2D drawings could be merged and fitted together.

Discussions with vendors revealed that the buyer who had taken time to prepare the benchmark, generally bases it on actual company information and drawings. It was decided to break this tradition at Boart however primarily for the following reasons

(a) company information is very familiar to the buyer, but unfamiliar to the vendor,

(b) drawings of the company are based on design and production requirements, and not for the purposes of evaluating the software,

(c) company information of any significance is often confidential.

Lockett [21] suggests that successful projects can often be assisted by prototyping which he defines as *"the development of small systems of restricted scope and/or functionality which users can test for themselves"*. He states that there are limitations to prototyping but the principle can nevertheless be useful in the context of requirement representation.

A conventional Boart detail drawing will include many stated dimensions, the number of which being dictated by the requirement to manufacture the item, as a critical number, without which the component cannot be made. To test if the computer software could dimension the drawing efficiently however will become clear after each different type of dimension is tested (horizontal, vertical, angled, with and without tolerances, etc.). To complete the design against the manufacturing requirement, would therefore be wasted effort within the benchmark environment.

To complete this argument another example can be considered. A Boart sub-assembly included two or often many more items, some of these being sub-assemblies in their own right. It was apparent that the ability to recognise sub-assemblies was important especially as the company wanted to automatically produce parts lists and build specifications for their equipment. It was estimated that the average sub-assembly was made up of 20 items, and so in conventional benchmarking, it would have been such a design that would have been used for testing. Furthermore, to ensure that the test is representative, the sub-assembly of 20 items would then itself be included on another sub-assembly of 20 items.

In its simplest form, sub-assembly recognition means that the system must have the capability to take two separate items, and to treat them also as one parent (without them losing their individual identity). It must also be possible to then use this parent with another single item, to make up another parent. This is illustrated in Figure 5.1.

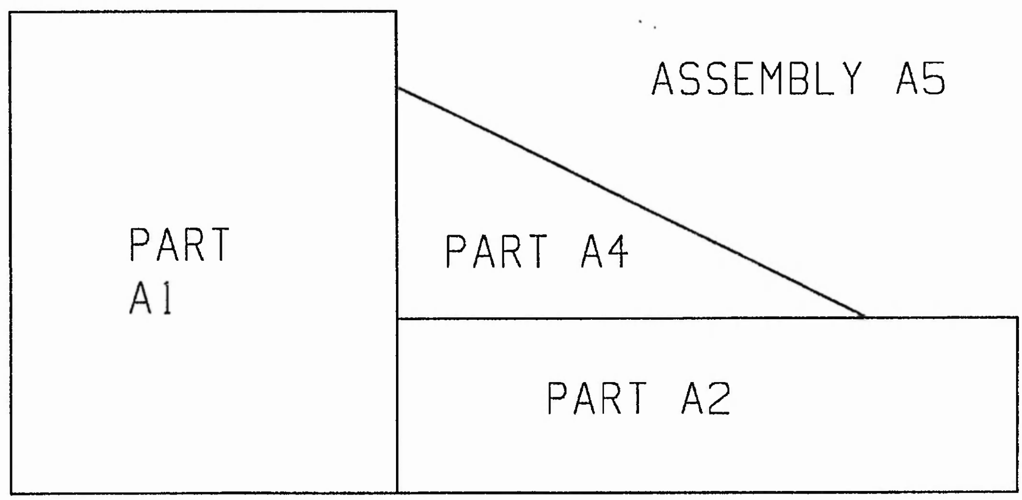
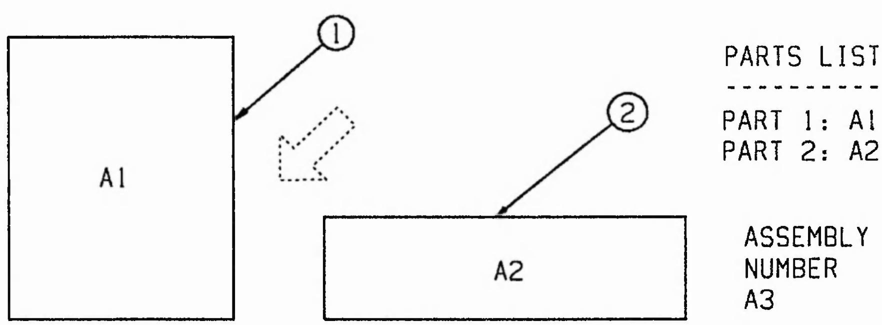


Figure 5.1. Representative Build for Benchmark

This can be represented in benchmark form by the following operations shown in Figure 5.2.

(a) join 2 items together to make a sub-assembly



(b) join a new single item to the sub-assembly

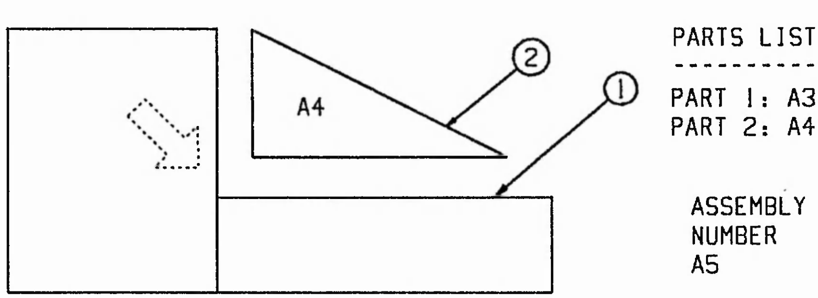


Figure 5.2. Benchmark model of sub-assembly capability

If the benchmark highlights systems that are capable of fulfilling the two operations depicted in Figure 5.2., it has shown that sub-assembly capability exists to potentially any depth of build. From the simplicity of the tests, it is arguable that a conclusion could be drawn within a matter of minutes.

The essence of the previous example is that it shows how a model can be used to represent a process or processes - similar to prototyping considered earlier - and it was this approach that was adopted in preparing the benchmark material for Boart.

It was hoped that two further advantages would be achieved. Firstly, it was envisaged that representative modelling would assist those involved with the real daily activities, to assess the processes and procedures involved, more objectively than if real daily examples were used. Secondly, due to the reduced amount of information required for testing, it was planned that everyone attending the benchmark would all become very familiar with the information being used, and at the same time in quantity, there would be sufficient to ensure that the behaviour of the software was genuine.

5.3. Benchmark Compilation and Execution

The benchmark for Boart UK comprised three tests. The first two tests were split into two sections as the vendors required some background information prior to actually performing the benchmark. All three tests can be seen in Appendix C, the point of each being summarised below.

5.3.1. Test One: The Process Test.

This was designed to be the primary test. The main objectives were to ensure that the most frequently used packages e.g. 2D, drawing management and database, were suitable both independently and when information was passed between them. There were also the parametric capabilities to consider. A model was used throughout this test in keeping with the discussion above.

Each vendor was informed well in advance of the benchmark meeting, as to the flow of information required by the company.

Also information relating to the processes for the tests was divulged. As the model had been kept simple, no geometrical information was presented to the vendors before the date of the benchmark itself.

5.3.2. Test Two: A Final Result Test

Throughout the evaluation process, the importance of the database had been steadily increasing. It was apparent that the foundations laid by installing a database that was integrated with the engineering computer systems, could form the basis for a company wide management information system (MIS). The database was therefore an important factor in the overall, long term success of the system. Figure 5.3. shows the proposed database packages being offered by the remaining vendors.

CAD System vendor	Database Package	Database Structure
Applicon	proprietary	hierarchical
Cadlinc	Empress	relational
Computervision	proprietary	hierarchical
Hewlett-Packard	Adimens	hierarchical
Pafec	Oracle	relational

Figure 5.3. Proposed Database Packages

A Final Result test was compiled to test the capabilities and speed of the databases. One of the objectives of the Process Test defined in Section 5.3.1. was to ensure that the database could transfer information to and from other packages. Test two therefore, was designed to concentrate on the database package itself. As Boart UK would have a full-time system developer working to satisfy the requirements of the company, it was felt that the main feature of this test was to ensure that the database would ultimately be able to manage all the necessary information, and to manipulate it in an acceptable time frame.

5.3.3. Test Three - 3D, Wireframe and Solids

None of the initial vendors had suggested that the company design in 3D on a daily basis. Hewlett-Packard had suggested that this could be possible in the future. It was apparent to Boart that 2D software was appropriate for general design work. All planned development work related to the management of information created in the CAD environment, and not the development the application packages themselves. In short, Boart were prepared to commit in-house resources to the overall development of the system, but each application program was to be off-the-shelf.

Three areas of the company's technical operation had been defined as ones that would benefit from three-dimensional work. They are as follows

- (i) the design of complex components,
- (ii) the compilation of technical documentation including 3D exploded views,
- (iii) customer demonstrations.

In keeping with the company's aims, a 3D exercise was included to evaluate the potential of the vendor's 3D software, and to increase the knowledge of those selecting the system regarding the capabilities of 3D and Solids Modeling software.

Once the benchmark material had been compiled arrangements were made to execute the tests therein. It was Boart UK who prepared the agenda for the day. From the response given by each vendor, this is not often the case. The benchmark meeting usually takes place at the vendor's premises, and as hosts, they dictate what happens during the day in a similar vein to the demonstration. This can lead to many digressions from the tests prepared by the buyer; especially if the tests themselves are not going well. Consequently, Boart set the agenda in an attempt to ensure that all tests were undertaken.

6. Selection of the CAE System

"Hewlett-Packard and Apollo have announced their merger...Lockheed Corporation has put Cadam and Calcomp up for sale, and Schlumberger Graphics is continuing its quiet quest for a suitor...The CADCAM business is as unusual as ever with more than just technical suitability playing on the mind of the buyer." [22].

6.1. Results of the Benchmark Tests

The benchmark tests were successful as they qualified accurately the suitability of each system. It is not the aim of this section to evaluate the performance of each vendor during the benchmark, but to consider in broad terms the factors that lead to a successful or unsuccessful benchmark.

The tested vendors were Applicon, Cadlinc, Computervision, Hewlett-Packard and Pafec. As each had been sent the necessary information ahead of the benchmark day, a first impression was formed when witnessing the attention vendor's had paid to the specification. Although no one vendor had prepared exactly to requirement, an indication of the flexibility of each system was gained as each vendor attempted to alter their systems to suit.

The initial perception that testing the application packages in isolation was an inappropriate test, was without question correct. One vendor in particular performed extremely effectively within the 2D environment. In trying to manage and manipulate the information created however, their overall proposal became unacceptable.

The duration of each test can be seen below.

Test Number	Average Duration (hours)	%
One	6	75
Two	1.5	19
Three	0.5	6

Figure 6.1. Benchmark Test Duration

The evaluation of each benchmark was undertaken with the assistance of the selection table below. Each person who attended the tests completed such a table.

Feature Description	WF	Pafec WFxScore	HP WFxScore	Cadlinc WFxScore	C'Vision WFxScore	Applicon WFxScore
Turnkey Vendor	7	14.0	28.0	14.0	21.0	14.0
Vendor Location	5	25.0	15.0	25.0	20.0	15.0
Size/Turnover	3	3.0	12.0	9.0	15.0	12.0
Long Term Support	10	35.0	50.0	35.0	45.0	45.0
Worldwide Support	5	5.0	25.0	17.5	25.0	25.0
CAM Potential	6	18.0	18.0	27.0	21.0	27.0
Cost	8	24.0	24.0	40.0	24.0	16.0
Methods of Payment	6	18.0	24.0	24.0	24.0	24.0
Hardware Configuration	7	27.0	28.0	28.0	28.0	21.0
Hardware Make	5	15.0	20.0	17.5	17.5	17.5
Operating System	6	24.0	21.0	24.0	24.0	21.0
Network Media	6	18.0	18.0	18.0	18.0	18.0
Full Integration	7	21.0	28.0	21.0	21.0	17.5
System Aesthetics	3	7.5	15.0	10.5	10.5	10.5
Command Styles	7	21.0	28.0	24.5	28.0	21.0
Menu Customisation	6	21.0	24.0	27.0	27.0	21.0
2D Software	10	35.0	50.0	45.0	40.0	20.0
Parametrics Software	3	3.0	3.0	12.0	12.0	9.0
3D Software	6	18.0	30.0	21.0	30.0	24.0
Drg. Man Software	8	32.0	16.0	32.0	32.0	28.0
Database Software	8	40.0	16.0	32.0	28.0	16.0
D.T.P. Software	6	24.0	24.0	27.0	24.0	24.0
Macro Programming	6	18.0	18.0	21.0	21.0	18.0
2D Properties	4	20.0	20.0	14.0	16.0	16.0
Dynamic Manipulation	6	21.0	30.0	27.0	27.0	18.0
Isometric Creation	7	24.5	31.5	24.5	35.0	35.0
Parts Explosion	7	28.0	24.5	27.0	28.0	24.5
Instancing	6	24.0	12.0	24.0	24.0	24.0
Control & Issue - drgs	7	28.0	21.0	31.5	31.5	35.0
Control & Issue - mods	7	28.0	14.0	28.0	31.5	35.0
Link: CAD - Database	9	45.0	31.5	40.5	36.0	18.0
Report Synchronisation	5	15.0	15.0	15.0	15.0	15.0
Format Design	7	21.0	14.0	24.5	24.5	14.0
Adhoc Enquiries	8	36.0	16.0	36.0	20.0	16.0
Capability for custom.	7	28.0	21.0	31.5	28.0	21.0
MIS Potential	10	50.0	20.0	45.0	40.0	20.0
Total		835.0	805.5	920.5	912.5	756.0

Figure 6.2. The Selection Table - Results from one benchmark attendee

The process of completing each table, required each participant to enter a weighting factor (WF) for each category, and subsequently enter a score for each category. The completion of these tables was undertaken independently.

The main aim in preparing the table was to capture each person's impression against a list of features, common for all. It should be noted that the table was used only to refine the shortlist further, and not to make the ultimate decision.

The results were subsequently collated and can be seen in the table below.

	Applicon %	Cadlinc %	Computervision %	HP %	Pafec %
Person #1		75	84	57	71
Person #2	65	79	78	69	71
Person #3	68	81	84	61	73
Person #4		85	87		75
Average	67	80	83	62	73

Figure 6.4. The Selection Results Table

Following a discussion of the results it was decided to remove Applicon, Hewlett-Packard and Pafec from the shortlist, and to concentrate the remaining efforts on Cadlinc and Computervision in an attempt to ensure that Boart UK extracted the optimum price from the ensuing negotiations.

6.2. Commercial and other Non-Technical Considerations

It would be misleading to suggest that the selection of the CAE system was a wholly technical evaluation. In reality, this is for the most part true, but a system's performance cannot be judged in isolation. Boart UK were looking for the best value for money. An example of this can be seen in Chapter Four wherein Intergraph were dropped from the evaluation as their quotations were very high in price, so high that a suitable value for money would never have been achieved.

At this penultimate stage of the evaluation process, both vendors were informed that they were on the final shortlist with one other company. The following weeks comprised negotiations regarding price and the content of the systems with the order ultimately being placed with Cadlinc. The additional reasons for this decision are listed below.

Cadlinc were able to offer

(i) a system with a better user interface and including icons and strokes - the ability for the software to interpret patterns on the screen as commands,

(ii) a database that had true MIS potential due to its structure and development capability,

(iii) a computer-aided manufacture package should Boart UK ever expand into this area,

(iv) a secure maintenance contract and far quicker shipment of the hardware.

(v) an overall system with true customization capabilities paramount if the company was to achieve the expected result, and

(vi) better value for money.

An order was placed with Cadlinc for the sum of £145,000. A complete commercial and cost evaluation was undertaken and can be found in the document "The Selection of a CAD System for Boart UK" between and including pages 38 and 43 [23].

Cadlinc changed their name to Cimlinc during 1989. For consistency, they are referred to as Cadlinc throughout this thesis.

7. Installation of the System

" New technologies, 'robots' or office 'automation' with computers, create both excitement and fear." [24].

There was a period of six weeks between the ordering of the system and the time to deliver and install. This period of time was dedicated to planning the implementation of the system, preparing both the physical space to house it and as importantly preparing the users for its introduction.

7.1. Development of the Implementation Plan

7.1.1. Personnel Attitudes

It had always been a long standing objective to keep the future users of the system aware of the progress being made regarding its selection. Two specific meetings had been arranged where presentations were delivered, and questions answered.

The first meeting took place within the opening three months of the evaluation process. The purpose of this meeting was to explain, not only to those future users of the system, but to anyone in the company who was interested, why Boart were going to invest in CAE, and also why Boart had decided to undertake the process under the Teaching Company Scheme.

Presentations were given by both the academic supervisor of the author, and the author himself. The meeting was successful and it was found in subsequent discussions that a higher level of enthusiasm had been achieved especially within the design team.

Nadler and Robinson [3] discuss the importance of effective communication at this early and important stage of the project. They make the point that solutions to defined problems are likely to be rejected by those who do not share the definition of the problem. They go on to suggest that just because a company's management is convinced that the implementation of new technology is an appropriate step, it does not necessarily follow that the remainder of those effected by it will be. They define this misconception as *"the 'altruism myth': that quality-of-life programmes are for the benefit of the workers - who ought to be grateful..".*

The first meeting went on to show that the company had a genuine and tangible need for a CAE system, and that people would contribute largely to its success or failure. This attitude was encouraged at every opportunity, to make the users realise that they were part of the final solution, and would influence whether or not the company would achieve the expected result.

Although not consulted at the time for obvious reasons, an article in Professional Engineering - April 1989 [25] discusses the importance of making people part of the overall scenario. Hamlin discusses that a CIM strategy should be based upon the philosophy that people provide opportunities for profit growth by using their capabilities of intuition, knowledge and subjective judgement. He states that this is in direct contrast to the minimally manned factory where the humans carry out the tasks that cannot be automated.

Due to the nature of the designers' job, there was no concern regarding redundancy as a result of implementing the system. The main areas of concern were related to the transition from drawing board to computer screen, mainly due to the reduction in size of the designer's working area. This was not going to be a problem however. Due to the overall dimensions of the company's products, generally only the simplest drawings and some single items could be drawn full size on the A0 drawing board. Consequently, in reducing the designers area of view, i.e. from board to screen, no precedent was being broken, but merely a greater negative scaling factor was being introduced.

The second meeting took place around the time at when the system was ordered from Cadlinc. Some of their senior personnel attended, and the presentation was intended to inform those present as to why Cadlinc was the chosen vendor. The meeting gave all the future users a chance to talk directly with Cadlinc personnel.

A third meeting was planned at this stage. Its purpose was to ascertain how effectively the designers use the CAD system. This meeting will be discussed in Chapter Nine: Discussion and Conclusions.

7.1.2. System Location

It has been discussed above, that the implementation of a computer system will generally be more successful if those who will be using the system feel some form of ownership. This idea of ownership however was only applied to the underlying ideas, not to the physical installation itself, as it was determined in Chapter Three, that six seats were to be purchased for use by eleven people. The result of this decision led to a change in working location.

It is often the case in a design or drawing office, that each designer will have a drawing board situated adjacent to his desk, and that the drawing board is considered his property. This was sensible because it meant that once the designer had his drawing arranged on the board it never had to be moved to allow someone else to use the board, the designer had a fixed place of work and only one chair was often required. Allocating each designer with a drawing board was also financially sensible.

The implementation of the computer system meant that there was going to be a break in this tradition however, and it was decided in the case of Boart UK that the systems should be located near to one another, and should be used on an as and when required basis. This idea also had the inherent advantage, in that the system would be easily maintainable.

The layout of the system can be seen in Figure 7.1.

Unlike many mini-computer based installations, a workstation network only requires a clean power supply, i.e. free of voltage spikes and power surges. Consequently, no comprehensive planning was required regarding the design of the office. Lighting, suitable heat extraction and sufficient power supply points were all considered however.

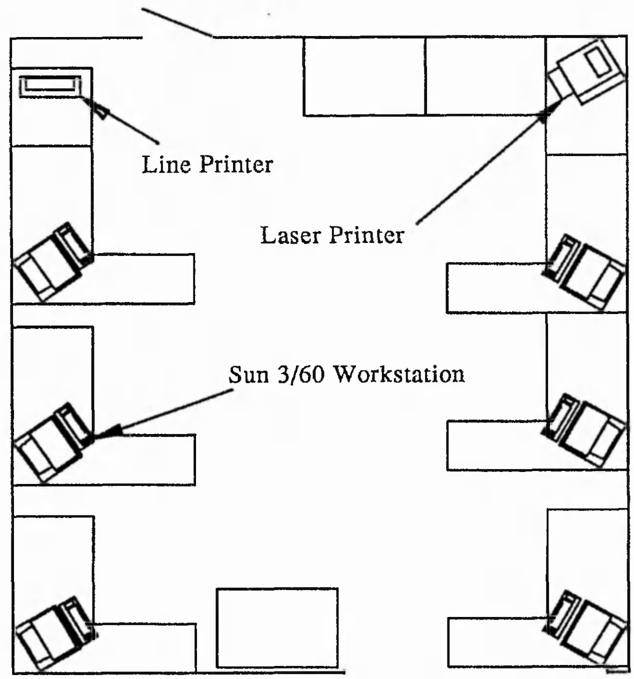


Figure 7.1. Layout of the Workstations.

7.1.3. Training

Prior to the delivery of the system, the appropriate people were sent on a 2D training course, the duration of which was 1 week. Many authors refer to the importance of a high quality training programme, to ensure that users become proficient as quickly as possible, and also to demonstrate to the users that they are influential regarding the ultimate success or failure of the implementation.

The author attended a number of courses relating to the administration of the system and program development tools.

7.2. System Installation

The hardware was installed as shown in Figure 7.2.

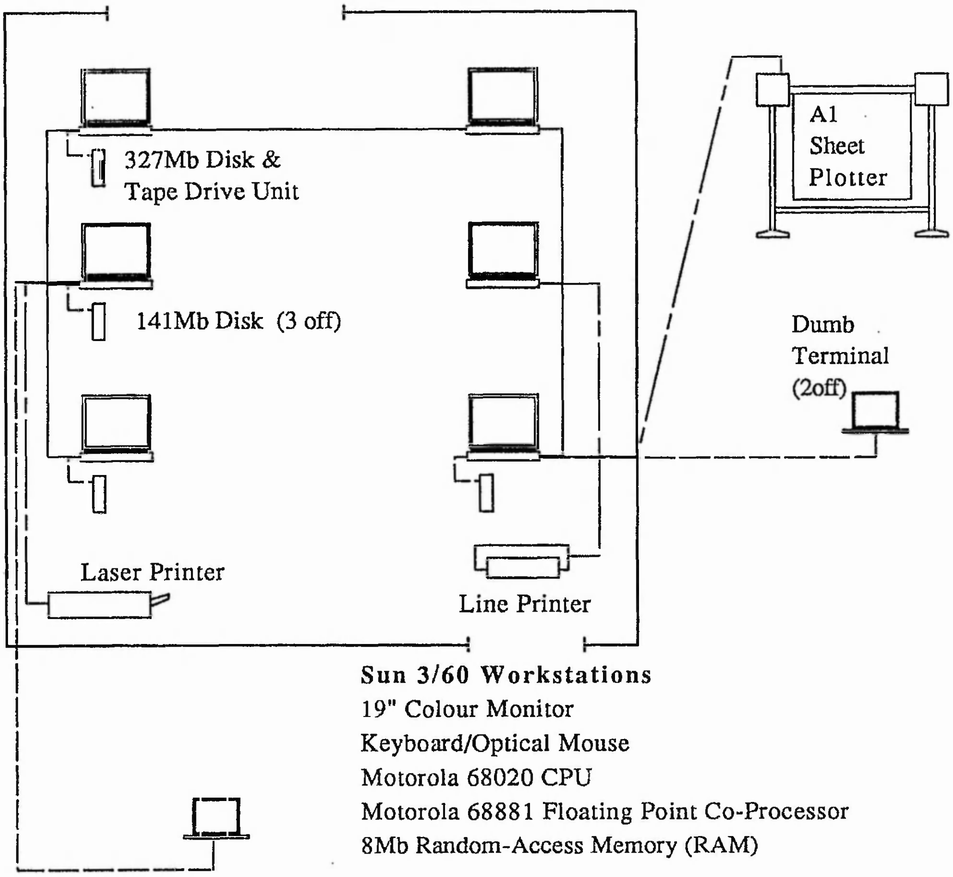


Figure 7.2. The Configuration of the Sun Workstation Network

7.2.1. Setting up the System

Prior to the designers using the system, a period of time was defined to allow the author to set the system up ready for general use. Examples of areas that required consideration are

(i) Establishing the network.
(ii) Creating the user groups and privileges.
(iii) Creating "login" codes and password protections.
(iv) Installing the peripheral devices.
(v) Creating the routines for secure data backup.
(vi) Disk space allocation.

Medland [26] discusses pertinent areas regarding disk space allocation. He states *".. [a] major problem caused by a CAD system arises from the ease with which data can be created and stored. The system quickly becomes overloaded with files, no matter what size of disk storage is provided."* The system was configured with these points in mind, and work relating to efficient use of disk space was undertaken during the following months. This will be expanded on in Chapter Eight.

The management of the network is performed by the Sun proprietary software package Network File Software (NFS). Although a user's files are stored on one disk, NFS manages the network in such a way that, to the user, it appears his files reside on the workstation at which he is working. In short, a workstation network running NFS gives the user the impression of a mainframe where all files and resources are available to everyone (privilege permitting), yet due to the distributed nature of the network, the performance of each machine is mainly independent of all its neighbours.

7.2.2. Loading of Information

A well documented area within the subject of computer implementation is the transfer of information from the original manual system on to the computer's disks. In the case of CAD, i.e. geometric information, there are a number of possible methods.

Scanning is suggested as one method [27]. A scanner works in a similar fashion to the reading heads of facsimile machines. The software that would be included with the installation of the scanner, would to a greater or lesser extent convert the image into useable geometry. The traditional problems with this method however are that

(a) problems occur in the process of vectorising raster images, a process that is required if the resultant drawing is to be useable,

(b) extraneous markings and imperfections are also entered onto the drawing. For example, a coffee stain on the original document or drawing would be translated into a circle of 50mm diameter.

The technology at the time of writing was beginning to make significant advances in scanning techniques, with certain articles suggesting that scanning is now a viable proposition for the entry of engineering drawings.

As Boart UK had no manufacturing facilities at the time, drawings from the CAD software required production on mutually acceptable media, to both Boart and the sub-contractor and so it would be necessary to produce paper drawings. This requirement had one major inherent advantage in that it eliminated the need to load all the company's drawings on to the system. If paper drawings were to be produced then they would still constitute the company's legal document. If therefore all drawings were loaded on to the system, not only would the disk space require immediate expansion, but a drawing would have to be plotted back on to paper as and when required. Due to the prototype nature of the company's designs, it is often the case that following production, a drawing may never be referred to again. Consequently, by a bulk load of data, the system would become full quickly, and full of a high proportion of unnecessary information.

The decision was subsequently made, that all new drawings, or modifications made to existing ones, would be performed on the CAD system, and that the design office management system should have the capability to include paper drawings in addition to those created on the system.

8. Implementation of the CAE System

"The greater the level of integration, the greater the potential disaster." [28].

The term "expected result" was discussed in Chapter Five, and consideration was given as to whether the systems under test at the time could meet the expectations of the company. The design office procedures in place under the manual system had also been discussed (Chapter Three), and it had been decided that the methods of design and drawing administration therein, were to be carried through on to the computer system.

Evaluation of progress at this stage in the overall implementation process often reveals a great deal regarding the suitability of the purchased system. From discussions with many companies using a wide variety of CAD and database systems, it was evident that not one had achieved their expected result without further work and expense. The most significant area of deviation from the expected result often occurred in the area of design office management systems, where companies in believing that their choice will come closest to meeting their requirement specification neglect the differences that nevertheless exist between one system, that based on the "old" manual design office procedure, and the other system, that based on the "new" design office management software. This will be discussed further in the Chapter Nine. It was stated in Section 3.1.1.2. that in the case of Boart UK, a dedicated system developer would work on the computer in an attempt to obtain the expected result.

8.1. Initial Administration of the System.

The early stages of CAD implementation at Boart were dedicated to "housekeeping" activities and the setting-up of efficient administration procedures. In some cases, one such case being information backup, computer programs can be written which in the longer term will reduce the overall need for manual monitoring and maintenance of the system. As considerable development was planned at Boart UK, it was apparent from the outset, that the administration tasks needed to be managed efficiently. Although vitally important to the smooth running of the system, these tasks themselves play little part in fitting the system to the requirements of the company. For this reason therefore, administration and the programming that this area of system management encompasses, will not be expanded further at this stage.

8.2. The Design Office Management System.

It was outlined as an objective in section 3.1.1.2. that time absorbed in collecting supporting data, administration and re-entry of information were to be minimized allowing the engineer more time to design.

The main objective in writing the Design Office Management System (DOMS) therefore, was to automate those procedures defined in the Design Office Handbook [11]. The project that followed took nine months to complete, with programming undertaken in the graphics related programming software (GRPS), the Empress application package MBuilder and UNIX. Figure 8.1. shows how the relevant software packages integrate with each other.

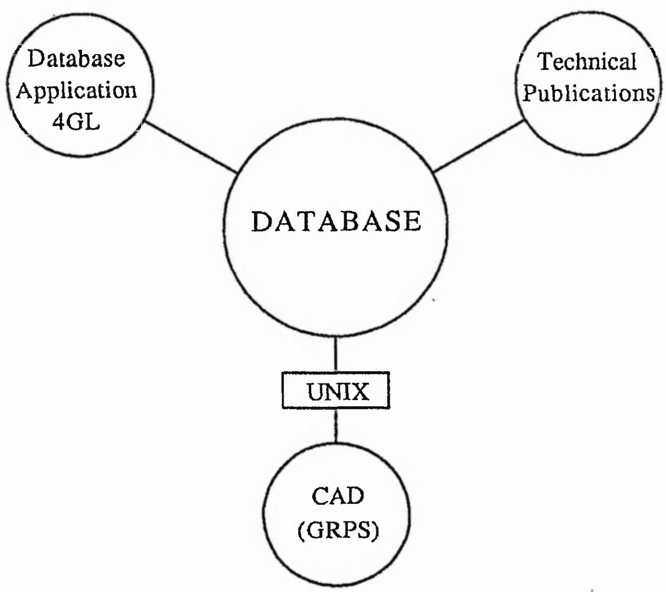


Figure 8.1. DOMS: The Links between the Packages

Before considering the development work undertaken in each area however, it is appropriate to highlight some of the significant working principles of DOMS.

8.2.1. The Working Principles

8.2.1.1. Part Type

It was a requirement (already established) that the system had to cater for more than just computer generated drawings. Many of the assemblies include bought-in items and also well proven sub-assemblies that exist on paper. It was also stipulated that the system must demonstrate effective archive management.

The term Part Type was therefore introduced, with 5 types ultimately being defined. These are summarised in Figure 8.2.

Part Type	Definition	Implications	Examples	% of total
s	system generated drawing	detail drawings exist and can be found on the system	all new, in-house designs	50
n	no drawing	a detail does not exist in any form	bought-in items	30
a	alternative	a detail drawing can be found on the system, of a part with similar geometry and application - a suitable alternative. It has no detail drawing of its own.	Some Boart inter-changeable parts	2
p	paper drawings	a detail drawing can be found in the storage cabinets or on microfilm	many pre-DOMS designs	10
o	obsolete/archived	a part, that in its life has existed on the system, but has now had all issues archived off on to tape.	proven designs in the field	8

Figure 8.2. Part Type Definitions

8.2.1.2. Issue Status

The work of the design office at Boart UK as already discussed is very project based, with a designer being responsible for each project from concept to the creation of production drawings. Furthermore, if problems occur during the assembly of equipment, the designer will often become directly involved in trying to find a solution.

Many of the drawing office management packages seen throughout the evaluation, offered secure, highly inflexible operating environments. None however gave the designer the authority to control his conceptual drawings, whilst subsequently offering a common, but highly secure database of issued production drawings. It was a requirement that the Boart design office management system, DOMS, could manage a part from concept through checking to issue, and from modification through re-issue. This was accomplished by the introduction of the Issue Status (see Figure 8.3.)

Issue Status	Definition	Description
r	reserved	a drawing of the part is registered in the database. It can only be altered by the user that registered the drawing. It will stay at this level until it is sent for checking.
c	checking	the drawing is awaiting checking and must therefore remain unaltered. It will stay at this level until it is either approved or rejected.
i	issued	the drawing is issued and resides in the common issued drawing directory. It will stay at this level until it is either changed or modified.
m	under mod.	the drawing is currently undergoing change or modification. It can only be changed by the user undertaking the action. It will stay at this level until it is sent for checking.

Figure 8.3. Issue Status Definitions

Under DOMS, the combination of the part type entry, and that for the issue status, gives the user all the necessary information, regarding the location and status of any part.

8.2.2. Programming Development

8.2.2.1. CAD Development: Macro Programming

To develop a system with a high quality user interface, it was decided that all design work should be possible without the user having to leave the CAD environment. The resultant macro routines enabled

(a) the development of ballooned assembly drawings from screen geometry, differentiating between in-house, bought-in and hidden items,

(b) creation of detail drawings directly from assembly drawings,

(c) automatic production of Item List (comprises item number, part number, description, quantity)

(d) all drawing border information produced automatically and directly from the database, for up to eight sheets of various sizes,

(e) plotting utilities,

(f) drawing view utilities

and (g) interface to the database window.

Although no indication of the quality of the programme, an insight into the amount of work therein can be gained by noting that the file size and number of lines are 90kb and 3200 respectively.

8.2.2.2. Database Application Development: MBuilder

In addition to storing all necessary information, the database programmes controlled all procedural aspects of DOMS, governing the flow and access of drawings and associated information.

The database applications could be accessed directly or through the CAD user interface (see section 8.2.2.1.(g)).

Specifically, the database development enabled

(a) secure management of drawings from concept through to redundancy,

(b) the automatic collation of printed and on-line parts lists and build specifications (see Appendix D).

(c) access to "where-used" information,

(d) the management of both current and previous revisions of equipment,

(e) secure change and modification control,

(f) storage of supplier and cost information,

(g) the checking and subsequent issue or rejection of drawings,

and (h) improved part numbering allocation.

The database application comprises 2000 lines of programming, and its structure can be seen in Figure 8.4.

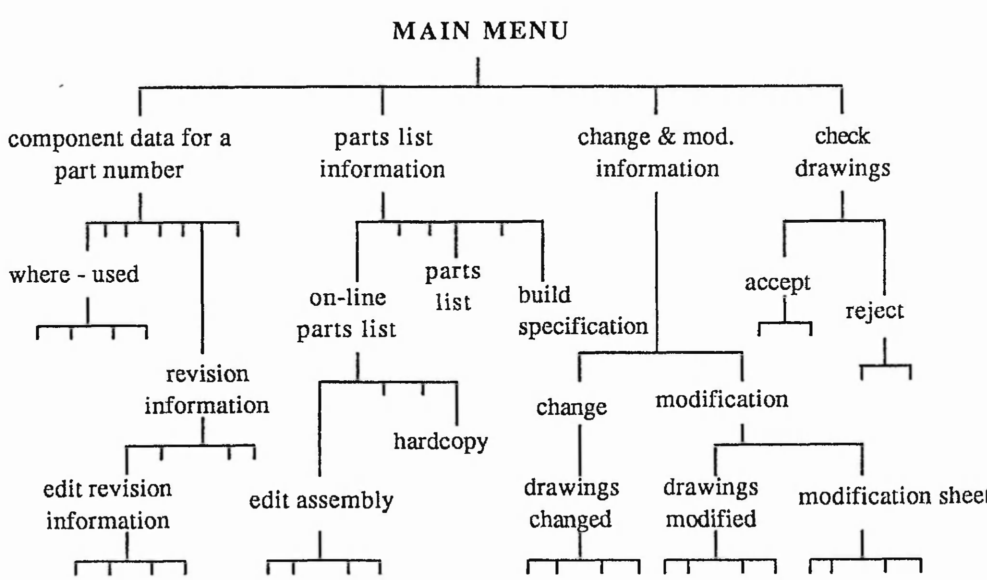


Figure 8.4. The Structure of the DOMS Database

At the time of writing, a new version of the DOMS package, DOMS2, is near completion. Due to the interest from a number of different external sources, DOMS2 is to be marketed and made commercially available.

DOMS was installed in August 1989. Prior to the users being given access to the program, each person underwent a 2 day, in-house training course, which in conjunction with the documentation [29], ensured that the user was fully conversant with all the features of the system.

To complement the DOMS user manual, the document "A Beginner's Guide to Cimcad" [30] was produced, to enable both new and existing users to have assistance at hand should they require it, in all aspects of the computer-aided design function.

9. Discussion & Conclusions

The information that currently exists on the selection and implementation of engineering-based computer systems varies considerably between one subject area and the next. Many books consider for example the various configurations practical for numerous application environments, whereas few discuss the importance regarding the content of the benchmark and its relevancy to the company it is representing. This inconsistency in the availability of appropriate information resulted with some parts of this thesis being based on research, while others required a higher input of original material. This chapter will concentrate predominantly on those areas that required original action and discuss how successfully it was undertaken.

It was in Chapter Five that the term "Expected Result" was first defined to describe the perception a buyer has of a computer system and the benefits he will achieve once it is installed. It has also been discussed that it is the purpose of the benchmark to ascertain whether or not this expected result is achievable.

9.1. The Necessity of the Benchmark

It could be argued that the benchmark would not be needed if the buyer

(a) accurately defined his requirement,

(b) found a vendor that indicated he could fulfil this requirement,

(c) paid the vendor only when the proposed system was implemented successfully.

There are many reasons why the benchmark is often the most important part of the evaluation however, simply because it is never actually possible for the buyer to put the responsibility of fulfilling his requirement onto the vendor. Consequently, it is the buyer who has to satisfy himself relating to every aspect of the selection. The most significant ones are discussed below.

9.1.1. Understanding the Technology

From discussions throughout the duration of the project, it was evident that many people in a position to invest in CAE technology, were unsure of what it could offer. Furthermore, it was their impression that without a full understanding of computers, they could not benefit from what there was available. It is suggested that this has partly evolved through the buying and selling techniques that are prevalent in the computer marketplace. For example

(i) the buyer thinks that a computer could assist him in a certain way,

(ii) he invites vendors to tender, and

(iii) the vendor who begins his quotation with a number of days for evaluating the company's requirement, and the obvious costs associated with this activity, is the first vendor to be excluded from further scrutiny as his price is too high (see also section 9.1.4.).

Consequently as the shortlist is progressively refined, the buyer is taking more responsibility on himself, to choose on a technical basis, the most suitable system, hence he must understand the technology.

9.1.2. The Buyer's Requirement

Another observation that was made on a number of occasions within the two-year period, was that buyers frequently neglect to comprehensively define their requirement, and the evaluation is based on little more than the expected result. With unclear objectives, the buyer has no qualified measure of whether or not the system is exactly what he wanted, and no basis with which to ensure the vendor provides a solution.

9.1.3. Manual Systems

It has already been discussed that computerisation of manual systems can be problematic. An additional observation was that as a result of unstructured evolution, a surprising amount of manual systems were inefficient. For successful implementation of computers, flaws in the systems need to be rectified. An irony occurs in that improvement in these manual systems alone would arguably result in a productivity increase worthy of the effort required, and yet these inefficient systems are left unhindered until the upheaval of computer implementation is imminent.

9.1.4. Commercial considerations

An astute company will encourage their sales people to sell more higher contributing products at the cost of selling less products with lower profit margins. From Cadlinc, Sun and a number of hardware and software distributors, profit margins for a range of products and services were obtained, so that this area could be discussed further. Figure 9.1. highlights how profitable each item is to a software house such as Cadlinc.

Product / Service	cost of sales - time (% of sale)	payment of source (% of sale)	gross profit margin (%)	estimated revenue breakdown on £100K sale	estimated contribution breakdown on £100K sale
third-party hardware	0	60	40	48,000	19,200
proprietary software	10	0	90	40,000	36,000
third-party software	0	55	45	5,000	2,250
training	15	0	85	4,500	3,825
pre-sales consultancy	35	0	65	2,500	1,625
TOTAL			63	100,000	62,900

Figure 9.1. Contribution breakdown for an arbitrary system sale

It can be seen from the table that for a £100,000 proposal, selling their own software is twice as profitable for the software house as selling any other product or service. Based on the values in the table, the following example is used to illustrate how in selecting systems, the buyer (he who wants to fulfil a requirement), and the vendor (he who wants to make the most profit) have two different outlooks on the make-up of a computer solution, especially when the buyer attempts to negotiate a better price.

The example buyer

- (a) is unclear of his needs,
- (b) in truth has a complex requirement,
- (c) has four project engineers all without computer experience,
- (d) outlined a £100,000 budget to the vendor, but is in fact only prepared to spend £90,000.

Figure 9.2. outlines (a) what this buyer should have been offered and (b) what the vendor actually offers.

Product / Service	(a) to suit the buyer		(b) to suit the vendor	
	est. revenue breakdown on £100K sale	est. contribution breakdown of £100K sale	est. revenue breakdown on £100K sale	est. contribution breakdown of £100K sale
hardware (third party)	36,000	14,400	48,000	19,200
software (proprietary)	30,000	27,000	40,000	36,000
software (third party)	3,750	1,690	0	0
training	6,250	3,825	2,000	1,700
consultancy	7,500	4,875	0	0
TOTAL	90,000	(57.5%) 51,790	90,000	(63.2%) 56,900

Figure 9.2. Comparison of contribution breakdown to suit the buyer and the vendor

(a) to suit the buyer

For the implementation of CAE to be successful for this buyer, he has not been offered the fourth seat, which would not be missed as the project engineers' job would often take them away from the computer, but instead have proposed that more of the budgeted £90,000 be put into the evaluation of the requirement, and into preparing the engineers for CAD through comprehensive training.

It can further be seen that whilst all the consultancy is undertaken by the vendor, some of the training budget has been used to send the engineers on seminars or courses, not run by the vendor, resulting in a reduced training profit margin of 61.2%.

(b) **to suit the vendor**

Ideally the vendor would make up the £90,000 by selling products and services in the order of descending profit margin. Whilst he cannot do this completely as, for example, software (with the highest profit margin), requires hardware (with the lowest profit margin), before it can be sold, it will nevertheless influence the vendors offering. It can be seen in this example that the vendor eliminates the third-party software and pre-sales consultancy, in preference for training. It should be noted that for true turnkey vendors, where the profit margins on hardware are potentially greater than those for the software houses, negotiating over price will certainly see the vendor relinquish everything, before the physical hardware and software assets of the proposal.

It is argued therefore, that in this example, when under pressure in attempting to convince the buyer he is offering the best solution, the salesman will try to demonstrate to the buyer, that the requirements of the buyer's company are standard and can be fulfilled without pre-sales consultancy.

It is proposed that the above example illustrates accurately one major reason why only *"two in five [companies] reckon they do not* *have the most appropriate system for their needs .. and .. As few as five out of every hundred firms using CADCAM technology reckon they had come anywhere near to achieving the benefits they anticipated. One in six thought they had derived very little or no benefit at all."* [31]. In the current climate, the buyer should therefore always benchmark the systems on his shortlist.

9.2. The Objectives of the Benchmark

One of the main areas the successful benchmark will highlight relates to the matching of systems, and the difference between individual software packages, and a number of packages linked together. The main difference is that in the first scenario, there is no information flow. Whether a spreadsheet, database or CAD package, information is created, manipulated and interpreted only while that package is running and solely within the one environment.

In the second instance however, the requirement is to use the information created in one environment in a subsequent application. In a manual system this is witnessed on an everyday basis. For example, the designer will complete a detail drawing, access a parts register, enter the necessary information, send the drawing to be checked, perform any alterations if necessary, re-submit for approval if necessary, and then file it in the cabinet with the other issued drawings, after updating the parts register.

This process can be automated. The detail drawing would be completed in the CAD software, the parts register could be a database application, and database programmes could control the file location and issue level of the drawing. The oversight arises however when the buyer perceives that his existing manual system, will match the automated version being offered by the vendor. This is as unlikely as the manual design office management system of one company, being identical to that of another. In a number of discussions, it was also found that buyers expected to change their drawing methods as it is expected that drawing, using CAD on a computer, is different to drawing on a board. The same buyer however, will expect to keep all the underlying information management processes the same. The conclusion that can be drawn, is that systems cannot be matched without one of the two conceding, and falling in line with the other. A very simple example can be given if the plotting of CAD drawings is considered.

Under the manual design office procedure, the designer would, on completion of his design, enter all the required information into an area of the drawing border. During the evaluation process at Boart UK, it was calculated that in plotting the simplest drawings, 80% of the overall drawing time would be related to the output of border information. As a result of this calculation, it was decided to plot onto pre-printed, pre-cut drawing sheets. The underlying procedure for creating and final appearance of the drawing was therefore unchanged from the manual environment.

It is unlikely that there is a CAD package on the market that does not have the capability of plotting drawings. It could be argued therefore that in setting the benchmark, Boart should have omitted any plotting requirements, and dedicated the tests to other areas. It was realised however, that Boart were attempting to match their manual system for producing drawing border information, with that of the CAD software package.

All the CAD packages could output the screen information onto the plotter, but this did not enable the draughtsman to locate the border information at the necessary places. It was found that some companies create a drawing template, enter the information, delete the template and then plot the drawing. In the case of Boart UK and the Cimcad software, a macro routine was written to prompt the designer for the required information. The routine then placed this information in the drawing border and subsequently plotted the drawing. Whichever option is chosen, a concession had to be made to match the systems, and time (and therefore money) had to be dedicated to this activity.

In the case of Boart UK, the above was the first and by far the simplest application to be addressed following the installation of the system. The principle applies however to any system matching that has since taken place.

It was found at Boart, that the computerisation of manual based systems included an additional problem. The fact that a manual system can often depend on some form of human interpretation, makes it inherently harder to computerise. If an inadequacy exists in a human-based process, the person involved potentially has the intelligence to make a decision regarding further progress, and will usually then go on to repeat this without any adjustment being made to the base process. If this system is then translated directly on to the computer, a break will occur when the program is run.

The successful benchmark will give the buyer a comparison between the result he desires, which at this stage has become the expected result, and the actual result. It should allow him to quantify any additional work that will be required to make the two results the same. Using this criteria to evaluate the benchmark at Boart UK, it was concluded that the tests were successful, as the purchased system has by now fulfilled, or still has the potential to fulfil, all the expectations of the company. These expectations will be considered later in this chapter.

One factor on which the success of the evaluation can be judged, relates to whether or not the company is sufficiently convinced as to follow the conclusions of the evaluation report.

At the time of purchasing the system, Boart UK was wholly owned by the Boart International Group. The Head Office based in Sandton, South Africa has approximately 50 people who direct and co-ordinate the group's activities, leaving the chief executive to provide the direction for each operating company - the result being a very autonomous environment. For an investment of this size however, once the management at Boart UK were satisfied with the recommendations regarding which CAE system to purchase, approval from Head Office still had to be obtained, especially the original approved budget of £128,000 was to be exceeded.

The CAE related capital investment was 2.5% of forecasted turnover and 59% of all capital expenditure for 1988, and it was gratifying that all recommendations were followed even though Sun hardware and Cadlinc software was new to the Group, and Hewlett-Packard, Applicon and Autocad were all well established.

If the benchmark is successful, and the resultant recommendations followed, the most appropriate system will be purchased, and therefore the evaluator and buyer of the equipment have fulfilled their roles, and it is at this stage that the words "installation", "implementation" and "development" are used frequently, and are sometimes considered as being interchangeable.

The installation of a computer system is complete once the hardware is in place, up and running the purchased application software packages. Development denotes the on-going projects which take place once the system is fully implemented, in an attempt to fully exploit the resources of the system. The implementation of the computer system is far broader than either of the preceding categories however.

The implementation of a computer system cannot be achieved without first considering the buyer's requirement, and it can be considered successful if and when this requirement is fulfilled. By this definition therefore, the implementation of the system encompasses all sections of this thesis, and it is within the scope of this chapter to consider whether or not the implementation was successful in the case of Boart UK.

For the objectives to be achieved and the implementation to therefore be considered successful, it was necessary to ensure that the designers were making effective use of the CAD package. In an attempt to qualify the effectiveness of CAD use, it was decided to hold a third open evening.

Partly as a result of the first two open evenings (page 55), the then future users of the system were enthusiastic about its introduction, and appeared to understand that they played a great part as to whether the implementation of the computer system would be successful or not. This level of enthusiasm continued throughout the initial training programmes and has been maintained. In discussion with the designers, not one expressed a desire to revert back to the existing manual system.

The third open evening therefore, was not to monitor or increase the users level of enthusiasm and ownership of the project, but was to provide some on-going evaluation, to see if those responsible for producing the company's production drawings, were still improving regarding their usage of CAD.

The specific objectives for the evening were as follows

(a) to enable the designer to witness the drawing style and methods of others on the CAD system,

(b) to obtain information regarding effective use of the CAD software,

(c) to enable the designers to socialise with Cadlinc users from other companies, and Cadlinc personnel.

(d) to determine whether further training was necessary.

In keeping with the nature of previous evenings, a mechanism was needed that would enable fulfilment of the above objectives, and at the same time keep the occasion light-hearted. To these ends, a CAD competition was devised, and is summarised below.

The list of competitors comprised 7 designers, 2 systems engineers, 1 Cadlinc applications engineer. Unfortunately, although invited, two further visitors were unable to attend. The competition material was devised specifically for the occasion, and was based on the usefulness of the geometry, and not the functionality of the component. Further information relating to the content of the competition can be seen in Appendix E.

The exercise was designed to last approximately 40 minutes. Firstly, one designer drew for 20 minutes whilst his partner made notes regarding the methods used in constructing the geometry. The pair then changed roles. Discussion between the designers was encouraged by the fact that as much emphasis was placed on the notes made, as was placed on the speed with which the assignment had been completed.

The competition and the evening in general was successful, and it was found that although some of the designers used a wide range of the CAD capabilities, others still used manual drawing techniques. It was encouraging that the teams made up solely of Boart designers ranked first and second, but it was discouraging due to the recognition that without assistance, those that had always used manual drawing techniques would continue to do so, and as such their very potential for improvement was limited.

The results of the competition highlighted a flaw in the implementation process at Boart. It had been assumed that as the enthusiasm of the designers was high around the time of the system purchase, and that the training programme for the 2D CAD software was arranged, the transition from board to computer had been sufficiently addressed. This in fact was not the case, as the designers had not been provided with sufficient chance to understand the differences in manual and computer based design. It was agreed that an introductory course would have been helpful, covering the different drawing philosophies involved.

Although not as competitors, senior managers from Cadlinc attended the evening, and expressed their interest in developing such a course. It was decided at Boart, that the in-house training would focus on this matter. It should be noted however, that the competition did bring these same concerns to the designers attention, and in ensuing conversations it was apparent that it had broadened the outlook of the designers.

In subsequent discussion with other Cadlinc users, and from the experience gained at Boart, it was concluded that training was often the most underrated area of computer implementation. The specific nature of the training varied between companies, but it was usually the case where training accounted for less than 5% of the overall monetary investment. In the case of Boart, 7% of expenditure was allocated for training, partly as there was a belief that this initial outlay would be recouped through having in-house expertise (see also section 9.1.4.).

As Boart had a system developer, fully trained in the software packages in general use, it was intended that the design team would always have help nearby. There is undoubtedly and advantage in this arrangement in the first few months of computer implementation, but it was found however, that the amount of assistance required by the designers had not significantly reduced after the first 6 months. With the system developer so readily available, it was found that he was being asked to give assistance before the designer had given any thought to solving the problem either himself, or by the help of another designer close at hand.

A decision was made to put more emphasis on to training, specifically in areas of common difficulty, to reduce the unscheduled assistance required by the designers, and in doing so free the systems engineer to allow more actual development of the system to take place.

Finally in considering why training is often to some extent overlooked, it highlights once again the commercial nature of computer implementation, as it is both easier and more lucrative for a salesman to sell a tangible asset such as a workstation, than the intangible asset of training.

It is not valid to judge the success or failure of any computer implementation based on one instant in time. A low-cost database package for example, allows the user to create a form, with a number of fields, and to subsequently enter all the required information. This type of application would show reward within a very short time frame. Conversely, an expensive database package, provides the buyer with nothing more than development tools, and as such the capability to create whatever application he desires. Depending on the sophistication of the requirement, this type of package may not show reward during its first six months, and unless fully developed will bear no fruit whatsoever. To put the implementation at Boart UK into perspective therefore, it is necessary to give consideration to the length of time their CAE system can be expected to offer an acceptable value for money in relation to the computer marketplaces of the future.

Throughout the evaluation process a significant time difference was noticed between the state-of-the-art and the state-of-the-market, and it was found that in some cases the general marketplace was up to three years behind the technological limit. An example of this can be seen in the case of Finite Element Analysis (FEA), where although, at the time of writing, the technology was not new, the sole customers of FEA packages were the larger companies who had considerable research facilities. Smaller companies, whilst wanting to invest in new technology often do not have the funds to do so until the technology is proven. This observation was discussed and borne out by Amjad Umar, Associate Professor in Business Administration and Computer Information Science at The University of Michigan, following a database conference he presented attended by the author.

By observing the state-of-the-art therefore, the probable forward path of the marketplace can be ascertained. In the case of Boart UK, the specific area of consideration was that of design completely within a three-dimensional environment. It was found however, that this would not become a practicality until the screen geometry could be manipulated significantly faster and to a greater extent. This will be achieved in the future either by the introduction of more powerful computers, or by that of more effective software programs. Again, it could be seen that only the largest companies, especially those in the automotive industry had significant investments in this area. It should be noted however, that even in these cases, 3D had not superseded many 2D applications, but had generally been purchased to enhance specific application areas.

Whilst the state-of-the-art will continue to pull along the commercial marketplace with new technology especially in areas of hardware and application software, it is suggested that the next few years will see better application of current day software in preference to exploitation of the very latest technological advances. Discussion about final result and process tests in Chapter Five considered how substantial computer solutions are made up of application programs and the flow of information between neighbouring application programs. A simple model is defined in Figure 9.3., to illustrate that by no matter how much the productivity of one application area is increased through technological advance, the result may have far less impact on the business as a whole.

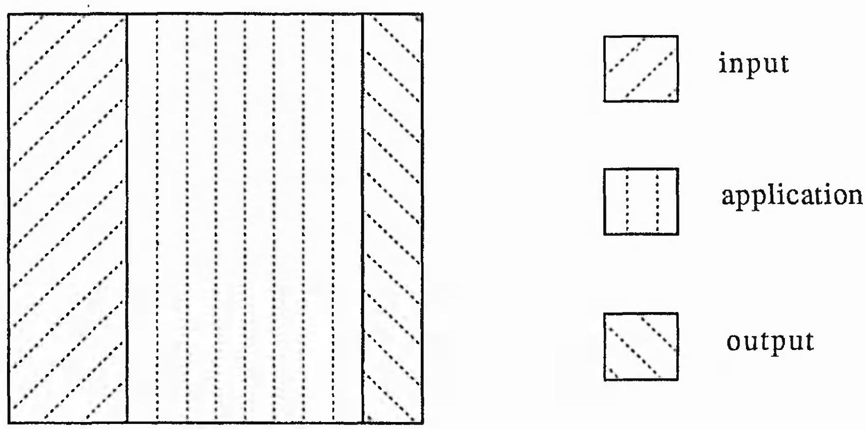


Figure 9.3.(a) Components of an Application

If there are three consecutive applications in the overall process, where output from applications (a) and (b) is used as input for applications (b) and (c) respectively, then the overall process can be depicted as shown in Figure 9.3.(b).

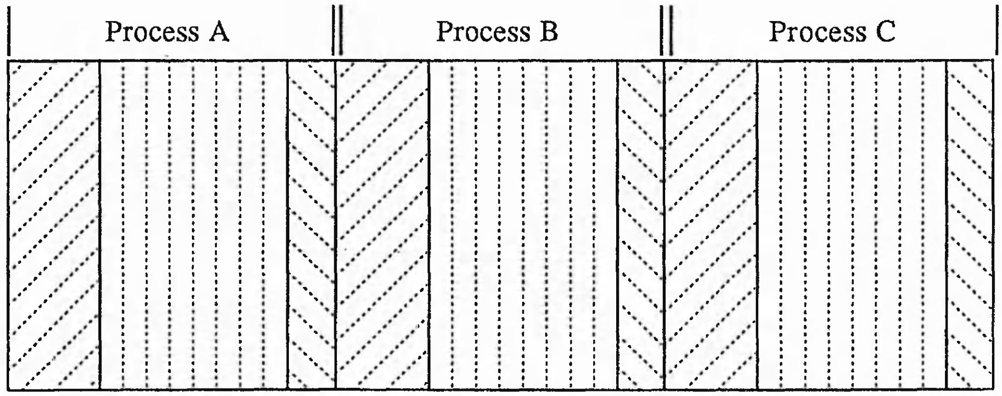


Figure 9.3.(b) Applications in a Process

It only remains to highlight that a technological advance in application AII for example, that was so great that it made the time taken in processing almost zero (see Figure 9.3.(c)), would not provide as greater reward than an advance that meant output from applications (a) and (b) were automatically formatted and transferred into applications (b) and (c) respectively (see Figure 9.3.(d)).

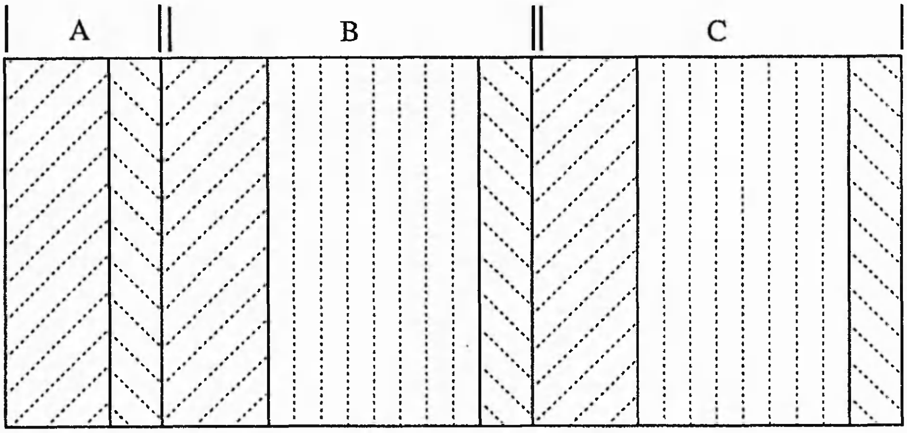


Figure 9.3.(c) The Process with AII reduced to zero

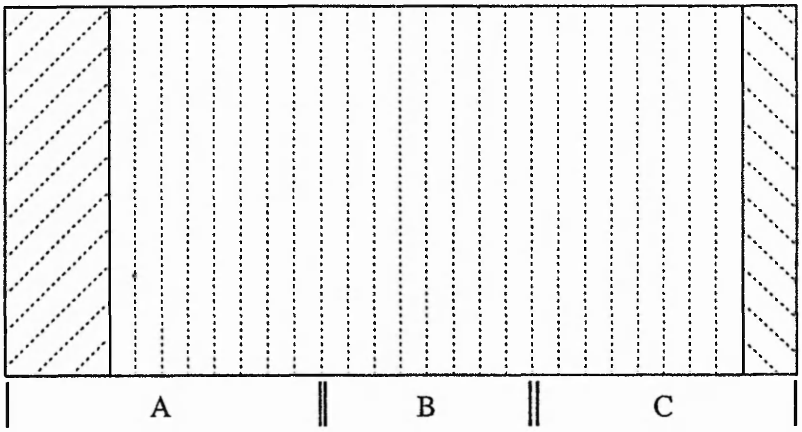


Figure 9.3.(d) The Process integrated throughout.

At the time of completing this thesis, more attention was generally being given to the flow of information by buyers and vendors alike. Engineering Data Management is the most commonly used name and in all articles reviewed, each concurs positively with the philosophy behind the system now in place at Boart UK [32,33,34,35,36,37].

In Chapter One, two sets of objectives were defined. Firstly the specific objectives of this project and the brief of the Teaching Company programme, and secondly in introducing Boart UK, five company goals were outlined. To determine the success of the project therefore, it is necessary to address its objectives, and also to give consideration to the company's position in relation to its more widespread goals at the time of writing.

The specific objectives were all fulfilled. The installed system is used by all the designers, the majority of technical illustrators and also by the systems engineers. The manual design office processes have all been implemented onto the computer, and this has allowed a greater integrity in drawing information, as the design office management system has enabled the re-instatement of the drawing approval procedure.

The company goals have been partially achieved as

(a) the tendering rate increased from 35% to 90% over the period, whilst maintaining a success rate of 2%, from essentially the same enquiry rate,

(b) the number of design engineers remained at seven,

(c) the product range has been broadened, and this was made easier by the implementation of CAD and the flexibility with which the designer can conceptually design. In discussion with Mr Brian James, Divisional Manager - Drill Rigs, he commented that " CAD to the designer is like wordprocessing to the secretary - it gives them a great deal of flexibility and allows them to freely manipulate the information with which they work",

(d) development into surface mining was not furthered. This was a strategic decision and as such was not influenced either way by the implementation of CAE,

(e) all drawing work relating to computer-controlled rigs was completed on the system. A subsequent decision based on cost, resulted in no further progress being made.

The information for (c), (d) and (e) was obtained from an interview with the Divisional Manager - Drill Rigs.

The work on which this thesis is based generally took place between September 1987 and November 1989. The Teaching Company contract was completed in December 1989. In January 1990, the author was appointed as Manager of Computer Technology for the Company.

Appendix A: Flowchart - The Production Process

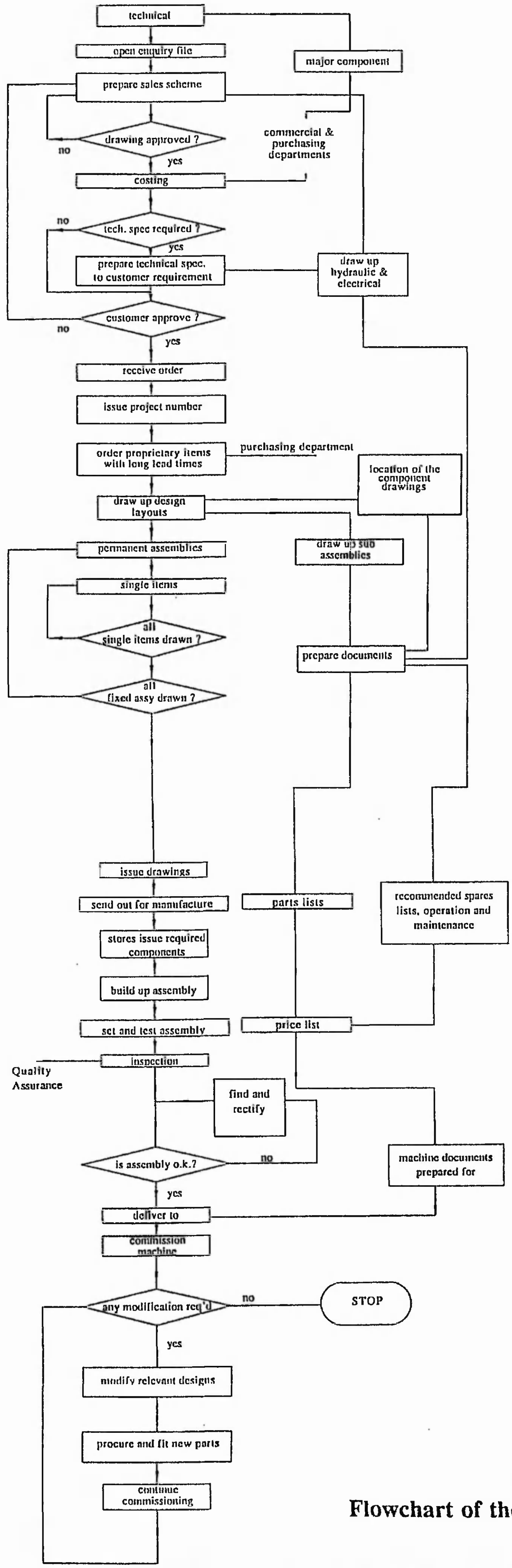
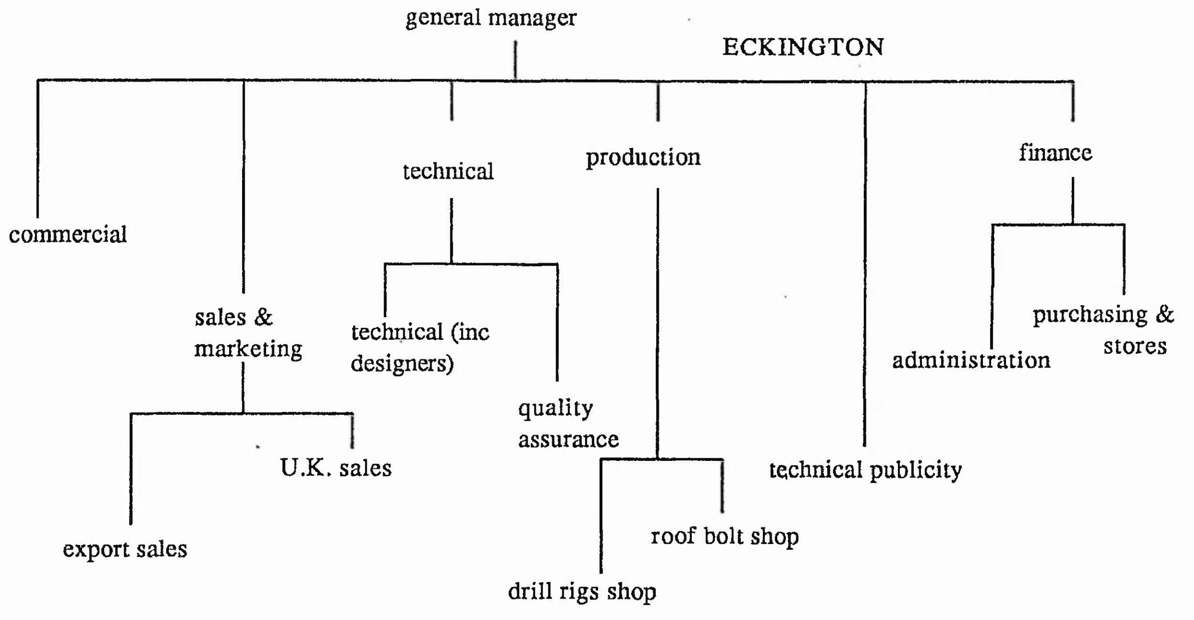


Figure A.1.

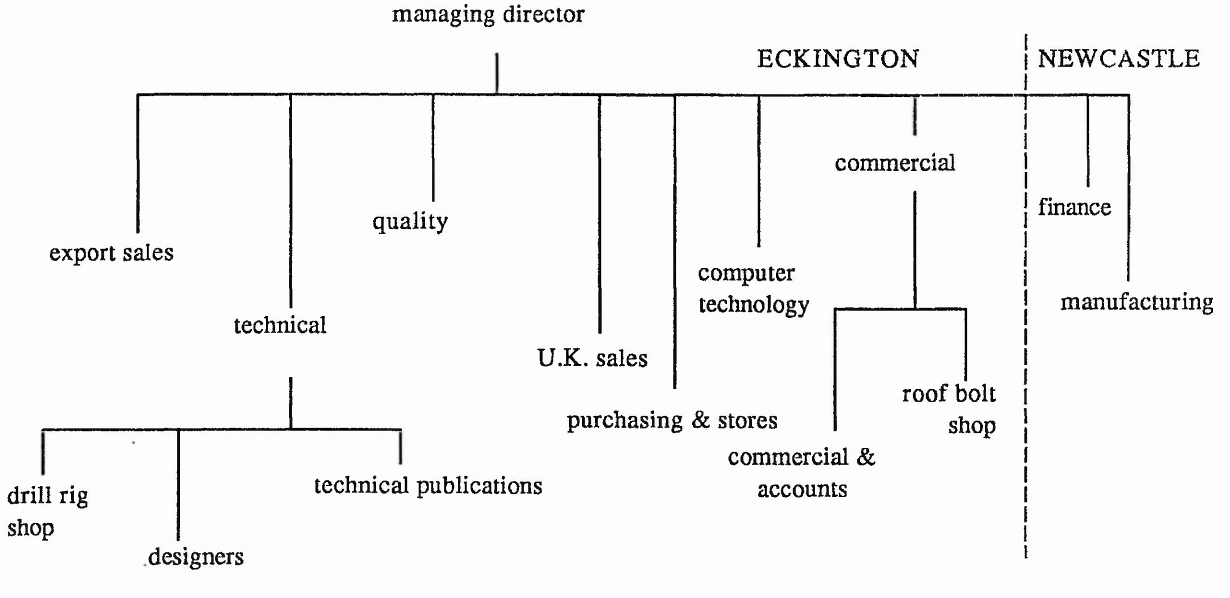
Flowchart of the Production Process

Appendix B: The Structure of Boart UK Ltd

(a) The Structure of Boart UK at the outset of the Project



(b) The Structure of Boart UK at the time of Writing



Appendix C: The Benchmark Tests

The relevant sections of the Benchmark tests have been included below.

C.1. Test One: The Process Test.

An audit trail is required at the end of this test. An exploded view is also required part of the way through the tests.

1. Set up the given component in parametric form (Figure C.1.).

2. Produce a component where A=50, B=C=10, D=15, E=2, G=10, F=12. There is no need to store this result.

3. Design component number 111-777-0001 using 150 for optional dimension (Figure C.2.)

4. Calculate the area, centre of area (C of A) and give the component a price of £2.50. Store this and subsequent components with their attributes in such a way that any single attribute can be located independently. Note - in future this part will need to be retrieved by its part number. Also note - each part number should be stored with a description. In this case "Shaft".

5. Design component number 111-888-0001 (Figure C.3.). This is to be the working drawing as parts are to be added to it but it needs to be given its own drawing sheet (111-888-0001), part number (111-888-0001), cost (£10.00) and its area, C of A need to be calculated and all attributes stored as before. Description: "Housing".

6. Using parametrics program, create component number 111-666-0001 (Figure C.4.)with current working drawing. Calculate area, C of A, attribute a price of £5.00 and store as before. Description: "Cap".

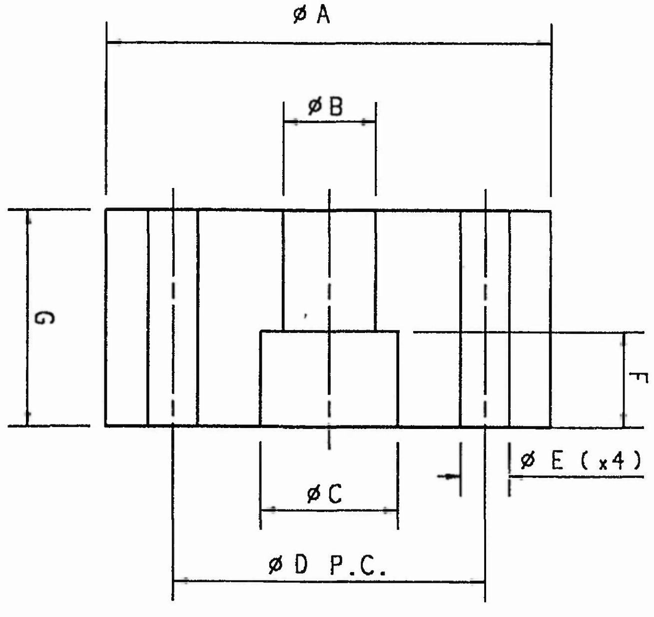


Figure C.1. Component in Parametric Form

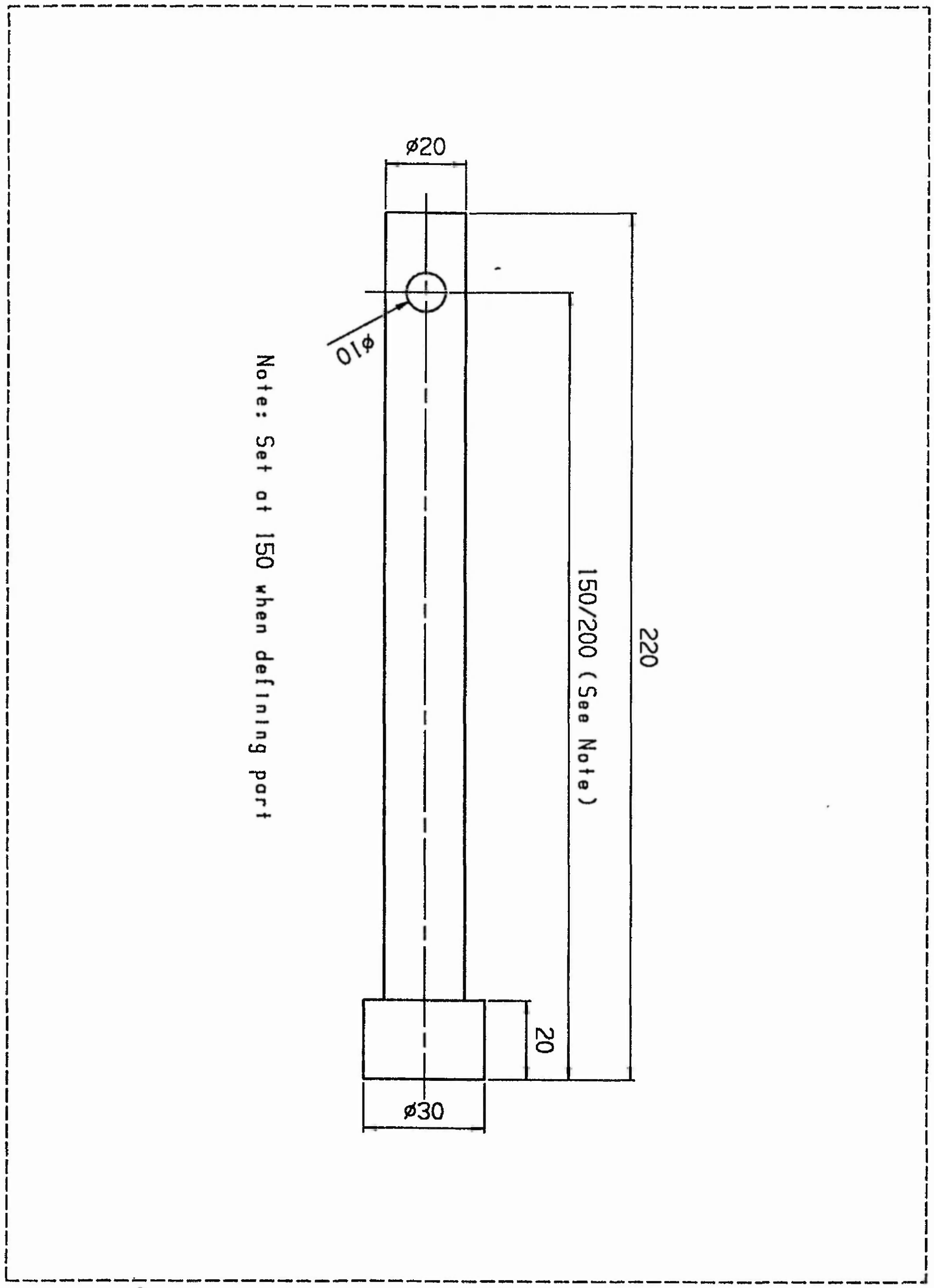


Figure C.2.Component 111-777-0001

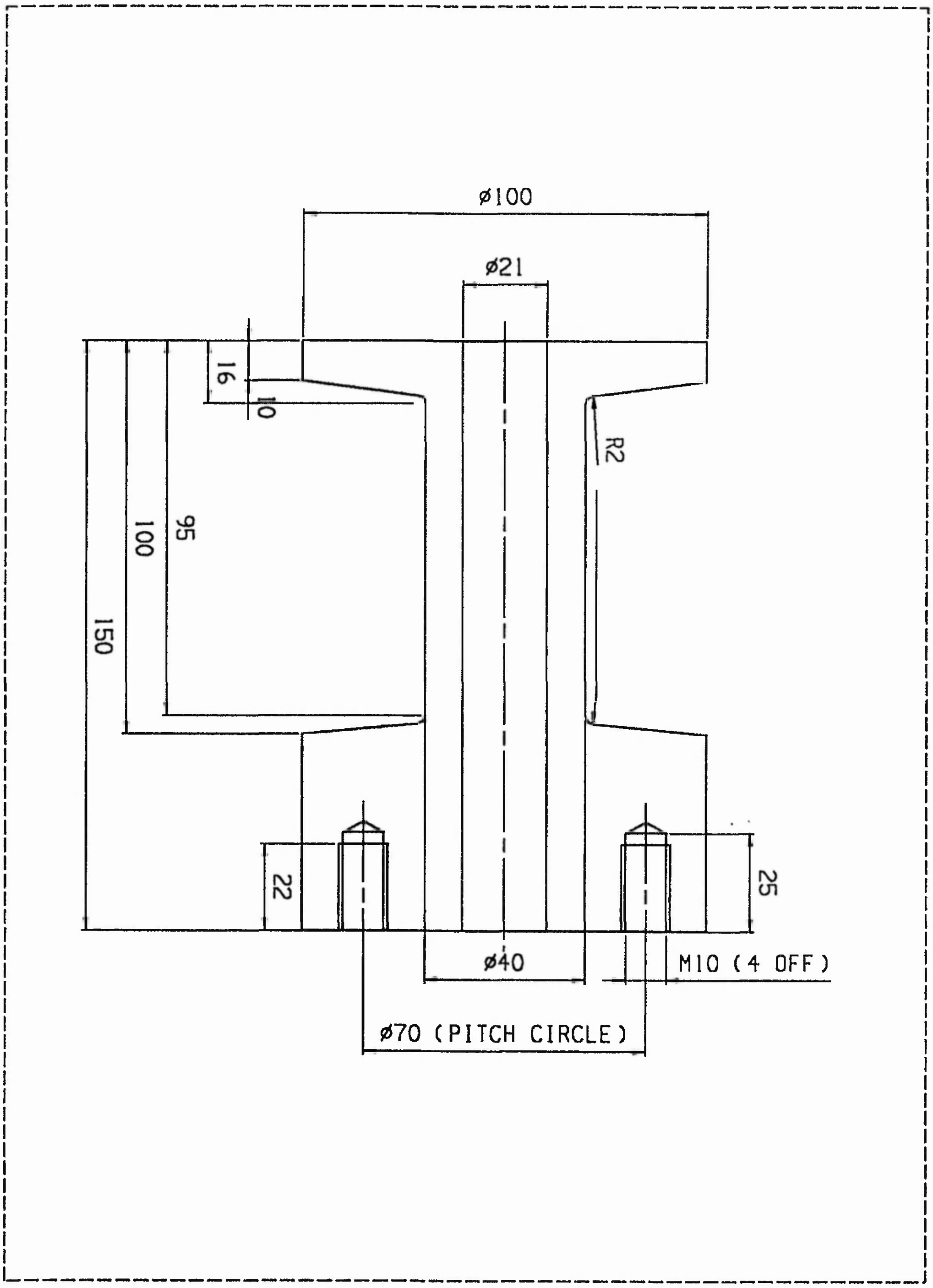


Figure C.3.Component 111-888-0001

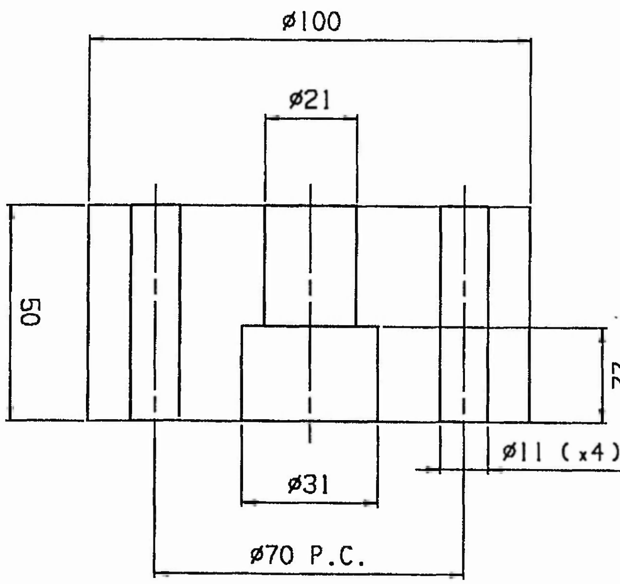


Figure C.4.Component 111-666-0001

7. Locate 111-666-0001 as shown on 141-999-0001 (Figure C.5.) and secure by introducing bolts which are to be designed on the working drawing. Calculate area, C of A of bolts and attribute a cost of 50 pence each. Also, create a symbol out of the designed bolt and store in relevant library. Store bolt under part number 311-555-0001. There is a total of four bolts. Description: "Bolt - M10 x 70".

8. List all parts designed with their description and then retrieve "Shaft" by its part number and locate as shown. Note - all this is to be done with 141-999-0001 being the current working drawing.

9. It is noted during the initial design stage that a revision is required to 111-777-0001. The hole at 150mm is to be moved to 200mm. Assuming no change in cost, perform this revision including all attributes and database changes.

10. Calculate the complete area and C of A. (No need to store.)

11. What is the total cost ? (No need to store.)

12. By running a separate "window" compile a parts list from the data already stored. The format of the list was given prior to this Benchmark.

13. From the Parts Lists fill in the Item List on the drawing.

14. Store drawing number 141-999-0001.

15. It is noted that a modification is required on drawing 111-888-0001. Retrieve and fully dimension.

A "grub" screw is required 50mm from left hand end as shown (Figure C.6.).

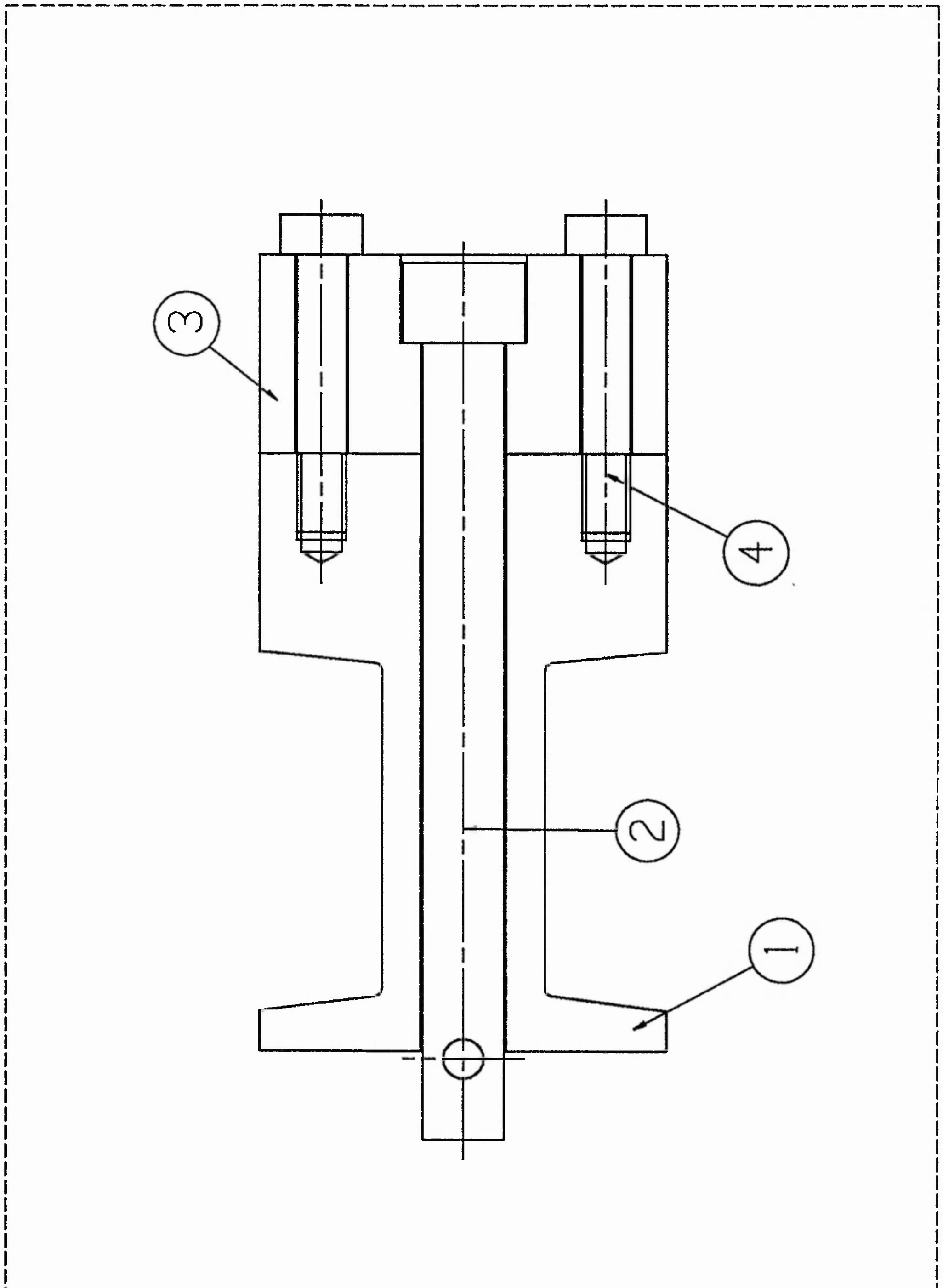


Figure C.5.Assembly 141-999-0001

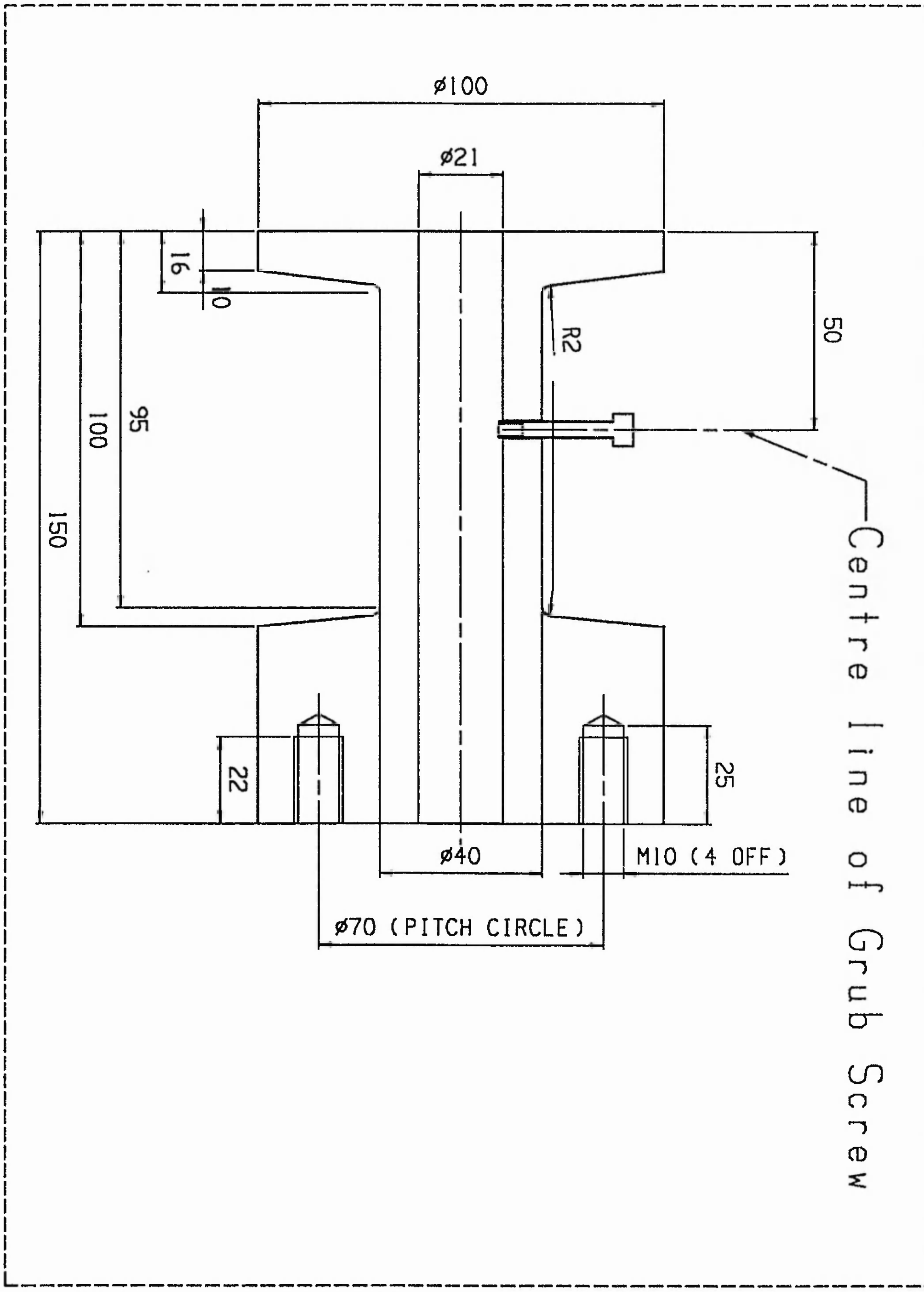


Figure C.6.Introduction of Grub Screw

16. List symbols library.

17. Retrieve symbol created by M10 x 70 bolt. It is a requirement that the shank of the bolt is M4.

18. Scale down symbol to 0.4 times the size and locate as designated 1mm below hole bottom.

It was found that the Housing needed to be substantially thicker. The actual increase in thickness is determined by the fact that the grub screw must not protrude past the overall boundary (Figure C.7).

19. Dynamically or otherwise stretch the Housing to locate just under the bolt head and then stretch both to suit 18.

20. Give the bolt part number 311-555-0002, store and enter into parts list under description "Bolt M4 x X". Area and C of A need not be calculated.

21. Delete bolt from drawing to leave actual details. Providing drawing dimensions are associated the modification is complete.

22. Complete modification column and input date. Store.

23. Complete Modification Record in format designated. On completion the record should be stored, executed or otherwise, in such a way as to issue the modification and update the relevant drawings.

24. Recall assembly number 141-999-0001.

- Have all relevant issue levels updated ?
- Has actual drawing been updated ?
- Has all information been updated in modification columns ?

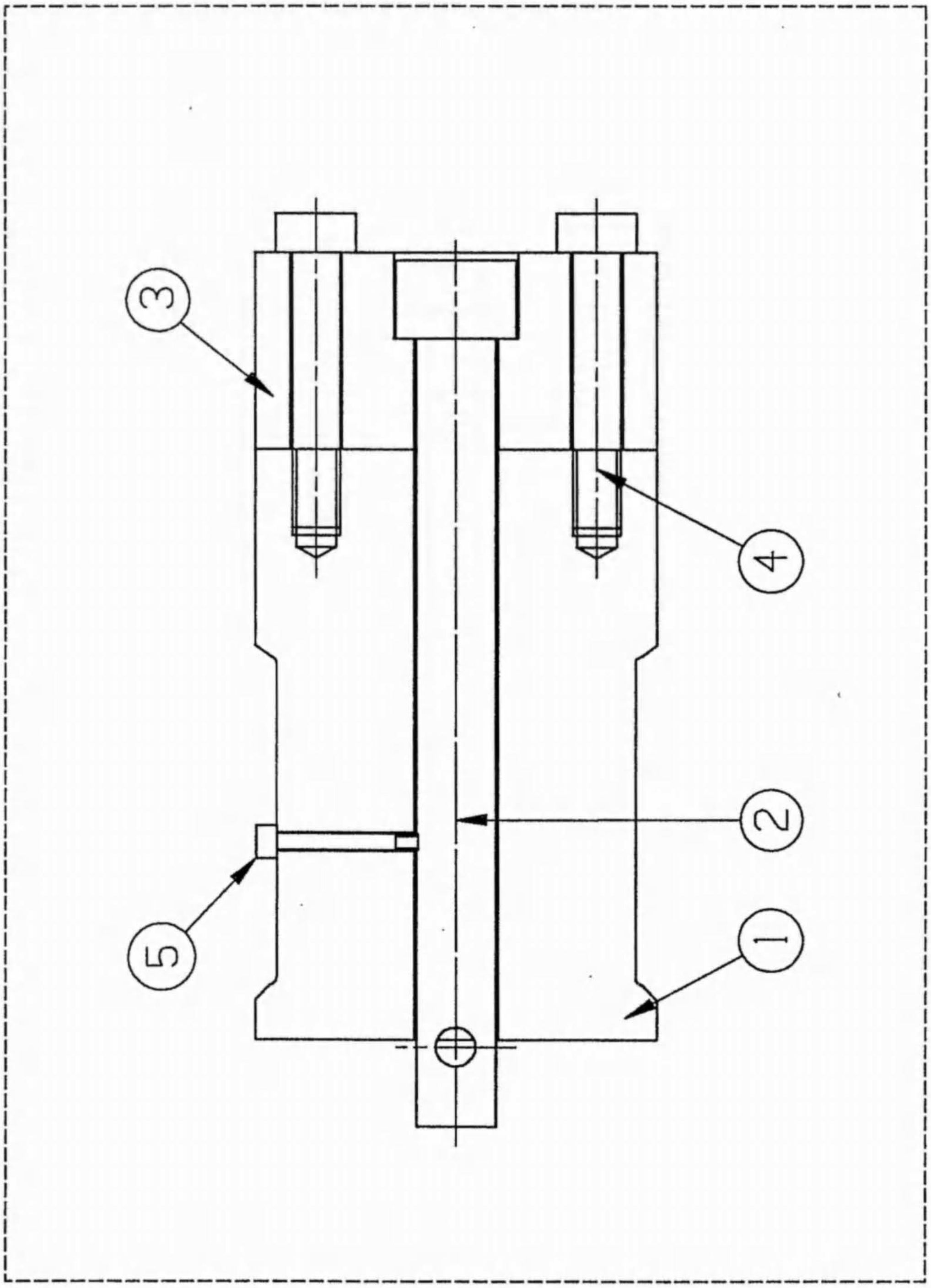


Figure C.7.Thickened Housing

25. Create isometric / 2.5D / 3D view.

26. Explode parts then store drawing.

27. Demonstrate how the boundary information, e.g drawing number, item list can be kept at the same size even if the scale of the drawing is changed.

28. Demonstrate the audit facility as stated at the beginning of the test.

29. How much disk space has been used in the storage of this data ?

30. Plot/Print off all drawings and lists that have been generated in the above test.

Data relating to Process Test.

Part Number	Qty	Description	Area	C of G	Cost £
111-777-0001	1	Shaft	4521.5	*	2.50
111-888-0001	1	Body	6460	*	10.00
111-666-0001	1	Cap	2630	*	5.00
311-555-0001	4	Bolt	850	*	2.00
111-777-0002	1	Shaft after mod.	4251.5	further right	2.50

* Centres of Gravity have been left to observation.

C.2 Test Two: The Final Result Test.

1. Produce a complete list of components in ascending numerical order of part number. Include quantity, description and on what part they are used.

2. Produce a complete list of components in ascending numerical order of the last nine digits. Include quantity, description and on what part they are used.

3. What is the total quantity of components used ?

4. How many different components are used ?

5. List all parts on sub-assembly 132-112-000006.

6. List all parts that are common to assembly 151-152-000114 and sub-assembly 132-112-000006.

7. List all seals (***-169-******) by part number, description and quantity.

8. On which assembly is part number 332-169-063176 used and how many on each ?

9. List all in-house designed assemblies and sub-assemblies in descending numerical order.
   (15*-***-******, 14*-***-******, 13*-***-******).

10. List all bought out parts that are **not** mechanical but are single components, in ascending numerical order.
    (312-***-******, 313-***-******, 314-***-******).

11. List all those in No. 10 which are also "Plug" by description.

12. List the description and quantity of all parts used in a quantity of 5 or more.

13. Locating by description, list all washers, excluding "thrust" washers, by part number and quantity sorting with the last six digits in descending order.

14. Locating solely by description (and cross-referencing, if necessary), list all safety washers used for 12mm diameter bolts. Include where and in what quantity they are used.

15. How much disk capacity has been used in storing the software packages under consideration ?

16. How much disk capacity has been used in the storage of this data ?

C.3. Test Three: 3D, Wireframe and Solids Modeling

1. Using (i) 3D wireframe, (ii) solids modeling software, complete the diagram shown in Figure C.8.

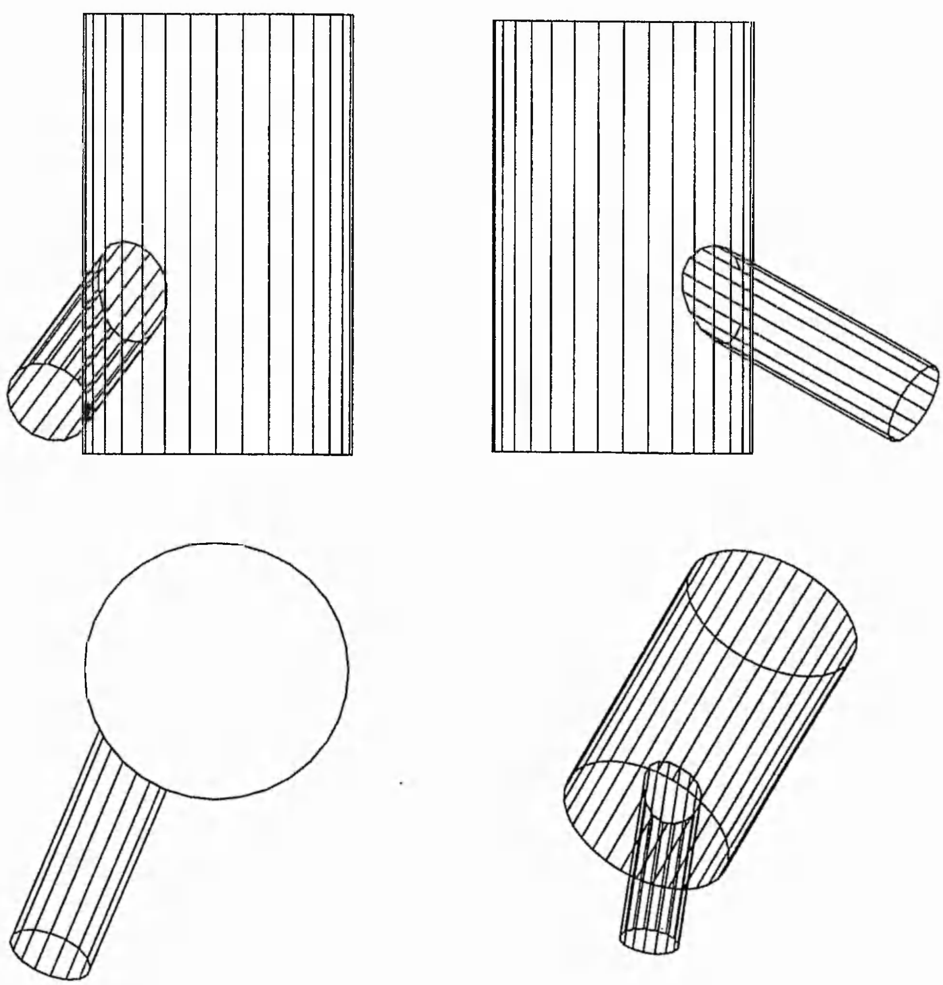


Figure C.8. Representation of Complex Intersection

2. Include lines of intersection and cylinder end lines for angled cylinder.

3. Develop the surface area of the angled cylinder.

4. Plot off resulting diagrams.

NOTE: This test should be run around the network on a separate processor.

Appendix D: Design Office Documentation

The following pages are examples of a Parts List, a Build Specification and a Modification Sheet.

BOART UK

PARTS LIST

Sheet of

Compiled by:

Part Description:

Part No.

Part No.	Qty	Description	Recomended Supplier	Supplier Code

Boart UK

Build Specification

Build specification number ______________________

Product ______________________ Quantity ______

Customer ______________________

Requirement Specification ______________________

____

General Arrangement Drawing ______________ Issue ___

Serial Numbers ______________________

____

____

____

____

____

Compiled by ______________________

Date ______________

Boart UK
Build Specification

Assembly number

List of Assemblies & Sub-Assemblies

Part Number		Part Number		Part Number	

BOART UK

MODIFICATION SHEET

MODIFICATION NUMBER: M

TITLE:

PURPOSE OF MODIFICATION:

Compiled by:	Priority Catagory:	Reason:	Effect on cost:	Effect on Interchangeability:

PRIORITY

'A' top priority	all components in service, on order and work in progress
'B' immediate	components in stock, on order and work in progress
'C' future	components on order if without penalty

REASON

1 -design/drawing error
2 -design improvement
3 -health & safety
4 -requirement change

COST

-2 -considerable reduction
-1 -moderate reduction
0 -no change
+1 -moderate increase
+2 -considerable increase

COST DEFINITION

no change	<= 10%	
moderate	> 10%	<= 20%
considerable	> 20%	

Drawings affected showing new issue level	Parts Lists affected	Stock Affected		
		Location	Affected	Mod Complete
		On Order		
		In Stock		
		Work in Progress		
Complete	Complete	In Service		

Appendix E: Content of the CAD Competition

The following pages should be indicative regarding the nature and content of the CAD competition.

Regulations of the Competition

1. The competition is divided into 2 stages. Firstly the assembly drawing (sheet 1) is to be completed, with one person drawing and the other noting the appropriate actions (we shall cover this in due course).

2. The pair then swap positions with each other. The detail drawing (sheet 2) should then be completed.

3. The "co-pilot" at any one time should be happy with the actions of the "pilot" as these actions must be monitored and the appropriate ones recorded on Sheet 3, Part A.

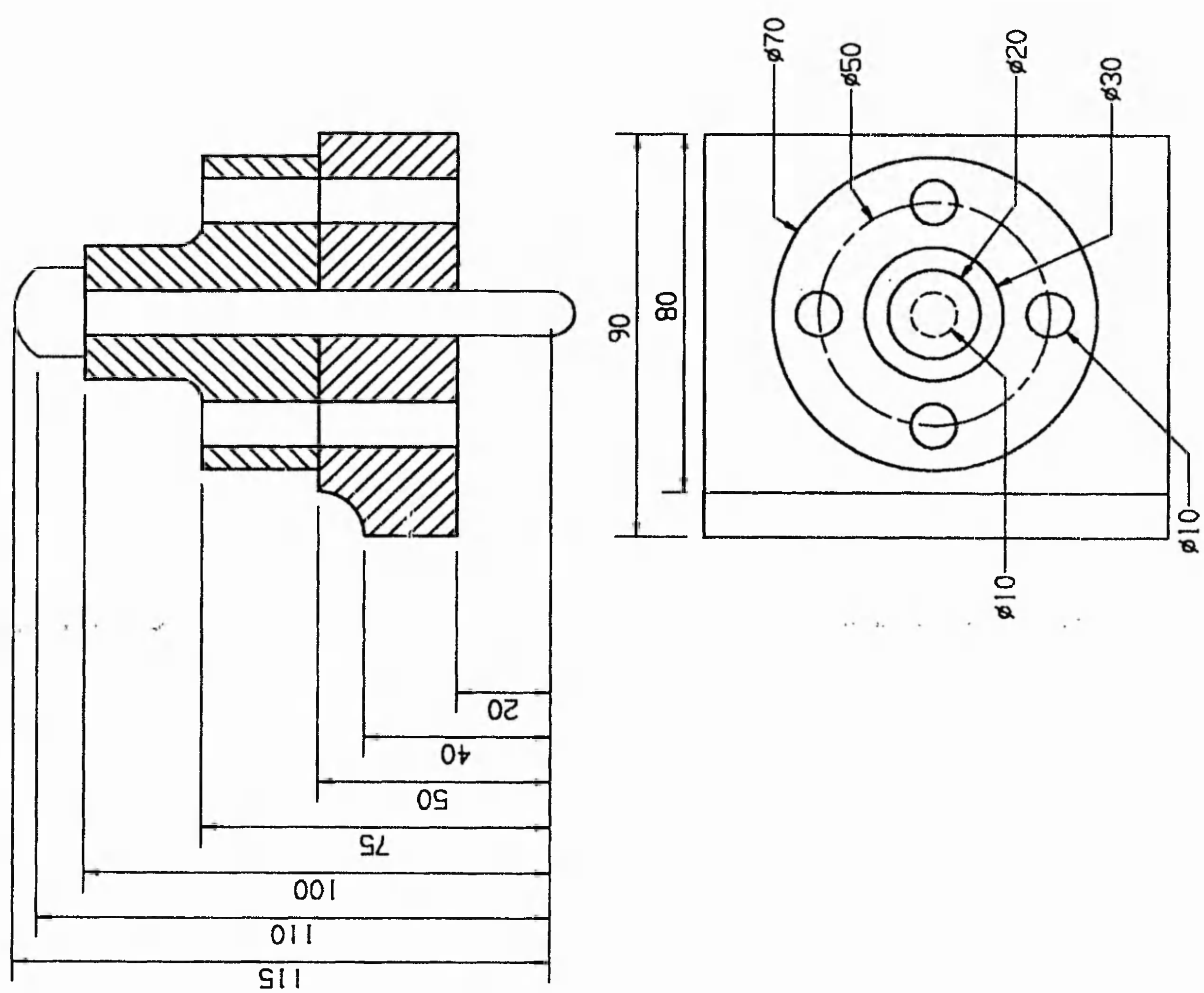
4. On completing the exercise, save drawing under filename '/tmp/cadcomp.drg', and leave the screen as it is. The clock will now be stopped. Part B of sheet 3 must then be completed.

5. The scoring system is as follows:

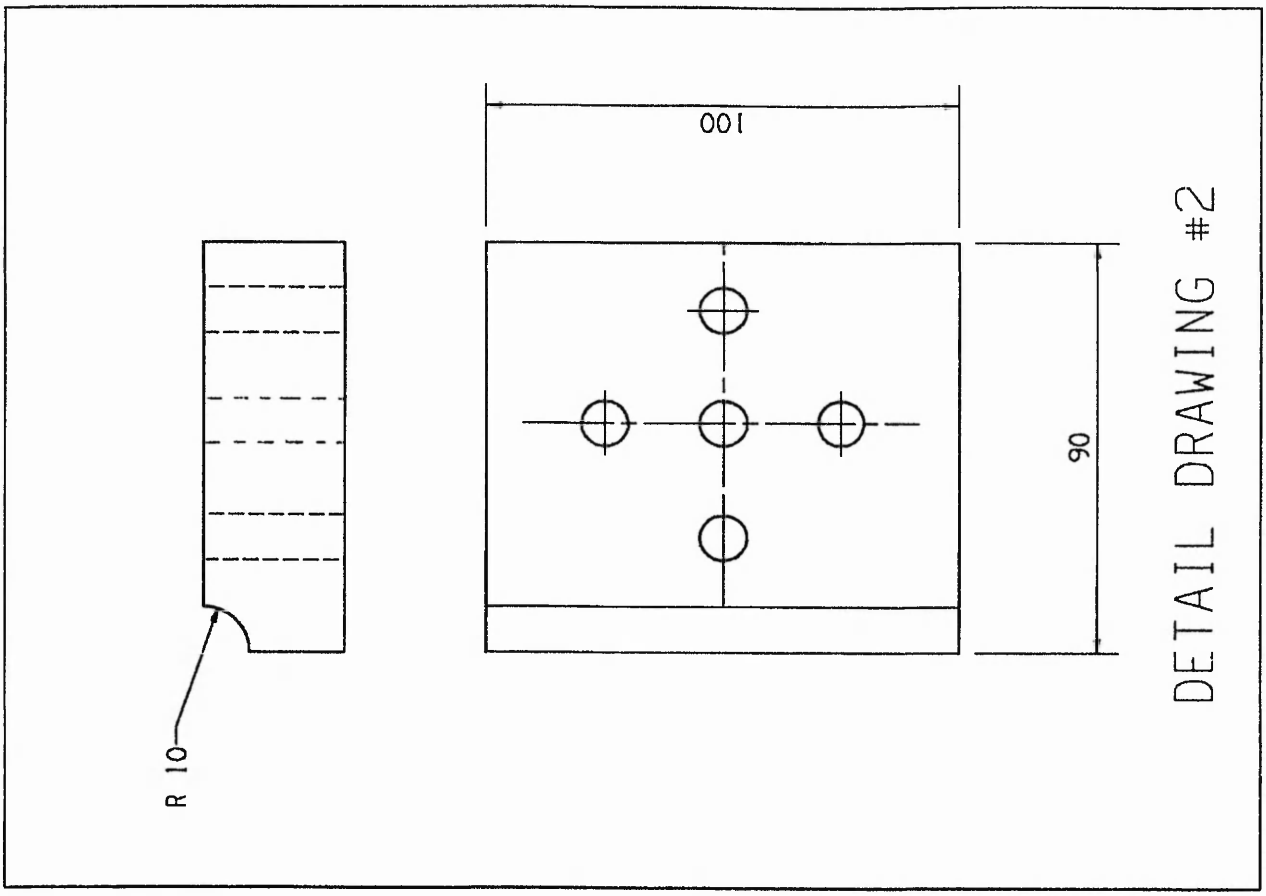
   40% is based on the speed in which the drawing is completed.
   40% is based on the way in which the drawing was created. This is why Sheet 3 is necessary.
   20% is based on the judges' impression. This will have been gained from watching the battle take place.

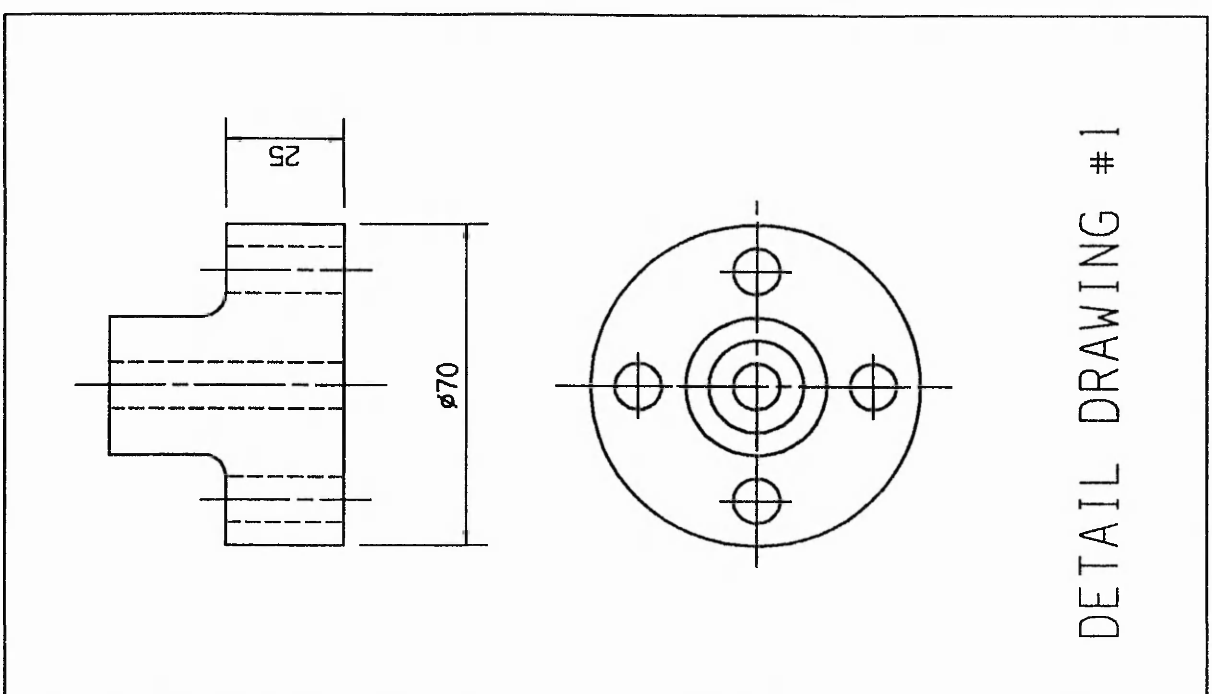
NOTE: CONSTRUCTION LINES SHOULD NOT BE REMOVED

SHEET 1 - GENERAL ASSEMBLY



SHEET 2 - DETAIL DRAWINGS





SHEET 3A - MONITORING SHEET

Class Manipulation (moving, mirroring, copying, rotating, hiding, etc..):

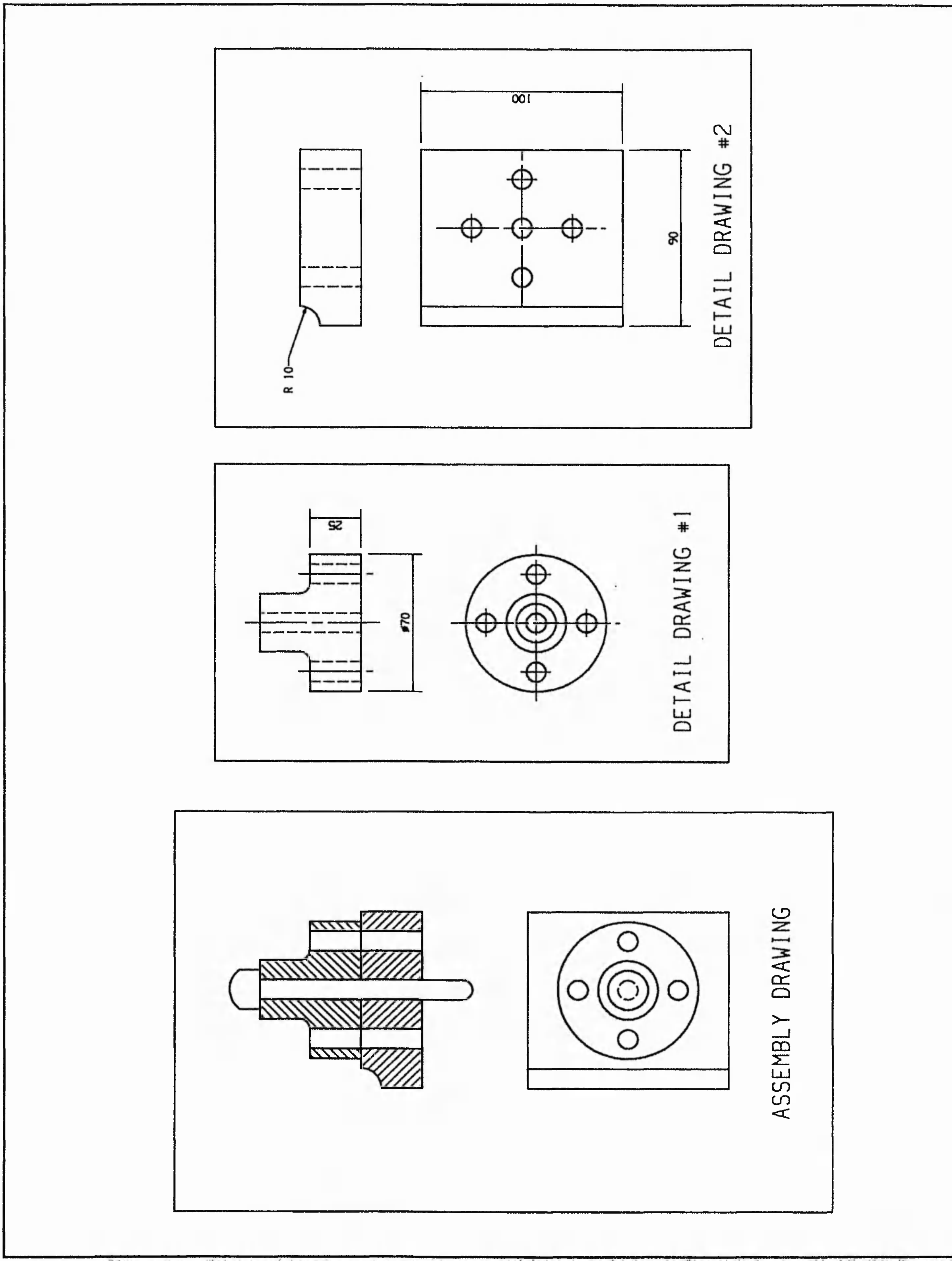
Keys, Strokes, Long Commands:

SHEET 3B

Some of the geometry that goes to make up your drawings should resemble the outlines below. Taking each of the below in turn, "pick" the line on the screen at the point "P", and move round the line. Sketch your findings and number each point.

NOTE: USE OUTLINES FROM THE ASSEMBLY DRG.

SHEET 4 - SCREEN LAYOUT



References & Bibliography

(a) References

[1] Toby D. Wall, Chris W. Clegg and Nigel J. Kemp
The Human Side of Advanced Manufacturing Technology - page 8
John Wiley & Sons Limited (1987)

[2] Gary R Bertoline
Fundamentals of CAD - page 30
Delmar Publishers Incorporated (1988)

[3] As [1], page 22

[4] A.J.Medland and Piers Burnett
CADCAM in Practice - page 143
Kogan Page Limited (1986)

[5] As [4], page 144

[6] As [4], page 147

[7] As [4], page 168

[8] M.O'Callaghan for Boart Hardmetals (Europe)
The Selection of a CAD System
Unpublished. (1987)

[9] As [1], page 24

[10] As [4], page 148

[11] B.H.James for Boart UK Limited
The Design Office Handbook
Unpublished. (1986)

[12] A.J. Medland
The Computer-Aided Design Process - page 95
Kogan Page Limited (1986)

[13] Harry Atherton
Designs on your Desktop - page 159
Sigma Press (1988)

[14] Cassidy
Sunday Times
February 1988

[15] Peter C.C. Wang
Advances in CAD/CAM Workstations - page 158
Kluwer Academic Publications (1986)

[16] G. Lambert
A Comparative Study of System Response Time on Program Developer Productivity
IBM Systems Journal Volume 23, Number 1 (1984)

[17] Book as [12]

[18] J. Orr
Turnkey Systems provide Single-Source Solutions
CAE Computer Aided Engineering Penton/IPC Incorporated (1984)

[19] Anna Kochan and Derek Cowan
Implementing CIM - page 28
IFS (Publications) Ltd (1986)

[20] P.L.Primose
Selecting and evaluating cost-effective CADCAM
Computer Aided Engineering Journal (February 1988)

[21] Lockett

[22] Comment
CADCAM International (May 1989)

[23] Andrew J Miller
The Selection of a CAD System for Boart UK Ltd
Unpublished (1988)

[24] Book as [1]

[25] Hamlin
Human-Centred CIM
Professional Engineering (April 1989)

[26] As [12], page 117

[27] As [15], page 185

[28] Michael Skapinker
Financial Times (3 June 1990)

[29] Andrew J Miller
DOMS: User Manual
Unpublished (1989)

[30] Andrew J Miller
A Beginner's Guide to CIMCAD
Unpublished (1989)

[31] Miscellaneous
Technology "Shambles"
Sheffield Star - Business Section (1990)

[32] Engineering Data Control
Industrial Computing - page 25
October 1986

[33] The Changing Face of CAD
CADCAM Show Preview - page 14
February 1991

[34] Engineering Database Management
Industrial Computing - page 21
May 1990

[35] Manufacturers tip-toe to EDM
Industrial Computing - page 9
April 1990

[36] Drawing Control
CADCAM
September 1990

[37] Software cuts paper from engineering data
Industrial Computing - page 17
July 1990

(b) Bibliography

In addition to the books referenced directly:-

1. Jean Mermet
CAD in Medium-Sized and Small Industries
North-Holland Publishing Company (1981)

2. A.A.Berk
Computer-Aided Design and Analysis for Engineers
BSP Professional Books (1988)

3. CAD/CAM Systems. Justification, Implementation and Productivity Measurement
Marcel Dekker Incorporated (1984)