HUMAN FACTOR INFLUENCES ON EFFECTIVE COMPUTER AIDED DESIGN IMPLEMENTATION

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ABSTRACT

Computer Aided Design (CAD) has the capability to influence a company's competitiveness in terms of quality, flexibility and cost effectiveness of design. Consequently, the opportunities provided by the efficient and effective use of CAD techniques are vital to a company's operational and business success.

The aims of this research have been to;

1 Ascertain and identify the contribution and relevance of human factor and technological issues within a successful CAD implementation methodology.

2 Develop a human factor understanding which, when incorporated into an implementation methodology aids the introduction of CAD technology and increases the likelihood of realising opportunities.

The initial research is based on a review of the literature on CAD and a pilot study of six companies employing CAD. This identifies the mix of issues involved during implementation as being, Technical, Organisational and Human. It also highlights the main problems experienced by companies as a function of the levels of Support, Direction and Communication.

The above issues have been incorporated into a CAD introduction framework based on quality criteria. The results of this initial stage of the research have been substantiated by in-depth case studies of three companies, in various stages of CAD adoption and "Best Practice" activities have been identified for each area of the framework and related to the overall performance of the companies.

To widen the scope of the investigation and provide more evidence, the framework was then employed in the in-depth analysis of six further case studies. These identified CAD support as playing a key role in maximising CAD potential.

From this evidence a "Support Framework" has been proposed and validated via the results of a written postal questionnaire distributed to 1000 UK companies. Evidence from the 100 respondents of the postal survey strongly supports the proposition and suggests that companies are experiencing human problems, especially in the area of advanced 3D CAD. The problems are a result of inadequate internal support systems and can be overcome by the methods proposed by this research.

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LIST OF ABBREVIATIONS

AMT	Advanced Manufacturing Technology
AQUAP	Association Pour La Qualite Des Appareils a Pression
BS	British Standard
CAD	Computer Aided Design
CADCAM	Computer Aided Design & Computer Aided Manufacture
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacture
CE	Concurrent Engineering
CNC	Computer Numerical Control
DFM	Design for Manufacture
DTI	Department of Trade and Industry
EN	Euro Norm
GID	Graphical Information Distribution
IGES	International Graphics Exchange Standard
IIP	Investors in People
ISO	International Standards Organisation
IT	Information Technology
JIT	Just in Time
MACRO	Macro language
MOD	Ministry of Defence
NPD	New Product Development
SIC	Standard Industry Classification
SME	Small/ Medium Enterprise

TCA	Teaching Company Associate
TICKIT	Tick Information Technology
TQM	Total Quality Management
TUV	Technischer Uber Wachungs-Verein
VDE	Verband Deutsche Electrotechniker

ACKNOWLEDGEMENTS

In a study as large and varied as this it is necessary to rely upon the assistance of many parties. In the early stages of this research contributions were by six companies to a pilot study aimed at identifying research issues. Participants were quite worried about the consequences of their comments should their companies become aware of them and thanks must go to these courageous individuals, without whose assistance the research focus would not have been identified.

Contributions were also made by many other individuals and companies who took part in the case studies and national survey and I would like to acknowledge their assistance. In particular I would like to thank PLM Redfearn Glass for their help as a collaborating company and Simon Marriot (CADCAM Manager) for his assistance in providing technical information and guidance.

I am grateful to Professor D.R. Tranfield for his suggestions during the early part of this research and to Professor G. Cockerham for his help, guidance and continued support during the course of this research and for reading the numerous drafts of this thesis.

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Lastly, I am particularly indebted to my wife and daughter for their support and silent suffering during the many hours of research work done at home and also for their assistance with the mammoth task of collating the questionnaire survey and filling envelopes. Thank you Susan and Claire.

DECLARATION

I wish to declare that the work contained in this thesis is my own original work.

As the research developed, various elements of this work have been presented at conferences and published in proceedings on an ongoing basis. However, these publications represent my own work with contributions from academic and industrial colleagues.

In particular, Simon Marriot, from the collaborating company PLM Redfearn and from my supervisor Professor Graham Cockerham.

1.0 INTRODUCTION

The objectives of this chapter are to:

- Present and discuss the aims of the research.
- Give the reader a brief overview of computer system development and the role of CAD today.
- Summarise the structure of the thesis.

1.1 AIMS OF THE RESEARCH

The aims of this research are to:

1 Ascertain and identify the contribution and relevance of human factor and technological issues within a successful CAD implementation methodology, Specifically in terms of:

  a A company's capability to achieve opportunities available from the technology for enhancing company performance.

  b The individual employee's personal skill requirements and developments necessary to attain capabilities for themselves and the company.

2 To develop a human factor understanding which when incorporated into an implementation methodology aids the introduction of CAD technology and increases the likelihood of realising personal and corporate opportunities.

It is widely recognised that CAD has the capability to influence a company's competitiveness in terms of quality, flexibility and cost effectiveness of design. Consequently realising the opportunities provided by the efficient and effective use of CAD techniques is vital to a companies business success.

Human factors research is concerned with enhancing human skill, endeavour and welfare and its application to achieve greater effectiveness of the use of systems by personnel. However, perception of the meaning of the term "Human Factors" varies with the field of work and the objectives of the researcher but for this research human factors are taken to involve the cognitive aspects of computer interaction (1).

1.2 COMPUTER SYSTEM DEVELOPMENT

Modern computers have developed in the last fifty years, although their historical development can be traced back as far as prehistoric man. He began by using the most convenient tool he had, his fingers, to count his possessions. Hence the word "Digit" and the decimal number systems evolved from this. More sophisticated counting devices included the use of the Abacus and it is even suggested that the circle of stones at Stonehenge was a digital counting device constructed by ancient astronomers (2)

Mechanical computing originated in the seventeenth century with the device invented by Napier (3). In 1645 Blaise Pascal invented a gear operated device, which was the forerunner of the desk calculator. However his design was improved a few years later by the French mathematician Gottfried Leibniz.

In 1801 a punched card system for controlling the weaving patterns on looms was developed by Marie Jacquard and this formed the structure upon which Charles Babbage developed his "Analytical Engine" in 1883. Punched cards were also employed by Herman Hollerith in 1889 for an extremely accurate, electro-mechanically operated tabulating device. In 1890 the device was used to carry out the census in a third of the time that it normally took and it continued to be used up to the late 1940's.

Computing took an accelerated step with the coming of the second world war and particularly in 1943 with the need to provide trajectory and firing charts for a range of shells, at a pace which kept up with advances in weapons technology.

Aimed primarily at addressing this technological pace,. Mauchly and Presper Eckert of the Moore School of Engineering at the University of Pensylvania developed ENIAC (Electronic Numerical Integrator and Calculator) in 1946. This was the first electronic digital computer, but it weighed thirty tons, filled the space of a double garage and employed 1800 vacuum tubes with a failure rate of one every seven minutes.

Computers such as these were termed "First Generation" computers and were generally unreliable.

"Second Generation" computers evolved in the late 1950's with the development and use of transistors in place of valves(4). The resulting computers were smaller and more reliable than the previous generation of computers and generated less heat and required less power.

The major transition to "Third Generation" computers occurred between 1956 and 1962 with the developments in photolithographic techniques which allowed a number of transistors and their associated connections to be produced on an extremely small scale, and as a result the Integrated circuit evolved. Coupled with this, developments also took place with the linking of CRT hardware to computers and increased the mode of graphical interaction.

Further development led to the Intel corporation producing the first microprocessor (ie a micro-computer on a chip) in 1971. The first of this generation of computers were less powerful than today's computers and were extremely expensive.

Since that time the cost of computers in relation to computer power has reduced significantly, placing the technology within the financial capability of most companies, small, medium or large. Coupled with the reducing costs was a big increase in memory and computing power available from the technology.

The most important stage in the development of CAD however, came in 1963 when Ivan Sutherland, of Massachusetts Institute of Technology (MIT) displayed his "Sketchpad" system for drawing in 2D (5). This revolutionised the interaction of designer with computer and allowed drawings to be produced using a screen and light pen. Designers could input relatively simple drawings and obtain some simple analysis of such things as stress on the component.

In 1974 the Micro Computer (or PC) was born but initially lacked the memory capacity to operate well as a computer aided design tool (CAD).

However, since then advances have meant that even PC's have become available at low cost and with sufficient memory to run fairly complex CAD packages.

In the 1980's companies became more concerned with the rise in labour costs, trends towards more complex components and the high cost of design. As a result they also became more aware of the potential benefits of CAD(6) and wanted/ needed to implement CAD for a number of reasons.

Companies who were experiencing problems with reducing profits saw the advantages of implementing CAD to reduce inventory, increase Return on Investment (ROI) or to reduce the workforce. Other more successful companies saw the opportunities to implement CAD to increase their competitiveness whilst re-organising their operation or expanding into new markets. Others simply saw their competitors implementing the technology and felt they were being left behind if they did not implement the technology as well.

The major CAD vendors addressed these markets by offering a range of off the shelf computers with CAD capabilities and CAD became a viable commercial proposition for many more companies.

1.3 CAD APPLICATIONS

1.3.1 The Design Process

There are many extremely good publications which provide a source of information on CAD, its uses and applications (7-9) and so this will not be elaborated on in too much detail here. However, it is pertinent to provide the non- CAD reader with an overall view of CAD in order to identify its relevance to the following chapters in the thesis.

CAD is the application of a computer system to the design process with the intention of achieving one or more of a number of potential benefits, some of which are for operational efficiency and effectiveness and some more strategically aimed towards business benefits (10). In its infancy, CAD was introduced by companies purely to replace the drawing board and was expensive, with limited capabilities and quite slow. Often the implementation of CAD was based upon productivity increases, ie increase in drawing output which had limited impact on the overall business activity of a company.

However, the rapid advances in CAD technology have meant that implementation of the technology can have a much greater impact on business in terms of, increased sales, better designs, time and cost savings, reaction to customer requests through greater and more effective use of information within the company and greater efficiency and effectiveness of manufacture. Such benefits are particularly relevant to companies whose products:-

- Have long design/ lead times
- Require advanced techniques to define the design
- Require large numbers of drawings
- Have complex shapes (internal or external)
- Have strict weight and space constraints
- Require complex drawings, parts lists or large & detailed product support documentation

- Are part of a standard family of parts

However for many users, CAD still only implies "Computer Aided Draughting" and the automation of the draughting process. Essentially however, computer aided design (CAD) relates to using a computer system to translate an idea into an engineering design. As such, it is a tool which can be employed at various stages within the design process, not just for drawing output.

Shigley (11) describes the design process, as do others (12-13) as following the format below.

- **Specification Analysis** (*defining the constraints of the problem*)
- **Synthesis** (*Generating concept solutions to the problem*)
- **Analysis and Optimisation** (*Mathematical analysis to define optimum design*)
- **Evaluation** (*Ensuring that the solution matches the specification requirements)*
- **Presentation** (*The production of engineering drawings and sketches)*

Today's computer aided design systems are complex compared to earlier systems, but the principles are the same. CAD involves the representation of a geometric form stored within the computer system as either a two or a three dimensional model (2D or 3D). Both CAD representations can assist with the last four aspects of the design process ie Synthesis, Analysis, Evaluation and Presentation. However a purely 2D system will only represent shapes as flat objects, unlike 3D which stores information about shapes in three axes. Thus a 3D system (dependent upon the type) can provide greater visualisation of the product being modelled and knowledge not only of size or shape, but of volume and mass properties such as second moment of area (14) moments of inertia (15) centres of gravity, mass, geometric data for CNC machining etc. Many 3D systems also provide the facility to generate 2D drawings (used for production) directly from the model.

Current and future developments of CAD involve artificial intelligence in the form of expert systems(16) to build into CAD systems the basic rules and knowledge concerning the design of products.

1.3.2 Types of 3D Modellers

3D CAD is extremely useful for complex drawings such as, Forging or Moulding Die design (17) and chemical or process plant design where it is important to be able to identify clashes between pipework in three dimensions etc.(18)

Because the 3D model contains a complete record of the geometric design data, numerical analysis such as (FEA) finite element stress analysis, heat or fluid flow, vibration of components etc can be carried out with the appropriate integrating analysis software.

Three dimensional modelling of components on a CAD system takes three forms:

- Wire Frame Modelling
- Surface Modelling
- Solid Modelling

Wireframe modelling provides the ability to model pictorial views using a series of points in space joined by lines to represent the edges of the object as shown in Figure 1.1 below. Its advantage is that it can provide pictorial views of components which are not easy to interpret from 2D drawings, however as the model consists of lines, it can be confusing . The surface area or volume of the model is indeterminate and it is not possible to produce mass properties or machining information from the model. Because of this wireframe modelling has generally been overtaken by surface and solid modelling.

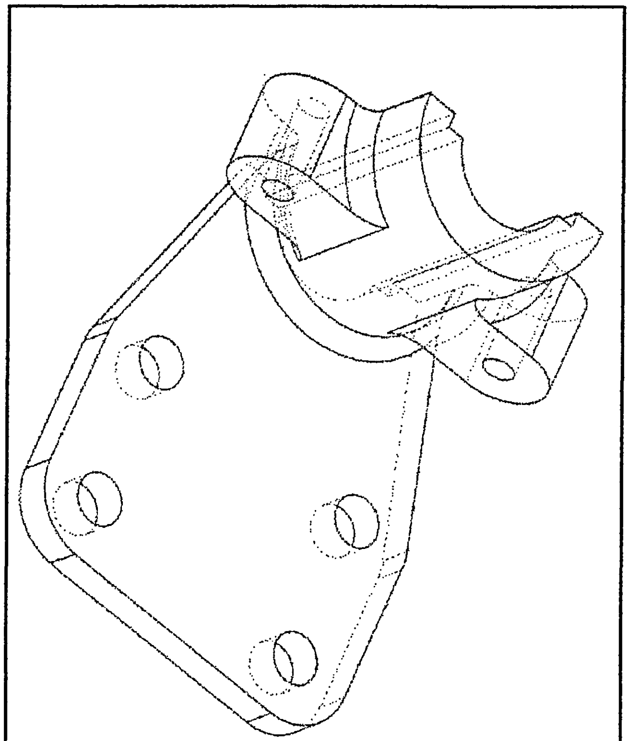


Figure 1.1 Wireframe model of a bracket base

Surface Modelling, shown in Figure 1.2, allows the presentation of the component in the form of a mesh, the fineness of which can be specified by the user. It is more generally employed for defining complex doubly curved 3D surface geometries for styling such as car bodies, aircraft structures etc. The surface model consists of points in space linked by "Patches" which form a surface skin of zero thickness. Surface mesh information can be used to provide machining information to produce a component or production tooling or passed to "Finite Element Analysis" (FEA) packages for stress and heat flow analysis to be performed.

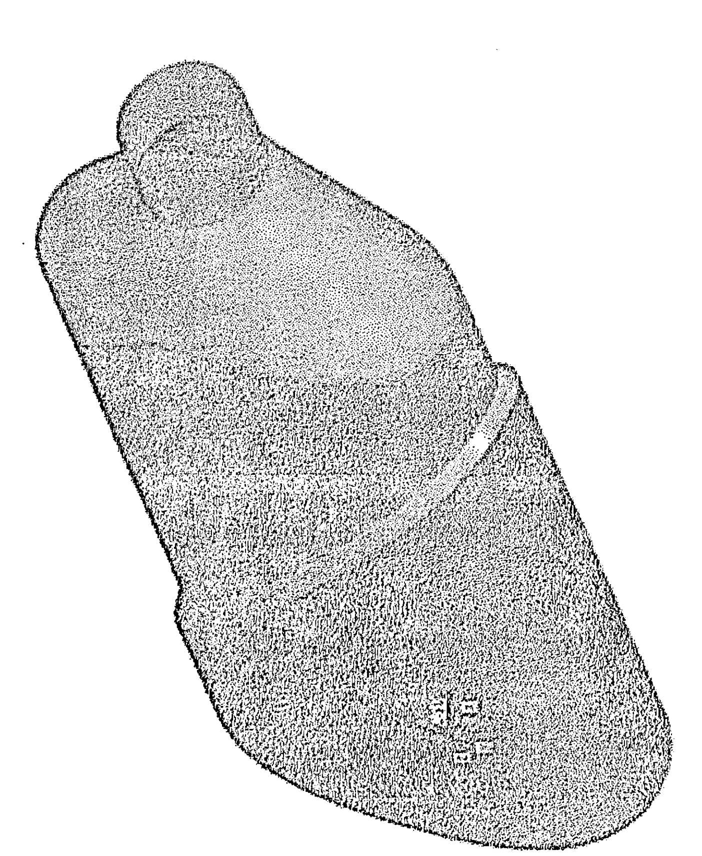


Figure 1.2 Surface model of a plastic bottle

Solid Modelling, illustrated in Figure 1.3, in which models are built up from 3D shapes, provides greater visualisation of a component, especially where the use of colour shading and highlighting is used. A solid modeller defines both the outer skin of the component and the material or spaces contained within it. It is possible to generate areas, volumes, weights, centres of gravity and moments of inertia from the model. The same is true of surfaces, but solid modelling computers are faster because "standard shapes" are used with formulae for calculating the areas and volumes etc.

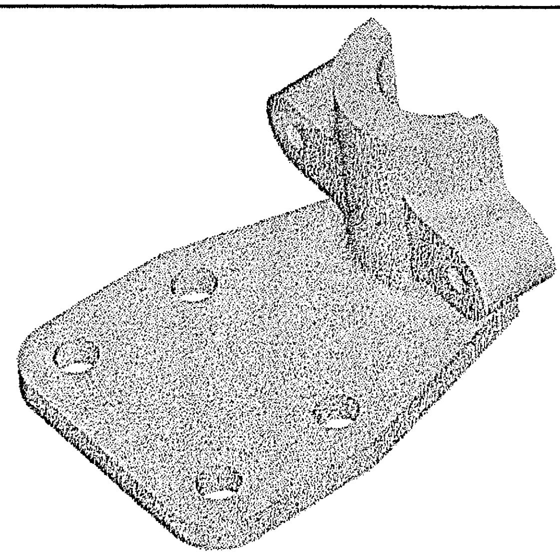


Figure 1.3 Solid model of a bracket base

However, although 3D may be regarded as the ultimate system in terms of potential benefits, there are drawbacks. A solid model is far more complex than a wire frame or surface model and the definition of a complex 3D object requires a large memory store, especially where companies are networking 3D modelling applications(19). The construction of models can be time consuming and difficult and great emphasis must be placed on accuracy of models where CNC/ CAM is to be employed than with models intended for drawing output or FE analysis. Generally it is not possible to machine a solid model directly, however many modern packages allow the user to convert to a surface type model before machining.

The time taken for designers to become fully conversant with such packages can be as much as a year and it is almost impossible to use, know or remember every aspect of a given system.

1.3.3 CAD- Fields of Application

CAD is used in every branch of engineering, too numerous to list completely, but as an example it is employed in:

- Mechanical Engineering
- Aerospace Engineering
- Petrochemical Industry
- Medical
- Agriculture
- Architecture
- Electrical and Electronics Industry
- Automotive Industry
- Food Processing Industry

Within these categories there are individual CAD packages written specifically for that industry and other packages that transcend the industry or product area to provide a package which can be used generally by any discipline. An important point to note is that over the last 10 years there has been a multitude of different CAD systems on the market from low cost to very expensive.

Compatibility between systems and the integrity of data can be a problem in transferring drawings from one system to another, in spite of the standard data exchange formats of IGES, STEP and DXF (20-22). This may generate problems for companies transferring data to, or from, customers and can negate the benefits to be gained from electronic format. Many companies employ more than one CAD system, often because companies have a number of separate departments, are subsidiaries or are part of a larger group and no strategic control exists over its use or purchase.

CAD is not just a function of the design department but is an integrating technology (23), having the capability to integrate activities and information across the company using geometric models for marketing, design and manufacture functions to provide a strategic impact on company performance.

Hence the aims of this research, to ascertain and identify the contribution and relevance of human factor issues within a successful CAD implementation methodology and to develop a human factor understanding for aiding effective CAD introduction is an important contribution to the engineering design field.

1.4 THESIS STRUCTURE

This thesis consists of eleven chapters and five appendices

Chapter 1

Reviews the aims of the research and the historical development of computers leading to the current day use of 2D and the more complex application and use of 3D CAD.

Chapter 2

Reviews the literature in the areas of Human Factors and relates the topic to the implementation of new technology and in particular CAD. It identifies three critical factors which influence CAD implementation, Strategic planning, Organisational change and Training and proposes their use as the initial basis of the research from thereon in.

Chapter 3

Describes and justifies the research methodology chosen for the initial pilot study and presents the results, identifying the focus for further research via case studies.

The chapter proceeds to describe and justify the methodology used for case study research and the framework employed for selecting companies for inclusion as case studies.

Chapter 4

Presents the results obtained from initial case study work and identifies the next phase of research development via further case study work.

Chapter 5

Presents the results obtained from further case study work.

Chapter 6

Discusses the results of case study work and presents a Model for effective CAD implementation together with propositions for further validation of the model via a national survey of UK companies.

Chapter 7

Describes the research methodology chosen for the national questionnaire survey and presents justification for its use.

Chapter 8

Presents the results of the national questionnaire survey.

Chapter 9

Discusses the results of the national survey. It identifies problems which companies are experiencing, indicates the limited internal support provided by these companies and the poor ratings which staff give this support.

Chapter 10

Reviews the three stages of the investigation, Pilot Study, Case Study and National Survey and draws together conclusions from each stage to show the significant influence of the research issues on CAD implementation.

Chapter 11

Presents conclusions and recommendations for further work.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews the literature in the areas of CAD and human factors in order to provide:

1) An understanding of:

- The issues involved in a successful CAD introduction and development.
- The meaning of human factors and their application to CAD.
- The role which CAD can play in the current and future operational and business success of UK companies.
- CAD implementation strategies and models for success.

2) Identification of the critical factors which influence CAD implementation as a basis for the research from hereon.

A) Requirements for Successful CAD Implementation

The results of a keyword search of the INSPEC Computer & Control Abstracts database, shown in Figure 2.1, clearly indicate that most research previously undertaken has been concentrated primarily on the technical aspects of CAD followed by organisational aspects, with little emphasis on human factor issues.

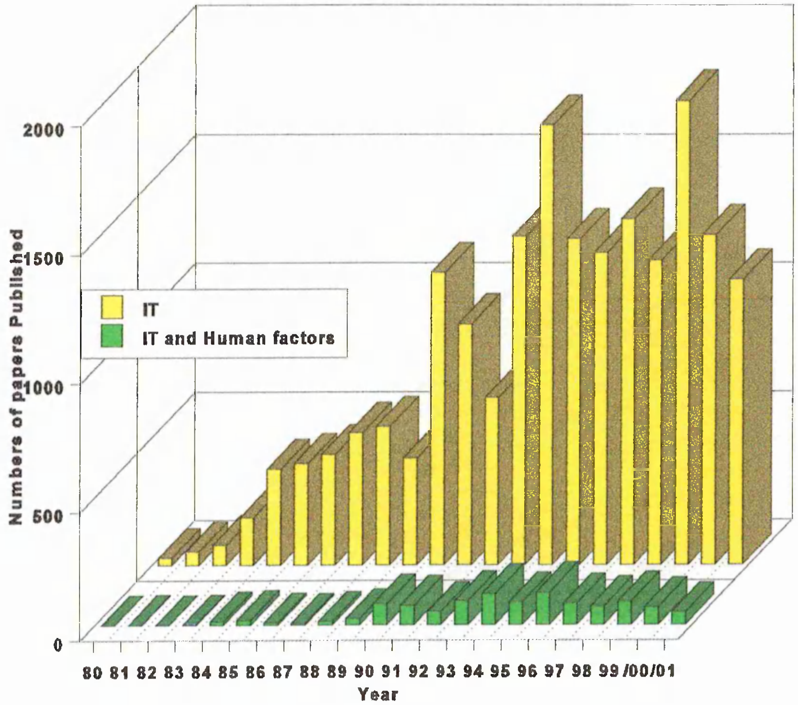


Figure 2.1a Results of search on the INSPEC computer database

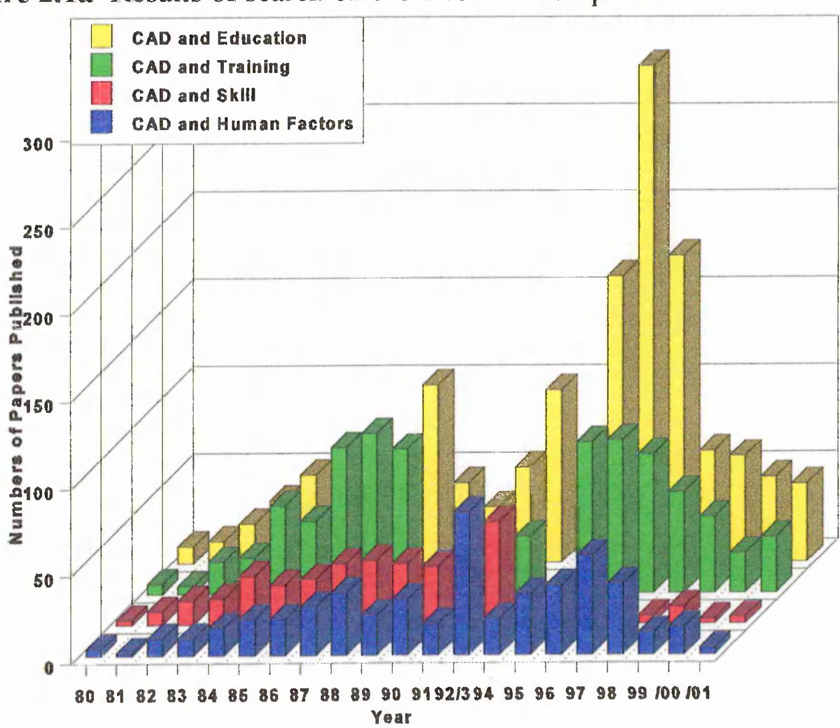


Figure 2.1b Results of search on the INSPEC computer database

Original in Colour

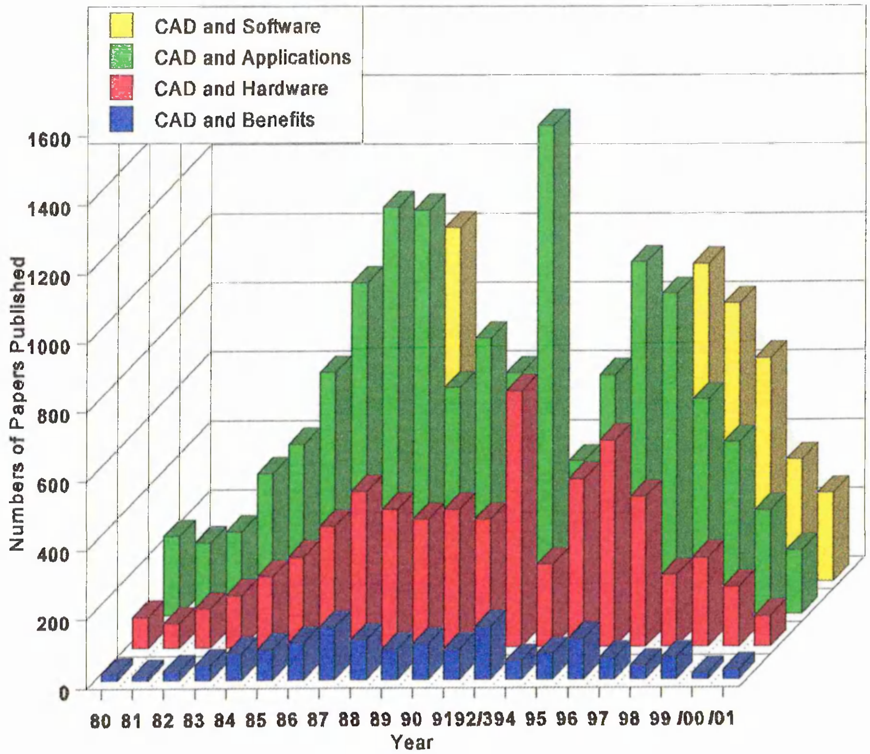


Figure 2.1c Results of search on the INSPEC computer database

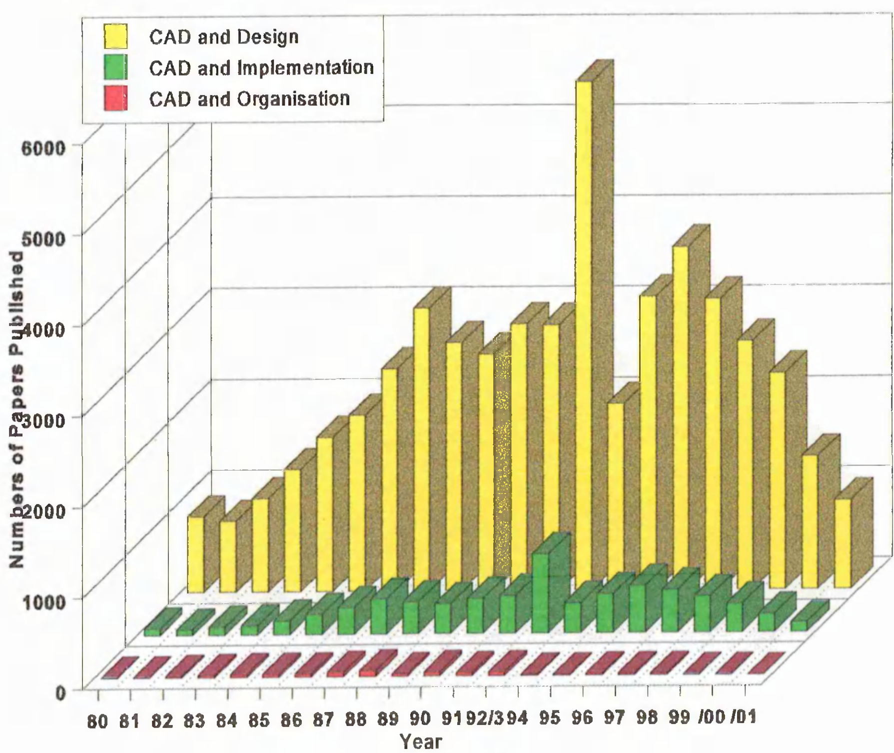


Figure 2.1d Results of search on the INSPEC computer database

 Original in Colour

However a more detailed review of the literature on CAD implementation suggests that to achieve both greater success and staff job satisfaction, companies should consider Technical, Organisational related (ie structural) and Human issues.

For instance, in 1988, in a report by Coopers and Lybrand (24) Stark reported that although CAD had been in use for the last 25 years, many companies were not able to report significant effects on the business. He states the reason for this is that companies do not address both organisational and human issues. Stark acknowledges that no one single form of organisational structure will be relevant to all companies or industrial sectors. Instead he suggests that what is required is an organisational structure which allows the CADCAM system to be used as effectively as possible.

Part of this structure will be the introduction of CADCAM procedures and he highlights three main ones as:

- Design office procedures- How design is carried out at the company.
- User interface- Procedures for creating symbols, 3D models.
- System procedures- by system support staff; eg printing, plotting, back-ups, archives, enhancements, security .

With reference to people, he advocates wider job classification and responsibilities, coupled with better training and job advancement linked to skills and results.

In the same year, Strachan, Cross and Black (25) reported on barriers encountered during the implementation of CADCAM at one Scottish company, classifying the critical barriers to effective implementation as "Organisational" and "Technical". They quote several organisational barriers which include:

- Middle management approaches/ CADCAM management
- Control of information.
- Responsibility and accountability.
- Training/ learning curves.
- Project/ workstation utilisation.

Strachan, Cross and Black suggest that technical barriers to effective implementation included:

- No CADCAM system expansion.
- The user interface.
- Applications ability of the system.
- Database size and re-use of data.

Their description of these "technical barriers" however show that many of the technical problems observed are really a result of management and organisational planning and decisions taken during the implementation process.

One year later in August 1989, Majchrzak and Salzman (26) also reported that research had shown that 75% of firms had not achieved their intended benefits of CAD. They too suggest that the reason for this was in-adequate planning by managers concerning organisational/ structured new technology change. Majchrzak and Salzman's viewpoint is to suggest that managers feel that the introduction of advanced manufacturing technology (AMT) does not require organisational and structural change and that any such changes would occur as a result of the technology; an unwise "Before the event" approach to CAD implementation. However, they cite research examples to suggest that when organisational change is considered alongside the technology, companies have a greater opportunity to achieve the anticipated benefits.

In 1988 Beaty and Gordon (27) in looking at a range of North American companies and surveying 200 managers and operatives, identified their own independent three barriers to successful CAD introduction :

- Structural- ie organisational structures and systems.
- Human- Employee perception, skills and biases.
- Technical-ie As a result of the incompatibility of CAD systems and the ability to transfer data between different systems.- *However, they consider such technical problems the easiest to overcome.*

Interestingly though, they cite that North American managers preferred action ie a short term, reactive/ firefighting approach to managing rather than careful long term planning. They traced these attitudes to the many implementation mistakes which they suggest they observed during the course of their research related to hasty decisions based upon impulse rather than any structured analysis of the technology. Beaty and Gordon therefore suggest that long term planning is desirable.

However, in conclusion they cite cases where companies did not undertake advance planning but still had successful results- provided that they:

- Did not make serious people mistakes.
- Had a facilitating organisational structure.

During 1989 Mortensen and Nehring (28) outlined some of the critical factors involved in increased CADCAM/CAE productivity in the USA through a study in which participants rated on a scale of 1 to 10, their perceptions of the effectiveness of planning, management support and training during and after the introduction of CAD. From their survey of 216 users, managers, vendors and consultants in a range of small and large companies, effective internal support organisation for the system is cited as the most important aspect required for achieving CAD effectiveness.

In conclusion they propose six critical factors for CAD effectiveness shown below.

- Formal procedures for review and evaluation of CAD issues and problems.
- Regular user/ management meetings.
- Use of the system for 3D as well as 2D.
- Use of an implementation plan.
- Continued formal involvement and support from vendors.
- The establishment of in-house support organisational system.

A more European perspective, within the field of electrical engineering was provided in 1993 by Kratzer and Kratzer (29). They emphasise the embracing nature of CAD on other departments in a company as well as the design department and propose that CAD introduction should be a project under the control of a committee made up of expert members from each department.

They further emphasise however that implementation is foremost an organisational activity and a technical activity second. They further suggest that CAD implementation without effective planning, preparation and structured training provides little improvement over conventional manual methods. Where an effective implementation methodology is employed, the benefits include productivity, quality, user and customer satisfaction. They particularly indicate that the "Human factor" role (ie employee motivation, job satisfaction and success with the system) is the prime element of any introduction methodology.

Even though the previous research cited above had resulted in significant recommendations for effective implementation, reports of problems with the implementation of CAD were still appearing in 1994 and the reasons for such failures were suggested by EDS Unigraphics at their 94' roadshow (30).

ie.

- Lack of clear business objectives.
- Lack of top down commitment.
- Lack of commitment on a day to day basis.
- Failure to address human and organisational issues.
- Training rather than educating users

B) Definitions of Success

Success may mean different things to different companies and individuals. In an earlier study by Short (31) 94% of companies believed their CAD implementation to be successful. Unfortunately 69% of the companies failed to achieve the benefits that they initially anticipated. Equally important is that most of the benefits were purely productivity related rather than technology exploitation related.

Black (32) and Kidd (33) suggest that to compete successfully in the future, success ought to be based upon competitive factors such as, quality, flexibility and cost effectiveness rather than just productivity increases. These early proposals were still being re-emphasised in 1999 by Kunwoo Lee (22) as vital for companies to survive worldwide competition.

Unfortunately, to date, the UK marketing of new technology has been instrumental in shaping the economic and productivity related selection and implementation criteria adopted by companies in preference to exploiting the potential of technology for human reasons. Bjorn-Anderson (34) highlights the above in a research paper concerned with human factors and the introduction of computer systems and suggests that "At the moment all we are doing is to adapt the technology to the known human weaknesses in order to reduce the resistance to the technology, rather than providing a technology which will help to liberate the intellectual capabilities of human beings ".

2.2 HUMAN FACTORS

A) Definitions of Human Factors

Perception of the meaning of the term "Human Factors" has been found to vary dependent upon the views and working objectives of the user. McCormick (35) suggests human factors research is concerned with enhancing human activity, skill and welfare and its' application to achieve greater effectiveness of system use by personnel, whether that system be mechanical, electrical or computer based etc. However, he also suggests the term may be known as biomechanics, engineering psychology or ergonomics.

Meister (36) attempts to give a more complete range of meanings of the term from:

a) The physical interaction of personnel, equipment, environment and job roles.

b) Skill requirements of personnel.

c) The effects of systems on personnel and vice-versa- ie effects on use, motivation and attitudes.

d) The term used to define the field of work undertaken by human factor specialists.

Beard & Peterson (37) give a more traditional view of the term; they consider physical aspects of computer interaction to be placed under the heading of "Ergonomics" whilst "Human Factors" would be involved with the cognitive aspects of computer interaction.

A definition obtained from the world wide web (38) indicates that in North America, ergonomics is known also as human factors and is used to interpret the science that relates to the design of products, systems and environments for human use. However, it appears to be more physically based with emphasis on the physical interaction of people and products.

Stanton (39) supports Beard and Peterson's view of Human factors but uses the words "Human Factors" and "Ergonomics" interchangeably. He concludes that the overall objectives of human factors are to " Optimise the Effectiveness and Efficiency with which human activities are done". He also emphasises its objective in improving the quality of life and makes specific reference to such things as stress, comfort and satisfaction.

This latter definition is the one which is used as the main thrust within this research work because it fits more closely with the organisational and structural introduction of CAD, rather than its physical introduction and use, although due recognition is given to the contribution of ergonomic factors to effective system use.

B. Approaches of Human Factor Application to Computer Systems

Clegg (40) points to the fact that even with the large endeavour that has taken place in human factors understanding, there remain very few models or methodologies which can be used practically to aid with the human/ organisational definition or application of what he terms appropriate systems requirements.

Clegg points out that this may be linked to the great variances in company organisations, cultures and subsequent requirements for new technology; which subsequently leads to requirements for different implementation strategies.

However he does accept that there can be some general trends which could be common to most companies' irrespective of their strategic differences.

Such commonalities and general trends between companies could be used to form the base point for providing tools and methodologies which could then be incorporated into an implementation plan for achieving maximum effectiveness; technical, organisational and social. To achieve this means that companies' would require a corporate identity of human factors which could be included into a corporate strategy.

The foregoing perspective falls somewhere between conventional approaches to human factors and that proposed by Kidd (41). He recognises the need to discard technology led approaches in favour of one which considers technology, organisation and people, but suggests that traditional human factor approaches also need discarding since their objectives have been concerned more with the technology than with appropriateness to company and employee. He emphasises the need to change thinking based upon organisational concepts developed in the 19th century and beliefs that employees in manufacturing were not required to use any skill, creativity, judgement or experience in their jobs.

Further evidence of such views abounds in the literature on I.T. Cross and Bawden (42) emphasise what other researchers have said and suggest that effective use of technology will only be achieved if sufficient consideration is given to human and organisational issues. They also emphasise the effect that I.T would have on the "blurring of job boundaries"

McCluney (43) also addresses the problem of employees. He observes that most businesses (especially IT) provide long term strategies for the maintenance and development of machines and equipment but often fail to provide similar long term strategies for the development of personnel.

More recently, authors are still indicating that the competitiveness of industry should be based upon human aspects and not just technological or price related aspects eg

Kochan(44).

Bullinger (45) points to human problems encountered by users of standard computer packages when applied to non-standard problems. He suggests that any computer application programme provides standardisation of problem conceptualisation and that should a problem fall outside the standard capabilities of computer packages it is the competence, experience and qualifications of the user that will influence the problem solution.

An example of one type of problem that may fall outside the constraints of software packages are given by Wolfe (46). He emphasises the irrational behaviour of CAD systems due to very small defects in CAD model representations which can result from:

- Operator error.
- Programming errors in the CAD software.
- Illegal geometry.

He suggests that in order to achieve effective CAD, both CAD users and their managers must be aware of the type of defects in CAD models, when and how they occur and how such problems are rectified. Clearly more fundamental understanding is required from a CAD user than just operating a system to reproduce a drawing or geometric model.

Bullinger states that to cope with non standard situations, users must have a commitment to continual training, particularly towards a self centred training approach.

This suggests that for companies to achieve objectives of technical, organisational and business success requires a rethink on organisational and policy approaches in order to engender this culture into the company across the board.

On a practical level this culture change therefore needs to embody the concept of structured training and education in a wider sense than immediate training perceptions of the workforce. ie broad based training within a range of subject areas; structured training for tomorrow not today.

Unfortunately the incentives to persuade a workforce to accept the need for such training are not always there. In particular, Liker & Fleischer (47) undertook a survey of two large companies involving seventy four CAD users and thirty non-CAD users. One of their results was that whilst the general perception is that managers would choose the better educated and qualified personnel to use CAD, for some reason education reduced the chances of being selected to use CAD. Further to this they suggested that a ten year age difference between designers produced a 20 percent lower probability of being selected to use CAD. To some extent, certainly in the early days of CAD but less true today, age discrimination may be related to younger staff being more computer literate and keen to further their careers than older staff.

Mandeville (48) in a quantitative survey to discover the impact of a CAD system on the design and draughting personnel within an American product design engineering company relates their job characteristics' perceptions in terms of skill variety, autonomy, responsibility, team working, work based learning and their degree of involvement in the work etc. to the routineness of the job.

He finds that the role of draughter & designer correlates closely with individuals perceptions of routine and non-routine work. An idea which is probably backed up by the traditional view of the designer as an innovator and creator of ideas with a wide knowledge of engineering topics, able to apply critical thought to new and challenging problems, whereas the draughter would be involved in the more mundane work of translating the ideas into working drawings.

According to Mandeville those involved in doing routine work appear to have reached a lower educational level than the non routine group. It is within the low experience group of routine workers that he sees his main conclusion; ie this group tends to perceive more negative aspects from the introduction of CAD than more experienced users.

Obviously the very subtle differences between employee perceptions are difficult to analyse or pre-determine since they will depend upon background and experience.

For example, some people would perceive a half cup of water as being half full and some as half empty; perhaps the perception being a function of accustomedness to having or not having and the need to have.

Consequently the above set of factors, although not leading to an understanding of individual perceptions, does indicate that their perceptions may be modified by experience and training.

This suggests that prior to and during implementing a change from manual design to CAD, a company will need to consider aspects such as:

a) Preparing the workforce early on to accept this and any other future technological change through continual training, education and support.

b) Ensuring a need that the technology is relevant to the company and the workforce.

2.3 THE NEED FOR CAD

There appears to be fairly widespread agreement amongst experts and practitioners regarding the general benefits and limitations of CAD (49-50) such as increased productivity, quality, visualisation etc. and these were indicated in chapter 1, therefore they will not be discussed in detail here.

However as Black(32) points out the realisation of these benefits is related to the corporate strategy formulated by the company towards product design and its' effect on business success. He suggests that such a strategy is strongly influenced by the market place and should be directed towards achieving the development of "New" products able to compete with other companies products.

In his paper on human factors in computer aided manufacture Kidd (33) quotes Bolwyn et al-1986 and gives evidence to support the above idea indicating how non-price factors have become significantly more important than price factors since the 1960's. Kidd suggests that flexibility had become a competitive factor requiring companies to be able to continually update and customise products. He further predicts the way forward for achieving a competitive edge in the 1990's and beyond as involving quality, flexibility & cost efficiency. To do this successfully he suggests that companies need to become "learning organisations" in order to continually improve operational and business activities.

These factors are now more prominent because of the requirements of the market for large product variety, short product lives and lower production costs.

CAD (both as a stand alone or integrating technology) has the capability to help companies achieve the competitive factors outlined above and examples from the literature are discussed below.

Macphee (51) illustrates the influence that CAE can have on the quality of design and subsequently on the overall product cost during the design and construction of process plant. His paper considers the design of process plant using an integrated CAE system, ie a series of databases linked together with a 3D modelling system. He identifies five areas where he sees cost benefits being obtained by using CAE:

- Design Quality.
- Design Effort.
- Programme savings.
- Materials.
- Design visibility.

Macphee quantifies the overall cost savings as being in the region of 4% to 5% for typical process plants, which on a multi-million pound project is a significant sum.

Mills (52) parallels Macphee's proposal within the field of automotive engineering and quotes examples from Ford and Rolls Royce to show that 70% to 80% of the manufacturing costs of a product is influenced at the design stage.

Consequently the opportunities provided by the efficient and effective use of CAD techniques is vital to a companies' business success.

Mills also suggests that designers can be helped to improve their designs and consequently final costs, by employing tools such as Design for Manufacture (DFM), design for assembly (DFA), failure modes and effects analysis (FMEA), value analysis, and material selection etc. which are integrated into the CAD/CAM system.

Ebel & Ulrich 1987(53) undertook a comparative study of CAD from eight different countries; France, Germany, UK, Hungary, Sweden, USA, Japan and the USSR. At that time they hypothesised that the use of CAD provides new or additional fields of technical work such as 3D, macros, kinematics & simulation etc.

Any new fields of work will require staff to be both trained and supported to execute their job roles efficiently. Thus part of the research strategy adopted within this thesis will be to examine the take up of such training and support issues by companies in relation to the length of time that CAD has been employed at the company and the length of time CAD technology has been available.

From his experience as a consultant and involvement with a number of CADCAM implementation projects, Looney (54) emphasises the human aspects of CAD usage and suggests that the technology provides opportunities to improve personal characteristics of the employee in terms of personal effectiveness, motivation and development etc. However he warns that because managers believed the introduction of CAD would generate resistance to the change, they limited training to "basic" or "awareness" training and as a result were not therefore achieving the maximum potential from their systems.
One company's view, based upon experience (55) encompasses both of the above themes. Davy (Sheffield) were forced to implement new technology because of competitive needs but believed that the changes would also have an important effect on human issues such as the attractiveness of the job and upon other peoples image of engineering.

2.4 IMPLEMENTATION STRATEGIES

Several authors suggest that CAD is an integrating technology. Majchrzak et al(56) stated that CAD should not be introduced in isolation but should be integrated with the other sections and departments within the company so that there is joint use of information. O'Reilly (57) discusses the integration of CAD and CAM into an electronic CAE system for PCB and hybrid microcircuits. He too identifies the benefits but explains that the systems available were not completely integrated and users were not sufficiently CADCAM aware to be able to plan the implementation of a new technology and at the same time plan the integration of the CADCAM tools.

Miles (58) supports the views of Majchrzak and re-iterates the comments made earlier in the literature survey about changing market requirements in terms of quality, cost and lead time and discusses the role of Simultaneous Engineering in addressing those issues. In particular he emphasises the benefits of integration of information, such as:

- A common database and data input.
- The ability to re-use/ extract information and data.
- The ability to trace the history of decisions.

He illustrates how integration of data is employed between concurrent engineering design tools such as DFM, DFA, FMEA, QFD etc and explains that the use of such tools is a critical requirement for effective product introduction.

Such design tools, originally developed as design philosophies and techniques, can be employed both manually or as computer tools.

Therefore in undertaking the case studies and national survey within this thesis, evidence of the use of such manual tools or their integration will provide a view as to whether a company is doing more than just using CAD as an electronic drawing board.

Bessant et al (59) however make the point that the full potential of the technology is often restricted because companies fail to achieve simultaneous organisational and technical change.

However they also argue that it is impossible to plan organisational change simultaneously with technological change; their solution being concerned with finding the best fit between choices and contingencies.

In a paper on AMT Smith & Tranfield (60) propose that it is possible to derive broad trends which will presumably aid obtaining this best fit, even though companies have different organisational structures, markets, products and abilities etc.

They suggest that the pivotal trend should be focused on providing an organisational structure which embodies the concept of flexibility and decentralisation. Such comments are also supported by Stark (61). He suggests that there is no one CADCAM organisational form but that traditional hierarchical forms of organisation are not appropriate for a CADCAM environment. Instead he recommends flatter organisational structures together with broader job responsibilities and free flow of information between functional areas of the company.

In a latter paper in 1988 Tranfield & Smith (62) also note the importance of a culture (such as the Japanese) which sees planning as being a shared responsibility and experience between all levels of the workforce. They also identify the "pace" of change in terms of a "sprint" followed by a period of calm, as being a key element of any strategy which will lead to the successful implementation of technology.

The "pace" of change suggested is really a common sense logical idea that most people would acknowledge in practice but unless it was formalised, may well not accord effective planning and control.

Any change will not occur overnight and employees need such periods of calm in order to consolidate their learning & to recuperate from the 'Sprint".

Fleischer et al (63) see key factors in CAD/CAE implementation being encompassed by the socio-technical domain. They provide a model of this for effective CAD use which they categorise as shown in Table 2.1.

TECHNICAL FACTORS	SOCIAL FACTORS
Technology	Designer
Design Task	Implementation Process & Support
	Job Design
	Organisational Design

Table 2.1 Model for effective CAD implementation

They state that the social factors are often not considered by companies during the planning and introduction of CAD. In talking about these social factors in respect to Implementation and support, they suggest that "Training" and "Support" are important issues to be addressed. In particular they cite that effective training should be spread over long periods of time, with adequate opportunities for practice and feedback, unlike conventional short, intensive, vendor CAD training courses.

More importantly, they identify a number of support issues such as:

- Support for the Initial Design, Update and Maintenance of the Database.
- Training for new procedures.
- Support for upgrading software and Hardware.
- Support for learning the system.

One very major warning statement made by their paper is that the cost of support may well exceed the cost of CAD. Therefore this aspect will be borne in mind within this thesis and the levels of investment in support and particularly training will provide an indication of the levels of support afforded by companies.

Based upon his vast experience as director of Coopers & Lybrand and particular responsibility for CADCAM & CIM marketing and development, Stark (64) states that to achieve the benefits of CADCAM, rather than just drafting, it is necessary to undertake substantial investment both in people and in developing a suitable organisational structure. At the time of his paper he suggested that the organisational structures of many companies did not support effective use of CAD.

He suggests that managers will be the key personnel who can influence and develop an effective organisation and therefore they should possess a good understanding of CAD/CAM.

Within this organisation he identifies several elements for success such as a relatively flat hierarchical structure, well defined roles, responsibilities and limits of authority.

But he also gives recognition to the fact that the lack of motivation by the workforce to the goals of the company can have a significant influence on success even if a suitable organisational structure has been adopted.

He offers ideas for management to motivate staff, which include the need for more human centred flexible approaches to organisation, broader job specifications & responsibilities and improvements in education & training coupled with clear opportunities for advancement and promotion. Opportunities which he suggests should be linked to abilities and achievements and not to hierarchical position.

In his final keynote address at the 1991 Effective CADCAM conference, Turner (65) of Rolls-Royce plc cited the status of CADCAM within engineering as a whole and his own company. He concluded that too many people introduce CADCAM as an electronic drawing board, without using the opportunity to employ the technology to gain the full potential benefits associated with it, as a strategic weapon for improving business and functional success.

With the latter idea in mind he sees success being related to the full utilisation of a systems capability in conjunction with the facilitating ability of Concurrent Engineering (66).
However a report in the 1991 Engineering Computers journal (67) tempers such thoughts with a note of caution; when using concurrent engineering the blurring of responsibilities due to the flat or matrix organisational structure can sometimes mean that it is not obvious who has responsibility to sanction decisions and costly mistakes occur unless a well documented authorisation system is in place.

Parreti (68) and Black (69) also approach the use of CAD together with a simultaneous engineering process re-0rganisation as an influencer of success. Parreti concludes that it is imperative for companies to implement CAE and Concurrent Engineering if they are to remain competitive.
Within this field Black sees the need for both organisational change and effective use of the CAD facility. To support the design process he urges the use of several techniques eg design reviews, value engineering/ analysis, failure modes & effects analysis, taguchi methods and design for economic manufacture etc. and further suggests the use of multilateral communication structures for the design group.
Although Black does not refer to it, such supporting techniques will also help companies (with or without CAD) to develop standards leading towards Total Quality Management (ISO9000) and a right first time approach to design, thus leading to a more competitive business.
Although the foregoing ideas may be what are required for success, Farrar (70) discovered that many vendors of CADCAM suggest these basic design techniques are not employed in user companies. This implies either that the company does not perceive any use for these

techniques or that there is a lack of training.

Unfortunately Farrar also states that diversity of training correlates strongly with the successful use of CADCAM. He suggests one of the main problems is convincing managers that a large proportion of the product cost and product value is determined at the design stage.

For Evans (71) the prime advantages of CAD arise as a result of the use of 3D visualisation and stress analysis etc. and relate to both the downstream time & cost savings made at the design stage and the improvement in product design because of the iterative capabilities of the CADCAM system.

Corbett (72) also highlights the link between the designer and reduction of costs at later stages in the production process. However he suggests from his studies that designers who used techniques such as design for economic manufacture could not be expected to have an in-depth knowledge of all manufacturing processes.

The answer may therefore be to provide suitable training or to use specialists for particular areas of a design.

As Whitney (73) points out though, design has become dominated by fragmentation and specialisation. He proposes the use of multi-functional teams as the most effective way of producing good designs.

In the editorial article on CADCAM by Evans (70), the use of multi-functional teams is also proposed as a method of improving the transfer of data between the design function and

and other areas of the company thus leading to improved productivity. However the article sounds a note of warning, suggesting the crossing of functional barriers is a problem which is not overcome easily.

Kristin (74) in his paper on the use of 3D-CAD for the design of chemical plants acknowledges the multidisciplinary nature of the groups of people involved in the project and proposes that a key factor in success is effective coordination and management.

Within this area Simmonds & Senker (75) illustrate some of the key lessons to be learnt from the implementation of CAD in the heavy electrical engineering industry.
They suggest that people are the critical determinant of success and as such require increased training, support and feedback in technical, design and interpersonal skill areas.

Sinclair (76) in his paper based on the ALVEY research programme, approaches human design issues in CAD from a technological solution rather than a human one. In discussing CAD systems of the future he describes user problems which occur with CAD and indicates developments which could lead to a more effectively defined model of the CAD system based upon design styles and user characteristics.

Traditionally high technology software firms have been seen to be relatively successful, and tend to be characterised as employing highly motivated staff. Whilst such companies cannot be directly compared with an engineering company, it may be possible to extract some elements which relate to their business success and apply these to the strategy that an engineering company should perhaps employ.

Licker (77) provides such elements as being concerned with:

a) Management of company structure.

b) Market awareness.

c) Product management.

Unfortunately in many engineering companies the intent is often to concentrate on (c) with little attempt to be involved with (a) or (b). Licker's ideas for success fall in line with the ideas of Coddington (78) for the requirements of engineers in the year 2000 onwards. Coddington perceives that engineers would need a knowledge which is broader than the immediate technical requirements of their jobs; eg a working knowledge of all company departments, communication & human factor skills and an ability to adapt to change.
All of this probably means more work, time and effort on the part of the engineer who will have to submit to many changes and maybe to the concept of continual development & learning. Whether or not staff would survive in such an environment and indeed operate at their maximum effectiveness or even remain with a company is thus very dependent upon that company and the strategy it adopts towards people and technology.

Garden (79) relates some of the reasons why people leave jobs. In brief they generally need to have recognition from senior management of their contribution to functional and strategic areas of the company. Obviously if such recognition is not forthcoming staff will lack the motivation to become totally committed to the work and both functional and strategic areas of the business will suffer.

This literature review has shown the very wide and varied opinions held by other researchers concerning the factors which influence the introduction and development of new technology. Opinions vary, as do researchers definition of terms. As early as 1988, Kidd in his paper on technology and engineering design (80) was warning of the dangers of developing technology without consideration of society and people. In his later papers he suggests that the use of new technologies for the 1990's must involve consideration of the technical factors of organisation and people (and not the human factors of the advanced manufacturing technology).

However all of the foregoing elements are influencers, to some degree, of the effectiveness of implementation and use of the technology and are associated with human involvement. Consequently all of these elements will be considered here under the umbrella of Human Factors; much like the broad definition of human factors proposed by Corbett et al (81) in their paper related to Esprit Project 534.

The continued interest in the introduction and implementation of CADCAM systems together with the optimisation of the use and application of such systems, is evidenced by the publication of specialist magazines such as CADCAM. In the period April 1998 to December 2000 there were eight articles concerned with these topics. For example, Hall (82) reports on the contribution to the successful introduction of 2D/3D by Rolls Royce and Xerox of continuing in-company training and support. In the same journal, 3 months later, Barker (83) describes the recognition by CAD suppliers of the importance of a help desk in ensuring best practice is introduced into their customers operations. In two articles in early 2000, Gott(84) and Matthews(85) introduce the concept of the user as the most valuable element in the CADCAM system. Matthews argues that training and support will always be important as part of the implementation process to enable even mature users to maintain competence as software vendors increase the functionality of their new software releases at a staggering rate. Gott says much the same thing by describing the concept of three kinds of capital investment deployed by organisations; financial capital, knowledge capital and social capital with the latter two representing a well-trained and supported design workforce. Even as recently as December 2000, Gamal Lashin (86) a senior engineer at the transportation systems division of Siemens, in describing the massive benefits coming from an integrated 3D system for product and tooling design, still pleads for patience and support for the development of trainees.

Other, less specific journals have reported work in relation to CAD systems in the 21st century. Leutner (87) describes a training and support technique for CAD called double-fading-support , which has proved successful for a variety of participants and software systems. Similarly, A group working in the US (88) have interviewed staff in 143 firms and comment that training is very effective in improving performance across the board; concluding that 'sophisticated state-of-the art CAD systems require more pro-active management than highly functional ones.

Lacy(89), technical manager of PDD innovation consultancy in London, states that the possibilities offered by 3D CAD, far outweigh those of systems from ten years ago. However he warns that such systems are often in the hands of newer and smaller users who are unaware of the management support functions required in order to achieve the maximum potential from the technology.

2.5 LITERATURE REVIEW SUMMARY

1. A great deal of time and effort has taken place in researching CAD.

2. Much of the research work carried out into CAD has been concerned with technical aspects rather than "human aspects".

3. Where research work has considered CAD together with human factor issues as

defined earlier, much of the research work has been qualitative rather than quantitative.

4. The overwhelming opinion of researchers appears to be that to achieve success companies must consider both human and technical factors.

5. They generally identify the implementation of CAD technology as being a long term, continuous process of change and development.

6. The critical factors which are seen to influence implementation relate to such factors as:

a) The formation of an effective implementation plan linked to a strategic business plan.

b) The near simultaneous technical and organisational change directed at obtaining the full potential benefits of the system.

c) The degree of training given to all members of the company concerning technical, human, social and business factors.

d) The engendering and controlling of an appropriate company culture which emphasises continual learning and provides suitable opportunities and rewards.

e) The degree of support provided to users

7. Very few tools, models or methodologies exist to provide companies with an opportunity to maximise the effectiveness of the implementation process; only broad trends exist.

3.0 RESEARCH METHODOLOGY

3.1 INTRODUCTION~SOCIAL RESEARCH METHODOLOGY

Investigating human factor issues in CAD implementations will rely heavily on techniques developed in the field of social sciences.

Research methodology is concerned with the strategies and techniques employed (by social science researchers) to assist in collecting, analysing and interpreting data. Being a mature subject, numerous books and other material describing the philosophy of social science research have been published over the last fifty years providing researchers with a range of methods for social inquiry. A large selection of chapters on these methods, by separate authors, are provided in a book by Shaffir and Stebbins (90). The emphasis of their book is concerned with the four aspects of research shown below and it provides examples of how others have conducted research previously.

- Entering the field.
- Working in the field.
- Organising relationships.
- Leaving the field.

Similarly chapters on social science research by distinguished social scientists are provided in a book by Burgess (91). In the editors preface, Burgess suggests that social science embodies two main elements which are considered equally important requirements for understanding; theoretical and empirical evidence. Much of the empirical understandings within the social sciences is obtained from exploration and investigation and may involve both qualitative and/ or quantitative inquiry.

Social research often employs qualitative enquiry in order to compose a more thorough understanding of the research area in question and because of its lack of quantitative evidence, is criticised by some researchers.

Stake (92) cites such critics eg Walker (93), Miles (94). However Stake suggests that although qualitative enquiry is subjective, this is not a fault and its use is justified and beneficial in obtaining a greater understanding of a given situation. He does acknowledge though that qualitative inquiry may take a longer time period and may change during the research. Stake's view is supported by Myers (95) who indicates that qualitative research methods are becoming more appropriate in industry as research tends towards managerial and organisational/ administrational issues rather than technological ones.

There are a number of qualitative inquiry methods which include:

- Naturalistic- Undertaking research in the natural setting without any prior, pre-conceived ideas about what to research and without any theories/ hypotheses. Lincoln and Guba (96).
- Holistic- The investigation of an overall organisational human system at a micro and macro level. Lippitt (97).
- Ethnographic- The fieldwork research study of cultures culminating in a written work which describes the culture. Neuman (98).
- Phenomenological- Relating to the study of human consciousness and awareness(99).
- Biographical- A written history of the life of something or someone- Websters English dictionary (100).

3.1.1 FIELDWORK

The qualitative research inquiry methods highlighted above are ideal for working in the CAD field and are particularly relevant to case study work; ie investigation in detail of a given case.

The field research work within this thesis is presented as an exploratory study of the area of CAD introduction and subsequent development. It employs an ethnographic approach, using mainly qualitative methods for case study investigation and evaluation; ie interviews, review of company documentation and participant observation. However, it also employs a limited amount of quantitative data, obtained from a national survey which is designed to validate the results of case study work.

This thesis describes single case studies in some detail and proceeds to compare and contrast the cases, proposing outcomes as indicative rather than representative of industrial/ organisational situations as a whole.

Cassell and Symon (101) suggest that qualitative case studies are ideal for exploratory work because they allow hypotheses to be formulated.

Case studies may include a number of methods such as:

- Active participant
- Observation- As a researcher.
- Structured, unstructured and/ or semi-structured interviews.
- The analysis of organisational, administrational and management data.

They also suggest that researchers will use a combination of the methods, dependent upon the complexity of the subject area and also to obtain Triangulation of data. Campbell and Fiske (102) suggest that triangulation involves using a number of research methods to analyse the same problem from independent viewpoints. The advantage of this is that greater validity can be given to the interpretation of results.

Jorgensen (103) describes "Participant observation" in case study work as the act of the researcher becoming an active participant in the daily life of people in the study (not just for observation).

Whichever definition you choose, in my research both active participation and observation as a researcher are employed; active both within the collaborating company and as an academic supervisor for a Teaching Company Programme and as an observer at other companies.

Jorgensen extols the virtues of participant observation in terms of a whole host of activities including researchers ability to study and describe processes, relationships and events and developments over time. In particular he emphasises that participant observation is very good for exploratory and descriptive studies.

Whyte (104) discusses what he calls "Participatory Action Research" and considers this one step up from the investigation of a total socio-technical system. He suggests that the traditional socio-technical framework provides the paradigm that work environment analysis depends upon the integration of social and technological factors and that such integration depended upon the skill and knowledge of the behavioural scientist. He concludes that a better approach, would be to involve the participants in the study as active participants in the research, because they have greater knowledge of the technology in operation within the area being researched.

To some extent, the approach of actively engaging participants in this research, has been employed in case studies B, C and to a lesser extent in case I; described in sections 5 and 6. However, it is possible that involving participants of a study as active partners could alter the neutrality of day to day activities and their subsequent observation.

3.1.2 Conclusion

The foregoing review of social research methodology indicates that employing several methods, such as active participation, observation and structured and un-structured interviews, rather than a single method, are important to establish understanding and develop and validate the propositions.

3.2 OVERALL CAD IMPLEMENTATION RESEARCH METHODOLOGY STRUCTURE

McCormik (35) writes that his objectives in surveying relevant human factor issues has been to delineate each topic and characterise main ideas and concepts. This is a method of working which many engineering and scientific practitioners adopt and then subsequently apply to real world situations.

History shows us, Spicer (105), however that the implementation of even a very simple technological tool, such as the introduction of the wheel to the Papago Indians, can create a multitude of changes to the working and social life of individuals and groups. Compared with such older and more traditional technologies, CAD is highly developed, complex and requires greater skill and training to maximise its effective application in the design and manufacturing industry.

Thus the complex linkage of CAD areas within a working environment is not easily analysed through such a piecemeal approach as McCormik's and is analysed here through a Total Systems Approach to the problem. Lumsdaine and Lumsdaine (106) suggest that typically, most people consider problems in isolation rather than adopting a more holistic systems thinking approach. They describe the difference in the two approaches by referring to the differences between Eastern and Western medicines where Eastern medicine treats the whole body not just the individual component part. For my research this means having initial research themes but considering them in the context of the individual companies being investigated.

The literature review in chapter 2 has shown the wide and varying issues which have been seen to influence the effective implementation and use of CAD. Previously these issues have been considered in isolation, whereas the proposition of this thesis is that they should be considered together.

To this end, the findings from the review have been collated and expanded into a number of research questions surrounding the HUMAN-TECHNICAL-ORGANISATIONAL framework.

The questions, which cover activities, behaviour and perceptions of individuals, groups and companies have been listed under the seven main research headings shown below and are presented in detail in Appendix A1.

1. Company history & culture.
2. Opportunities from CAD.
3. Effects of a change to CAD on company issues.
4. Effects of a change to CAD on human factors.
5. Group & intergroup activities.
6. Implementation strategy.
7. What problems have occured during or since implementation.

The research structure following on from the literature review is shown in figure 3.1. An initial pilot study of companies was employed, using the questions from the research headings above, to define the main research areas to be further investigated.

Following on from the Pilot Study, "Three" initial in-depth case studies (Companies "A", "B" and "C") were undertaken to provide in-depth knowledge of companies to ascertain good and bad working practices in the defined areas. They were also employed to ascertain the effects of human issues on CAD's effective introduction and development by addressing these issues accordingly at source.

Companies "A" and "C" were entirely separate companies from those used in the pilot study, whereas case study company "B" was company "1" in the pilot study.

The initial three case studies identified the main issues emerging from CAD implementation such that further research could focus on these areas.

Six further case studies (companies "D" to "I") were undertaken to validate the findings from the previous three initial case studies. For clarification, case study company "F" was company number "2" investigated during the initial pilot study. The rationale behind including a pilot study company in both the initial and further case studies was to provide a link between the two levels of study and to ensure that the issues identified were relevant throughout the study.

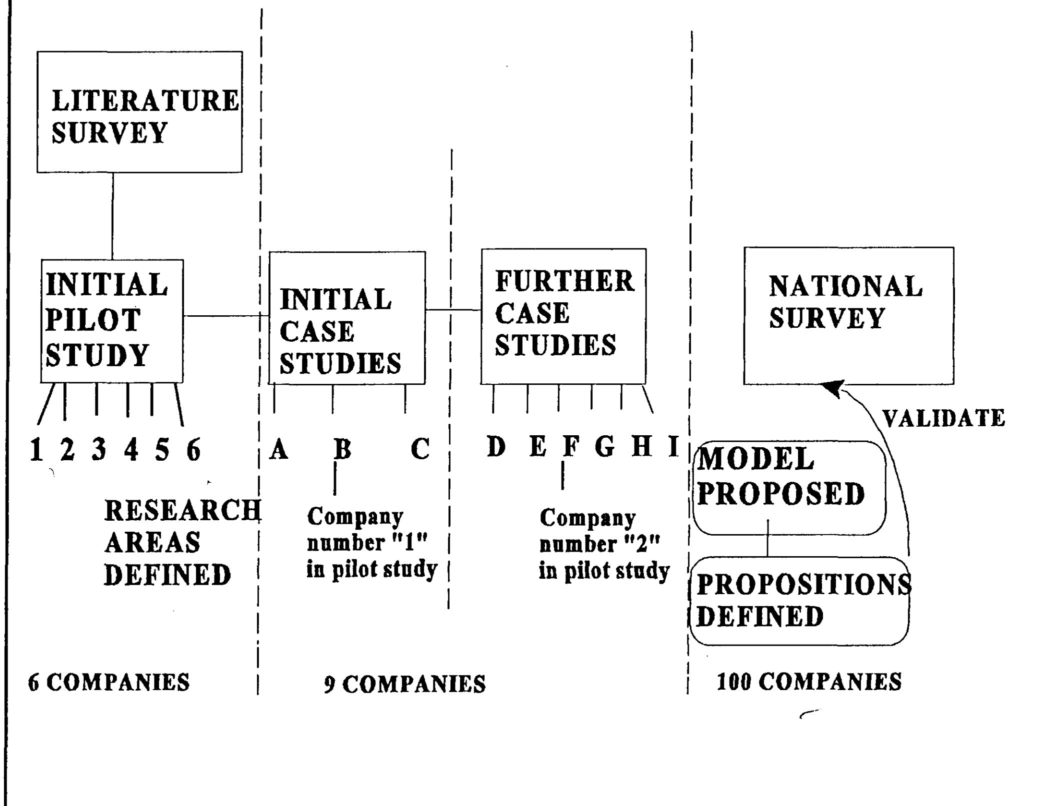


Figure 3.1 Overall CAD implementation research methodology structure

Generic themes drawn from all nine case studies are proposed as a model for CAD introduction and development and are discussed in detail in chapter 6.

The model is validated by a national questionnaire survey of industrial companies operating in a range of product areas and the methodology for the questionnaire design, distribution and analysis is discussed separately in chapter 7

Early results from the first three case studies indicated that in the perceptions of CAD staff, CAD training and support is a key role in ensuring employee and company success. A further 6 in-depth case studies were undertaken to widen and firm up the study as indicative of the engineering industry. The focus of this wider study being upon;

1 The CAD training and support infrastructures.

2 The support methods used to maximise employee, departmental and company performance.

3.3 INITIAL PILOT STUDY METHODOLOGY

Six companies in varying stages of CAD adoption agreed to take part in the initial pilot testing of the research questions. Companies were chosen on the basis of geographic location for ease of access, to provide a variety of product types, known companies with known key contact personnel to try to positively influence response rate, but all companies were involved in the use of CAD systems.

Initial contact with companies was via the telephone to ascertain their willingness to participate in the investigation..

All six companies were initially circulated with a "list" of the comprehensive questions derived from the review of previous research and as stated earlier, these are shown in Appendix A1. A questionnaire type approach was taken since there were a large number of questions for the companies to consider. The thought process behind this decision was that the respondents needed time to consider each question and to formulate their responses. For this reason three to four weeks were allowed for responses before being followed up by telephone. Traditionally responses to questionnaires are low, typically 30% or less but because the contacts were known and had previous involvement with Sheffield Hallam University (SHU) it was felt that the response would be 100%, which it was.

A separate questionnaire (shown in Appendix A2) accompanied each list and particularly requested that companies identify experiences and problems and to comment upon the relevance and importance of the issues presented ie.

a) The relevance of the research questions to them.

b) Whether they were the right questions to be asked, if not why not and what should be asked.

c) Which issues were the most important and which were least important.

d) Had their company pursued any developments relative to the enclosed research issues and what experience had they gained.

On return of completed questionnaires some responses were followed up by telephone to confirm statements.

Two companies agreed to an on site visit and one of these involved five separate 2 to 3 hour visits (over a five week period) to talk with staff from various departments; this particular contact then developed into a larger case study.

3.4 PILOT STUDY RESULTS

During the initial stages of this research, over 150 papers on CADCAM and related subjects were reviewed and it became clear that a great deal of effort has taken place in researching computer aided technologies. In chapter 2 it has been shown that much of this research effort appears to have been concerned with the Technical aspects of CAD, eg 2D, 3D, Kinematics etc. rather than the "human" aspects.

Technical research aspects have accounted for the bulk of the work, with organisational aspects coming second best and human factor aspects accounting for less than 10% of the total. However, many of the research papers reviewed, intimated that to achieve success companies <u>should</u> consider, Technical, Organisational <u>and</u> Human issues when implementing computer technology.

To identify the degree of consideration given to such issues by companies and to identify the perceived relevance to them, an initial pilot study of six companies was undertaken and contrasted with the results of the literature review.

The six companies chosen are shown in detail in Table 3.1. However, it is relevant here to emphasise that these companies covered a spectrum of products, organisational systems and sizes and included companies involved with glassware, hand tools, masonry drills, scientific instruments and furnace equipment/ cooling systems.

Comments from companies regarding the importance and relevance of the research questions to them are also shown in Table 3.1

The companies represented a broad spectrum of sizes and products and thus their comments are relevant to industry in general.

COMPANY	1	2	3	4	5	6
NUMBER OF EMPLOYEES	1000-1100	1100	90	75	241	10
NUMBER IN DO.	7	3-Product Design	6	2	3	1
PRODUCTS	Glass-wear	Hand Tools	Roofing Constru-ction	Masonry Drills	Scientific instru-ments	Process Cooling Equipm-ent
CAD SYSTEM USE	2D/3D	2D/3D	2D	2D	2D	2D
COMMENTS ON RELEVANCE OF RESEARCH QUESTIONS		Many Questions too broad		Questions too broad	Questions should address whole company	Questions too broad

MAIN ISSUES TO BE ADDRESSED	1	2	3	4	5	6
Lack of continual support for use of the system	Yes	Yes	Yes		Yes	
Communication problems	Yes	Yes	Yes		Yes	
Lack of direction after implementation has died down	Yes	Yes * Note	Yes		Yes *Note	

Table 3.1 Pilot Study- Company Comments

*Note- Company commented that a "Champion" is required to push the use of technology even after implementation of the CAD system

In spite of the difference between the companies, four of them independently suggested that the main issues which should be addressed are;

* Maintaining continual support for the use of the system.
* Maintaining direction after implementation has died down. eg. in terms of operational and strategic business plans.
* The technical and organisational communication of data and information.

The specific comments of the companies concerning these three issues are contrasted in Figure 3.2 with the findings of the literature review. Both show common agreement on the main issues which should be considered. The evidence suggests that companies should provide;

a) Support for the continual use of the system

b) Positive direction during AND after implementation is completed

c) Greater emphasis on communication and human problem support

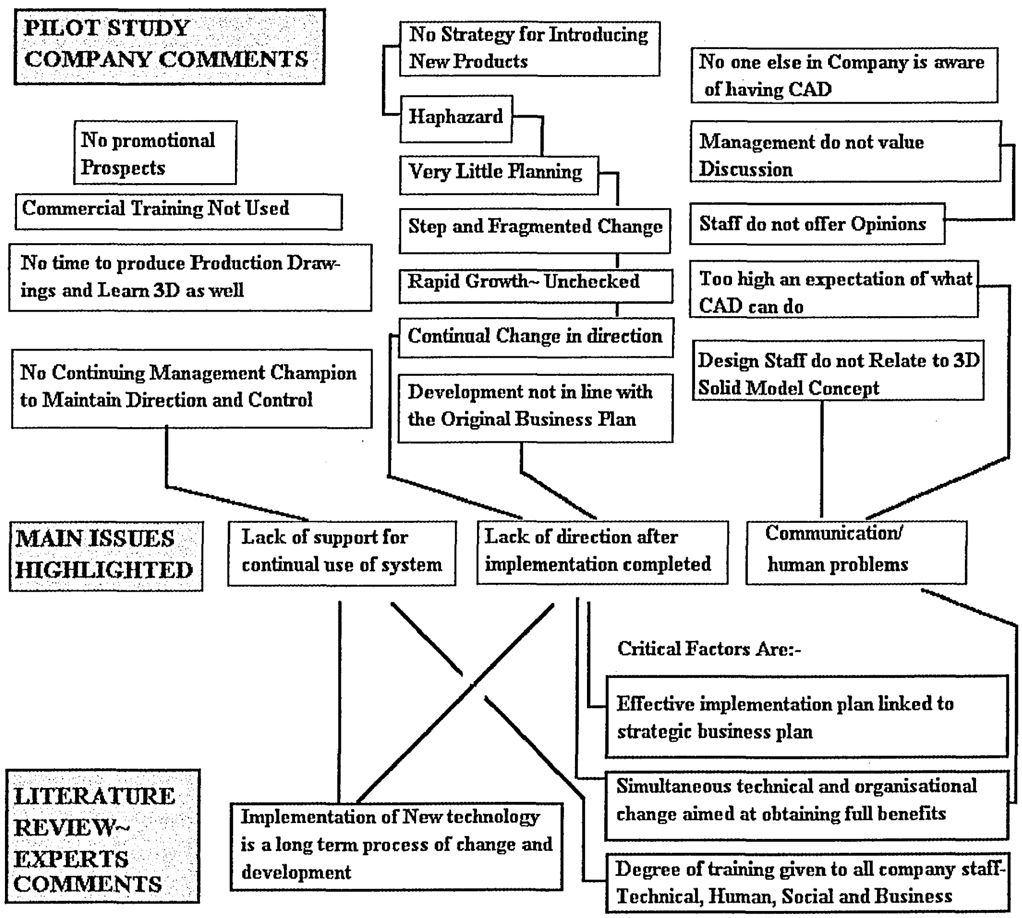


Figure 3.2 Themes suggested by the literature review and pilot survey

Original in colour

Thus there is a dichotomy in that companies are emphasising what their problems are, whilst researchers are emphasising what is needed for success, but there appears to be no interface between the two.

It is evident that some companies are still making the same old mistakes. The companies surveyed suggested that although there was initial enthusiasm from management and employees when CAD was first introduced, sometime later there was a cooling down and a gradual loss of linkage between the use of CAD and any business plan. Without this overall company direction the support to use the system to its maximum potential dwindles and design staff do not use the system as effectively as they could do.

Company "2" suffered such a problem, where design staff were not encouraged nor supported to use the expensive £50,000 3D CAD system. Consequently their preference to produce manual pictorial sketches has resulted in the 3D opportunities available, eg model data for 2D drawings, costing etc. being totally unused for the last few years.

Fortunately a recent review of the business and CAD facilities (Post pilot study) has alerted the company to the opportunities available from 3D CAD and Stereolithography and at the time of writing they are now actively re-appraising their CAD needs for the foreseeable future.

The issues identified from this initial study have been collated into, Technical, Organisational and Human issues and are shown in Figure 3.3. Companies perceptions of the main problems relate more towards organisational and human aspects than technical ones. This may be that they feel technical problems easier to solve, because they can understand the whole problem whereas "softer" issues require a broader understanding of the picture.

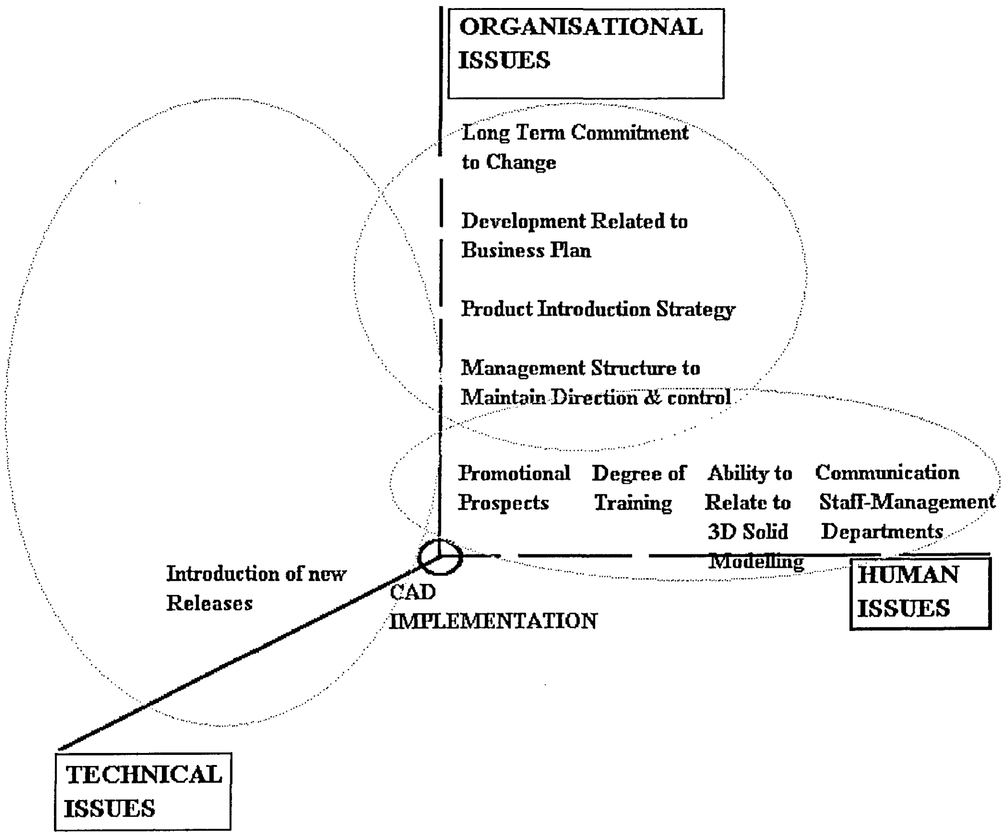


Figure 3.3 Technical, organisational and human issues in CAD implementation

3.5 CASE STUDY RESEARCH METHODOLOGY

The results from the initial pilot study provide a framework of features, based on human, organisational and technical issues and focus attention on the three main issues emerging, the issues being;

- How do companies support users
- How do they maintain direction
- How do they improve communication

These issues are based upon a comparison of the comments made by companies taking part in the pilot study and the documented evidence obtained from the literature review.

This framework was then developed further, as discussed below and employed as a Case Study tool for investigating three leading edge companies (companies "A", "B" and "C") in greater detail, in order to ascertain "Best Practice" in CAD implementation in relation to the three main issues discribed above.

Since in the literature review presented in chapter 2, competitive success is shown to be related to the factors of quality, flexibility and cost effectiveness, the case study framework employed here is based upon the criteria used in the USA, "Malcolm Baldrige National Quality Improvement Award"(107); with the features that represent a world class company being extracted for comparison within the case studies, but without the numerical evaluation which the award follows. This award, which is also similar to the Japanese "Demming Prize" (108) is awarded to companies through peer evaluation, for excellence in quality and leadership. The Baldrige criteria is chosen for use in this research because it is recognised in the USA as providing a framework for building world class companies. In 1991, 230000 copies of the criteria were issued to companies wishing to use them for self assessment and training.

Justification that such quality criteria can safely be used is given further credence from the approach of the British Quality Foundation (BQF). They promote a UK Business Excellence Model which employs similar quality criteria to score business performance and identify improvements (109)

3.6 FRAMEWORK FOR INITIAL CASE STUDY EVALUATION-COMPANIES "A", "B" and "C"

During the initial case study investigation the Baldrige criteria was used to ascertain the elements of companies' activities which are responsible for influencing success and competitiveness. A report in "Quality Progress" 1992 (99) states that the twelve companies winning the award to date had demonstrated success in terms of:

- Customer and employee satisfaction.
- Quality.
- Cost.
- Lead time.
- Financial indicators.
- Reliability.

Therefore its seems justifiable to accept that the award criteria is successful in assessing company performance and that similar criteria may be extended to use within this study.

In terms of the criteria from the Baldrige award, the factors which appear relevant to the results of the pilot study/ literature review and to this study as a whole are shown in Table 3.2.

Leadership	Top-down+ Bottom up-Two way communication- enthusiastic-Customer/ quality focus-Encouragement through' fast response/ decisions- Personal contact with employees, customers & suppliers-
Reviewing	Recognising key indicators- improving performance for employees and company
Participation	Sharing- working in partnership-Clearly defined employee involvement-
Planning	Proactive- Long range-Participative-Strategic focus- Commitment to long term goals.
Teamwork	Increasing involvement, responsibility-encouragement-empowerment
Human Development	Increasing employee skill and knowledge, well being and satisfaction
Support	Employees thro' retraining, flexibility and mobility of work-Reviewing of training needs for employees & company-To achieve maximum potential- Processes & organisation
Problem solving	Proactive approach
Quality Focus	In design phase, on support services, response time

Table 3.2 Case study evaluation framework

It is interesting to note that both the Demming quality philosophy and BS5750/ISO 9000 support the above framework, since they both emphasise the need for senior management leadership and commitment, support of employees, training for improvement, the importance of the design process, focus/direction, planning and reviews.

Demming suggests that his management philosophy can be applied to any process, in any environment regardless of size. The aims of achieving quality through BS5750 (110) and /ISO 9000 (111) are well documented and relate to improving competitiveness and improving efficiency and effectiveness through employee development. For these reasons, it is felt that the criteria used within the case study evaluation framework is given even greater validity.

If such criteria truly reflect the overall performance of a successful business then in an ideal situation we would expect to see similar traits for individual departments and subsections of the same business.

Conversely, in examining one department or subsection of a completely different company, and finding similar traits it should be possible to say that the particular department has all the requirements for operating successfully.

The validity of this statement must however impinge upon the interaction of the department with the rest of the business and similar traits should exist for this linkage. Not all companies will concentrate the same level of effort in each area identified in the framework nor might they consider the same method of approach to achieving results relative to each area.

The research methodology chosen for the case studies used triangulated data collection methods for the reasons stated in section 3.1.1 and was based upon, personal observation, documentary evidence and interview studies at each company. The use of documentary evidence provided a means of ensuring accuracy and validity of data rather than relying purely on employee's perceptions and memory. Preliminary analysis of field notes provided a means of validating data with the companies.

The methods chosen were employed for two reasons;

a) As Gordon (112) indicates, questionnaire observation is restricted to noting written responses only, whereas interviews allow the opportunity to sense the feelings of respondents through their tone of voice, body movements and facial expressions.

b) Traditionally response rates to questionnaires are low, even where companies have no objection to their staff responding to them.

However, case study "A" discussed in the next section specifically stated that they had a policy of not responding to questionnaires, although they had no objection to interviews on their premises. Thus it may be better to use interviews where only a small number of case studies are involved, but in great detail.

3.7 FRAMEWORK FOR SELECTING COMPANIES FOR IN-DEPTH CASE STUDY

It was considered that the type of company to be approached for investigation relative to this research could be anywhere along the continuum of implementation, either at the beginning, middle or end of some "Technological Change". Ideally this would be specifically related to CAD or CADCAM as an individual activity or as part of a much larger company-wide technological development or restructuring. Since now all sectors of industry are becoming involved with CAD and CADCAM, from large multi-national companies to small manufacturing enterprises (SME's) no attempt has been made to select companies from a specific sector size.

Instead this research has attempted to identify companies that were demonstrating achievement in terms of either;

1. External recognition- eg through publications in journals, books or conference proceedings.

2. The successful acquisition of external ie "government" funding for business development through the implementation of new technology.

3. Increases in sales and or product quality over a number of years.

3.7.1 Initial Case Studies

The three companies involved in the initial case studies were chosen as leading edge CAD companies on the following basis.

Case study "A", initially arose from a contact at an IMechE (Institution of Mechanical Engineers) design conference in Bled, Slovenia, 1993. The theme of the paper was that the company had just completed a five year programme of large scale, technology "Change", in terms of design & manufacture, were demonstrating substantial improvements in manufacturing competitiveness and had been awarded an IMechE "Manufacturing Effectiveness" award. Over the five year period the company had doubled their sales per employee to achieve an increase in annual sales of 42%, increased export orders from £13 Million to £34 million, reduced factory space by half and increased return on capital employed and operating margins. After spending a week at the conference with the production engineering manager and discussing his company's activities in detail it was felt that the information provided a good basis for a case study.

From further investigations of "Key British Enterprises", the directory of Britain's top 50,000 companies (113), it was discovered that the group to which the company belonged was ranked number four in the country in terms of sales (£800 million) and number one in terms of employees. Added to this the company were quality assessed for BS5750 PT 1-1987, ISO 9001-1987, EN29001-1987, and NATO's highest quality standard AQUAP 1 Edition 3.

Hence the use of this company as a case study is considered valid.

Case study "B", involved a three year study with monthly visits to the collaborating company PLM Redfearn Glass, who were also included in the initial pilot study. They are a well respected company with a long history, large markets and an equally large variety of glass bottle products. In the three years from 1990 to 1993, their turnover rose from £68.8 million to £76 million and their percentage profit margin was, 11.4, 13.9 and 11.9 respectively.

They have a wealth of experience in mould design and manufacture for glass bottle production and were initially involved with Computer Aided Design as early as 1975. The company obtained a DTI grant of £75000 in 1986 for the introduction of a flexible manufacturing systems scheme. By January 1987 and to January 1988 the company were demonstrating increased departmental visits by companies and the numbers of jobs undertaken per quarter had risen substantially(ref internal PLM report Appendix B1)

Case study "C" provided the opportunity to study the implementation of CADCAM from scratch, for one day a week over a two year period, as an academic supervisor for a teaching company programme. George Turton Platts are part of the Aurora group which forms part of the distribution and manufacturing arms of Australian National Industries'. Again it is a well respected company with a reputation for high quality design and manufacture of forgings in carbon, stainless and nickel alloys. The company has a turnover of approximately £13 million and serve Aerospace, defence, marine, nuclear, power generation, mining, oil, railway and vehicle industries. They export into Europe, India and the USA. Their customers include some of the top names in industry, Rolls Royce, Thompson Defence and GKN Sankey etc. They are also quality assessed for BS5750 PT 2, AQUAP 4-MOD-CAA and TUV-ISO9000 approved.

The results from these three case studies, discussed in detail in chapter 4, provided a clearer focus for undertaking six more in-depth extended and further case studies and justification for their selection is detailed below.

3.7.2 Further Case Studies

Case Study D

A recommendation from a leading CAD vendor provided the contact for case study "D". This provided the opportunity to investigate a company (albeit over a short time period of six weeks) involved in wet and dry vacuum cleaners, tea makers and steam cleaners plus a range of garden products, where the design and development team often had to focus on "Product launch" , "Time to market" and profit making potential.

The company was also chosen because it had progressed from the implementation of 2D CAD (with limited solid modelling capabilities) ten years ago to a full 2D and 3D surface and solid modelling system with which measurable success was now being seen.

The company was established in 1926 and since then its' products have developed rapidly within what is a fast moving market due to the seasonal nature of their products. For the five years up to and including 1995, the company had an average turnover of just over £24 Million and market many well known brand names

The site incorporates the group's European design and development facilities for all electrical powered products and the UK distribution centre..

Case Study E

During the literature review, and to some extent from the previous case studies a feeling that success may be influenced by company culture was emerging. In particular, references to the link between company culture and success of companies working in the newer technology area prompted an attempt to consider investigating a company involved in some form of I.T. development within a design and manufacture framework.

Using the "FAME", Financial Analysis Made Easy computer package (114) and running a search on companies involved in design and manufacture an arbitrary selection was made on SIC code 2924 for the Manufacture of general purpose Machinery.

From this company "E" was selected and three, one day visits were arranged. The company was established in 1983 and has an average turnover of around £50 Million and is involved in the research, development, manufacture, sale and service of ink-jet printer systems for bar coding.

On their publicity and sales literature the company proclaim themselves to be world leaders in this field of engineering.

Company "E" was awarded the Queens award for Export Achievement in 1987 and again in 1992 and is one of the hundred DTI Best Practice reference sites for Inside UK Enterprise. It holds USA, UL Approval (Underwriters Laboratories) for products which bear the UL Mark which approves for third party product certification; it also holds the European CE (Conformite Europeene) mark for safety, the German VDE (Verband Deutsche Electrotechniker) mark for electro technical safety and is ISO9000 registered for total quality management at all of their sites.

The inclusion of this company into this research is thus seen as highly beneficial and relevant to the research objectives.

Case Study F

Company "F" was one of the initial pilot study companies and was chosen as a case study because of the apparent major problems it was experiencing at that time, with use, or rather, non use of its' CAD system. The thinking behind adopting this approach being to investigate how the company was developing with time and experience Ongoing contact with the company has provided the opportunity to review progress at three stages, September 1992, February 1995 and again in June 1998.

The company is part of a large worldwide group and is well known for the design and manufacture of low-Tech Hand Tools.

It holds BS5750 and ISO9000 accreditation and was awarded the Local Newspaper Business Award in 1995

Case Study G

Company "G" was identified by recommendation and provided the oportunity to undertake a nine month investigation of a leading manufacturer of advanced heating and plumbing equipment.

The company is a subsidiary of a larger group but its own name is well recognised and has been respected since the early 1900's. The company is ranked in the mid-range of the top 5000 companies in the UK and is in the major five heating and plumbing companies in the UK.

It was one of the first companies to gain BS5750 certification and it now hold ISO9000 accreditation. The company is listed in the 1998 Quality Assurance register (115) (The UK Register of Quality Assessed Companies) for a number of BS conformity assessment standards.

It exports to over 110 countries worldwide with an annual export sales of typically £15.4 million. By its own volition the company emphasises, through publicity material, its commitment to a number of areas which it sees as being crucial to its success; namely:

- Quality.

- Development.
- Competitiveness.
- New Product Development.

Currently the company is also investing in new technology and is aiming towards World Class Accreditation which also includes gaining IIP (Investors in People) (116)

The company also boast that "No one can offer the same depth of product range" and "It has few equals in terms of quality, service and reliability".

Consequently the inclusion of the company as a case study is seen as highly desirable in relation to the research objectives.

Case Study H

Following on from the visit to company "G", a random search was made on the WWW for companies involved in similar product areas and the search yielded company "H". This involved a nine month investigation of a company involved in the design and manufacture of a range of industrial valves for a wide number of markets, which include gas, water, steam, oil, steel and petrochemical industries.

Comments on the companies web page emphasised that it had a structured programme of continued investment and that it had a team/ cellular approach to Total Quality Management which involves the use of extensive CNC and CAD facilities and maximises the companies efficiency and effectiveness.

The company was established in the early 1800's and again is a well respected name. They hold BS EN and ISO 9001-1994 accreditation plus British Gas Quality standards (117)

Case Study I

Contact with Company "I" originated through professional institution activities and personal contact with a member of the IED (Institution of Engineering Designers) council.

On a number of occasions, the author and staff from the company have chaired professional reviews for the institution, for candidates wishing to pursue chartered membership status. The council member, being the drawing office manager at the company and aware of the research themes herein suggested that his company was good as a company and had a great amount of experience of design and of using and supporting technology for design. Weekly contact was made with this council member for information over a one year period, whilst the actual discussions with the CAD manager ran over two half days.

The company is part of a group involved in the design, manufacture and commissioning of heavy industrial plant on a worldwide scale with an annual turnover well in excess of $10 billion and approximate number of employees in the region of 56000. It is a recognised world leader in a whole range of industries and rank in the top third of the worlds 1000 companies(118). It is BS EN and ISO 9001 accredited for project management, Design, Procurement, Manufacture, installation and testing plus they are accredited for instrumentation and control system & software in accordance with ISO9000-3(TickIT) (119)

All nine of the above companies are recognised as successful and are demonstrating some achievement in terms of the selection framework. For this reason they were considered as valid case studies for investigating and extracting elements of best practice in CAD introduction and development and a sound base for addressing the research objectives.

4. INITIAL CASE STUDY RESULTS FOR COMPANIES "A", "B" and "C"

4.1 INTRODUCTION

Using the research criteria identified in section 3.6, three companies (Companies "A", "B" and "C") were investigated as part of the initial case study research to identify areas of good practice.

Six other companies (companies "D" to "I") were selected for further case study investigation to substantiate the model of good practice determined from the above three case studies and to focus on the issues emerging (Vis a Vis, the Support area) and descriptive results for these companies are presented in chapter 5.

General details of all three initial case study companies, "A" to "C", are shown in Table 4.1. They cover Medium SME and large multinational companies with annual turnovers of £55m, £76m and £13m respectively. Each company is using different CAD systems to provide 2D and 3D design and to provide a degree of CAM.

They appear to be generally successful and have significant exports to Europe and other countries.

The markets, products and sizes of the companies are very different which delineates against any tendency for the results to be market, product or size specific.

COMPANY	A	B	C
NUMBER OF EMPLOYEES	1000	1000-1100	220
PRODUCTS	Electric motors 10KW-300MW	Glass Containers-pharmaceutical & food use etc.	Carbon, Stain-less, Nickel & Titanium alloy forgings
CAD SYSTEM USAGE	2D draughting, design & CNC programming 75 stations	2D draughting 3D modelling CNC programs 8 stations	2D draughting 3D modelling CAM-link
ANNUAL TURNOVER	£55 million	£76 million	£13 million (£80 million for group)
NUMBER OF D.O. STAFF	Approx 90	7 in design (1 in CNC)	7
ORGANISATION-AL STRUCTURE	Moved to Flat structure	Hierarchical	Hierarchical
SITES	One	One	Two
MARKETS	60% export Worldwide	UK, W. Europe	Europe, India, USA

Table 4.1 Comparison of initial case study companies "A", "B" and "C"; Markets, sizes and activities

4.2 INITIAL CASE STUDY EVALUATION RATING SYSTEM

The performance of case study companies "A", "B" and "C" has been evaluated in two ways:

Subjectively by "Comment" writing in tables constructed to compare companies for each of the criteria in the framework, an example of which is shown in Table 4.2. Good features of company activities relative to the criteria are awarded a "+" score and features which appear to positively act counter productive are awarded a "-" score

The inclusion of a "+" or the lack of a "-" in a category does not in itself suggest that all is acceptable. Comparison has to be made with one company against another to infer performance

SUPPORT FOR THE USE OF THE TECHNOLOGY	**Through employee retraining, flexibility and mobility of work; Reviewing of training needs for employees and company- to achieve maximum potential- processes and organisation.**

COMPANY		
A	**B**	**C**
+ Annual employee appraisals against	**+ Users meetings plus CAD strategy ....**	**+ CAD and CAM team joint co-operation to ....**

Table 4.2 Typical "Comments Writing" table employed for evaluating company performance

The second strand of performance evaluation is achieved by converting subjective comments into a numerical evaluation system to provide a comparison (not particularly a numerical assessment) of performance, an example of which is shown in Table 4.3. (Actual numerical results evaluation for companies "A", "B" and "C" are shown in Appendix B2 and are discussed in detail in chapter 6). Within the design field the use of subjective criteria within a structured design process is often employed, successfully, to provide objectivity throughout the concept selection phase (120-121)

Each criteria of the framework has been awarded a "rating value" by the author, based upon allocating 10 marks between activities to reflect their importance. The ratio of rating values to areas of activity within each category, eg leadership, have been compiled by reference to the Baldrige numerical rating system. A more simplified points rating system has been employed and an attempt has been made to maintain a similar ratio between activities

CATEGORY	**RATING**						
	RATING VALUE	**MERIT RATING (10)**			**OVERALL RATING (10)**		
LEADERSHIP		**A**	**B**	**C**	**A**	**B**	**C**
a) Top down	**5**						
b) Quality focus	**3**						
c) Two way communication	**2**						

TOTAL

Table 4.3 Structure of numerical evaluation system

Companies have been awarded a "merit rating", from 1 to 10, which reflects their performance against this criteria. The two ratings multiplied together then produce an "Overall rating" for the company and the total scores achieved by a company then reflect their performance in that category.

The maximum total score which a company can gain in any category is 100 and the minimum is 0. For comparison therefore, the following scale of total performance has been adapted from the Baldrige scoring guidelines

- 0- Poor- Little evidence that criteria is addressed
- 25 Average- Some aspects of criteria addressed
- 50 Good- Indication that trends are positive
- 75 Very Good-Most aspects of criteria are effectively addressed
- 100 Excellent- Clear evidence of results- Moving towards world class

In order to provide a visual indication of a companies performance in relation to individual categories and as a whole, the results from the evaluation are plotted onto a Radar or Wheel diagram as shown in Figure 4.1. Justification for this approach is to be found in similar uses of the technique eg I.T. Effectiveness (122), Design for the Environment (123)

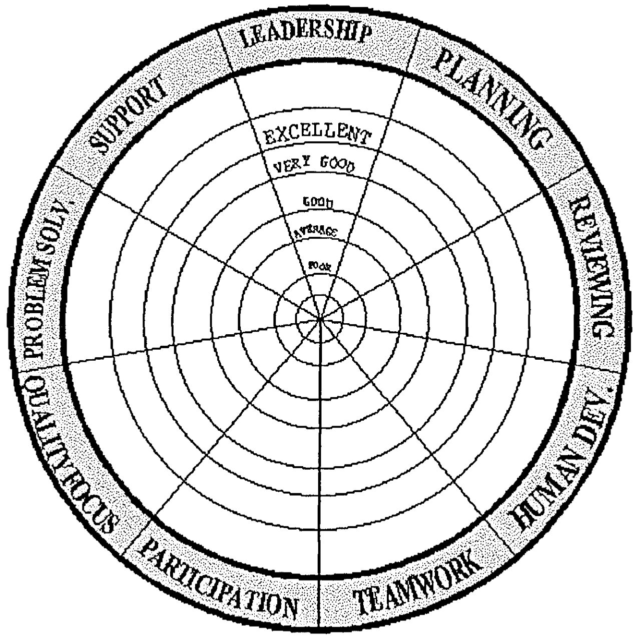


Figure 4.1 Quality wheel used to provide visual indication of company performance

4.3 INITIAL CASE STUDY RESULTS-COMPANY CAD OPERATION AND SUPPORT-

4.3.1 Case Study "A"

Introduction

The company employs 1000 people with sales of £55 million per annum but are part of an extremely large group, which at the time of the case study in November 1993 had around 80 000 employees worldwide and were involved in "Power Engineering" for electricity generation

In line with the activities of the group, the company itself were involved in heavy engineering, covering the design, manufacture and commissioning of very large electric motors and generators for worldwide use in just about every industry possible from power generation, marine, petrochemical and process engineering.

The company has a relatively complex organisational structure, but for simplicity however, the figures below show simplified versions of the situation. Figure 4.2 shows the post CAD structure for the whole company (not the group) and does not show the Personnel, Finance, Scheduling or Procurement sections of the company. Figure 4.3 shows the organisational structure for one section only, "Engineering"

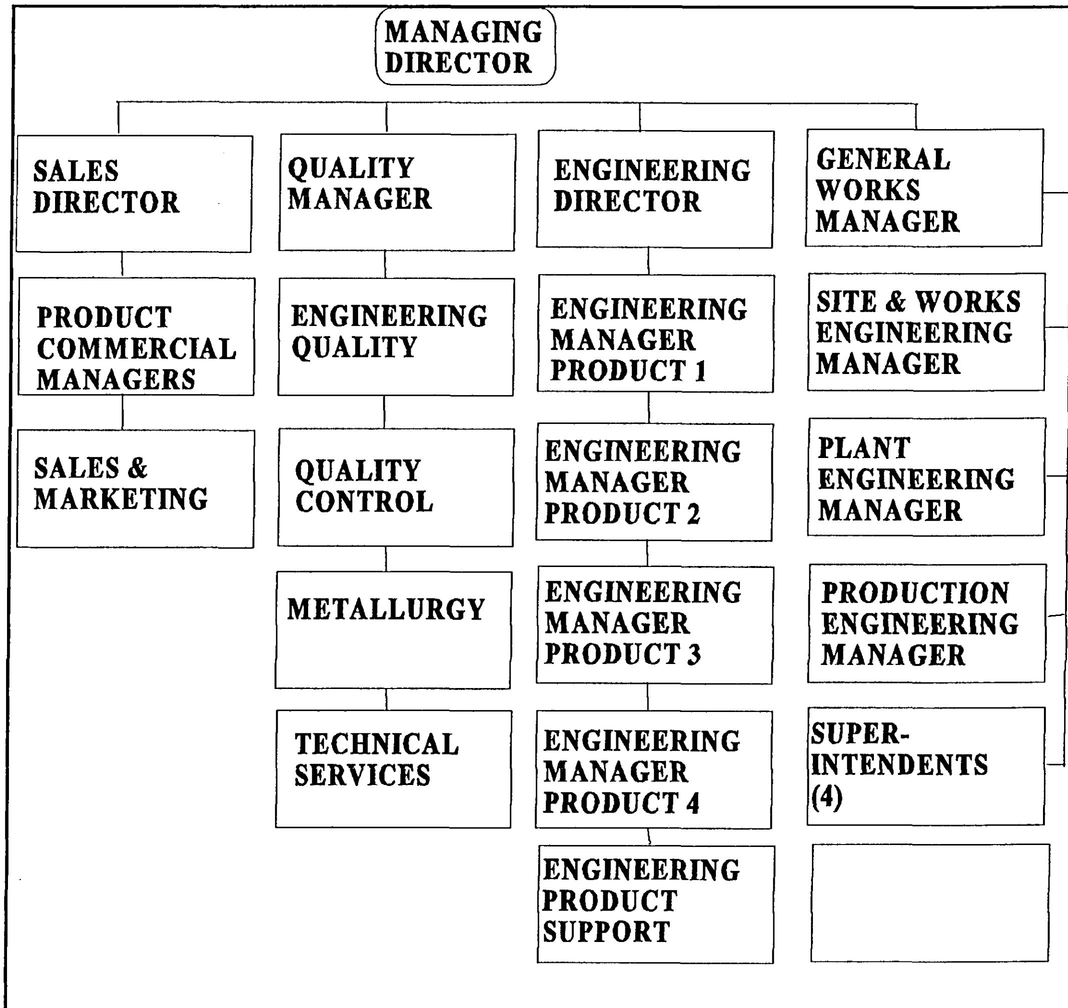


Figure 4.2 Post CAD organisational structure for company "A"

Design sits within the engineering department as shown in Figure 4.3

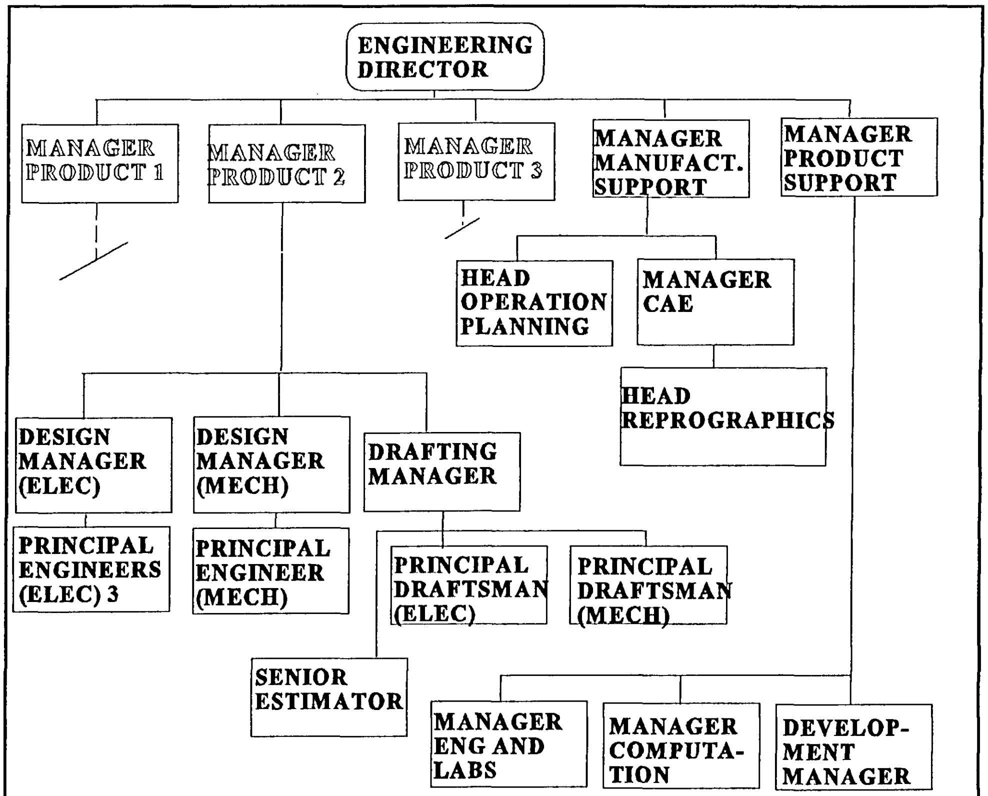


Figure 4.3 Organisational structure for Engineering at company "A"

The case study involved a full days site visit to the company with the time being split between discussions with the Production Engineering Manager in the morning and the CAE manager together with a graduate working on a GID system (Graphical Information Distribution) in the afternoon. Informal discussions continued over lunch with all three parties.

At the time of the visit in 1993 the company were reviewing their position after successfully achieving a massive five year restructuring programme between 1987 and the completion date in January 1993. During that time the company had reduced its staff from 1500 to 1000 whilst increasing turnover from £35 Million to £55 Million.

Design Process

In 1987 there were around 50 engineers and 50 designers, with the majority of draughting being undertaken manually on the then 70 available drawing boards, with limited access available to 21 CAD draughting workstations (but it is unclear what this facility was or how it was used).

Contrasting this with the situation in 1993 there were approximately 50 engineers and 40 draughtsmen working within the engineering section, with access to 41 CAD workstations, 34 engineering workstations and 5 drawing boards.

The draughting and engineering functions were restructured into a "manufacturing support group" which encompassed five product groups. Each product group sat together headed by a manager supported by a supervisory Principal Designer, mechanical and electrical engineers plus other draughtsmen.

Engineers had the responsibility for the design of new gearboxes, modifications to existing products and the calculation of design constraints.

The role of the draughtsmen was to produce assembly, fabrication and detail drawings from engineers instructions.

CAD Introduction & Development

In 1987 the company realised that they were in a vulnerable position with other companies aligning themselves for a take over bid.

The then, MD and his team realised that they had to do something fairly radical to remain competitive and so they went to the board of directors with a plan and asked for £28 Million to revitalise the company.

This plan involved a major restructuring of the company and a large investment in technology, NPD, TQM, DFM, JIT and buildings together with a massive workforce training and culture change programme with the goal being to attain world class capability.

Part of the technology investment included the implementation of a total CADCAM system and support structure. The basis of its introduction was to reduce existing product development times and costs and to increase the companies capability to introduce new products.

The company chose to implement 75 seats of an integrated MEDUSA 6 draughting system with CNC part programming and an in-house engineering design system running on Sun workstations

Support Structure

The support structure for CADCAM is shown in Figure 4.4. Relating this figure to the organisational structure in Figure 4.3 it can be seen that essentially it is a separate department from the design function and sits within the "manufacturing support" area. It is headed by a CAE manager who is assisted by two other staff. Together they support the use of the CAD system by all the product groups, production engineering, CNC programming and the engineering computation department.

The CAE managers role is twofold. One is to support CAD users so that all new drawing work is electronic and produced in the most effective and controlled way in order that designs are produced quicker and are of better quality. His second role is to improve systems and integration of data. The other members of the team provide operational support for hardware and software.

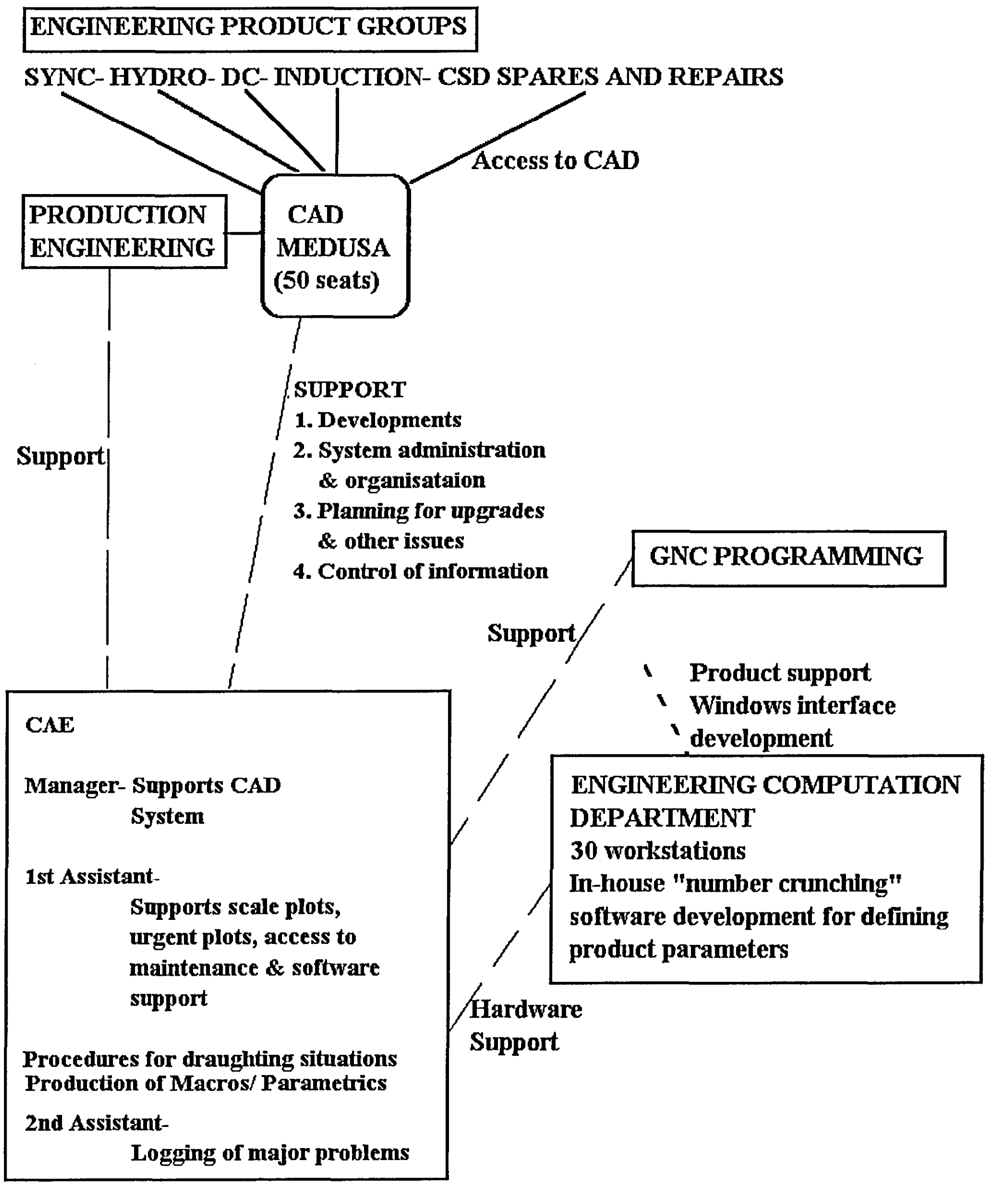


Figure 4.4 Support structure for company "A"

Training

The background of the large number of engineering staff has not been obtained but it is stated by the CAE manager that formative training has generally involved them all undergoing an engineering apprenticeship. Initially all engineering staff undertook psychometric testing and spacial ability tests to ascertain their suitability to use 3D. Motivation to accept the technology was assisted by a sign on fee for all CAD users. It is worth noting that Company "A" appears not to have experienced any problems relating to 3D visualisation. However, this may be because of their proactive approach in appraising their staff for 3D spacial ability.

All draughtsmen were trained on MEDUSA and underwent a CAD induction course. Some staff were given extra training to become CAD "Aiders" to cover contingencies. All training was undertaken in house by the CAE manager and CAD aiders on company products. CAD aiders/ managers were given extra training through team building and supervisor courses.

In terms of formative training years the support group have a good mix of skills which they can bring into use into their everyday work. The CAE manager has an engineering degree and is apprentice trained, the 1st assistant has a degree in mathematics whilst the 2nd assistant has an engineering background and an MENG degree.

The CAE manager attended the basic vendor training course, a 3D course and a programming course on "Basis" the MEDUSA Macro language.

The 1st assistant has undergone the basic CAD training but has also been trained to do the specific tasks shown in Figure 4.4 which include performing urgent plots, defining draughting procedures for different situations, accessing maintenance and software support etc.

Impact on Company

Because the company operate a continuous review policy each department is able to demonstrate achievements or otherwise in performance. There is a weekly review of the CADCAM system operation and management effectiveness. Locally this refers to;

- The number of drawings right first time
- Number of errors/ modifications
- The performance of individuals measured from the average trend

On a more strategic focus the company view point is that customers want the most cost-effective solutions backed up with delivery and quality.

They showed that CAD was helping to win business back by providing electronic data. Customers were impressed with the models which resulted in the companies ability to keep contracts and build business relationships.

Six new product ranges had been developed in the last three years, to take advantage of a potential market and a further twelve new products were planned for the next three years. Lead time from concept to production reduced from 3 years to 18 months and a part reduction of 30% was obtained.

During the period between 1987 and 1992 the company increased output from £35m to £60m . It should be pointed out that this is not just attributable to CADCAM since the scale of the company five year restructuring plan covered every aspect of the company from restructuring design, manufacturing cells, test facilities, to reduction in site facilities and energy consumption and the introduction of technological and cultural change. However, the production engineering manager and the CADCAM manager are certain CAD is having an impact.

4.3.2 Case Study B

Introduction

Case study B is the collaborating company associated with the earlier stages of this research. PLM Redfearn Glass. They have existed under a number of business names and in a variety of forms since being founded in 1862. At that time of course production of glass containers was all manual but they developed through to semi-automatic production to a fully automated production facility in the 1990's. At the time of the case study (which involved collaboration over a three year period) the company were designing and manufacturing three million glass containers per day on a 100 acre site in the Monk Bretton area of Barnsley, South Yorkshire. (Currently however, they have expanded to one of the largest producers of glass bottles in Europe and produce 1.2 billion containers per year on a 90 acre site(124))

The market for glass containers is forever changing to suit customer requirements and attract consumers and in earlier years, 1991, the total sales of glass containers in the UK reached around £459.1 Million. The variety of glass containers just in terms of size is enormous from small perfume bottles, Marmite jars, wine and whisky bottles etc but added to this is the complexity of shape, form, weight, strength, volume, colour, transparency, opaqueness etc as well as production volumes.

The production of glass containers requires product design, mould design, mould manufacture and bottle production and this process is reflected in the organisational structure of the company shown in figure 4.5

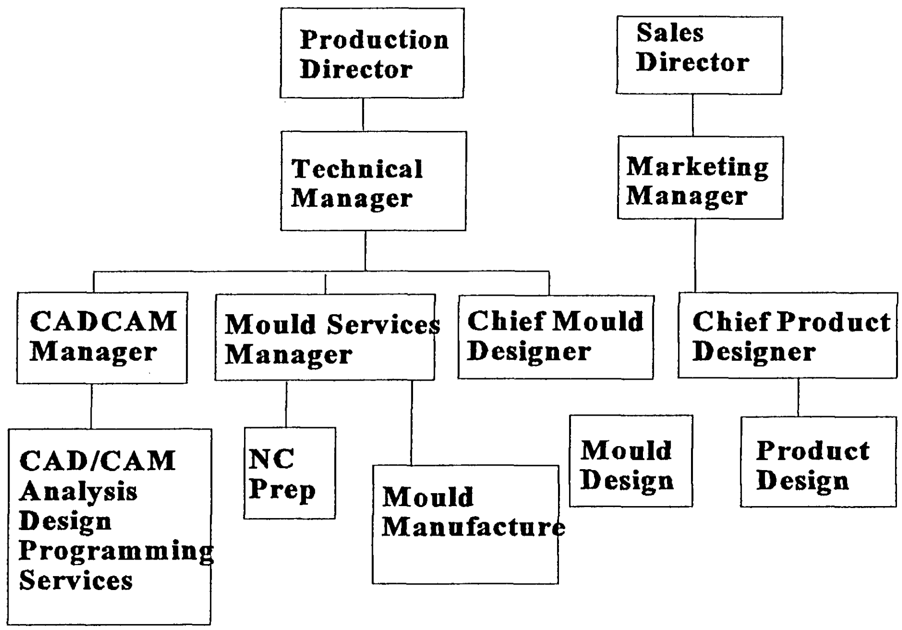


Figure 4.5 Organisational structure for company "B"

Design Process

All design is undertaken using a 3D CADCAM system.

Generally design briefs come direct from the sales department to the product designers who report via the chief product designer to the marketing manager. Very often the product designer sits at a terminal with a customer or sales staff and uses the 3D CAD model to illustrate the product in an interactive way which aids visualisation and modifications.

Once the product design is acceptable the design is passed to mould design staff. The company suggest they have developed a method of working which encourages cross-functional understanding so that each designs with the next departments requirements in mind. Typically this relates to product design being aware of mould design constraints such as the location of parting lines on complex non round shapes or the minimum radius that can be used in a particular situation. Equally, mould design are conversant with manufacturing tolerances and acceptable machining materials.

On completion, the mould design is then passed to mould manufacture for CNC programming direct from the surface model.

One exception to the use of CAD for design is in the area of artwork. Many glass bottles require colour artwork and presently the CAD system cannot be used for this without a large financial investment in more software. Therefore artwork is done manually using a method known as "Colour Separation" which employs separate sheets of acetate for each colour of the bottle label. Each acetate is drawn in dense black, a requirement of the photographic process which converts the acetates into a silk screen for the decorating department.

CAD Introduction & Development

Prior to 1975 all drawing and design was done using conventional drawing boards and pencils.

In 1975 the company installed two Hewlett Packard desktop computers and developed their own software to draw simple product specification drawings and mould design drawings for cylindrical glass containers only. The more complex shaped containers had to be designed in the normal way but unfortunately this often meant that development lead times were four months or more.

By 1985 Redfearn Glass were beginning to appreciate the potential of extending their markets in non-round, complex shape glass containers. As a result the company put together a bid for grant aid to the DTI who awarded them 20% of the costs of installing a fully integrated CADCAM system (up to a maximum of £82,000). In 1986 the company introduced such a system, at a cost of £153 643. A Hewlett Packard 9000 computer and associated GRAFTEK Geometric Modelling System with two workstations. This was extended further so that two terminals are employed in product design, five in mould design and one in CNC manufacture.

At the time of the case study, the company had been operating the software for six years.

Support Structure

The support structure for CADCAM is shown in Figure 4.6. The support department service all areas affected by CADCAM to ensure the smooth translation of activities and information flows to and from each department. The manager provides support in terms of trouble shooting, problem analysis, program changes etc. Part of this role has been the setting up and monitoring of standardised CAD working practices and the development of CAD "user meetings" and CAD strategy meetings to provide a forum for discussing problems and identifying solutions and areas of improvements.

CADCAM is also championed and driven by the production director who monitors progress through formal monthly reports and follow up meetings. This helps to maintain the use of the system in line with the business plan of the company.

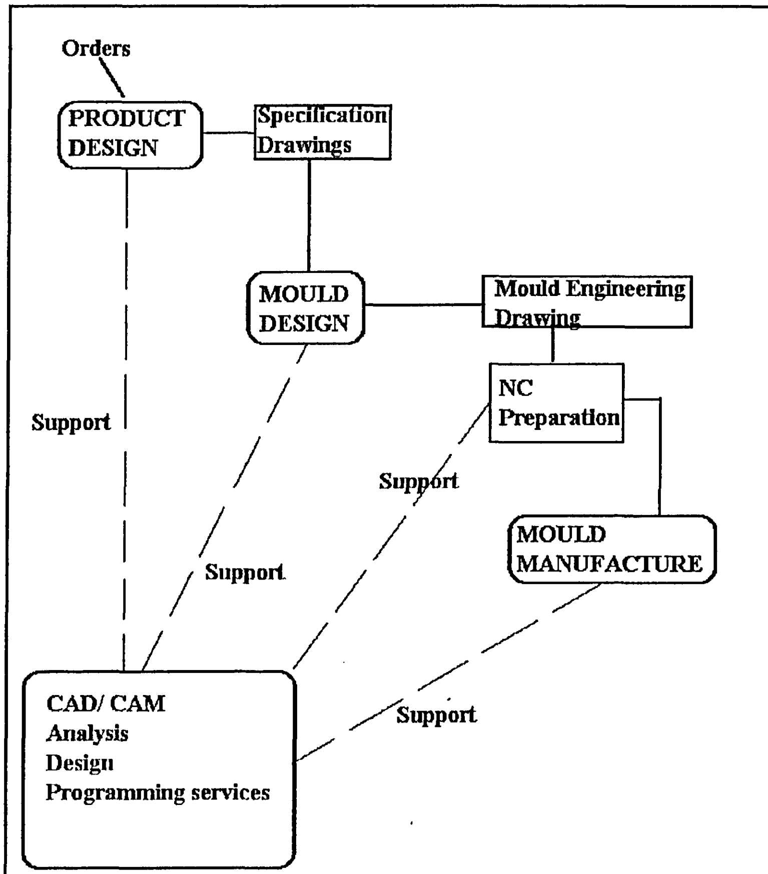


Figure 4.6 Support structure for company "B"

General support for users is on both a specific and broad front. At the specific level users have attended CAD courses at vendors sites at basic and advanced levels. The CAD support department have provided fundamental "Unix" training to users to enable them to overcome system problems at a user level.

On the broader front, all staff are encouraged to gain product experience through working in both design and manufacture, either by job flexibility/ mobility or by extended periods within different posts. An example of this is the level of training and experience gained by the current mould manufacture supervisor. He is apprentice trained with fours years experience in mould design, eventually progressing to "Mould Designer" and after a further six years in this post being promoted to mould manufacture supervisor. Training and support continues for this person with emphasis on basic and advanced 3-axis & 5-axis CNC machining plus supervisory training.

In spite of their experience and training, the company did experience one problem, which without adequate support may not have been identified.

For purely personal preference, mould manufacture preferred to re-draw the mould design model rather than use the previously derived surface model. An organisational support issue in terms of time and cost at the very least!

However the main visible problem occurred when designing a square bottle mould. Mould design would model a half the bottle and then mirror. Mould manufacture however would model by drawing a quarter of the bottle and mirroring twice. The result was two separate models, virtually identical, but with different volumetric capacities. Unfortunately the CNC model was the one which was incorrect. On an operational level this means time and expense for the company in re-modelling and or re-manufacturing the mould. On the wider strategic level this could mean failure to deliver bottles to customers on time with subsequent penalties or loss of orders. The three departments, product design, mould design and manufacture had little knowledge of the wider issues in system use in terms of how the system treated radii as splines ie mathematical equations and approximations based on cubic equations (125)

Figure 4.7 shows a typical spline curve and its approximation.

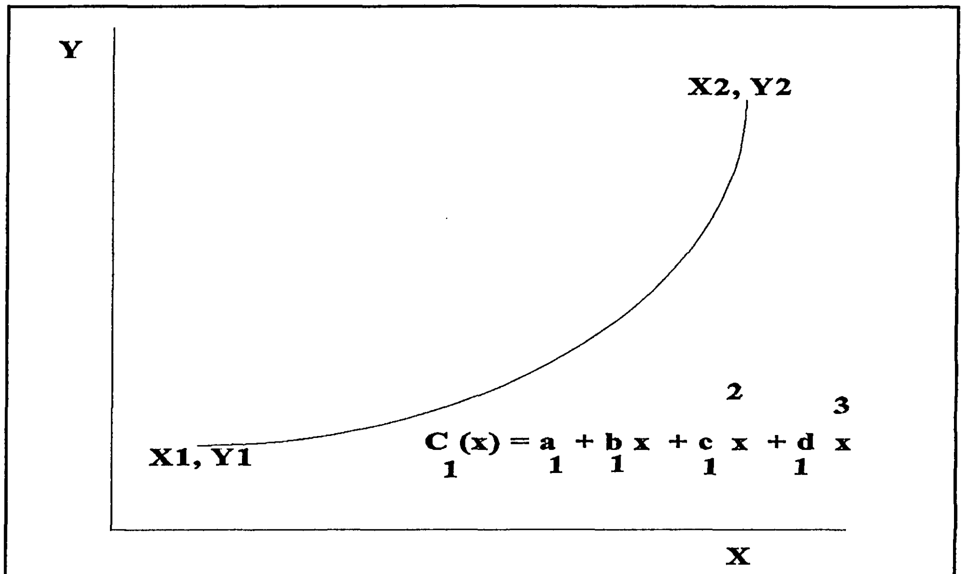


Figure 4.7 Typical cubic spline

CAD support were able to identify the problem as a " double precision problem. ie a cumulative error occurring when working on a quarter view x 4. The problem arises when working with the same software on slightly different hardware platforms. The efforts of the CAD support department led to a visit to the user group in Colorado and final convincement of the vendors of the software problem. The problem experienced by the company was a mixture of technical, organisational and human problems and required staff to have a knowledge greater than just how to use the modelling system.

Company "B" although not using appraisal for design staff is actively considering appraisal to identify staff suitability for CNC modelling training.

Training

The product design department is run by a senior designer, whose formative training includes seven years experience in engineering coupled with an HND in engineering and an industrial design degree.

The engineer in charge of mould manufacture and CNC programming served a traditional apprenticeship at PLM before moving into the mould design department to learn the trade, during which time he attended a course to become a mould designer. He worked in mould design for ten years before moving to mould manufacture. During his time in this department the company have sent him away on various courses, two supervisor courses, ECS training, basic GMS, advanced geometry, extended geometry, 3 axis and 5 axis CNC machining courses.

The CAD/CAM department is managed by a designer with ten years experience at PLM, an ONC and HNC in mechanical engineering and a degree in computer studies

The company philosophy is training orientated and encourages staff to identify training needs and courses which they feel would be beneficial. It is a company where staff generally stay or if they move to a competitors company, very often return to PLM.

Training on the CAD system was reasonably comprehensive compared with some companies.

All the designers underwent a basic CAD course at the vendors site to gain experience of the basic functionality of the system. Further training courses were attended for 3D surface modelling at a later date. Once competent with the system, in-house UNIX training was run by the CAD department to provide the designers with a broad appreciation of the system and the ability to interact with the operating system at a level whereby they could solve minor problems for themselves.

Impact on Company

At the time of the case study the use of the CADCAM system has resulted in increased productivity, increased numbers of customer visits and increased design activity and this is shown in Appendix B1. The precision of the system has also resulted in the ability to rough machine round bottle moulds thus reducing finished lathe machining time by 60%

4.3.3 Case Study "C"

Introduction

Company "C" are one of eight companies that belong to the Aurora group with a total turnover in the region of £80 million and a total workforce of approximately 1000 employees. The group offers expertise in the manufacture of special semi-finished materials and forgings.

Company "C" is based on two sites around two miles apart. It has a turnover of £13m and 220 employees and the organisational structure for the company is shown in Figure 4.8. They specialise in the design and manufacture of small batch (5 to 100), high variety, quality forgings in exotic alloy steels using two processes (126)

- Closed Die Forging (utilising drop stamping)
- Extrusion Forging (for cylindrical products)

Besides forging facilities the company also have CNC and copy turning facilities as well as the traditional manufacturing machines on site.

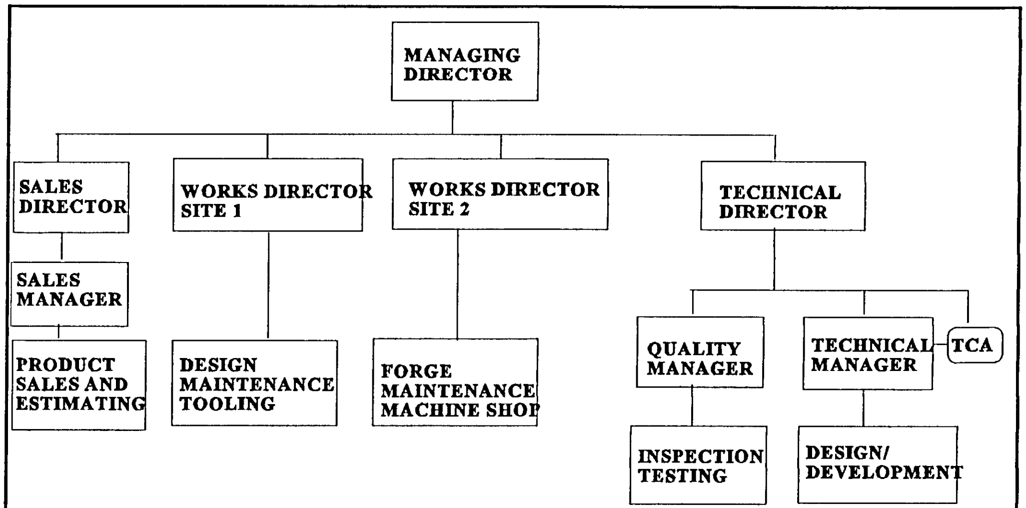


Figure 4.8 Organisational structure for company C

Design Process

At the start of this case study no drawing was performed on the drawing board but design followed an approach using 2D CAD as an electronic drawing board to draw the products and tooling for forging extrusion. For more complex products, ie forging die designs with geometrically complex shapes the CAD system was also used to draw 2D sections at various points along the die length in order to manufacture templates from them as a means of inspecting the finished/ semi-finished dies.

The use of the current system, EDS Unigraphics has meant that the design process is much better. For instance at one site the designers produce a 3D model of the relevant die cavity and place the model in a directory using an extension file name ".BDX" to indicate that the model is complete. The drawing is then passed down a multiplex link via a modem to the manufacturing site two miles away. Manufacture can pull drawings out of this directory and commence to program tools/ toolpaths.

CAD Introduction and Development

In 1990 the company decided to invest in a £70 000, four seat 2D Hewlett Packard ME10 CAD system to aid with tool and die design. Prior to this, in-house tool manufacture was dependent upon copy turning and milling of cavities and clipping tools from models manufactured by external suppliers. The lead times of six to eight weeks for tooling was thought to be particularly restrictive towards winning orders for work. The system was a partial success in that it allowed product designs to be converted quickly into tooling drawings, thus providing a productivity increase, and it was also used to provide 2D section drawings of complicated shapes which were used for manufacturing templates for inspecting dies.

However after 1 year the company had recognised that there could be some benefit, particularly in productivity, of improving the then current 2D system and introducing a 3D Surface Modelling System.

Initial investigations suggested that improving the 2D system could save £15 000 per year and provide opportunities for increased sales of around £500 000 per year whilst introducing 3D surface modelling and NC toolmaking would reduce toolmaking costs by around £150 000 per year.

In 1994, recognising that the implementation was longer rather than a shorter term project, the company instigated a Teaching Company Scheme (127) and employed a Teaching Company Associate (TCA) as CAD manager to undertake specific activities towards achieving their goals.

One of his first primary roles was to develop, implement and test "Macros" which could be employed with the existing 2D-ME10 software for the improvement of forging and tool design procedures. His second, but still vitally important role was to investigate the companies 3D requirements in terms of the CAD and CAM to suit the complex component geometry of their product.

After four months, macros had been developed for the majority of standard tooling used for extrusion forging and were now generated interactively by all the production designers resulting in a productivity increase of four. Typical Macros developed fell into categories of:

- Extrusion Forging Design- eg ejector pads, nozzles, standard liners etc
- Drop Forging Design- Punches, clip tools, flash and guttering
- General drafting- Adding brackets to dimension lines, thread macros etc.
- Documentation- Drawing frames, tolerance tables, issue note

A review of the companies needs and the available CADCAM systems resulted in two further CAD systems being considered; Solid Designer and Unigraphics.

Solid designer, although offering a link to the current 2D ME10 draughting package turned out to be functionally unacceptable whereas the Unigraphics package was seen as being the best in the world and was employed in other parts of the group. Consequently a three seat Unigraphics system was purchased at a cost of around £99 000 and introduced to the normal operation of the drawing office. Complementary to this was the retro-fitting of existing Keller milling machines with CNC at a cost of £250 000. Resistance to the implementation of the technology was overcome by the use of one to one discussions with staff and by involving all staff in the selection of the equipment. Monthly meetings with staff provided feedback on production and sales figures.

Support Structure

The support structure for CAD or rather CADCAM is shown in Figure 4.9. Group CADCAM support is essentially made up of two components. On a daily basis support comes from the TCA who was eventually upgraded to CAD manager. He takes responsibility for both CAD and CAM support in terms of 2D drawing, 3D modelling, development, procedures, documentation and training etc. However, assistance was also provided by the CAM manager. The second component of support, in terms of guidance and direction at strategic times, comes from the group expert, who is also professor of CADCAM in Australia.

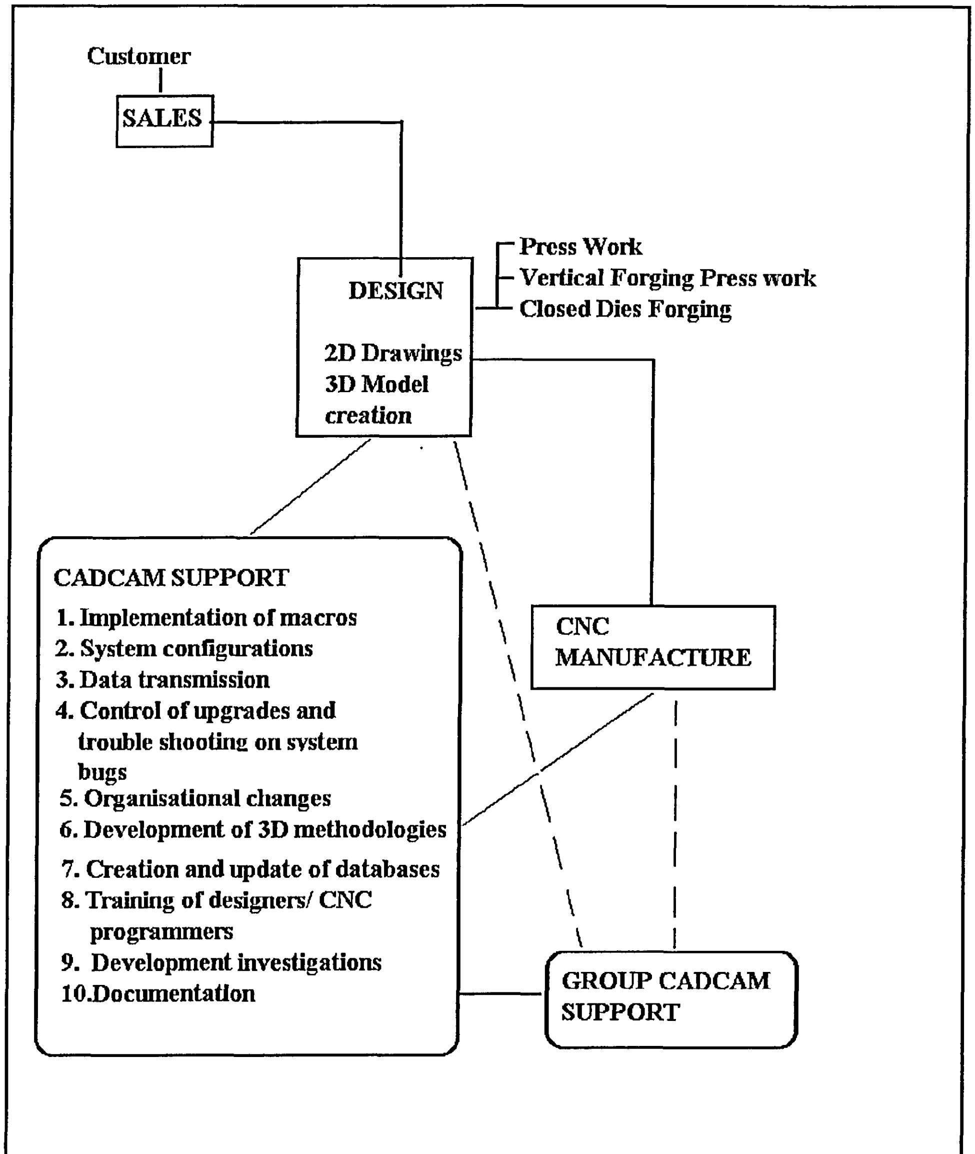


Figure 4.9 Support structure for company "C"

Training

The CADCAM manager was a time served apprentice miller and turner, had undertaken an MEng degree at university and had extensive experience of the CATIA CAD package and programming in fortran.

During the implementation process he was assisted with developing the CAM side of the CAD package by the senior production engineer acting as a CAM manager. Formerly the production engineer had been the machine shop foreman and had served a five year apprenticeship in general maintenance and production of the RB211 engine at Rolls Royce. He held both city and guilds craft and technicians certificates and had attended courses on part & advanced programming, Autotrol/ EDS/ Unigraphics packages and management courses.

Company C work with products with an extremely high level of shape complexity requiring the 3D modelling of drafts and tapers on internal and external sculptured radii, pockets and cavities etc. for closed forging dies.

External CAD vendor training, both basic and advanced was employed to train staff and covered training for three CAD operators and nine CAM/ CNC operators.

However to expect staff to return to work and model the complex shapes, efficiently and effectively, on a production basis, with the required degree of model validity for smooth manufacture was a problem.

Support to do this involved the two key staff, CAD and CAM managers spending one month with the group "external CAD expert/ consultant" sat at the side of them, with the expert producing the models whilst they watched. After this they were then able to work on production jobs, whilst at the same time the expert was able to give technical assistance, advise on the suitability of the CAD design methods employed in different product modelling situations and to get them out of trouble when they had exhausted their current knowledge.

To aid their competence and under the watchful eye of the expert the two staff produced a list of 16 new production jobs, and graded them from easy to difficult and proceeded to model each one sequentially, recording problems and solutions and defining a design methodology for modelling. After three weeks they were competent on the system and the two managers then employed the same proactive training approach to train the other CAD users.

From observation of these other CAD users during this training period some conclusions have been made. It appears that some designers are very mechanistic and in trying to solve problems and will continue to try to use the same ways to solve them. Others are more creative or adventurous and will try different solution techniques. Generally the designers knew what they wanted to do, but not how to do it. A simple half day course which showed designers which techniques and functions eg Bezier Curves and Bsplines could be used in which situations was all that was required to jump a hurdle.

Impact on Company

The implementation of the system meant that the company then had the capability to model extremely complex forgings and tools, something which hitherto had been impossible. They were modelling components on CAD, simulating CNC cutting on the CAD system and cutting forging dies using CNC. The effectiveness and efficiency with which they were achieving this was also being influenced by their ability to create and use macros.

Initially the effectiveness of their use of the system was obviously not at its highest potential, but it was much more effective than if the staff had been left to fend for themselves. The reasons for the introduction of 3D CAD, improvement in quality and a reduction in response and manufacturing time was more than justified by the companies approach to CAD support. Within the first month a number of jobs were undertaken which resulted in reduced machining times of between 30%- 70%. The company were also seeing improved quality of recut/ support for recutting dies, reduction of this recut work overload in progress and the potential to improve lead times on conventional jobs by the removal of hand finishing operations. Coupled with these reductions the company saw drawing office productivity increase by 8%.

The ability of staff to visualise 3D models appeared generally very good. This may well be related to the previous method of manual drawing. Design staff were required to visualise the complicated product and produce a number of 2D CAD section drawings of sections at various points along the axis of the product. Such section drawings were required for the production of inspection templates for semi-finished and finished inspection of forging dies.

One issue that was not addressed at the time was that the Unigraphics system was a very popular system and demand for CAD drivers was high. Design staff were generally unhappy and resistant to the technology mainly because of the change in conditions in relation to shift work and lack of pay inducements. Consequently they were not averse to moving to other more favourable companies.

4.4 DISCUSSION OF INITIAL CASE STUDY RESULTS

The organisational structures of the three companies in the initial case studies are different, with company "A" having a relatively flat structure whilst companies "B" and "C" have a conventional hierarchical organisational structure. Globally therefore, communication and operational systems are very different in each of the companies. However, the in-depth analysis has highlighted many positive aspects of company activity, together with a few negative aspects and these are summarised in Tables 4.4 to 4.12 inclusive (Not in any specific order but to suit the layout of the thesis)

LEADERSHIP	**Top down-bottom up. Two way communication. Enthusiastic. Customer/ quality focus. Encouragement through fast response/ decisions. Personal contact with employees, customers & suppliers.**

COMPANY		
A	**B**	**C**
+ Recognition by MD. of business position and need for new technology. **+ Goals stated thro' meetings with workforce** **+ Workforce given option to support changes or go (everyone on board)** **+ Monthly;** **all employees kept regularly informed of business position & Plan thro' meetings, bulletins and posters/ notice boards with graphs of sales, output etc**	**+ Recognition by board of need to enter new markets for renewed company growth**	**+ Group recognition that technology may help** **+ Group strategy to assess need for technology thro' academic expert.** **+ Top down decision to link with local university for CADCAM implementation**

Table 4.4 Summary aspects of company activities KEY: (+) Good Practice

(-) Bad Practice

PLANNING	**Proactive, long range, participative, strategic focus, commitment to long term goals of the company.**

COMPANY

A	B	C
+ 1987;Strategic view of opportunities that would accrue from 1993 Euro-pean market + Commitment to phased implementation of new technologies, philosophies, training, new products, company & culture change over several years. + Target; achievement of world class capability + Multidisciplinary team of 40 staff set up to oversee developments; three sub groups with specific individual tasks. + £21 Million capital budget & £5.4 Million revenue allocated and justified on operational benefits and increased sales + 130 man years of planning + CADCAM specific target; Introduce complete system & support structure to reduce lead times & costs Introduce new products to take advantage of new technology opportunities + Yearly plans from cell managers to fit in with company 3 yr plan + Future plans; Graphical data distribution database to anywhere on site	+ Strategic recognition by board of need to enter new market areas + Proposals to board for enhanced computerisation to cope with increased throughput and reduced leadtimes necessary to operate effectively in this market + Commitment to maintaining mould design & manufacture depts. The only company in this field to have these facilities. Provides fast response to customer requirements	+ Planning; weekly, monthly and quarterly focus on operational and strategic issues. + Targets; * Improvements in Quality * Improvement of lead times & tool making costs * Improvement in 2D drawing production by 10% * Introduction of 3D surface modelling for modelling complex shapes * Linking 3D modelling and CAM to produce 300% increase on current machine and 15% productivity increase overall in two years * Computerisation of reject re-working to allow more accurate production on work which represents £1 m annually * Translate cost savings into new business opportunities of around £2- £2.5 m with potential profit increase of £300k per year + Planned 24 month, weekly programme of work; reviewed on a regular basis with 6 "Milestone" reports throughout + Multidisciplined team; Design, manufacture & academics

Table 4.5 Summary aspects of company activities

SUPPORT FOR THE USE OF THE TECHNOLOGY	**Through employee retraining, flexibility and mobility of work, reviewing of training needs for employees and company- To achieve maximum potential- Processes and organisation.**

COMPANY		
A	**B**	**C**
+ Annual employee appraisals against agreed goals +Use of skill matrices to encourage gaining of new skills for career progression + CADCAM manager training- external; 3D, programming, macros + In-house training for CAD + All engineering staff do spacial ability test for selection to work with 3D	+ User meetings plus CAD strategy meetings +External vendor basic and advanced training for Users + Further in-house system management training for users +Support from CADCAM manager for operational features, trouble shooting, problem analysis & programmatic changes +Cross-functional collaboration between Design & Manufacture +Extensive use of parametric programming & libraries of parts- CADCAM support + Recording of software bugs & "work-around" solutions by design staff for incorporation into CAD development - Product design system in use for 4yrs but scaling problems still exist in transferring info from product to mould design Recognised problem but shelved	+ CAD & CAM team joint co-operation to produce booklets of; 1. Computing methods 2. Machining techniques for staff to work from + 10% of CADCAM managers time spent in supporting studies. + Monthly reviews plus training plans + Vendor training plus on-site practice PLUS 1:1 on-site tuition on production jobs (2 weeks per designer) + CADCAM team talks on modelling procedures Implementation of formal system of communication between design & manufacture a) Prior to work b) At model completion c) During & after manufacture thro' flexibility to visit other sites. + CAM training for Director, group expert and CADCAM manager - Initially no formal system for checking accuracy of models against 2D drawings

Table 4.6 Summary aspects of company activities

HUMAN DEVELOPMENT	Increasing employee skill and knowledge, well being and satisfaction

COMPANY

A	B	C
+ External training of senior management + Cascade training for internal trainers; 228 man days + Company wide awareness training programme + Structured training for specific personnel; CEDAC, DFM, TQM Action planning (886 man days) + Management staff encouraged to do OU courses; team building, supervisor courses, accounts, presentation skills, industrial disputes & role plays etc. + Sign on fee for everyone to use CAD + Inducements to allow sub contractors on site + P.R Pay related to hitting contract targets + All draughtsman CAD trained + CAD Aiders; extra training to cover contingencies + Young graduates selected for management opportunities + Draughtsman- ability to move to other departments-requested during annual appraisal + Production manager insists on staff job rotation every two years to gain experience + All staff Psychometrically tested for aptitude & motivation	+ Designers taught German to fit in with company needs; offices in Germany - No promotional structure - Feeling that design is no longer a springboard into management	+All CAD staff being taught 3D modelling and introduced to CNC +Staff encouraged to visit other sites prior to modelling to discuss jobs with manufacture personnel and discuss possible problems- Post manufacture discussions to identify any difficulties encountered in production. -Rumours about a 3 shift system and current pay scales providing employees with concern. -Promotional opportunities are small

Table 4.7 Summary aspects of company activities

REVIEWING	Recognising key indicators, improving performance for employees and company

COMPANY

A	B	C
+Company wide review of component buy-in or manufacture in-house philosophy + Weekly review of CADCAM operational & Management effectiveness * No. of drawings right first time * No. of errors/ modifications on drawings * Performance of individuals & general trend measured from the average	+ Costing system; constantly monitor machining of dies in terms of costs to make against cost to contract out eg times and overheads recorded	+ Weekly reviews of operational effectiveness by technical director. eg. Modelling times, Simulated machining times verses actual times. + Quarterly reviews; work done in last quarter, benefits to employees & company, work planned for next quarter, review of training requirements in order to carry out next quarters work, appraisal of CADCAM managers performance against goals. + Six monthly evaluation of implementation by group expert.

Table 4.8 Summary aspects of company activities

PARTICIPATION	Sharing- Working in partnership- Clearly defined employee involvement

COMPANY

A	B	C
All employees actively taking part in company operational and strategic direction. Shop floor workers aware of monthly & yearly plans	Design staff work in teams- close proximity- Not involved when system is shown off to special visitors- gives a feeling of lack of care on managements part	- Lack of involvement of CNC staff led to purchase of equipment without a required machining facility, causing vibration and tool breakage

Table 4.9 Summary aspects of company activities

PROBLEM SOLVING	**Proactive approach**

COMPANY		
A	**B**	**C**
+ Cross functional teams employed to encourage problem solving + Company 5 year proactive planning programme	-No overtly apparent strategic proactive approach to problems. -Tackle at the appropriate time	+Company approach is through proactive planning on weekly, monthly and yearly programme

Table 4.10 Summary aspects of company activities

QUALITY FOCUS	**In design phase, on support services, response time**

COMPANY		
A	**B**	**C**
+ All employees involved in TQM training + Operator certification in manufacture 269 out of 308 operatives + Company developed QA systems and procedures to attain ISO9001 3rd party accreditation in June 1992	- Design brief can be word of mouth; - Quality of information from customer or agency can be poor - Sifting through process necessary for designers to assume what is required by customer	+ Quality assessed for BS5750 pt2, AQUAP 4, MOD, CAA, TUV approved

Table 4.11 Summary aspects of company activities

TEAMWORK	Increasing employee involvement, responsibility encouragement and empowerment

COMPANY		
A	B	C
+Identical employment contracts for office and factory workers +Multidisciplinary product groups sited geographically together	+ Product groups co-located in the same office. + Method of working developed to encourage cross-functional understanding of each departments requirements + CAD "user" meetings and CAD "strategy" meetings employed to provide a forum for discussion	+ CADCAM manager & CNC manager work continuously together (through flexibility to visit each site) in order to maintain interaction of ideas. + Highly motivated; 1. To prove systems work to other staff 2. To complete current production jobs by promised delivery date

Table 4.12 Summary aspects of company activities

Although there are only three companies involved in the initial case study, there are nine categories of activities in the research framework and many individual and specific points are identified for each company and category. This makes it extremely difficult to discuss textually in a report, hence the performance of the companies in each category has been rated by the author on a comparative points basis, as defined in section 4.2 (see Appendix B2) and presented graphically in Figures 4.10, 4.11 and 4.12.

Company "A" is achieving " excellence" in all categories, as evidenced by the circular profile of the plot. Company "B" is also performing well, although not as well as company "A" and the tighter and somewhat "skewed" profile of the plot depicts this performance. Case study "C" is scoring in the "excellent" region in some categories, notably, teamwork, quality focus, reviewing, planning and support, and scoring the remainder in the "very good" category.

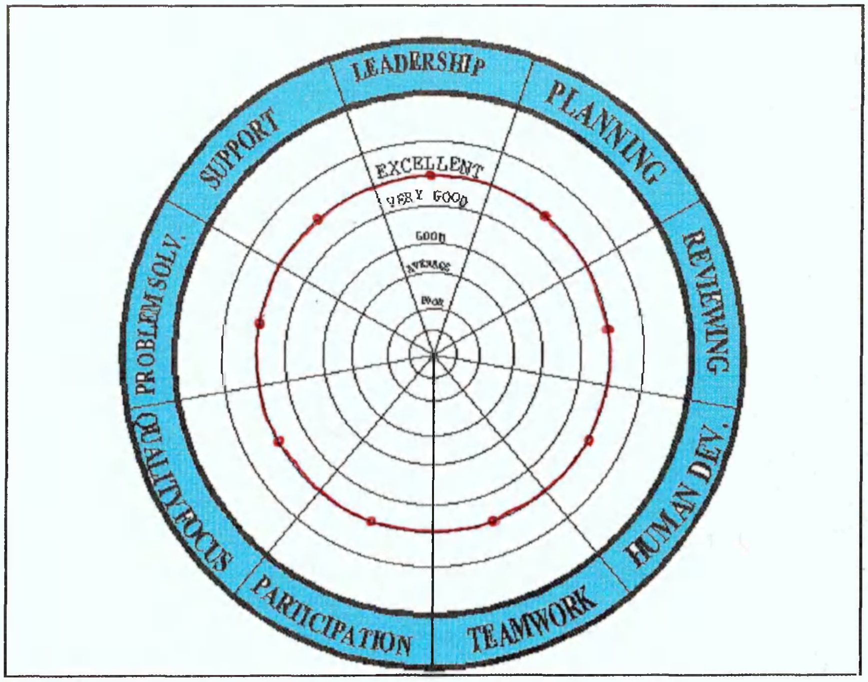


Figure 4.10 Performance of company "A" in relation to research framework

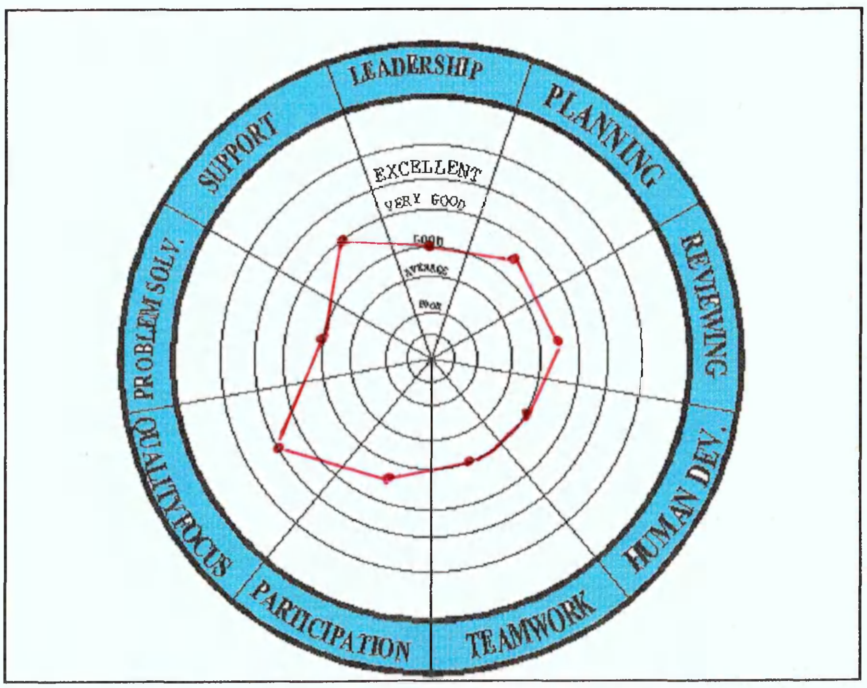


Figure 4.11 Performance of company "B" in relation to research framework

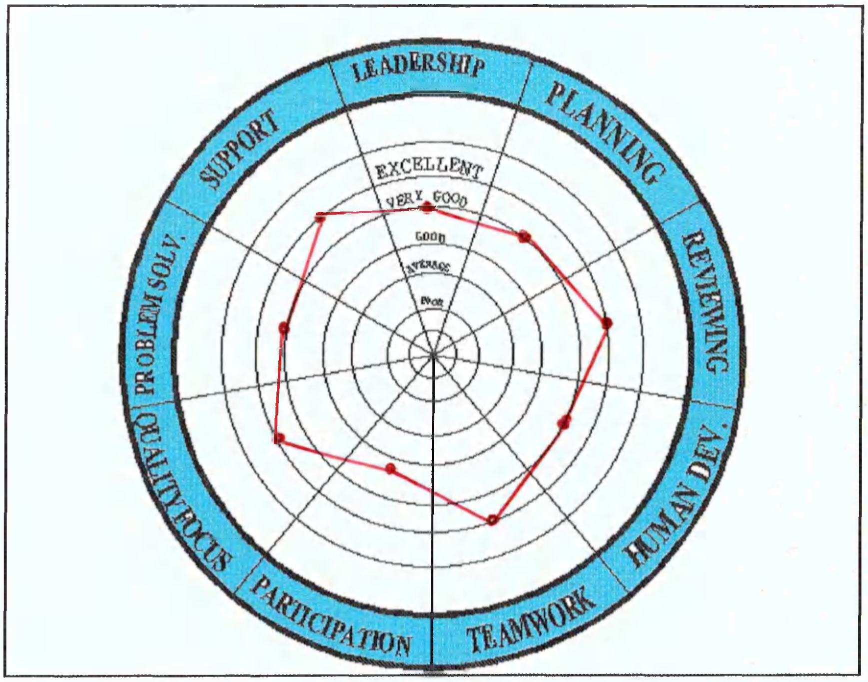


Figure 4.12 Performance of company "C" in relation to research framework

On the whole the three companies appear to be successful. They were demonstrating success, as shown below in Table 4.13, in terms of characteristics exhibited by previous winners of the Baldridge award eg Quality, cost, lead time etc.

They were also demonstrating many of the attributes embedded within the Baldridge award guidelines and those modified for use here within the research framework.

For these reasons it is considered justified to use these companies as examples of "Good" practice

Company	A	B	C
Increased Quality	Y	Y	Y
Reduced Costs	Y	N/A	Y
Increased Sales	Y	Y	N/A
Increased Turnover	Y	Y	N/A
Reduced Lead Time	Y	Y	Y
Increased Productivity	Y	Y	Y
New Products	Y	Y	Y

Table 4.13 Summary aspects of company activities

4.5 RESEARCH DEVELOPMENT

The initial pilot study and literature review has identified the following issues as prime in CAD introduction and development.

- **System support**- (ie Maintaining continual support for the use of the system)
- **Strategic direction**- (ie Maintaining direction in terms of operational and strategic business plans)
- **Communication**- (ie The technical and organisational communication of data and information)

The initial case studies have provided examples of good practice adopted by three successful companies in relation to the research framework.
In particular, they provide evidence of good practice which relate to and can be extracted in order to address the above issues.

The discussion of the initial case studies has also shown how " support for the use of the system" is affected by and affects strategic direction and communication. Hence development of the research in terms of six further case studies is directed towards the area of "Support".

An important point to note is that within each of the initial case study companies there is a specific department and associated staff identified with the role of CADCAM support. These three support infrastructures shown in Figures 4.4, 4.6 and 4.9 are different in structure and in level of support provided.

Differences occur in their structure and operation primarily as a result of the organisational structures of the companies, the products and the design to manufacture process. However, the role of the three departments are very similar and are aimed at both "**Operational**" and "**Strategic**" issues.

Essentially each department supports the use of CAD in the areas of;

* Design and draughting procedures and production procedures.
* Maintenance and software support
* Administration and organisation
* Training
* System development

Each support department interacts with several areas within their respective company, from design to engineering to manufacture. To achieve an effective support role requires an overview by each of these support groups, of several areas within the business, on Technical, Organisational and Human levels. This support plays a key role in maintaining and continuously improving CADCAM effectiveness, both for design staff and the company.

5.0 FURTHER CASE STUDIES- CAD OPERATION AND SUPPORT

5.1 INTRODUCTION

Results emerging from the initial case studies discussed in chapter 4, provide a clearer focus in terms of company performance in relation to the research framework. This clearer focus presents the opportunity to undertake further case study work in order to examine more closely, human factor issues and problems within the area of "support for the use of CAD". The objectives of this chapter are to present the results of six further case studies, using the same presentation structure as that employed for the initial case studies described in chapter 4. ie.

- Introduction
- Design process
- CAD introduction and development
- Support structure
- Training
- Impact on company

General details of all six companies included in the further case study work are shown in Figure 5.1. As with the initial case study companies, these further case study companies include SME, large and multi-national companies with annual turnovers of £24m, £50m, £2.6 billion, £15m, £10m and £10 billion respectively. They are also generally successful and five of the companies have significant export markets worldwide.

The companies are all using different CAD systems to provide 2D and 3D CAD capabilities, albeit for different products and product complexities.

COMPANY	D	E	F	G	H	I
NUMBER OF EMPLOYEES	113	447	1100	1000	82	5600
PRODUCTS	Vacuum, wet & dry cleaners, Garden product	Ink Jet printing systems	Hand Tools	Advanced Plumbing, heating and valve products	Industrial Valves	Heavy Engineering
CAD SYSTEM USAGE	3D Surface modelling 2 workstations, 2 on standby for complex models	2D for production. 2D PC based for sketches. 3D for new designs-2 seats	2D/3D	2D and Failed 3D implementation	2D + 3D Solid & Surface Modelling	2D & 3D Solid and Surface Modelling
ANNUAL TURNOVER	£24M	£50M	£2.6 Billion for the group	Export Sales- £15, 404,000	£10M	£10 Billion
NUMBER OF D.O. STAFF	2 plus manager	12 mechanical designers + 4 contractors	4 staff in each of 7 product groups	10	8	117
ORGANISATIONAL STRUCTURE	Organic	Flat hierarchical	Hierarchical	Hierarchical	Flattened Hierarchical	Hierarchical
SITES	Three (inc. two international)	Three	Several worldwide sites	One 20 Acre site housing all design and manufacture facilities; Subsidiary of a larger group	One 13 Acre site housing all design and manufacture facilities; Subsidiary of larger group	One main site Part of a larger group wit sites at other locations
MARKETS	Approx 98% UK-2% Export	Approx 23% UK 77% Export	Worldwide	Worldwide- Sales offices in middle east and USA	Worldwide	Worldwide

Table 5.1 Comparison of further case study companies "D" to "I": Markets, sizes and activities

5.2 CASE STUDY "D"

Introduction

The company were established in 1926 and have rapidly become a household name in the design and manufacture of upright and hand-held cleaners, wet and dry cleaners and steam cleaners The company are part of a larger group, with manufacturing sites in France and Ireland. As well as designing and manufacturing their own products they also distribute a range of other products , including garden products for the foreign based holding company. According to the company, the markets for the products are extremely fast moving due to the competition, market pull (128) and also because some of the products are seasonal. The market pressure is thus a major factor in the companies strategic operations. One months delay to a product launch could wipe out a major part of its profit making potential (129). They are essentially an organic organisation with strong communication links within the engineering office and between design engineers. The current design team are located at the main site which incorporates the European design and development facilities for the group. The team are housed in a large open plan office which co-locates teams of electrical engineers, product designers, graphic designers, marketing/ administration and manufacturing engineers. There are two members of staff in each team which provides a relatively flat organisational structure.

Design Process

The two designers use a 3-D CAD system for design and undertake every activity connected with projects from physical modelling in the laboratory, development of tooling, product design and liaison with manufacturing, customers and suppliers.

They have developed their own organisational structure for design based upon keeping a record of the model surface history so that it is possible to go back and make modifications once the model has been set. Projects are divided into sub-projects and all objects are created as sub-projects. Each design engineer is responsible for their own project work but they work closely together to resolve problems. Their responsibilities remain flexible and they are able to focus on all aspects of the design work including the opportunity to carry out their own laboratory tests on concept ideas.

CAD Introduction and Development

Opportunities from CAD were first investigated eight years ago when investment was made in a 2D CAD system with limited solid modelling capabilities. However, CAD use was restricted to that of an electronic drawing board with the result that the design team became frustrated with the system.

As the company adopted a concurrent engineering strategy they recognised that they were restricted by their 2D CAD system. The products designed by the company include a wide range of moulded and metallic components which form the basis of a number of larger assemblies and they recognised (partly from their previous 2D CAD experience) the opportunities from implementing a system which could allow them to derive an integrated core model from which all design and manufacture information could be extracted. This would provide them with the ability to use "Rapid Prototyping" for prototype modelling; they estimated that half of their development time was in making prototype models. Initially the company concentrated on 3D solid modelling systems, but realised that a surface modelling system was vital to meet all the companies needs.

In 1993, after spending 18 months investigating the CADCAM market and producing an evaluation shortlist of five CADCAM systems the company selected and implemented a five-seat, EUCLID- advanced 3D modelling system based upon the software's lack of constraints compared with other systems and the flexibility which it gave to allow designers and engineers to swap between solid and surface modelling; thus allowing staff to work in a way which suited them best The system incorporated photo-realistic rendering together with 2D and 3D surface modelling.

On implementation, the step change from 2D to 3D integrated system was daunting because of the range of capabilities and tools which the system offered. However, the design manager feels that the level of on and off-site training, general support and hand holding provided by the vendor has significantly helped staff to achieve the systems potential and since then a very good relationship has been maintained. Eighteen months after the initial implementation of the system a further three work stations were added to the suite of machines. The close relationship with the vendor helped to engender a culture whereby the vendor is trying to develop their new systems so that only the icons of activities that are relevant to a given drawing/ modelling action can appear on the screen.

Unfortunately after this implementation the design team was reduced from eight designers to two.

Support Structure

Because of the nature of the organisation, there is no separate definitive support structure for CAD as indicated in Figure 5.1. The senior designer has attained a wide breadth of experience in engineering, possessing an HND in Production engineering, OND in Marine engineering and a Degree in Physics and eight years experience of CAD at the company. Together with the design manager he supports and maintains hardware, software, new releases, bugs and the writing of macros. Their philosophy is that it is wrong to layer jobs in design and, where possible, it is best to let staff do everything to do with a job, from involvement with customers, marketing, design, prototype modelling/ experimentation, suppliers, through to manufacture.

The design manager is self-taught for macros and had written a number such as one for drawing all objects within a project.

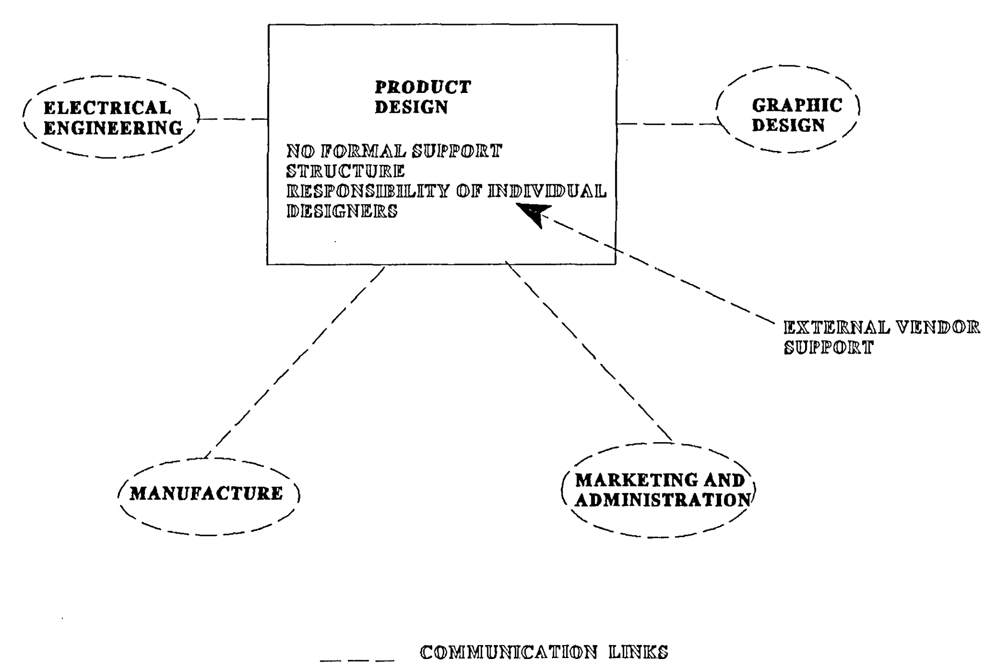


Figure 5.1 CAD support structure for company "D"

Training

Initially all the designers underwent a one week onsite training course operated by the vendor and this was followed up in two stages one week later, with half the group attending a one week off-site solids course followed by the remaining group the week after.

Once the initial designer training was complete manufacturing staff also attended a one week course.

Impact on Company

The company are finding it easy to transfer data produced with the previous system into the new system using the IGES translator and this clearly needs to be effective to protect the earlier investment in CAD in terms of time and effort.

The new system is providing major increases in speed and opening up new areas of work. After a few weeks practice with the system designers were sending 3D CAD model files away for the production of stereolithography components.

They are able to use SLA originals as master patterns for producing prototype products for test and user trials. On one project there was more than two months savings in terms of time. 3D files generated from the core product model are transferred directly to the company toolmakers for the production of mould tools. This typically means tool making lead times have been reduced by around a third which represents a six week saving on many projects.

The key benefit which the software is providing appears to be the consistency of information afforded by the core model. This allows the company the opportunity to obtain advantages across all areas of work from 2D design and inspection drawings (which can be generated from the core model within a few minutes) through to prototype modelling, tool making, final manufacture, sales and publicity.

The CADCAM system has given the company the capabilities which they expected, with their knowledge at the time of implementation. To some extent the company is moving down the road of "Integration" by introducing the CADCAM package at the other two main sites in order to simplify data transfer.

However, to move forward they need to address other issues of integration within the company. For instance Bills of Materials (BOMs) are currently produced on a separate computer at a different site even though the CADCAM software can issues BOMs.

The IT department look after and support a company wide purchase order and accounting system and integration with CADCAM data could provide efficiency gains.

There is a user friendly version of the CADCAM software available for the manufacturing team but there appears to be some resistance to its use and this needs addressing.

5.3 CASE STUDY "E"

Introduction

The company is a world leader in the design and manufacture of industrial ink jet laser printers for printing variable codes onto a wide range of industrial, commercial and consumer products.

The structure of the company is shown in Figure 5.2 and whilst hierarchical, it is approaching a relatively flat structure.

They are an interesting company, with a culture unlike most companies.

In manufacture they are completely focused on targets and quality. An MRP system and materials database is used to record components from suppliers and the mission target is that goods-in are on the shop floor by eight hours later at the maximum.

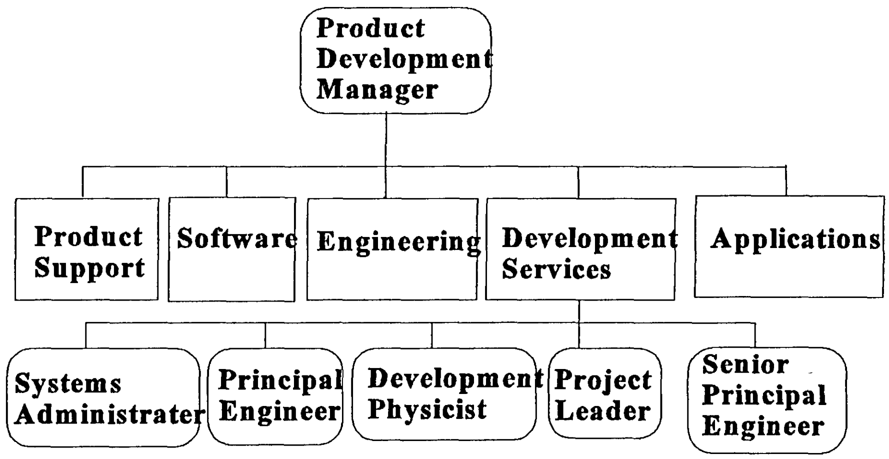


Figure 5.2 Organisational structure for company "E"

Five percent of goods are inspected in the companies own metrology lab next to the stores. If components are found faulty then the sales order is removed from the MRP system so that the company is not charged and faulty goods returned with requirements for the supplier to provide documentary evidence of a change of procedure to show how the problem will be alleviated in the future.

Lots of review of performance takes place on the shop floor. Each morning there is a team meeting for each team where targets are set and responsibilities/ tasks allocated. Achievement of targets are displayed on noticeboards throughout the shop floor detailing faults, scrap, production targets and actual times taken.

A Kanban system for print heads is employed.

There is an extremely well equipped customer exhibition area set up with a range of "Turnkey " printers for demonstration to potential customers. The company also have an HGV set up with systems to take to exhibitions.

A six monthly staff appraisal system is in operation linked to training and performance.

Design Process

The company produce industrial electro-mechanical products and therefore require electronics and mechanical design systems. Seventy staff work in engineering which is split into three groups as shown in Figure 5.3

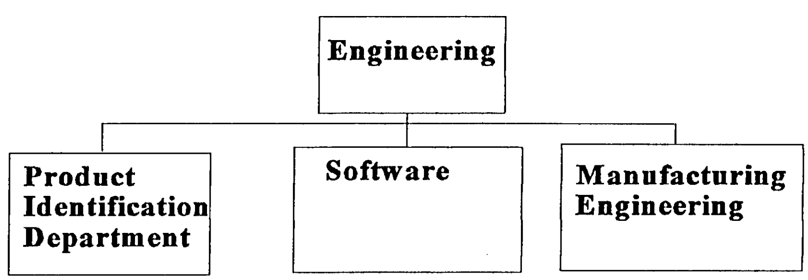


Figure 5.3 Engineering product groups for company "E"

There are three main sites and at the moment different software is used at the various sites.

Around twelve mechanical designers work in the design office, four permanently employed on mechanical design and four subcontractors. In general the designers are older but are very experienced and have come to CAD with great design skills. They are involved in "real Design" work and attend all project meetings and can freely interact with other departments. They are also able to visit external companies eg plastic moulding companies, attend exhibitions on rapid prototyping, stereolithography etc plus attend external courses on such aspects as tooling, parametric technology etc. Designers have access to a model shop where they create prototype models from their 2D Drawings.

Theoretically, marketing are supposed to work with the design department to agree and sign off product specifications but the criticism from the manager was that marketing often change specifications once the designs are under way

Production mechanical designs are undertaken using 2-D CAD whilst 3-D CAD is employed by two designers for new products which means one out of seven projects which are normally running.

Design problems are discussed by the team and a structured system exists for the administration of documentation eg. Changes are performed by a designer, checked by both the designer and the originator and further checked by an administrator

CAD Introduction and Development

Nine years ago all design at the company was done on the drawing board until the decision to implement six seats of a UNIX 2D CAD system. At that time every designer was trained on CAD and working as a group they provided their own self help training. Four years ago an investigation was undertaken into 3D CAD to show what could be done for manufacture and marketing with 3D and stereolithography. The group choice out of three pieces of software was Pro-Engineer and so the company virtually ditched the 2D CAD system and purchased one 3D seat of Pro-Engineer to test. At the same time they made two designers redundant so four others left. The test was then cancelled and one designer had to use the old 2D system for old work and use the 3D system for new work. To assist with the problem the company brought in external contract draughtsmen to do drawings, which they say proved really effective and they still employ contractors today.

For electronics design, two sites currently use the same two software packages; one for schematics, FPGA design & simulation and another for PCB design.

The third site currently use a different package for producing schematics with PCB design being done at the other sites. This creates a problem because new library parts have to be created for each new design, time and effort is required in generating the libraries and checking schematics against PCB layouts becomes difficult.

For mechanical design the company use a mixture of systems based on PCs and UNIX workstations.

At site number 1 the main software employed for production designs is a 2D design package running on sun workstations.

Other packages have been bought independently by departments, ie Generic CAD and AutoCAD Lite running on PCs for producing sketches and prototype designs. These drawings can be transferred to the main 2D package using DXF(Digital Exchange Format) but as this provides collections of lines rather than drawing objects it is easier to redraw drawings on the main 2D package than modify the lines. This of course can lead to errors

A 3D seat of Pro-Engineer running on a Silicon Graphics workstation and a further cut down version running on Windows NT are employed for all new designs.

AutoCAD release 13 running on a PC is used by the technical publications section for generating 3D drawings for manuals by redrawing original drawings from the main 2D package. Technical publications also employ 3D Studio for providing full 3D rendered images for sales and posters etc.

The second site employ AutoCAD 13 for 2D drawings running on PCs in all departments so that common transfer of data is available.. They also employ one seat of the main 2D design package used by site 1, but only for viewing drawings and they employ a single seat of Pro Engineer for training exercises but not for design work.

Support Structure

The theoretical support structure is shown in Figure 5.4 and indicates the complexity of the task. Basically all areas are theoretically supported by a systems administrator who looks after the areas of research, the CAD strategy group in terms of strategic focus plus the day to day management of CAD and other information systems ie concentrating on software packages and solving problems.

When presented with elements of the support model (section 6) he freely admitted that many of the activities were not embraced by the design department and indicated a considerable unease with having to admit this.

Much of the responsibility for design administration sits with the designers and is checked by the administrator. Design problems are discussed by the team and computer systems problems delegated to system administrator. For new products, project leaders together with two designers and a buyer have regular weekly team meetings and targets are set for design and prototype completion times.

However, it seems that if problems do occur, there is no system or procedure for logging them

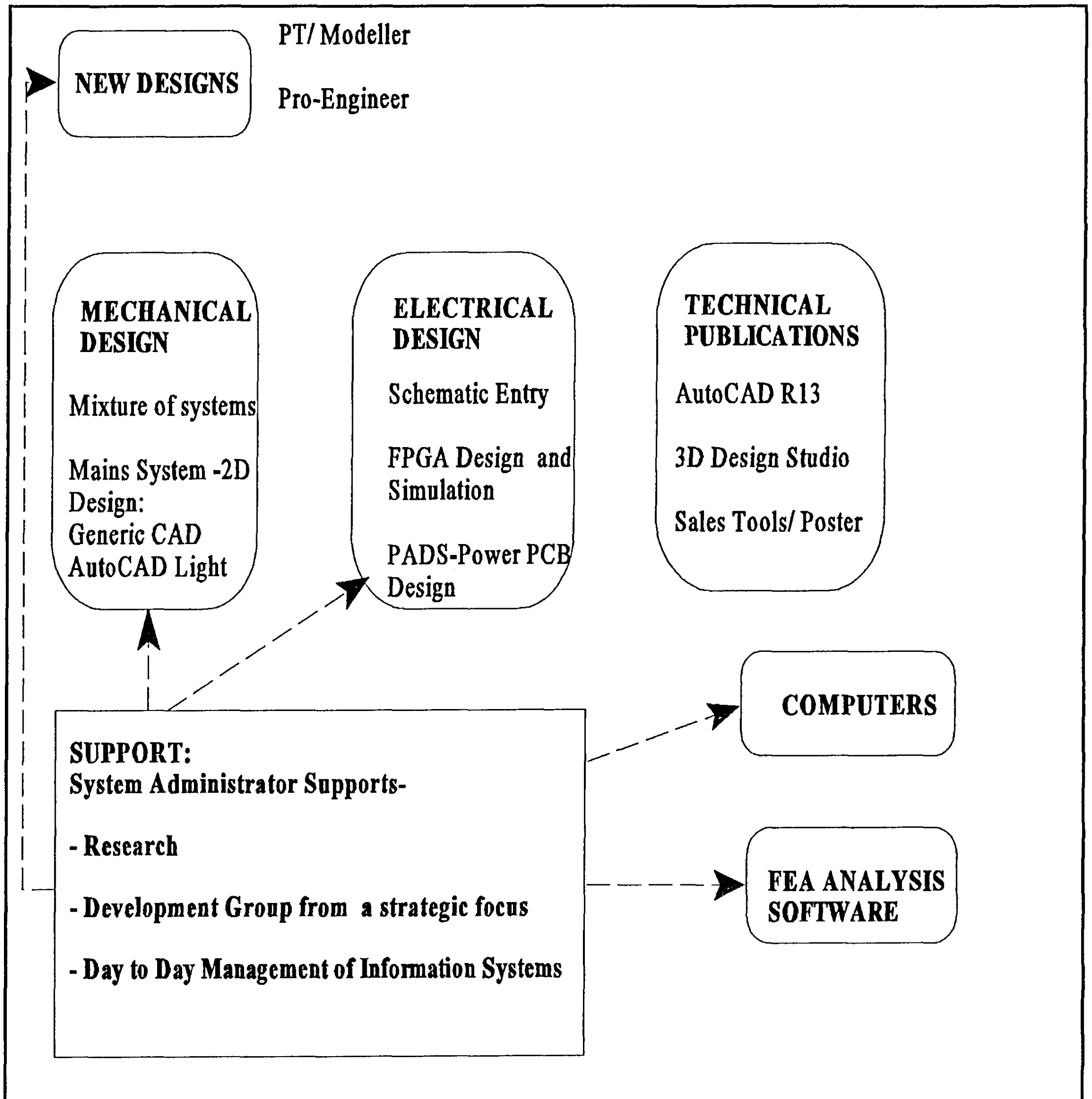


Figure 5.4 CAD support structure for company "E"

Training

Training is employed but appears not to have a strategic focus. For instance three days internal vendor training for the electronics package and internal training for system administration and use of 3D.

From discussions with many of the designers it seems to be that where staff are willing to instigate their own development, then the company is willing to support them. eg A technical illustrator taught himself AutoCAD and milling on his own (by attendance at C&G courses in his own time at night). His line manager recognised his ability and paid for his courses and exams.

The company operate what they call an "extra mile award" for extra effort put in by staff and the illustrator won himself a trip to America paid for by the company in recognition of his efforts.

Whilst not his line task, this illustrator provides expert support for other AutoCAD users in the company, especially in terms of the programming language "Lisp" and customising menus.

Impact on Company

The main problems that the company appear to have is that the 2D mechanical CAD system is a very specialised system. The vendors only have a very small market share and their system is not a common one. It requires specialist training to understand the drawing output and this output also causes problems of interpretation for the marketing and servicing departments.

The 2D drawing outputs from this system also provide ambiguity for the model shop when making prototypes because dimensions are either unclear or missing and this also creates time delays for external sub contractors in relation to moulded components and similarly for manual or CNC production.

Further to this, the large number of systems in operation at the company create problems, especially across different sites. The data exchange used is DXF (an unintelligent transfer method) and this results in design information being lost on transfer.

Having stated all the problems however, the 2D system has allowed the company to produce drawings three times faster than manually and to make modifications seven times faster. Quality is improved but errors still do occur which mean the product cannot be made.

The move from 2D to 3D was a big jump for the company but it has provided the ability to do things which they could not do before. Solid models of components have been generated from Pro-Engineer in 2-3 days instead of 2-3 weeks.

However, the obvious drawback is that the company do not appear to have a management champion to push the technical side of things and so the CAD/ Engineering department is suffering slightly.

Although in manufacture the company are focused on targets, in design they may not currently be as focused as they could be. In discussions with the CAD manager (ie systems administrator) it was clear that he was very depressed and de-motivated with the whole CAD structure and operation. When shown the proposed CAD support chart (shown in Figure 6.5) he admitted that they adopted few of the activities shown under "Back-up Support" or "Training".

However, he had just reviewed the whole area of CAD and developed a strategy for the future growth of CAD and CAE tools with the objective of obtaining step improvements in efficiency by changing to common tools across the group.(If management would listen!)

5.4 CASE STUDY "F"

Introduction

This company are a involved in the design, development and manufacture of DIY and industrial hand tools. As such they undertake existing work and new product development.

Design Process

The company are arranged into seven product groups (globally) with four product groups on site;

- Sustaining Products (ie existing products)
- Screwdrivers
- Knives and Blades
- Striking and Struck Tools

They are co-located in an open plan office, but sitting in teams, together with jig and tool design who also share resources.

Each team is headed by a senior product engineer and includes, a marketing person, a product engineer and a design engineer.

It is essentially the design engineers who use the CAD system plus two designers from the jig and tool group.

CAD Introduction and Development

In the late 1980's the company installed a Matra Datavision, EUCLID 2D and 3D solid/

surface modelling CAD system to be used for 2D drawings, factory layouts and new product draughting at a cost of £80 000 for the hardware/ software plus £13,000 per annum for maintenance.

By September 1992 some major problems were emerging. The commitment to employ the CAD system was not followed through with a commitment to support the use of the system. The system was not used how it should have been used and became a draughting aid. The software was never updated with revisions and investment was not maintained in new hardware. By this time the software was 5 years out of date and the hardware was obsolete and kept breaking down.

The company also vastly underrated the 2D work to be performed on the system and 2D dominated the use of CAD. Consequently the 3D facility could not be utilised efficiently because of the demand for 2D Work.

By 1995, the company had decided to ditch the system and the senior designer had a wish to create a network in the company with two workstations for 2D product draughting plus further training for 3D modelling together with one station for product design and additional surfaces and parametric facilities.

An investment was made in mechanical desk top CAD and seven seats of AutoCAD were purchased; two seats for jig and tool design, two for design+design surface solids, two for draughting and one for building and maintenance.

Outside consultants were employed to transfer EUCLID drawings to IGES format and to program them into AutoCAD.

In June 1998, the company are still employing this system. It is still used predominantly for 2D work although one designer uses the systems 3D facility regularly for new product development and the company have explored the extension of this facility to produce stereolithographic models.

Future strategic development across the whole company is however currently being tackled by a new chief Executive who is championing a global strategy for growth with the motto " Grow or Die as a Business". Part of this strategy is a 3 year plan from May 1998. Each product group has had to present their own 3 year development plan in the USA, detailing the introduction of new products and the phasing out of current products. As a consequence of this plan, new product development is considered in seven phases; eg

Phase 0- Basic Ideas

1- Specific product- Customer research-Prototype

2- Pre-production prototype

" - etc

During each phase there is a constant review and consideration of the financial aspects. However, the important point is that every month there is a "Phase review board" where each group reports to head office to monitor the progress of each NPD against the three year plan. As an example the Screwdrivers group have the task of bringing six new products to market during the three years. On a product group basis an important aspect of this is the team meetings which occur twice a week.

When the company initially undertook a feasibility study into using AutoCAD, great emphasis was placed on return on investment (ROI) justification by the head office. The new chief executive sees new technology in CAD as being part of the strategy for NPD and therefore a decision has been made to invest in 200 seats worldwide of Parametric Technologies, "Pro-Engineer" at a cost of several million pounds; to quote a senior designer " with some requirement for justification but without too much emphasis on ROI".

A change is therefore taking place at the company. Things are bubbling and people are generally moving along with the changes.

Support Structure

The support structure for CAD does not appear to be very visible and is developing still, especially with the advent of the new 3D system. However the structure is shown in Figure 5.5

Engineering is contained in one co-located office but staff sit in teams.

Support for computing and CAD, for all groups, for the implementation of new systems and upgrades etc is provided by a senior design engineer from within the screwdrivers product group.

Support for CAD hardware, Windows 95 and network, plotting, printing and software downloading is provided by a separate management information systems group who are also responsible for the companies MRP system.

General system organisation and administration is left to individual product groups to arrange internally,; "it just happens"

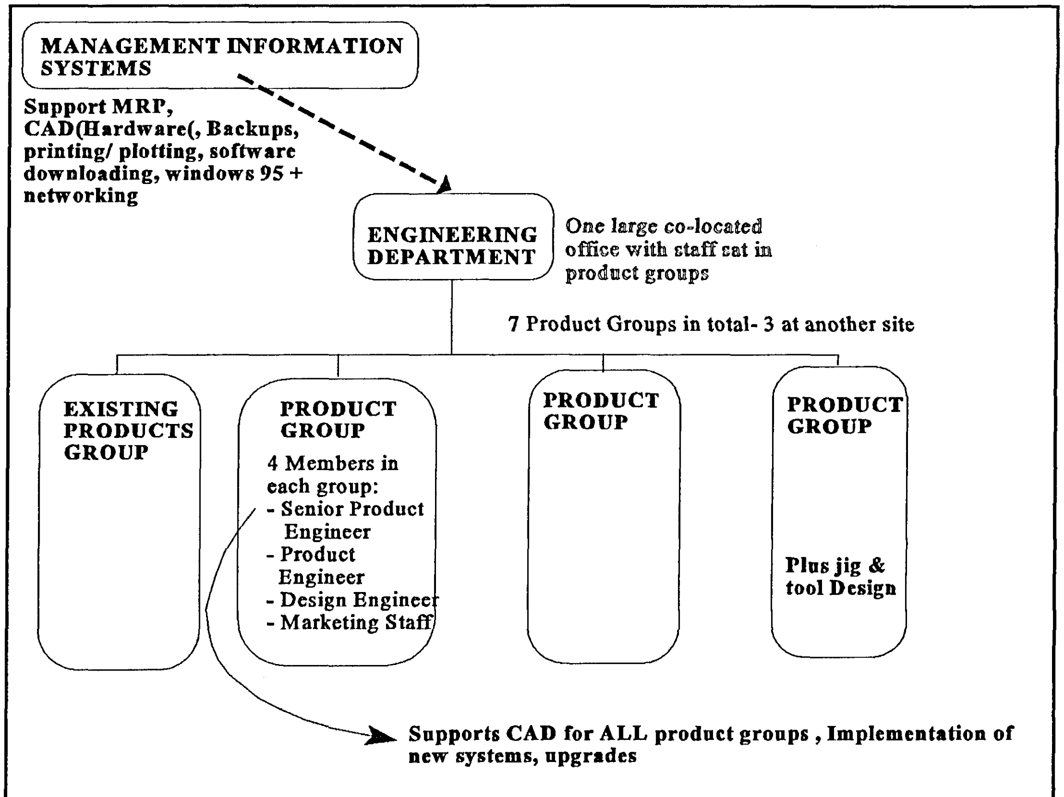


Figure 5.5 CAD support structure for company "F"

At the moment very little input is required for developing 3D methodologies but notionally if this were required it is the responsibility of a particular design engineer.

Procedures for draughting are constrained to standard company drawing sheets with layers already assigned. Since the majority of work is new and does not involve families of parts, the designers view is that macro's and parametrics are not needed.

No monitoring or logging of problems is undertaken; most problems are left to the vendor. However, there is a more robust system of reviewing and monitoring performance (which is part of a major change which is taking place in the organisation due to the advent of the new chief executive in the last 18 months.

Training

In the past the company have not been very proactive in sending staff on training courses

Training for AutoCAD involved external vendor training for the basics of using the software followed by cascade training within the company from good users. Designers complained that the training was not relevant to their field of work; ie training examples were more architecturally biased. Because the training was not related to their field of work they feel that they developed their own ways to use the system so that it worked, but that those ways were not necessarily the most efficient or effective

Since the introduction of the "new product development strategy" there is a big culture change taking place, primarily because the new CEO is very keen on training as an essential strategy for new products.

Now design staff have the ability to influence the need for further software or training and several are attending a one week course on NPD, another is also attending a one week FMEA course in the USA and is expecting to attend a project management course as a need identified in his last 6 monthly appraisal.

Impact on Company

The strategy being adopted by the new CEO places the business emphasis clearly on NPD. Contrasting this new emphasis with previous experience shows that speed to market used to be very bad at the company. Previously they were ambling along, developing prototypes for exhibitions and finding that by the time of the exhibition some companies already had a similar product on the market. For example, company records show that the marketing department identified a need for a product in 1987 but this was not brought to market until 1993.

5.5 CASE STUDY "G"

Introduction

This involved four half day visits over a nine month period.

The organisational structure for the company is shown in Figure 5.6 . It is well known for the worldwide manufacture of advanced plumbing and heating systems. The company occupies a 20 acre site where it undertakes all design, development, tooling and manufacture of the product. On site is one of the largest brass foundries in Europe and a range of techniques are employed including, gravity and pressure die casting and centrifugal casting. Components are machined on site using up to date CNC machining methods and all surface finishing eg chrome plating is done on site.

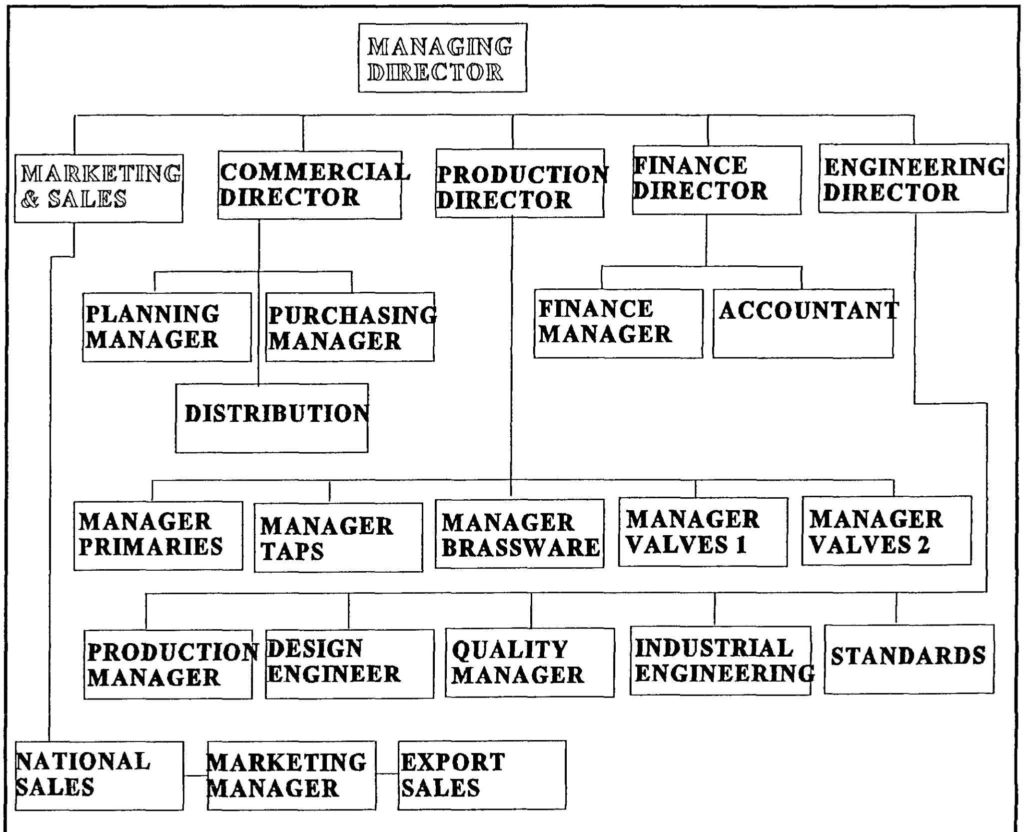


Figure 5.6 Organisational structure for company "G"

Design Process

The structure of the design department is shown in Figure 5.7

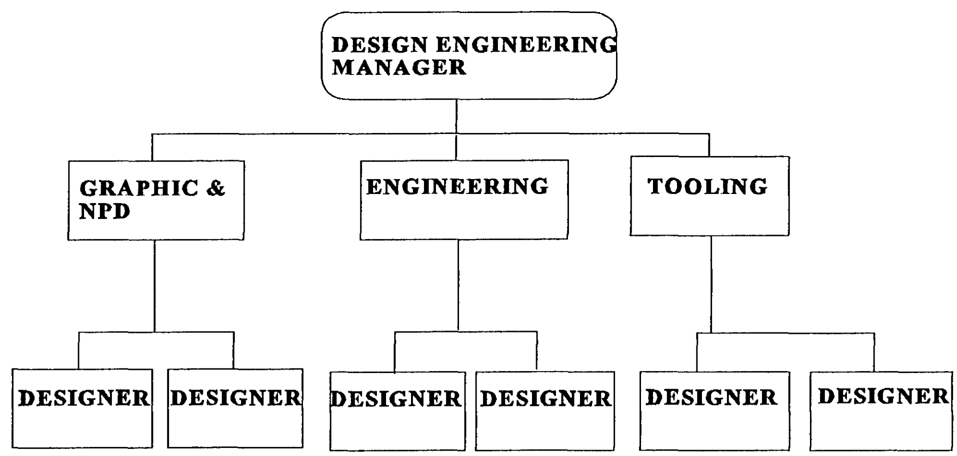


Figure 5.7 Organisational structure of design department for company "G"

There are ten staff in the design office, six draughtsmen, two designers and one model maker and test engineer. They are co-located with engineering staff who undertake value analysis and value engineering projects.

The designers currently use an ECS 2D CAD system for producing all new designs (except artwork) which comprise of general arrangement drawings, detail design and tooling drawings.

The current design process in the company involves:-

- Concept Designs being produced manually
- Hand-Crafted manufacture of prototype models- which require pattern and stamping dies and general milling

- 2D CAD for Tooling design

CAD Introduction and Development

The system was introduced in the late 1980's but has recently been upgraded to a windows based, networked system. The use of 2D has created success for the company in speeding up NPD.

Over the last six years demand for products has increased and the CAD system has helped speed the process and increase productivity especially on NPD.

However, as the 2D nature of the system does not provide realistic visualisation of the products the company have no choice but to manufacture physical models to show to customers. This results in a considerable lead time in drawing, manufacturing and modifying to suit customers requirements and then remaking. For instance, water tap models are made from a white resin to give as realistic an impression of the finished article as possible. The cost and time involved is considerable. Typical lead times to a working prototype model are around six weeks and yet the models still do not provide the same degree of visualisation as a chrome plated model.

Currently therefore the company are investigating introducing a 3D CADCAM system to enhance their capability to produce realistic 3D visualisations for marketing and to reduce lead times by 50%.

They do have some experience of 3D, although not necessarily a good experience. In the early 1990's the then technical director and head of design chose to implement a 3D CAD system at a cost of £90,000. The basis of its use being to;

- Improve on product visualisation

- Speed up NPD
- Keep up with the competition

The designers accept that the system was good, but unfortunately selection of the package was ad-hoc. There was no strategy in the company in relation to what 3D CAD would be used for, other than to speed up the overall process. The benchmarking process allowed the vendor to take away a drawing of one company product and produce a 3D drawing over quite a long time period ie a week.

Consequently, the experience of the CAD vendor together with the time available resulted in the production of an excellent 3D image. However, once the package was purchased company "G" found it extremely difficult or impossible to fillet the types of sculptured edges and faces that many of their products incorporate and really what the company required was more of a styling package..

Two designers were trained to use the system by attendance at a one week external vendor training course. They found the training very technical and difficult to learn. Support at the company was restricted and remained the same as the support structure in operation for the 2D CAD system ie little internal support and an external telephone help line with access to an on-call engineer. After a while the company discarded the system.

From this experience the company suggest that they learned that:

- Everyone must be involved
- It is necessary to benchmark systems realistically
- Functional requirements of company products must be defined

- Drawbacks of systems should be determined

As stated previously, the company are currently investigating implementing a 3D CAD system once again, at a cost of £114,400 and associated casting simulation software, CNC machines and tooling at a total cost of approximately £534,000.

This time however, the company do have a clear idea of what possibilities exist for such a system. They have benchmarked a system based on;

i Ease of use

ii Functionality

iii Compatibility with the current 2D system to provide a two way link for data transfer

By implementing the proposed system they hope to overcome a number of problems with the current design process, in particular speed, which would result in a capability to remain effective in NPD.

The need to pursue NPD is vital for the company to survive. They export products to 110 countries worldwide. Many of the product ranges are sensitive to the functional and artistic (Traditional or contemporary) likes and dislikes of different countries cultures and quality standards etc. They are also particularly influenced by the rapid product development undertaken by competitors and market push

The company have increased NPD over the last six years and have a strategic NPD policy of introducing 21 new product ranges by the year 2001, an increase of around 50%.

However the increase seen to date in NPD has placed a strain on design and in particular tooling where a backlog of tooling orders has been created which is exacerbated by a shortage of capacity on machines and the need to improve quality and delivery.
The company estimate that tooling orders are exceeding output by about 6% with order backlogs of around ten weeks.

The strategy of the company is that 3D is needed to:-

(1) Respond quicker to market requirements

(2) Allow greater visualisation and interpretation of the model

(3) Improve the NPD time to product launch (this is estimated to be a reduction of around 50% (ie from 6 to 3 weeks) by:

- Producing 3D visualisations and using CADCAM together with high speed milling machines to generate prototypes thus removing the need to manually manufacture models
- Reducing tooling lead times
- Reducing design times
- Reducing design and tooling re-do times by employing casting optimisation/ simulation software

Based upon this strategy the company have taken the decision to pursue the implementation and purchase four EDS Unigraphics CADCAM workstations together with two Heckert C800U High Speed Milling Machines, a Hittachi DNC package, Magmasoft casting simulation software and various ancillary equipment and tooling.

The graphic designers will be employed full time on the system to generate 3D models for greater visualisation and acceptance or rejection by the marketing department in collaboration with the customer. The old 2D system will be retained for transferring model data from the 3D system to generate 2D tooling drawings.

The general strategy for technology implementation in the past has not provided enough thought into the project and to defining why the system was needed and what it should do.

Current technology strategy at the company seems to have evolved based upon learning from experiences with the past systems and is reasonably well thought out. However the strategy for people is not so well defined. Within the design engineering department there is no hierarchical structure just seniority by experience. The intention is that the graphic designers will become dedicated to the 3D system without it having an effect on the department structure. They will be the prime recipients of training and use of the system although other designers will be trained. The design engineering manager feels that training will probably involve one week external vendor training with occasional support days/ workshops for resolving problems.

To move forward the company recognise the need to consider the support structure for the new system. It is a more involved system than the current 2D system and has implications for interaction with marketing, design, manufacture and tool manufacture, especially with the prospect of a DNC link from CAD to tooling.

However, the most interesting comment made by the design engineering manager was that when they move to 3D "Nothing really will have to change- the support existing at present will be the same".

Support Structure

In terms of using the 2D system there are no problems identified by the designers. Support appears to be fairly minimal but satisfies the needs at present. No internal support exists for the CAD software but just for the network.

A library of parts is held on the system, which any designer can add to but it is essentially the responsibility of the design engineering manager and one design engineer. Most support is delegated to the external vendor via a 9-00 to 5-00pm telephone help line.

Training

Training for the 2D CAD system mirrored the traditional trend with 1 week off site training plus a 1 day refresher course later on.

Impact on Company

Currently bottlenecks are experienced in product design and tooling manufacture due to an increase in NPD as a result of "Market Pull" and the companies response to this need to increase NPD.

The current 2D system allows drawings to be produced much faster than previously but is restricting NPD due to the flat visualisation of the design. This in turn has an intangible effect upon marketing and cost.

5.6 CASE STUDY "H"

Introduction

The company was founded in 1803 by an innovative engineer of the time, who is credited with developing the first paper making machine, inventing the steel pen nib and the tachometer for measuring machine speeds. His ability as an engineer undoubtably helped develop the companies expertise in engineering, although they did not become involved with gas valves until 1847, seven years before he died. However, the design for that particular valve was reportedly so good that it was made and sold until 1964.

Since that time the company have developed the products to cover valves from 1/2 " to 90" with working pressures of 50 bar and temperatures of 900 ^oC

In 1997 however, the company, was taken over by a large foreign concern and are going through a rigorous change. The company maintains the old name but each area of the company has been broken down into separate businesses, namely the valves design/ manufacture and the sales department. The organisational structure of the new group is shown in Figure 5.8 and the "Valves" business structure for the company is shown in Figure 5.9. The company occupy a 13 acre site where all design, manufacture, development and testing takes place (including, casting, machining and surface coating) The company is divided into four main sections with engineering essentially being where design sits in the company. Within the engineering section there are 3 staff operating as designers and mechanical engineers. Their job therefore entails more than just sitting at a computer screen all day and involves them in preparation of designs for CNC manufacture, trouble shooting, development and testing etc.

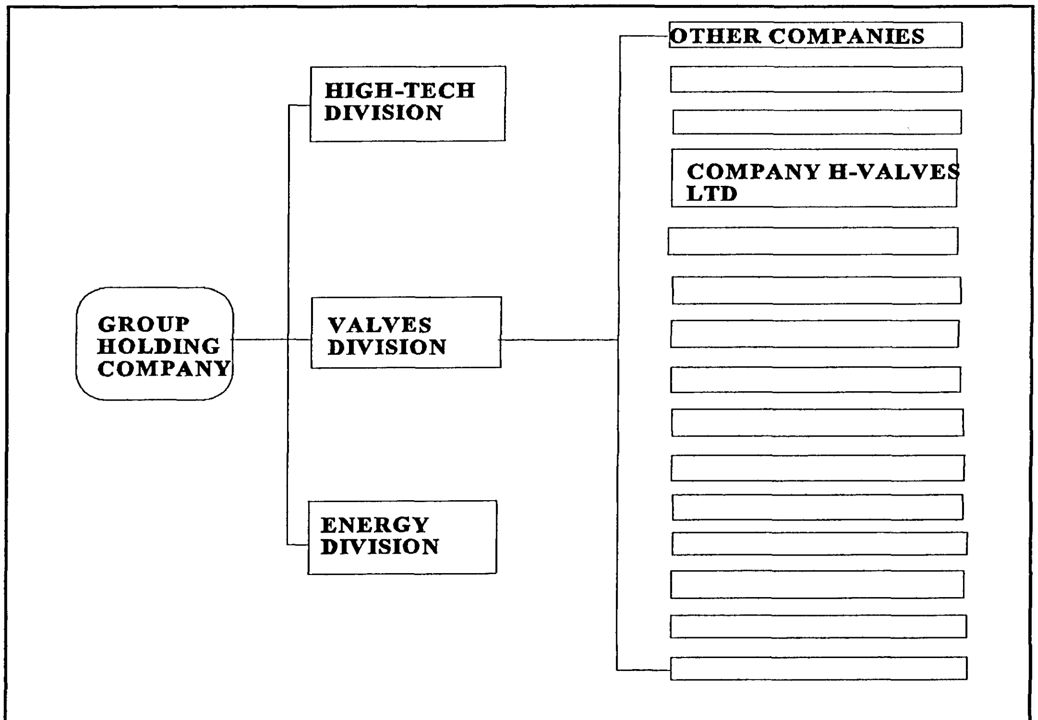


Figure 5.8 Organisational structure for company "H"

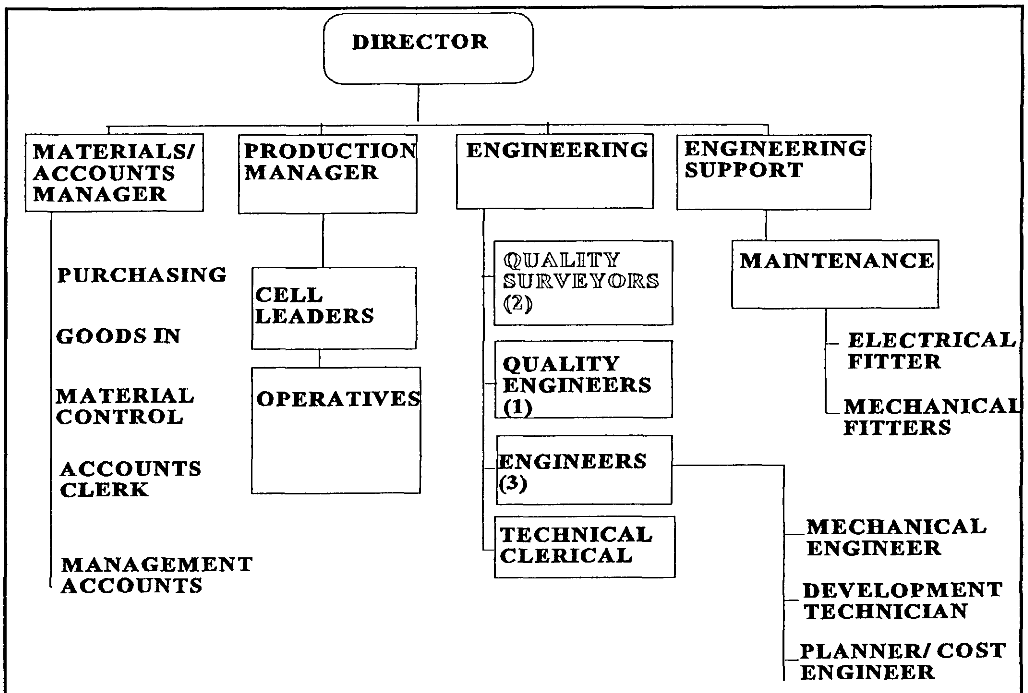


Figure 5.9 Valves organisation structure for company "H"

Design Process

In 1990 there were three senior designers plus other designers and draughtsman. The process of design followed the normal sequential process of specification, idea generation by pencil sketching and manual draughting on drawing boards with pencil and paper. Following this designs were passed to engineering production for the design of jigs and fixtures.

The current structure however makes use of concurrent engineering philosophy; the sales department identify markets and liaise with engineering. product design, CNC programming/ and the design and production of jigs and fixtures are done at the same time. Production staff are included in the design process and the four managers have one hour weekly meetings to discuss design and production issues.

All drawings are now done on CAD with engineers performing every task from defining the product, design feasibilities and mockups/ prototypes, numerical analysis and synthesis of products and casting etc, CNC programming, supporting production, testing products and materials, investigating problems with products, liaison with customers and suppliers.

The company have a great many old pre CAD drawings and the decision was taken not to convert the drawings on mass to CAD drawings but to do this at the time of need. Some drawing boards are still in existence but are only used if and when an old drawing needs updating

CAD Introduction and Development

From 1991/92 until the early part of 1998 the company were operating a PAFEC-DOGS 2D CAD system. This was basically a 2D electronic drawing board which could be employed for drawing and calculating areas of components but in the words of the design manager "did not do anything else and therefore was not any good at all". The system ran on a UNIX platform which meant that it was also slow. The company also operated a MRP system which ran on an IBM system but no link existed between this and the UNIX system.

As a result of the take-over and in an attempt to produce a step change in quality and productivity the group dictated to the company that they should consider installing a full PC network running packages such as excel, word, etc plus CAD, finance packages, stock control and a limited link to MRP.

In relation to CAD the group told the company to review three systems

- Intergraph 3D Solid Edge
- AutoCAD
- MicroCADAM- Helix

Each package was taken on trial for one month and the engineering manager worked through the tutorials. He looked to base his decision on ease of use and the ability, especially with 3D to still come back and use the software three weeks later without having forgotten how to use it.

Eventually the decision was made to install one seat of MicroCADAM- Helix 2D/3D desktop solid and surface modelling system at a cost of £9,500. It consists of 2D and 2D parametrics and provides 3D solid and surface modelling of mechanical parts and assemblies.

In this country this particular CAD software is not so well known. It is an American system used extensively by Japanese companies, Kawasaki and Soni in particular but it is also employed by Westland and Hopkinsons.

Support Structure

The support structure for design and CAD is shown in Figure 5.10 . Support does not entail a separate department but impinges upon key people in the engineering team to provide this. Although there are separate individuals with specific roles in terms of support, it is seen as the role of each individual to contribute to a team effort. The ease of use is seen by the manager as being a vital element of the support structure; the system provides online user documentation with hypertext support together with context sensitive help and the ability for users to add their own notes to the online material. Support for training does exist but is perhaps not as strong as it might be.

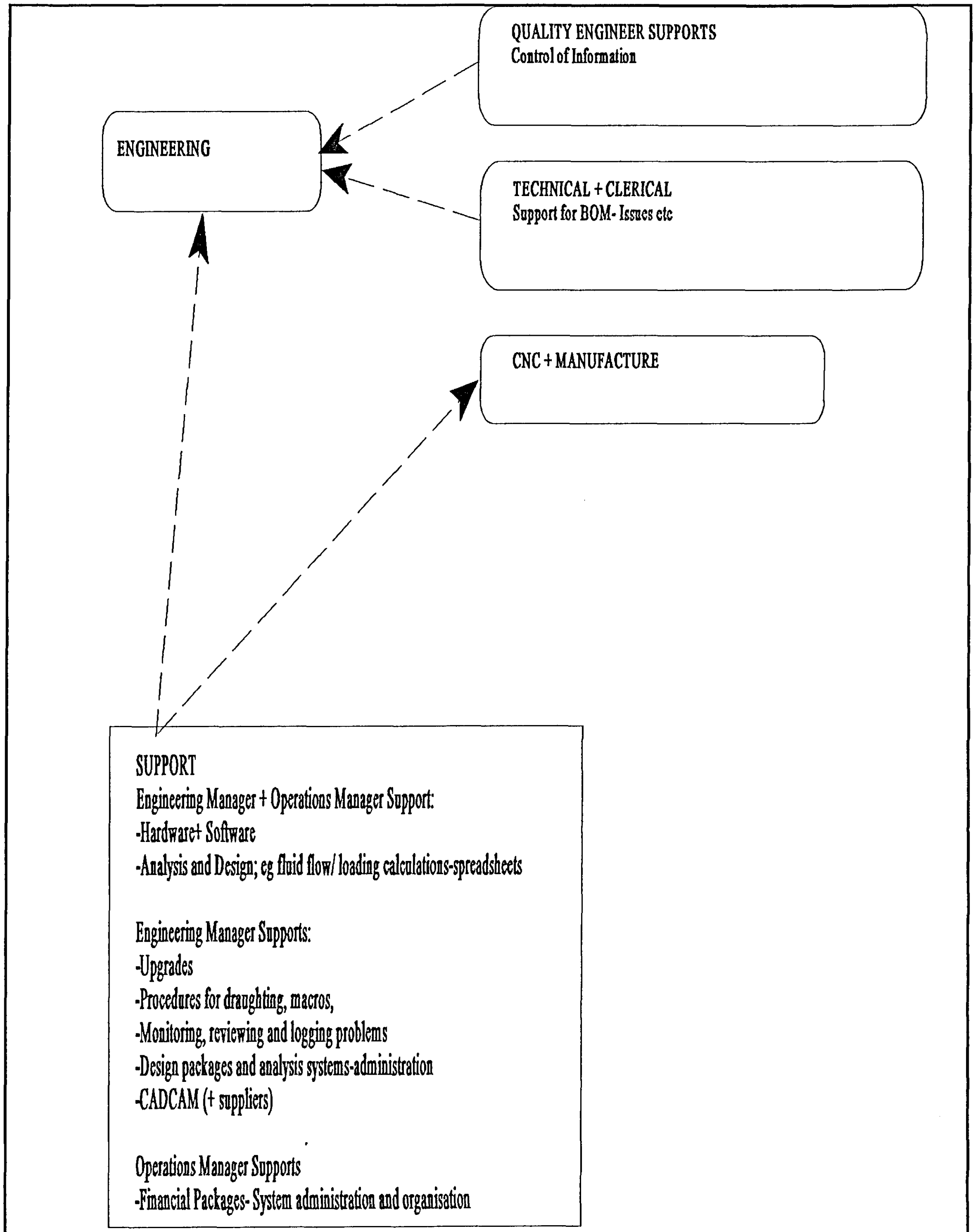


Figure 5.10 CAD support structure for company "H"

Training

All three of the engineers using CAD are degree trained, with two also being apprentice trained. However continuing education and training is only employed by the company if needed as part of ISO and knowledge of design, processes and techniques is assumed/ expected to be part of the engineering background degree training. No support training is given in such things as team working, communication etc, training being restricted to tangible aspects such as CAD.

CAD training has been brief with training undertaken by the vendor (essentially for 2D) on site, working on actual company products for one day. However the manager is committed to training both for CAD, to which he regularly dedicates one hour per day for staff to learn and for the whole range of other software which has been implemented onto the network. The PC network system was ordered at Christmas 1997, delivered January 1998 and was live by April; people were forced to put time aside to do one hours training per day.

Currently, the training agreement for CAD means that there are 3 training days left which may include the use of solids plus other aspects still to be identified.

Use of the CAD system is currently restricted to 2D and few problems exist at the moment.

Impact on Company

Because the company were basically new after the take-over, the group decided that the company should not produce any new products in the first fifteen months. Coupled with this settling down period, there is no specific requirement to justify the performance of the system.

What can be said however is that the change has meant a speed increase in 2D drawings plus a better product but more importantly has meant that the company can transfer files to other companies in the group. The change has been seen as positive and has resulted in the company placing an order for one more seat plus two new terminals and higher specification computers.
In terms of the full implementation of a PC network it now means that staff can copy and paste drawings into word documents etc and fax direct from the machines which means it is more efficient than the old system. Use of 3D is currently limited but the company see an immediate use being the inclusion of 3D models into sales literature.

Commencing in October 1998 the company were intending to commence a NPD strategy which aimed to implement five new projects. Each project would probably involve three designs, some using polymers, and make use of 3D modelling because the parent company in Holland can design mould flow analysis around a 3D image.
A bonus system is in operation for all employees in the company, based upon attendance/ time off and productivity with typical monthly bonuses of around £70.

5.7 CASE STUDY "I"

Company I provided the opportunity to do two things:-

a) To explore the relevance of focusing on the area of "Support" with a very well respected, experienced and successful company with many years experience of CAD

b) To use the company as a case study specifically because they state that they employ a strong support structure for CAD

Initially contact was made with the design office manager via telephone and after discussions a meeting was scheduled for one morning with the CAE Support manager. After briefing the manager on the research to date and identifying the focus of the research onto support, the following questions were asked;

- Does your company undertake any of the activities/ address issues identified in the support model (shown in Figure 6.2 on page 174)?
- In your experience, is Support a central determinant in a CAD introduction and development methodology?
- Is this the correct area to consider?
- What would be the effect of removing this support?

As will be seen in the detailed case study discussion below, the company address the majority of issues and have a strong and well detailed strategy for undertaking the activities.

In the opinion of the CAE manager, the issues are exactly the ones which companies should address, no matter what their size.

However, he suggests that an additional aspect be applied to the support model. The nature of support required by companies (especially where CAD moves towards networks and windows 95 type applications) means that support may come from different areas for different aspects eg MIS or IT departments' may support hardware, networks and other distributed software but not CAD software. Responsibilities for support aspects may be shared or picked up by anyone responsible for any aspect of support and thus the boundaries become "Fuzzy". Therefore the research model here will not restrict research on CAD support to just CAD but consider where appropriate the role of IT as well.

In answer to the last question, the manager suggests that removing support would not have an effect straight away. The inertia in the organisation would mean that for a while things would carry on as they were, maybe informally, but after a few months the organisation would descend into chaos:
There would be no tracking of drawings, no one would know which revisions of drawings were current and no one would have the responsibility for ensuring correct information was available.

Thus the initial meeting provide further validity of the research contained herein.

Introduction

The main case study research in this company involved a further half day visit and interview with the CAD manager identified above and separate visits to speak with the drawing office manager. The interview took place in the companies purpose constructed CAD training room with 10 terminals providing the ability for standard user access and support access. The focus of the meeting was directed towards the support structure in operation at the company, how it worked, what was particularly good about the support and what developments, if any were still needed to improve support even further.
A flip chart and marker pen provided a means for structuring the interview in a dynamic and interactive way, with both parties contributing to the elicitation of information and

also providing a record of the discussions.

There are around 117 CAD users in the company with 97 being regular users and a further 20 occasional users.

The company is located on one site but is part of a larger group which has a number of sites elsewhere. The company is split into a number of divisions covering engineering, sales and a number of product groups. Each of the groups are located on different floors of two office blocks.

The majority of CAD users (approx 75) are employed in engineering with half involved in general design and half in project design. The remainder are spread between the sales and product groups

The breakdown being approximately:

Nine in Sales

Two in product group 1(using AutoCAD)

Six in product group 2

Twelve in product group 3

Two in product group 4

The 75 regular users have both read and write access whereas occasional users are only allowed viewing access to relevant projects.

The CAD system currently employed is MicroStation 2D/3D solid and surface modelling and has been in operation for four years. It was installed at a cost of £1.4 Million with half being spent on hardware and half on implementation, which included training.

Logging of access times for staff to open the software revealed a saving of one hour per day for each member of staff compared with the previous system; a considerable time and cost saving.

The whole of the company is supported by an IT department and the structure is shown in Figure 5.11

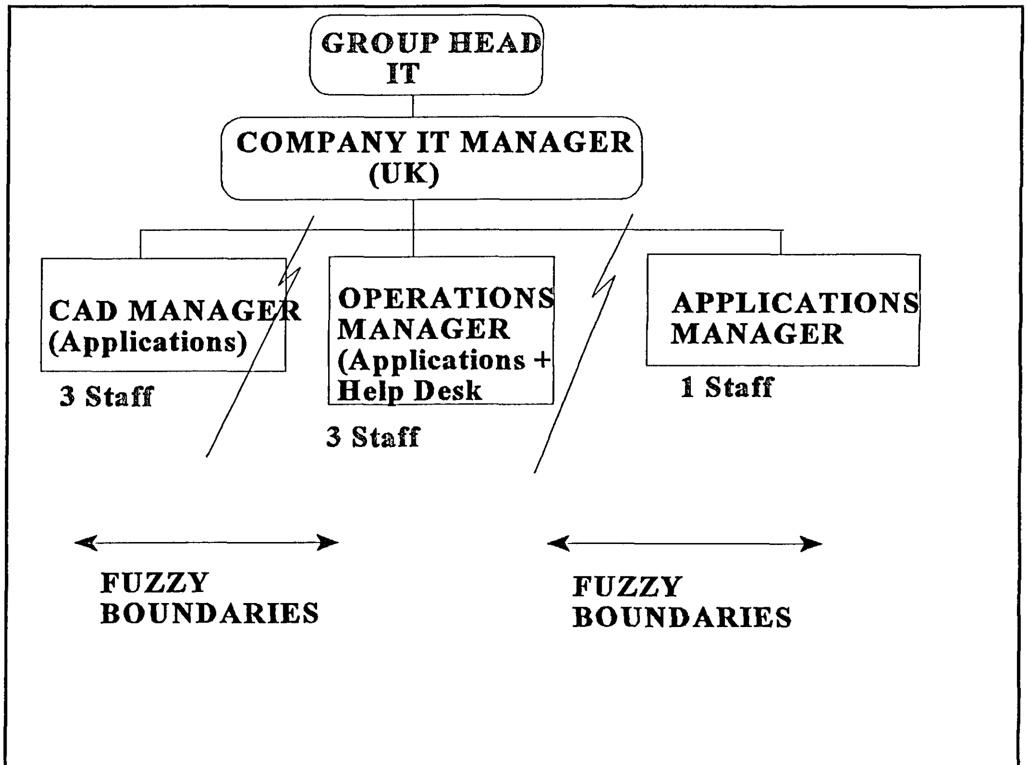


Figure 5.11 I.T. support structure for company "I"

A Group Head controls IT support for the whole of the group and a company IT manager provides UK support for two sites spending approx 50% of his time at each site. Each of the three departments have their own specific roles, but the role of IT support means that the boundaries between each department are a little fuzzy and departments may cross over each others boundaries to provide the necessary support to users. However, essentially CAD support is headed by the CAD manager (Applications) together with a team of three staff.

The primary function of CAD support is to support users ie "Users come first" so that problems are tackled at the time users require help and not several hours later.

A secondary, although still a main function of the support department is to improve systems for engineers.

The support structure for CAD is shown in Figure 5.12. Much of the work concerns general operational support as shown at level 1. Level 2 work involves projects identified and sanctioned as activities which will significantly improve systems for engineers.

Level 1 support involves installing and updating software, customising screens, administering the system etc. Users have telephone access to a "Help Desk" for the solution of every day non urgent problems or to just ask for assistance from CAD support. They also have access to E-mail with a 1.7 Mb limit.

For problems which are seen as needing relatively fast response and solution, users are encouraged to telephone CAD support directly. The department have implemented remote viewing of users screens and can talk users through problems whilst manipulating users screens from the CAD support department. This has speeded solution response by reducing the need to physically attend the users department (which are dis-located by office blocks and floors)

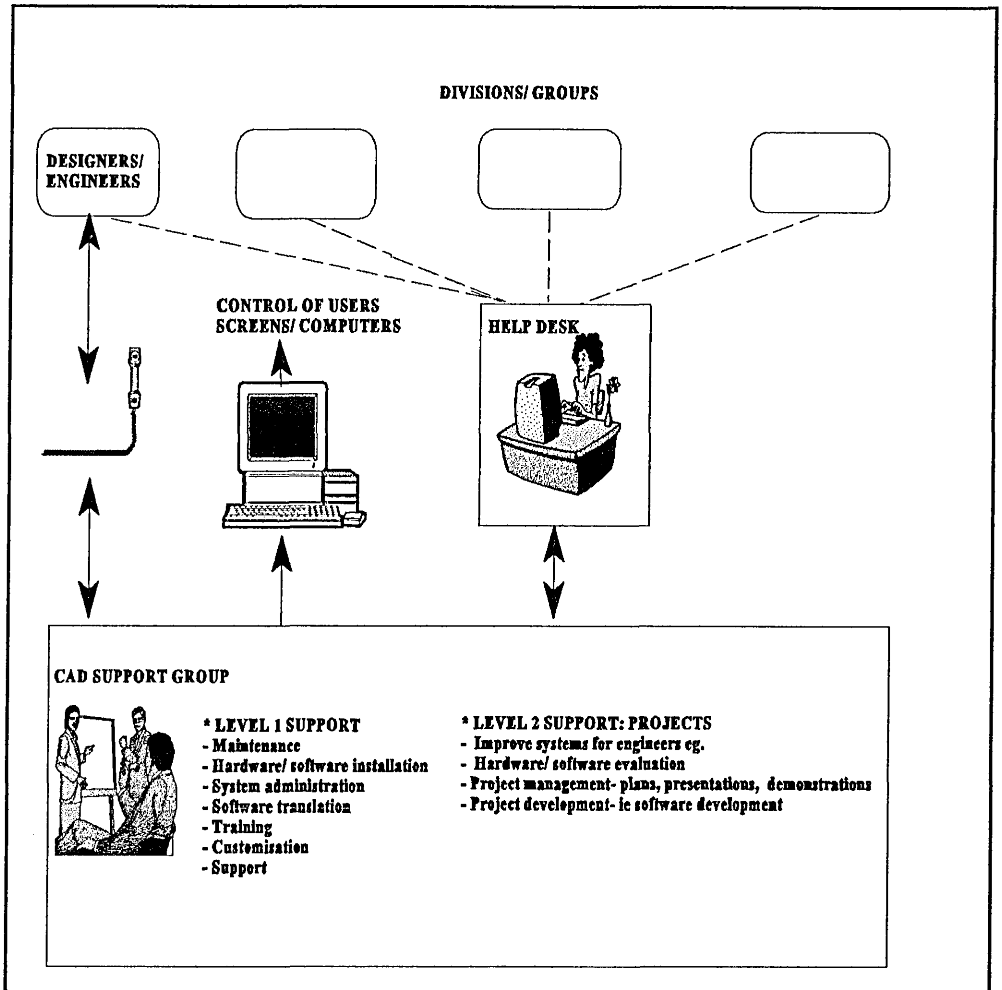


Figure 5.12 CAD support structure for company "I"

Level 2 projects may originate from CAD support or from engineering departments, the preference being for projects to originate from departments so that they "Own" the project which means a higher likelihood of success. Either way, CAD support have to perform projects in a highly visible way. Projects are reported to everyone in the company in a monthly report placed on the Web and to which all employees have access.

Such reports detail;

- Project objectives
- Background
- Specifications (Which must all be signed off by engineering and any external parties)
- Monitoring of project plans and functionality available

CAD support therefore have to show a level of performance that has a strategic influence on other departments operational performance and the business relationship.

Typical projects carried out include;

- Internet project which allowed engineers to view and modify drawings from anywhere in the world. The advantages were numerous. In terms of world viewing general security was better as there was no need to take laptop computers or CDs/ disks abroad. Lead times in obtaining drawings were reduced from 1 week to just a few minutes.

- Introduction of parametrics- This is a project currently under investigation to bring drawing times down. This is estimated to provide a saving of around £500,000 on a typical £13 Million project.

- Developing software to provide designers with appropriate design tools. For instance the development and integration of FE analysis software with "Core Functionality" rather than the full blown system. ie sufficient functions to provide engineers with a basic awareness and appreciation of a stress situation without the need for them to be experts.

The company recognise that they need to keep up to date with technology in the CADCAM area but similarly recognise the financial implications of this. Their strategy for this is shrewd. Recognising that the current technology does not perhaps perform some functions/ activities which would be beneficial to the company the CAD support area have forged a close relationship with the vendor. By proposing developments which would be beneficial to themselves and to many other CAD system users and working jointly with the vendor to develop the system, the company are driving revisions of the software to give them exactly what they need for the future, without the high financial implications. Thus the available technology is at the leading edge of their own requirements.

Training for the system involved 10 staff being trained in house. They were then allowed 1 year to practice. The company wrote their own procedures and based on the initial 10 staff, worked out a learning curve, in terms of time for other staff, before implementing the system fully- This generally equated to 1 months training for all staff. On an ongoing basis training is carried out in the companies purpose constructed training/ seminar room located next to the CAD support area.

The support structure in operation at the company works well. One reason for this appears to be because service level agreements exist between CAD support and engineering department. This allows CAD to provide the exact level of support required by different departments. Devolved budgets means that the departments pay for this support and the CAD support department can show financial viability for their activities.

In the view of the CAD manager the biggest problems with support (whether at the company or other companies) are related to

1 Setting up similar operational activities between various sites

2 Sharing training schemes

3 Having regular monitoring and reviews to show how/ that individuals and departments are viable.

6 DISCUSSION OF CASE STUDY RESULTS

6.1 INTRODUCTION

This chapter discusses the results of the further case study work, companies "D" to "I", presented in chapter 5. It identifies strengths and weaknesses of company activities in relation to the case study research framework developed in section 3.5.

The three initial case study companies "A", "B" and "C" were investigated using the same research framework, based upon quality criteria, and were shown to be successful and generally providing examples of good practice in the area of CAD introduction and development. For this reason, the strengths and weaknesses exhibited by the further case study companies are contrasted in this section of the thesis with the three initial case study companies.

Generic issues and themes are drawn from all nine case studies and are employed as a basis for the development of a model for effective CAD implementation.

The chapter summarises with propositions for further validation of the model via a national survey of UK companies

6.2 DISCUSSION OF FURTHER CASE STUDIES

The six further case study companies involved in the research were all selected for investigation because of reasons which indicated a level of success; either through recommendation or external recognition as discussed in chapter 3. The initial profile of these companies thus appears to be one which indicates success.

The case studies are presented textually in great detail in chapter 5, however in order to present a workable overview of the findings the discussion here is supported by tables 6.1 to 6.9 which summarise characteristics of the further case studies. What may be interpreted as strong characteristics of company activities are nominally represented by a "S" sign and weaker problem areas indicated by a "W" sign. The allocation of "S" or "W" is subjectively awarded in relation to the three earlier case studies, "A", "B" and "C".

Research Framework Criteria: SUPPORT

COMPANY	S	W
D	Strong communication link between designers	No formal support structure- Role of senior designer Support could provide efficiency gains and reduce resistance to CAD use
E	N/A	Role of one person- Mix of problems exist. Weak support of both technical and human nature is evident
F	Investment in new CAD in support of changes generally augers for progress	Weak and still developing Lack of coordination-ordination of both technical and human issues evident
G	N/A	Low level of support- Vendor hot-line. Support prevailing now will continue as and when new CAD is introduced- No change envisaged
H	Close cooperation between design team	Identified as individual responsibilities but little evidence of support
I	High level of support on operational and strategic business issues	N/A No evidence of any weakness in company CAD support

Table 6.1 Summary characteristics of further case studies

Research Framework Criteria:
HUMAN DEVELOPMENT

COMPANY	S	W
D	N/A	Training for CAD only. No training/ education for tomorrow- Little by way of human development apparent makes for a strong need in this direction
E	N/A	Non strategic- Left to individuals- 2D users need specialised training to understand drawing output- Little human development evident-Not a strong issue
F	An apparent culture change in progress with a new approach in adopting training for the future	Designers received basic system training through cascade process- Lack of organisation in training resulted in training being limited and not relevant to company field of work- Many changes currently in progress
G	N/A	Standard one week training course- No other support- Training too difficult and technical to understand
H	Good rapport between individual departmental staff evidences a good human relationship exists	Human development assumed to be part of engineers formative training years. very little support training provided. CAD training essentially brief and for 2D CAD use only- No training for using the system's 3D capability
I	High level of training for system use and administration	N/A

Table 6.2 Summary characteristics of further case studies

Research Framework Criteria: TEAMWORK

COMPANY	S	W
D	Work closely together to solve problems relevant to engineering/ product design	Lack of communication from higher level management
E	Regular meetings of relevant staff occur and teamwork is positive and active	The seeming omission is of a higher level involvement Design staff feel that they do not operate as a complete team to undertake concurrent engineering projects.
F	Some teamwork is evident by way of product groups and coordination-location of staff. Also strengthened by phase review boards for groups and objectives for new products	A distinct lack of teamwork and proactive attitude is present
G	Coordination-located design and engineering Reasonably well thought out strategy for technology application could also be applied to teamwork generally	To progress the company has to improve coordination-ordination of teamwork across the board
H	The links between interdepartment staff shows good teamwork	Albeit excellent interdepartmental teamwork exists, evidence of higher level involvement is lacking
I	Teamwork is very much in evidence as use of "Help-Desk" plus specific CAD support department-No evidence of any team weakness is apparent	N/A

Table 6.3 Summary characteristics of further case studies

Research Framework Criteria: PLANNING

COMPANY	S	W
D	N/A	No strategic business plan- Top level management not involved- not addressing problems
E	Weekly team meetings for product progress and a proactive approach for tomorrow	Evidence not of lack of planning as such, but lack of higher level support for implementing plans made. Strategic CAD group in disarray-not addressing problems
F	Previously planning has been weak. New management is developing a new strategy for growth for each product group and the company as a whole	Lack of commitment to support use of CAD technology and human issues relevant for progress to be made
G	New CAD technology being introduced to deal with new product development (NPD). General planning strategy for technology appears well thought out	Limited thought into planning previous systems Planning strategy for supporting people appears to be not well thought out, minimal and not of high priority
H	The need for a step change in quality and productivity drove company's planning strategy for CAD. This led to the consideration of a full running network integrated across departments	There are a few weaknesses with the company's planning strategy- Strategy is directed to the consideration of technology and not human/ organisational issues
I	Continuous planning and review is high on the company's priority list as evidenced by interdepartment activities and coordination-operation	N/A

Table 6.4 Summary characteristics of further case studies

Research Framework Criteria:
REVIEWING

COMPANY	S	W
D	Monthly progress meetings for design/ manufacture progress	No review of technology progress
E	Extensive use of review/ evaluation and team meetings for shop floor manufacture Project meetings for design product progress	Less obvious for design- No system for logging problems Cannot identify productivity/ benefits from CAD
F	Currently high review of performance and of global strategy for growth of product ranges	Previously no review of technology performance No logging of problems
G	Currently have aggressive NPD strategy to year 2002 with review of future support from technology	Previous 3D system virtually imposed on staff. Review technological issues, not human issues
H	A conscious effort in this area on an overall strategic front is evident as part of company policy	Apparent weakness is a lack of high level involvement in pushing operational review of activities for effective use of CAD technology During first 15 months of CAD system there was no requirement to justify its performance
I	Company place a high priority in continuous planning and review. Evidenced by review of CAD benefits via "projects" and liaison with CAD vendors to develop CAD system further	N/A

Table 6.5 Summary characteristics of further case studies

Research Framework Criteria: PARTICIPATION

COMPANY	S	W
D	N/A	Poor relationship with I.T. department
E	N/A	Lack of coordination-ordination of technology creates problems with some design issues
F	The global strategy is commendable but little evidence of participation in CAD strategy by users	Evidence of "sort it out yourselves" attitude prevails. A more coordinated effort is required
G	Current technology strategy appears well considered	Staff do not feel appreciated and a more coordination-operative participation is desirable
H	Evidence of working in participation as part of design staff's everyday job is good (But not in terms of more strategic issues)	Group dictated to company which three choices of CAD system could be reviewed Essentially selection decision made by engineering manager after working through tutorial for one month. Evidence of participation by design staff in CAD selection is limited
I		

Table 6.6 Summary characteristics of further case studies

Research Framework Criteria:
LEADERSHIP

COMPANY	S	W
D	What leadership skills prevail are those by the head design engineer alone.	CAD implementation was the responsibility of design team- No involvement by management in its' implementation
E	Strong point is regular reviews	Leadership is not strongly evident No management champion to push the technology side of things and lack of higher level involvement with the human issues is evident.
F	Leadership was previously very weak and lead to poor use of CAD system. Only recently has very strong leadership become in evidence with some strategic strength	A more co-coordinated "people centred" approach would reap great dividends
G	Company technology strategy is good. However improvement is possible via a more coordination-operative policy across the board	Limited leadership in the past- Clear leadership for the future NPD and CAD technology- But people may be forgotten
H	Leadership strategy for future product and technology is good	Leadership for obtaining opportunities and greatest effectiveness from CAD not apparent.
I	Interdepartmental leadership is much in evidence as part of company policy	N/A No apparent weakness evident

Table 6.7 Summary characteristics of further case studies

Research Framework Criteria:
QUALITY

COMPANY	S	W
D	Technology has resulted in more effective design output	Where "Quality" is related to human issues in terms of supporting staff to perform their job effectively for both themselves and the company, there is a lack of incentive
E	Quality of 2D drawings improved	Still errors on 2D drawings which mean products cannot be made
F	Quality related to the product is of a high standard as evidenced by the company's status in the market	Quality related to human issues may be better
G	Meeting quality standards for products	Insofar as personnel are concerned, human issues could be identified and addressed.
H	A better product has been attained plus better use of design data	N/A
I	A very high standard prevails both in the technology and personnel	N/A

Table 6.8 Summary characteristics of further case studies

Research Framework Criteria: IMPACT ON THE COMPANY

COMPANY	S	W
D	New work- 2 months savings on 3D jobs Tool making lead times reduced by six weeks on many projects	Lack of support means issues of integration of data across the company are not being addressed Resistance of manufacture team to use software not being addressed
E	2D drawings produced 2x faster-modifications 7x faster	Very few support aspects being supported Pro Engineer not being used for real jobs Great mix of systems causing problems
F	Previous experiences with NPD identified company speed to market very slow A new NPD strategy has been adopted and expectations of greater effectiveness and success are envisaged	Failed 3D system in the past No impact of new system yet
G	A NPD strategy is being implemented to motivate technology and human developments	NPD still restricted with 2D CAD with 6 weeks from initial concept to working model Failed 3D system in the past
H	Speedier output of 2D drawings plus improved end products.	Not using the new 3D system yet
I	Moved towards world class status through full use of symbol libraries-parametrics-variational geometry and associative dimensioning Reduced lead time on viewing drawings worldwide from 1 week to 20 seconds Employed parametrics to reduce drawing time in terms of cost by £500000 on a £13 Million project	N/A No serious weaknesses in evidence

Table 6.9 Summary characteristics of further case studies

6.3 SUMMARY CHARACTERISTICS OF ALL NINE CASE STUDY COMPANIES-COMPANIES "A" to "I"

Each individual case study has been described in detail previously in chapters 4 and 5, using a common structure for presentation and mapped into the research framework criteria previously presented in section 3.5 and 3.6. Also the results from the further case studies were mapped into the characteristics of "strong" or "weak" in section 6.2.

This section of the thesis summarises these detailed case study descriptions and mapped criteria and characteristics even further, in order to draw out and compare commonalities between the cases and to give a degree of quantification between them.

For example, if the support provided by a company is thought to be very strong (Using the results from companies "A", "B" and "C" as examples of good practice), it is awarded "S+". Similarly if it is particularly weak it receives "W-" and similarly within the scale exists "W+" and "S-".

This of course is a very qualitative way of interpreting the information gathered from the case studies, but it must be emphasised that the qualitative nature of the research was indicated in chapter 3 and justification made for its use. These justifications were also validated by reference to examples of design evaluation techniques such as FMEA in section 4.2.

For two of the further case study companies, results indicate that for some aspects of their activities, they were previously not as good as they could perhaps have been. However, indications were that towards the end of this research, significant changes were taking place because of a turn-around in strategy at the company; although the effects were not yet being seen. Thus for certain characteristics of their activities, they are awarded a "W/d" category to indicate that the activity has previously been weak but that the company is now developing in this area.

Direct comparison of all nine case study companies, in terms of "Strong" and "Weak" characteristics of company activity are illustrated in table 6.10. The indications are startling.

	CASE STUDY COMPANY								
RESEARCH FRAMEWORK CRITERIA	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
SUPPORT	S+	S	S+	W	W	W	W	W	S+
HUMAN DEVELOPMENT	S+	S-	S	W	W	W	W	W	S+
TEAMWORK	S+	S-	S+	S-	W	W	W	W+	S+
PLANNING	S+	S	S+	W	W	W	W	W	S+
REVIEWING	S+	S	S+	W	W	W	W	W	S
PARTICIPATION	S+	S	S	W	W	W	W+	W	S+
LEADERSHIP	S+	S-	S+	W	W	W/ D	W/ D	W	S
QUALITY	S+	S+	S+	W+	S-	S	S-	S-	S
IMPACT ON COMPANY	S+	S-	S	W	W	W	W	W+	S+

Table 6.10 Strong and weak aspects of company activities

6.3.1 Companies Exhibiting Strong Support Structures

It is apparent from the description of case studies "A", "B", "C" and "I" and evidenced in Figures 4.4, 4.6, 4.9, 5.12 (Support structures for CAD) and Table 6.10 (Strong and weak aspects of company activities), that each company has a strong and well defined support structure for CAD. These companies are demonstrating significant achievements in terms of the impact of the technology on the company. In each case the companies are using the technology to do more than just 2D drawings, ie using 2D and 3D facilities to link to and provide other capabilities which make a wider impact across the company.

6.3.2 Companies Exhibiting Less Strong Support Structures

Companies "D", "E", "F", "G" and "H" are exhibiting less strong support structures for CAD. Whilst it is not possible to identify an exact causal link between this and company performance it is interesting to note the similarities between the companies. They are all experiencing some benefits from the technology, however they are all experiencing some problems and not achieving anywhere near the full potential benefits from their systems.

Company "D" and "E" both purport to be exploiting the use of 2D and 3D. Company "D" use 3D surface modelling for all jobs with some benefits and some problems of integration of data still to be overcome. Part of the reason they work with the support structure as it stands is because of the strong organic culture of the company rather than the traditional bureaucratic structure found in many organisations. This has meant that designers there have traditionally had responsibility for their own project work but have had the flexibility to be involved in all aspects of the work from, design, testing, material investigation and selection and prototype manufacture, thus creating personal satisfaction with the job role irrespective of the monetary reward.

Company "F" have only recently changed to a new system with 3D capabilities and at the time of writing are not using or exploiting it. However, as stated in their case study, they failed previously in the past with 3D because there was no support structure to promote its' use.

Company "G" only currently use 2D, have failed in the past with 3D and are considering implementing a new 3D facility with a range of other CAM facilities. There is currently no support structure for 2D CAD, relying on vendor only, and they do not perceive any reason to change the structure after the implementation of any new 3D system.

Company "H" have a system with 3D capability but do not envisage using this in the near future

6.4 GENERIC THEMES SUGGESTED BY THE CASE STUDIES

The main generic theme drawn from the case studies is that the support role is an important aspect of any implementation. The general premise is that support needs to effectively address a mix of Technical, organisational and human issues. The support role appears to be important in that case study companies with stronger support structures have less problems and are more successful with CAD in a wider context

The themes are shown in the mind map see Figure 6.1 and present a structure from which to build a more detailed model of human factor issues in CAD.

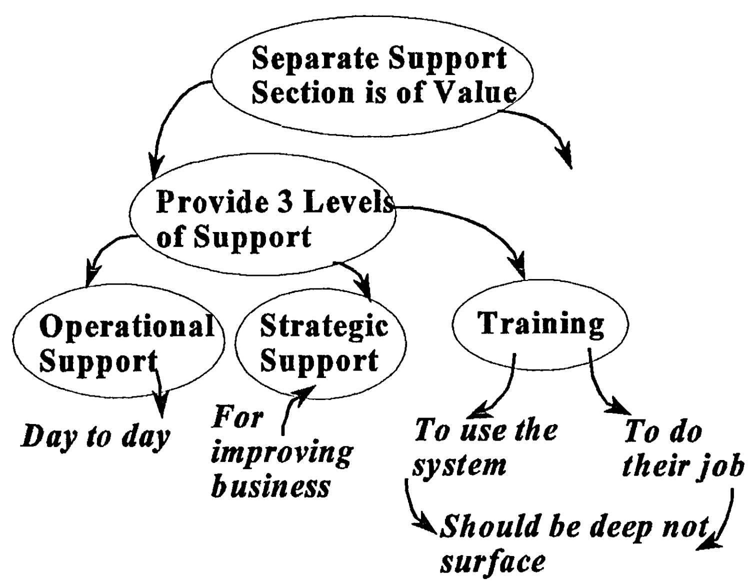


Figure 6.1 Themes Presented by the Cases Studies

6.5 THE SUPPORT MODEL

Building upon the themes in the mind map on the previous page, the support model shown in Figure 6.2 is proposed as a positive influence on CAD success when included as an element of CAD introduction and development.

The model is aimed specifically at the design area of a company and in particular at the introduction and development of CAD. However, within this specific area it addresses not only the generic themes extracted from the case studies in relation to CAD but also parallels at a sub-company/ departmental level, the attributes suggested by quality awards which should be displayed across the whole of a company to achieve overall success.

Thus, this is a valid check that the outcome of this thesis, ie a model of CAD introduction and development, satisfies the initial specifications which are built on quality criteria.

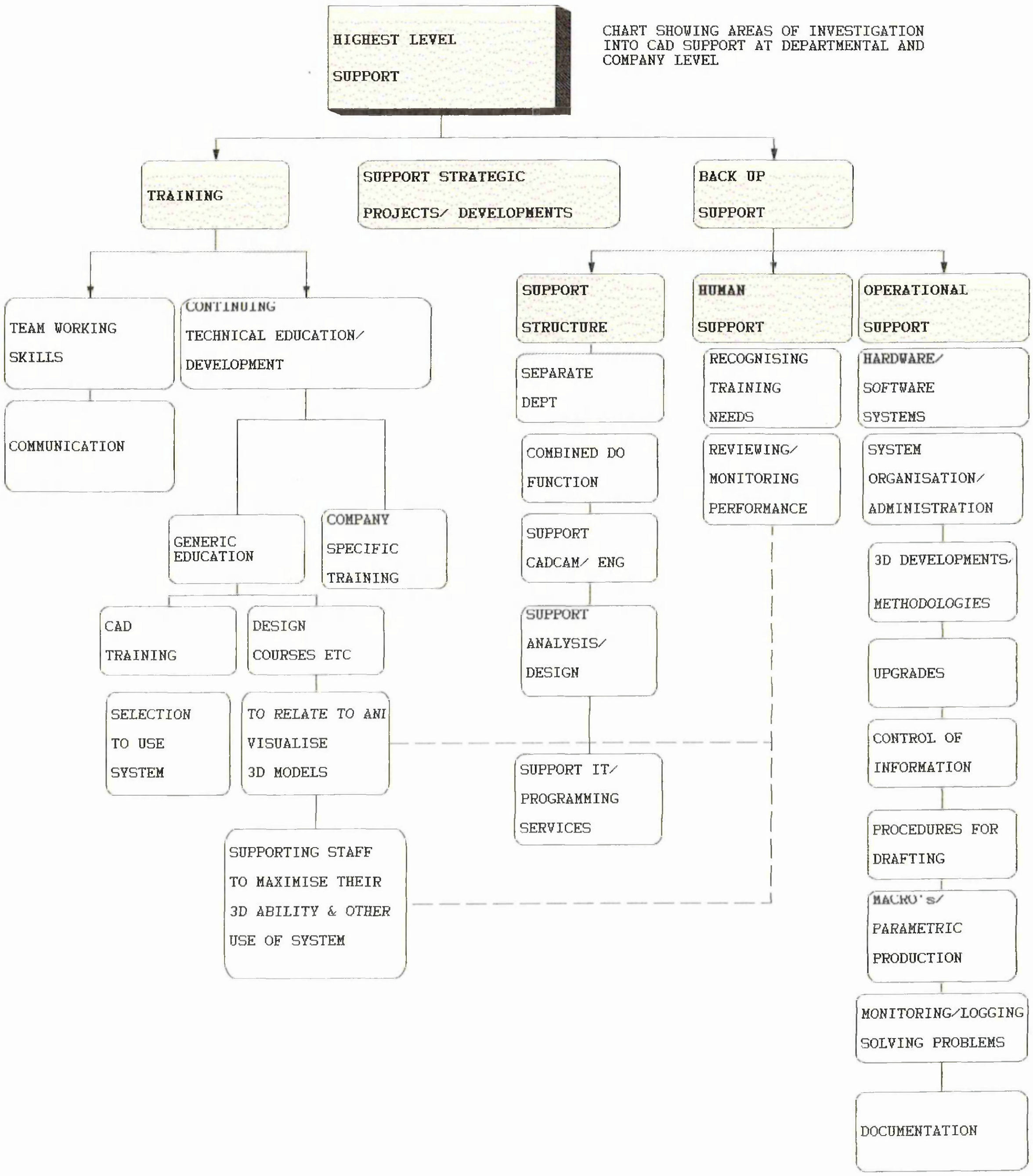


Figure 6.2 Proposed Support Model for Maximising CAD Success

6.6 PROPOSITIONS

In order to test and validate the model, a national questionnaire survey was carried out as discussed in chapter 7.

The previous research up to this point, particularly the case studies, together with the developed mind map of issues and the proposed support model enable the following propositions to be extrapolated about the practices adopted by engineering companies during the introduction and development of CAD

- The use of internal company support structures for CAD will be very few or non existent
- Where companies have a theoretical support structure for CAD, in many cases this will not entail strong effective support as identified in the model
- Where companies employ strong, effective internal support structures a greater degree of success and satisfaction will be likely.
- Many companies will be "Reactive", training staff only to use the facilities and features required for the immediate job. (Surface learning Not learning for tomorrow)
- Training will generally be restricted to a vendor course with little internal company training support.
- Companies employing 2D CAD may find it easier to achieve business objectives with less strong support structures.
- Many companies will employ CAD purely for producing drawings as opposed to design analysis, or integration with the manufacture process where more strategic

company benefits are to be made.

- Companies employing 3D CAD, with its' associated greater complexity, cannot achieve business benefits without providing a greater degree of internal support for staff.

7.0 NATIONAL (UK) CAD SURVEY

As stated previously, in order to test and validate the model developed in section 6.5 a national survey was carried out

The use of questionnaire survey methods are very well documented and too comprehensive to go into extensive detail here. However, Oppenheim (130) considers the term "Questionnaire" to include:

- Postal questionnaires
- Group and self administered Questionnaires
- Structured interviews- Face-to face or telephone

However he acknowledges that other researchers employ the term questionnaire to include only self administered or postal questionnaires. In this thesis the term is taken to represent a "Postal Questionnaire" only.

According to Wilson & McClean (131) postal surveys are relatively low cost methods of gathering data from large samples but they suggest that such surveys frequently suffer from low response rates which can subsequently make a sample unreliable. However Salant & Dillman (132) provide examples of evidence where surveys were successful and quote such surveys as Gallop(133) in political and social surveys and in particular make reference to the small sample survey of 2000 people employed to determine Bush and Clinton's support during 1992. For the above reasons it is considered suitable to employ a national survey in this thesis.

Guidance on constructing questionnaire surveys is provided for example by Erdos (134), Fink and Kosecoff (135), Frey and Oishi (136), Fink (137) and Sudman & Bradburn (138) as well as many other authors.

Frey and Oishi (136) in their book (although concerned with conducting interviews by telephone and in person) provide a useful description of how to determine a sample size, which is also relevant to postal surveys. They define the "Sample" as a portion of the population, which is representative of the total population. They further describe the use of a "Sampling Frame" from which researchers may draw a sample from the total population.

Essentially Frey & Oishi suggest two modes of obtaining samples either by drawing the sample from lists of records from areas specific to the research or by randomly selecting a sample from the total population.

Fink & Kosecoff (135) discuss random sampling and in particular the use of "Stratified Sampling". They propose this as a technique for dividing a population into sub-groups or "Strata" in order to select a given number of respondents from each group or strata. They state the advantage of such a technique is that a sample is obtained which represents the groups and patterns of characteristics in the desired proportions. They also highlight the disadvantages and particularly relevant to the research presented in this thesis is that less than twenty in a sample group may not produce statistically meaningful results.

7.1 TARGET COMPANIES

The generic themes suggested by the case studies do not appear to be product related although greater support (although not necessarily effective support) is provided by companies where 3D is employed, especially for complicated components. ie components which have complicated internal or external sculptured pockets, fillets and radii. 2D CAD appears to be afforded less support than 3D

7.1.1 Target Areas- Sampling Method

To maintain some conformity with the previous case studies, the samples in the national survey were chosen to include similar product groups and thus product complexity. However, as CAD is employed in all aspects of engineering, "engineering" is taken as a prima facia target area with an attempt to survey companies whose activities match those of the case study companies.

However, in order to increase the sampling size, the product groups chosen extend the product areas of the case study companies and the ten groups selected are:

- **Taps and Valves**
- **Glass Container Industry**
- **Tools**- Power and hand tools
- **Forging**
- **Domestic Equipment**
- **General Purpose Machinery**
- **Electric Motors/ Engines**
- **Pumps/ Compressors**
- **Heavy Engineering**
- **Other**-Cutlery-Cycles- Garden equipment-Health/ leisure equipment- Tractor manufacture

Initially it was considered that stratified sampling would be employed, categorising companies into the product areas and randomly selecting equal numbers of companies from each group. However, it became apparent that the numbers of companies within each product group were wildly different and the numbers of valid companies available in each product group (in terms of size and turnover) were significantly different. This suggested that some product group sample sizes would be low, eg glass, in comparison to others (especially as the intention was to undertake a survey of at least a thousand companies) and this could ultimately result in a low response rate in these groups.

For this reason and for the disadvantages identified by Fink & Kosecoff stratified sampling has not directly been employed. Instead grouping by product is employed to provide some characteristics of each group.

7.1.2 Target Companies -Sampling Size

The original intention of the research was to survey 100 companies within the UK to validate the case study results and to ascertain if the results were indicative of industry in general.

According to Fink (137) responses to unsolicited mail surveys are traditionally low, being in the order of 10% to 20% .

For this reason, surveying only 100 companies would have resulted in a possible maximum response of around 20 companies. Fink suggests that there are techniques which can be adopted to increase or maximise response rates, such as, follow up mailings, the use of graphically well presented surveys and monetary or gift incentives, but even so this would probably not provide enough evidence to illustrate that the results are indicative of engineering industry.

Consequently the initial sampling frame of 100 companies has been extended to allow consideration of a much larger sampling frame of the 18000 UK companies available within the FAME commercial database of industrial companies (114) mentioned earlier in the research. Thus the potential response rate is increased significantly.

7.1.3 Identification of Target Companies

There are a number of commercial databases available as electronic media either on stand alone PC's or over the internet which allow the searching and identification of companies by product etc. eg Computer Users Year Book(139), Thomas Register (140), Kompass (141) and Fame (114) as previously mentioned.

To identify companies employed in the activities identified in section 7.1.1 access to a networked CD ROM version of FAME (Financial Analysis Made Easy) has been the primary search source, with access to other packages providing clarification or confirmation of addresses where this was necessary.

The FAME database allowed several search criteria to be defined and combined, such as industry SIC code, company activity, company name, geographic location etc.

All companies identified from each target area were separately ranked in terms of turnover and number of employees to provide commonality with the case study companies for subsequent selection. This selection was based on choosing all companies within each product area, whose activity fitted the research and with a classification of SME, large or very large and displaying a suitable turnover in thousands of GBP.

The search results were exported from the database in Excel spreadsheet format and manipulated to identify and remove unwanted extraneous companies that existed in the results because of the industry classification code (Sic) rather than the actual activity of the company, such that a sampling size of 1000 companies remained.

The company details, names and addresses were imported as CSV Format into a Word 6 mailmerge to provide automatic generation of address labels.

No attempt was made to restrict the chosen companies to a specific geographic area and the survey was UK wide. CAD is employed by engineering companies all over the UK and the survey covered the North, Midlands, South of England, Wales and Scotland.

To enhance the response rate consideration was given to using known contacts within companies. Sixty of the companies identified matched up with students undertaking placements and questionnaires were distributed to these contacts asking them to take responsibility for passing the questionnaire onto the CADCAM manager and ensuring a response was made and returned.

Overall one thousand questionnaires were distributed to companies in the proportion indicated in Figure 7.1 .

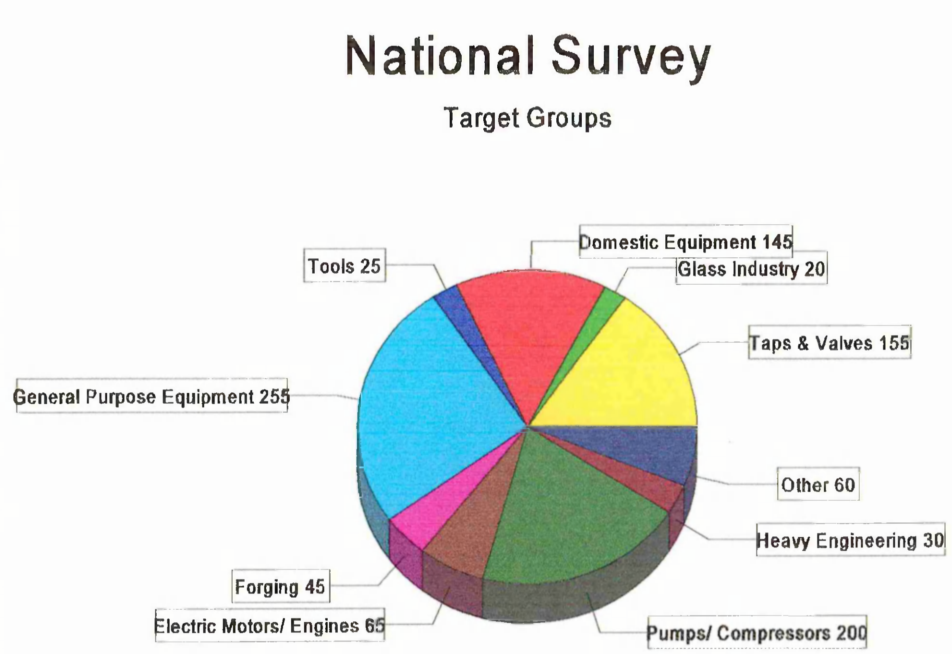


Figure 7.1 Numbers of companies targeted in each product group

An important issue in targeting companies is who in the organisation to send the questionnaire to (142) . For this survey the recipient of the questionnaire is deemed to be the CADCAM Manager and so letters were addressed accordingly. Consideration was given to the covering letter (shown in appendix D) in terms of increasing response rate from CADCAM managers. Use of the wordprocessing software was relied upon to assist in reducing the passiveness of the letter from around 50% down to 28% with a Flesch reading ease of 43.2 and a Flesch grade of 14. The Flesch grade (143) indicates the reading age which the reader needs to read the letter whilst the Flesh reading ease score indicates on a scale of 0 to 100, the level of reading difficulty (the lower the score the more difficult the letter is to read for that age group).

7.2 QUESTIONNAIRE DESIGN

The design of the questionnaire is based upon the propositions in section 5.1 however there are many factors which can influence the data and information gathered and thus the overall result. Erdos (134) illustrates such factors for consideration during the design of the questionnaire and they are listed below;

- The layout and structure
- The type of questions included ie open or closed questions
- The length of questionnaire and response times needed
- Colour of paper and printed text

Initially manual design of the questionnaire was employed which was then subsequently created electronically (and shown in Appendix D) using "SNAP 4 Plus" a Windows based

Survey Design and Analysis software package from Mercator Computer Systems (144) which allows pre-coding of responses and statistical analysis of results.

The initial design of the questionnaire had 99 variables (55 Active) with a total survey size of 103 Kbytes and a raw data size of 158Kbytes.

Layout and Structure

Although a covering letter was to be dispatched with each questionnaire identifying the survey theme, who was undertaking the survey and its' importance to industry the opportunity was taken to re-iterate this on the front of the questionnaire. Should the letter and questionnaire become separated the motivation to complete would still be as strong. The strongest motivation to complete was thought to be the link with the academic institution and the opportunity was taken to place "Sheffield Hallam University" as the first text on the page followed by the title of the research.

Following this a statement of the importance of the research to the competitiveness of UK industry together with an inference to "Best Practice" and the respondee's ability to influence industry's future development was employed in the hope that it would influence the response rate positively.

After this point the questionnaire is designed in sections, A to G inclusive with headings for each section and a number of questions under each heading. This provides the respondent with a feeling of achievement after completing each section and a sense of moving on and nearing completion. The sections are designed to match with the format used for the case studies in Chapters 4 and 5.

As with any interview technique it is normal to put the person at ease by allowing them the opportunity to provide information about themselves before asking more searching or important questions. Questions 1 to 5 in Section "A" are primarily concerned with this although the only real important issue is "Does their company employ CAD/ CADCAM" and to a lesser extent the name of the company for ease of organising and collating the research responses.

Section "B" gathers details of the company products and activities and an indication of the organisational structure.

Section "C" is designed to gather information regarding the design process in operation at the company whilst Section " D" aims to investigate the CAD development and introduction strategy.

Section "E" explores the support structure (if any) which is employed and Section "F" investigates the training philosophy for CAD and for the company.

Section "G" explores the impact of CAD on the company in terms of operational and business achievements.

The questionnaire was designed to end with a reiteration of the confidentiality and anonymity of the research work. According to Cummins and Porter (145) the lower left portion of a composition is supposed to be where the eye expects to find important information and so this was used to identify to who and where the questionnaire should be returned.

In an attempt to influence the response rate positively at the design stage of the questionnaire, potential respondents were asked to provide details of their E-Mail addresses or company addresses on the questionnaire in order to subsequently receive a summary of the research findings.

Type of Questions

The majority of questions employed in the questionnaire are of a multi-choice nature for ease and speed of completion. However, open ended questions are dispersed throughout the questionnaire both to reduce the monotony of simple ticking, to increase the interest of the respondent and to ask questions where it is important to obtain the respondent own comments rather than leading or guiding with suggestions.

Multichoice questions, where respondents tick the appropriate answer on the questionnaire are of the form of;

1) "Yes/ No/ Don't know" answers with obviously only a single response eg

Q5. "Does Your Company Employ CAD/CAM

Yes..[ ]

No...[ ]

2) A Range of multichoice questions with either "Single" or "Multiple" responses. eg

Q13. Percentage of work undertaken using CAD

Less than 20%..[ ]

20%-30%...[ ]

30%-50%...[ ]

50%-70%...[ ]

Greater than 70%...................................[ ]

None...[ ]

has only one valid response whereas question 7 can have five responses (ie each box may be ticked) each response being valid. eg

Q7. Which of the following activities are undertaken in your company?

Design and analysis of existing products [ ]

New product development......................[ ]

Manufacture..[ ]

Testing..[ ]

Commissioning.....................................[ ]

Some questions, such as question 29, are set up to illicit a "Quantity Response" and require the response variable to be pre-defined during questionnaire design.

eg. Has the implementation of CAD resulted in an increase in staff turnover. If so please indicate the approximate % increase requires the variable to be set up from 0 to 100% as shown in the Figure 7.2.

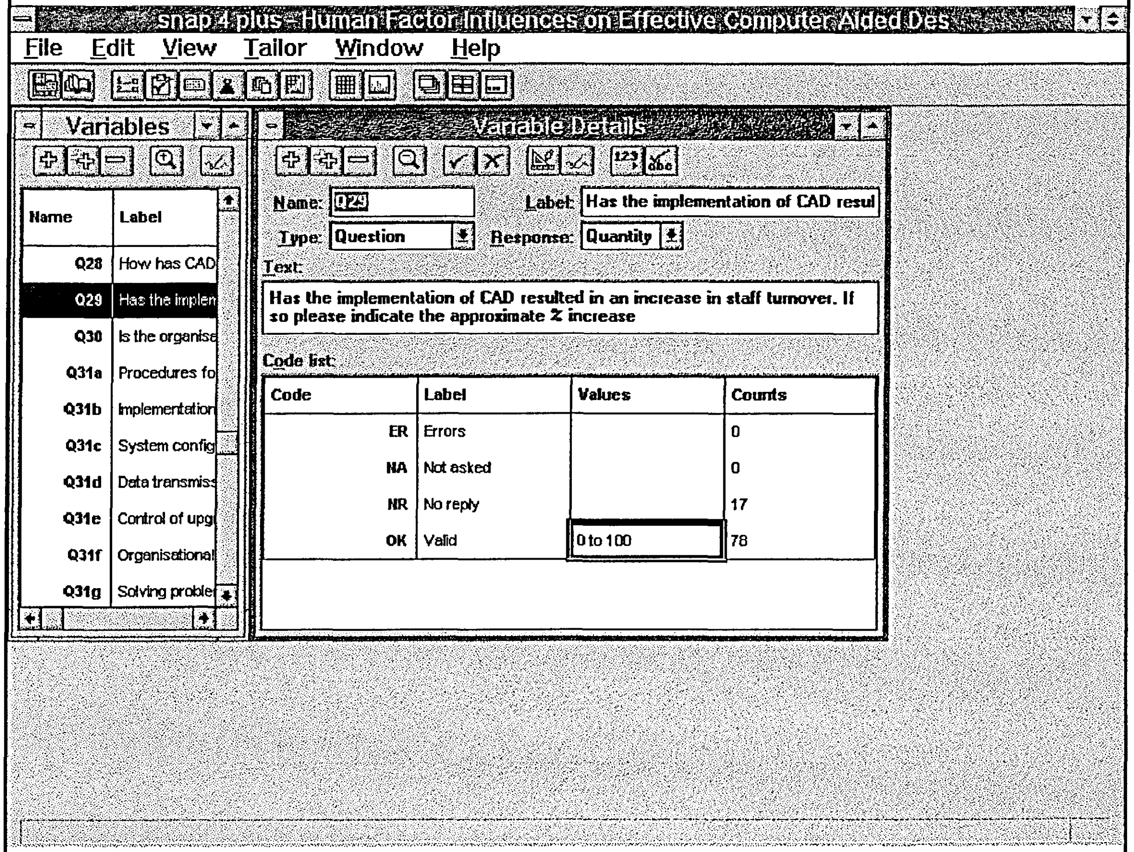


Figure 7.2 Pre-defining response variables during questionnaire design

"Literal" response questions such as question 37, "What were the main problems staff had in becoming effective users of the system" are used within this survey to gather the respondents own comments. Any response to the question is valid, provided it is a textural response, but obviously responses are entirely variable from respondent to respondent.

In designing such questions, the variables are designed with any textural response being valid as shown by the variable details in Figure 7.3

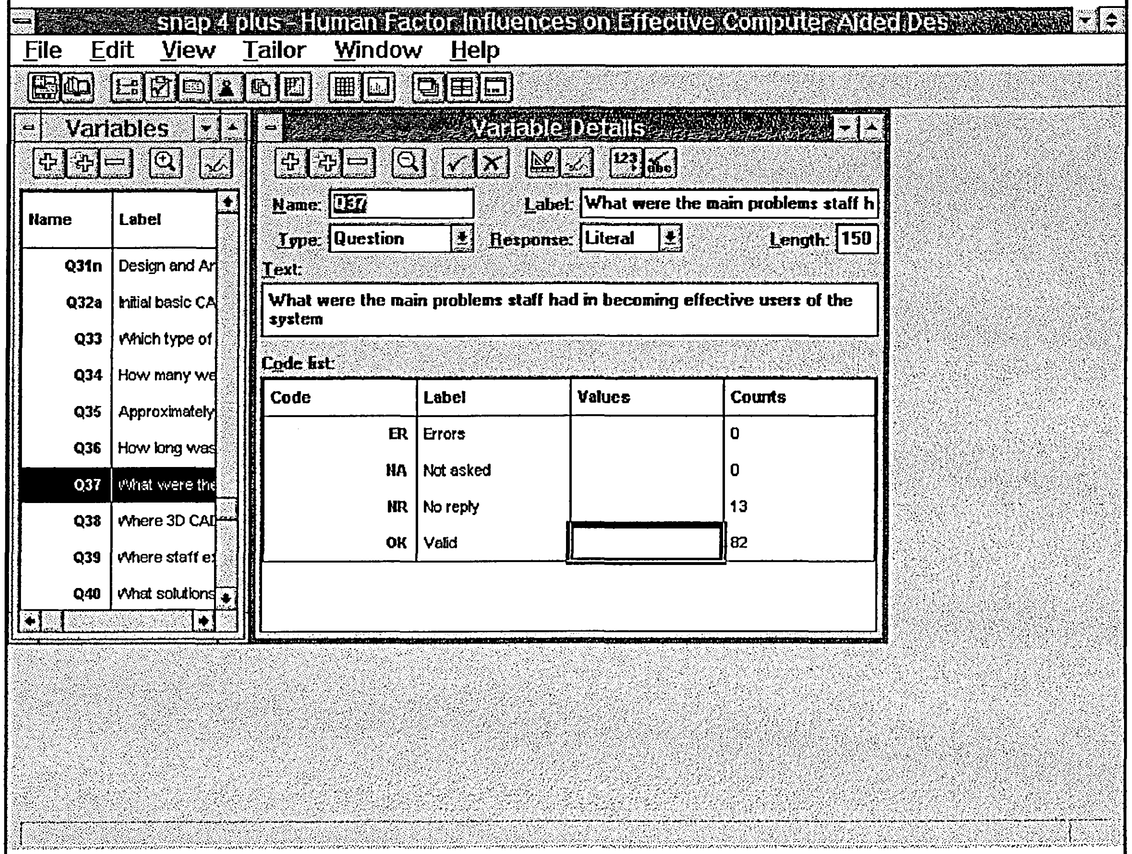


Figure 7.3 Showing all answers are valid responses to literal questions

For this reason, use of this type of question has been restricted. Where used, analysis of responses has been achieved by setting up a "Derived Variable" post design stage, to extract phrases or statements provided by respondents into groups/ categories of comments.

In order to illicit thoughts of respondents on the importance or effectiveness of a particular aspect of their CAD implementation "Grid" type questions have been employed, with multichoice questions and responses and the ability to rank or rate this response as illustrated in figure 7.4

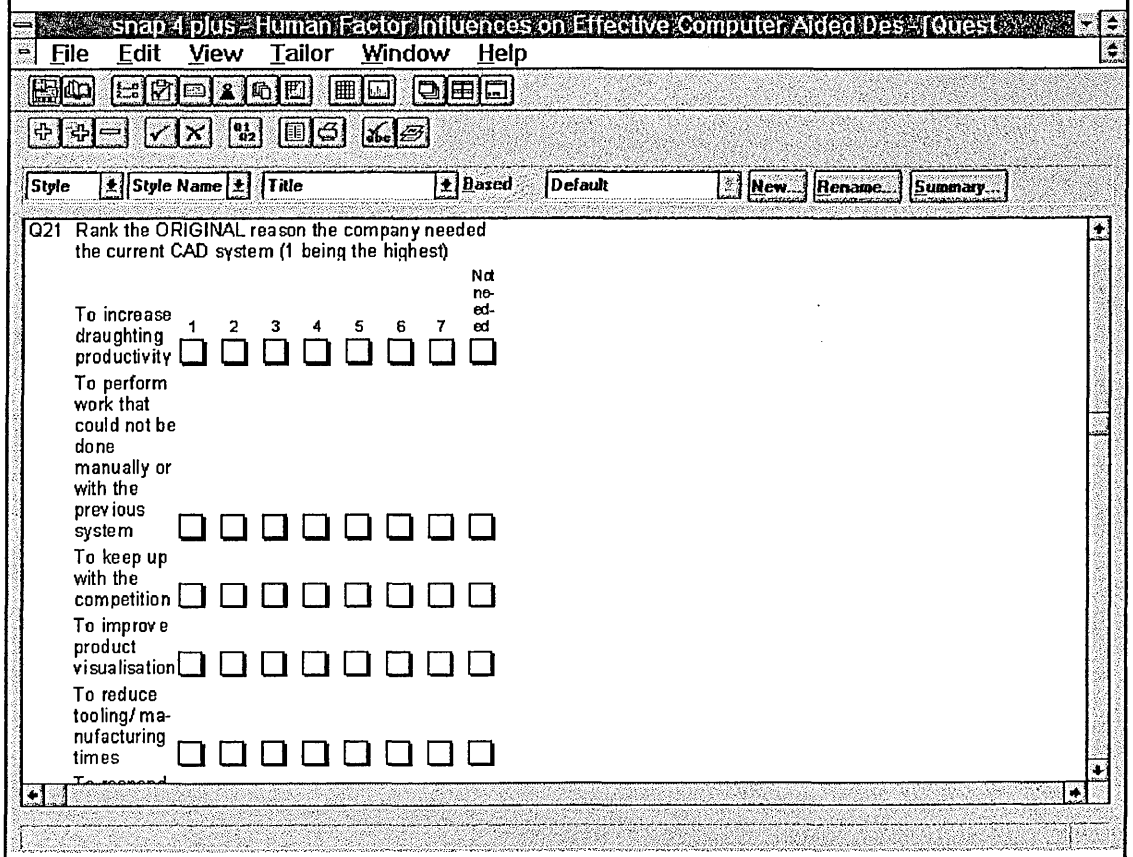


Figure 7.4 Example of "Grid" employed with multichoice questions

The Length of Questionnaire and Response Times

It is generally recognised that questionnaires should be kept as short as possible but the maximum limit at which respondents shy away from completing questionnaires is around six to eight A4 pages (146). Hoinville and Jowell (147) suggest that provided the survey topic is made interesting and important enough for people to use their time to complete then questionnaires may be designed longer than this.

Colour of Paper and Printed Text

Within the advertising world it is generally thought that colour has a significant psychological impact on the consumer. Cummins and Porter (145) suggest that it is also known that a significant increase in survey responses is obtained from using mailshots printed on coloured paper rather than black and white and that such use of colour provides a longer attention span.

According to Whelan (148) primary yellow colours symbolise life giving sun, activity and constant motion. He argues that it is impossible to feel despondent when surrounded by combinations of yellow.

This concept is employed within the design of the questionnaire in an attempt to psychologically influence possible respondee's to respond through employing sunset yellow paper for the questionnaire. Black text stands out extremely well on this background and photocopies well and has been chosen for the main text. A contrast of white on grey was chosen for the main heading.

7.2.1 Testing of the Questionnaire

Questionnaire testing followed three distinct phases;

- Pre-testing to ensure general grammar and comprehension was satisfactory and that no complex terms were employed which the target group would not understand.
- Pilot testing of the questionnaire to identify difficulties experienced by a test group of respondents and to incorporate any modifications, or improvements suggested

by the group prior to dispatch to target companies.

- Testing the questionnaire analysis with "dummy" data (Prior to inputting real data to the computer) to ensure that no errors exist in relation to the setup and coding of questions within the software.

Pretesting

Although the software used to design the questionnaire employs an English/ American Spell-Checker and was employed during questionnaire construction, family, friends and work colleagues were asked to provide feedback on any spelling errors. They also provided useful comments on the general layout and content of the questionnaire and overall reported a satisfaction with the questionnaire at this level of testing.

Questionnaire Pilot Testing

Pilot testing was carried out through six colleagues with very recent, or current contact with companies involved in CADCAM implementation ; either as part of their research activities or as part of technology transfer through academic supervision of Teaching Company Programmes.

They were asked to complete the questionnaire in relation to the company they were working with and to provide real data. They were also asked to annotate questionnaires where necessary with their views and comments. Initial contact was made by telephone to ascertain if colleagues were willing to participate and instructions then provided by letter. Staff were encouraged to be as critical as possible and to provide comments on changes or modifications they felt were needed.

To provide a framework for the pilot-testing staff were asked to relate their comments to the following points.

- Could they understand the questions and if there were problems what were they?
- Was there any difficulty in interpreting any of the questions; for example did any terms need clarifying ie Q43 does the statement "Significant Impact " etc need explaining?
- Was any difficulty experienced in entering responses onto the questionnaire or with its' layout; for instance did their responses fall within the available choices of answers to questions?
- What were their views, if any, concerning length of questionnaire and completion times?

All six questionnaires were returned within a week and highlighted a significant number of individual and common suggestions for improvements and modifications..

Overall staff indicated that the questionnaire was generally suitable and provided general comments related to emphasising confidentiality and defining an estimated time to complete the questionnaire. They also provided many other more specific comments related to the wording of individual questions and providing tick boxes for other choices. These modifications were so many and varied that it was not possible to include all modifications into the questionnaire whilst at the same time keeping its' length and response time to a sensible maximum. Comments concerning completion time suggested it was around ten minutes and "was not an onerous task".

Editing of the questionnaire post pilot-study was achieved within a two day period and was not pilot tested further.

7.2.2 Data Entry and Questionnaire Testing

The results obtained from the pilot test of the questionnaire provided "Dummy" (basically real company) data which could be keyed directly into the questionnaire software. A facility within the software provided a means of entering (but not storing) the data to test that the questionnaire has been set up with the correct question response settings and codes relevant to the question. eg Multiple choice, Single response, Literal response, Quantity response etc. The input of real data from returned questionnaires was achieved by manually typing responses into the questionnaire software and an example of this is shown in Figure 7.5

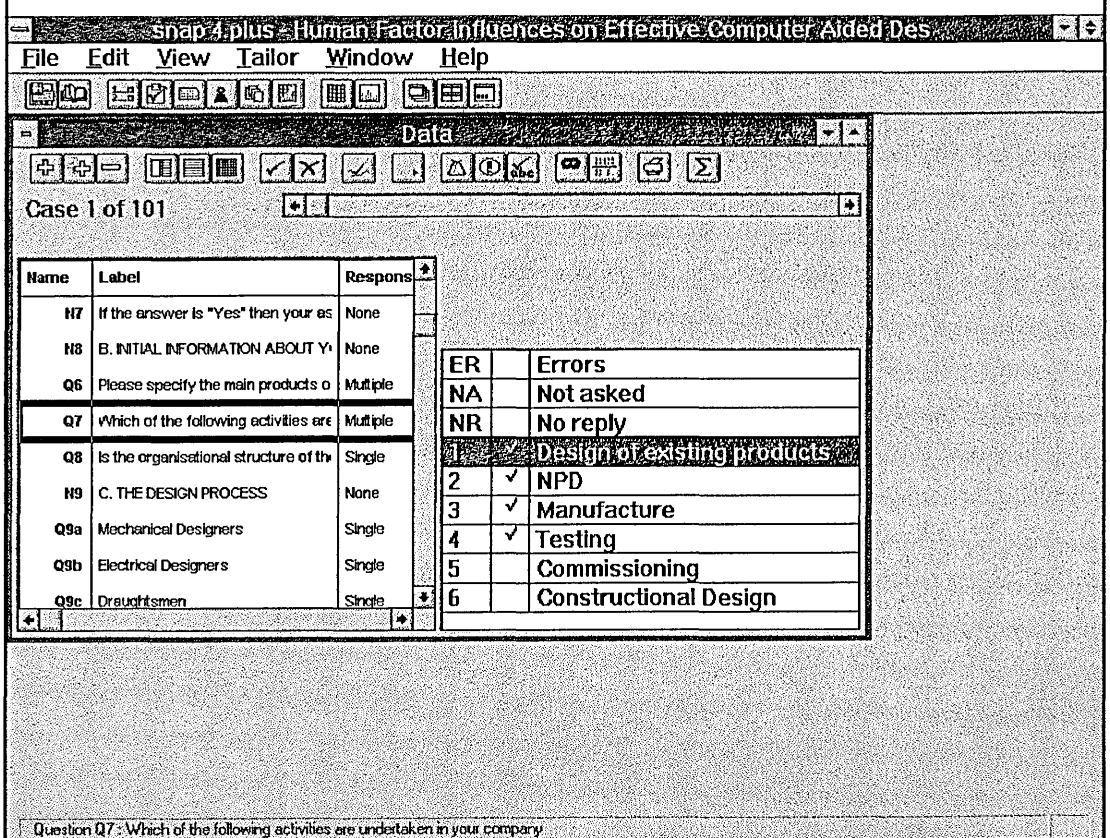


Figure 7.5 Screen shot illustrating the manual input of data to questionnaire software

Initial testing of data entry, using dummy data, had showed that input time per questionnaire varied from twenty to thirty minutes dependent upon how much detail respondents provided. This would therefore mean a data entry time of around fifty hours for the complete input of all questionnaires and represents a significant amount of time. For this reason a firm decision was taken to enter data for the first twenty questionnaires returned and then to review the results obtained.

This review process was employed to test the sensibility of results and to ensure that should any modifications be needed in order to be able to analyse responses to individual questions, that a situation did not exist where all data had been entered, and subsequent modifications resulted in a loss of, or corruption of data.

The early review of results proved to be extremely valuable.

Some responses fell outside of the range of choices given in the questionnaire and editing of particular question structures, within the database, was required to include these other responses. In editing the questions some data was lost and had to be keyed in again.

Also during the design of the questionnaire as many questions as possible were constructed as closed multiple choice. Others were left open to be able to collect respondee's own thoughts and so as not to lead them into choosing a specific response. For example, question numbers 39 and 40 relating to 3D problems and solutions were such questions where respondents provided a range of literal comments, many of which were common but which were stated in numerous ways.

The software used for analysing the results of the survey allows analysis of literal responses but the review showed difficulties present in trying to extract the literal responses from the range of responses obtained. These responses were therefore collated and categorised into groups to form extra multiple choice questions into which the responses could be re-entered so that analysis could take place easily.

At this point in time the opportunity was also taken to retro-fit questions concerning company size and turnover which had purposely been left off the questionnaires which were sent to companies for reasons of brevity.

Verification of Data Input

The survey design software provides the facility to verify data input (and thus reduce human error) by re-entering case data for a second time. The data is then cross checked with the original data input to provide verification that the correct data has been entered.
Because of the data input time required it was decided to verify only a 10% sample of the case data, rather than the whole cases. During this process no errors were found and it was accepted that any errors in the total cases entered would be few and minor.

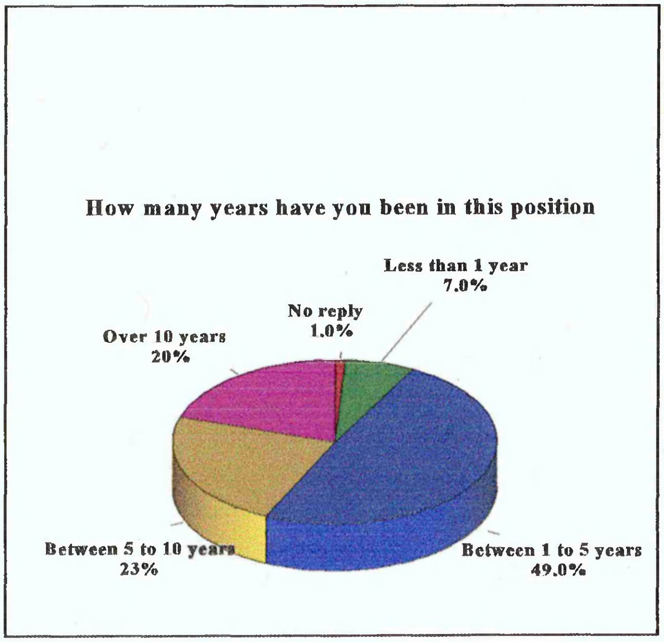
8.0 NATIONAL SURVEY RESULTS

8.1 INTRODUCTION

Once the questionnaire was constructed and the data from respondents entered into the questionnaire design software it was possible to "Build" tables and charts of the results by specifying a "Results Operation" from within the user interface.

A detailed description of how the "Snap" software generates such results has been extracted from the help file and is presented in Appendix D in order to inform the reader.

Essentially though, a "Chart" or "Table" as illustrated in Figure 8.1 may be produced for a single question such as question number 3- "Length of time respondents have been employed in their current position".



Absolute Analysis % Respondents	
Base	100 100%
Missing	
No reply	1 1%
How many years have you been in this position	
Less than 1 Year	7 7%
Between 1 to 5 Years	49 49%
Between 5 to 10 Years	23 23%
Over 10 Years	20 20%

Figure 8.1 Typical Charts and Tables Produced by SNAP

Such results are defined through the drop down dialog box shown in Figure 8.2

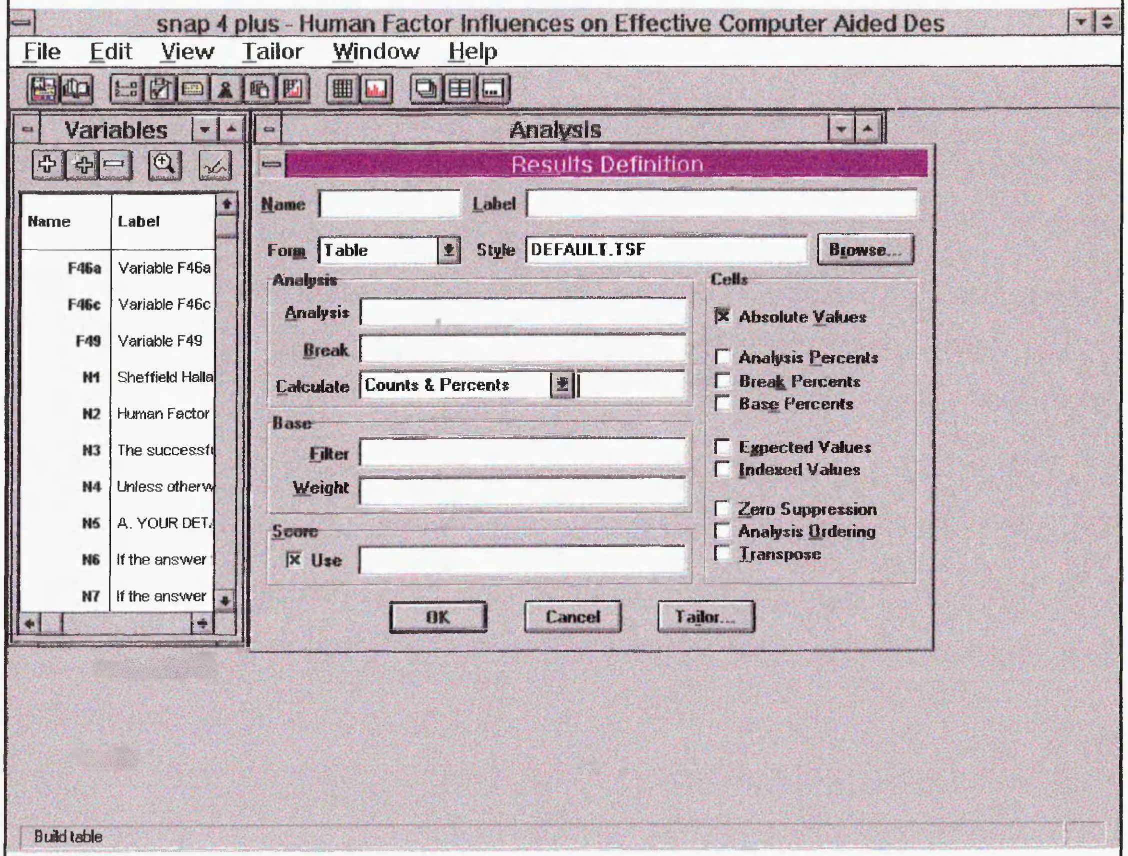


Figure 8.2 Drop Down Dialog Box for Results Definition

Many of the tables and charts produced in the results section have been "Filtered" to produce results for one group, such as, 2D CAD users only or 3D users only by specifying a Logical filter expression.

For example, question 10 in the questionnaire relates to users use of CAD for 2D and 3D. By specifying any of the logical filter expressions below, results are produced for that specific group.

CATEGORY OF USER	LOGICAL FILTERING EXPRESSION
All Users- 2D only, 2D & 3D, 3D only users	No Filter
2D Users Only	NOT Q 10=4
All 3D Users- includes 3D only users and 2D+3D	Q10=4
3D Users Only	NOT Q10=3

Table 8.1 Logical Expressions Used to Filter Responses of Specific Groups

If the filter is set to NOT Q10=3, this implies that any company who responded to item 3 of question 10 with a positive response (ie the company use 2D) will be excluded from the analysis.

CALCULATIONS

Having defined and built the appropriate tables or charts for particular question cross-tabulations, Chi-Squared tests (149) can be generated automatically from within the software to determine:

- If a relationship exists between two or more variables
- The strength of that relationship

A description of how the Chi-squared test establishes such relationships is provided in Appendix E, whilst the seven point scale employed by the Chi-Squared test is shown on page 200.

Chi-Squared Scale

There is a significant relationship at the 1% level

A very strong relationship exists between the variables

There is a significant relationship at the 5% level

There is a strong relationship between the variables

There is a significant relationship at the 10% level

A relationship exists between the variables

There is no significant relationship

Implies no evidence for or against a relationship

There is no significant relationship at the 10% level

There is evidence of no relationship

There is no significant relationship at the 5% level

Strong evidence of no relationship

There is no significant relationship at the 1% level

Very strong evidence that no relationship exists

The use of cross-tabulations and Chi-squared test are employed in chapter nine where discussion of the results compares and contrasts the derived results from questionnaires presented in section 8.2.

8.2 PRESENTATION OF RESULTS

The presentation of national survey results is based upon the format of the national survey questionnaire, addressing the six areas listed below. Results appearing in this chapter are presented in sections which follow those areas and in that order.

1. Initial information about companies
2. The design process
3. CAD introduction and development
4. Support structure for CAD
5. Training
6. Impact of CAD on the company

The structure of this section of the thesis against the above format, attempts to present results in such a way, that the discussion of results in Chapter 9 can compare and contrast companies in four areas.

1. All users- ie includes 2D only users, 2D/ 3D users and 3D only users
2. Users of 2D CAD only
3. All 3D CAD users (includes 2D/3D users and 3D only users)
4. 3D Users Only (ie they do not employ 2D CAD)

The majority of these results are presented to follow the above format and this is illustrated in Figures 8.3a to 8.3d.

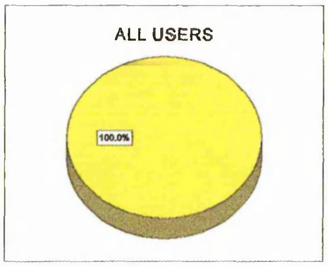


Figure 8.3a 100 Companies in sample

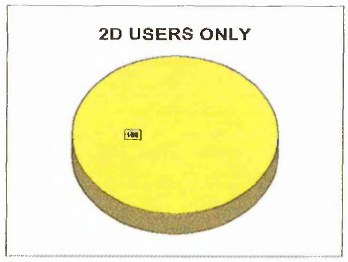


Figure 8.3b 53 Companies in sample

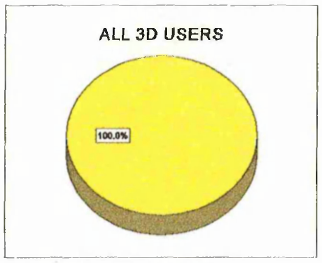


Figure 8.3c 47 Companies in sample

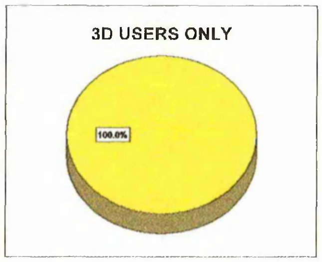


Figure 8.3d 8 Companies in sample

It should be noted that some questions are multiple-choice **AND** multiple- response and for this reason it is not appropriate to display results for these particular questions as pie charts (as the analysis percentage would be incorrect). Therefore responses for these questions (Figures 8.5c, 8.7, 8.9, 8.16, 8.26, 8.28, 8.29, 8.30, 8.36 and 8.39) are displayed as bar charts but they still maintain the same presentation format as in figure 8.3.

The number of absolute responses to each individual question on the questionnaire is shown in Appendix D1. They provide an overall indication of employees perceptions regarding their companies use of CAD, together with problems experienced and solutions adopted or to be adopted to overcome the problems.

 Original in colour

8.2.1 DETAILED ANALYSIS

One thousand questionnaires were distributed to companies in the proportion indicated in Figure 7.1 (chapter 7)

One hundred and twenty one questionnaires were returned from 100 companies employing CAD, eighteen not employing CAD and three returned from the Post Office with " Address not known" labels attached (Therefore providing an overall response rate of 11.8% and an effective CAD user response rate of 10%)

Percentage response rates by each product group are shown in Figure 8.4. Response was good with an average response rate of 10.9%, a maximum of 20% and a minimum of 4.1%.

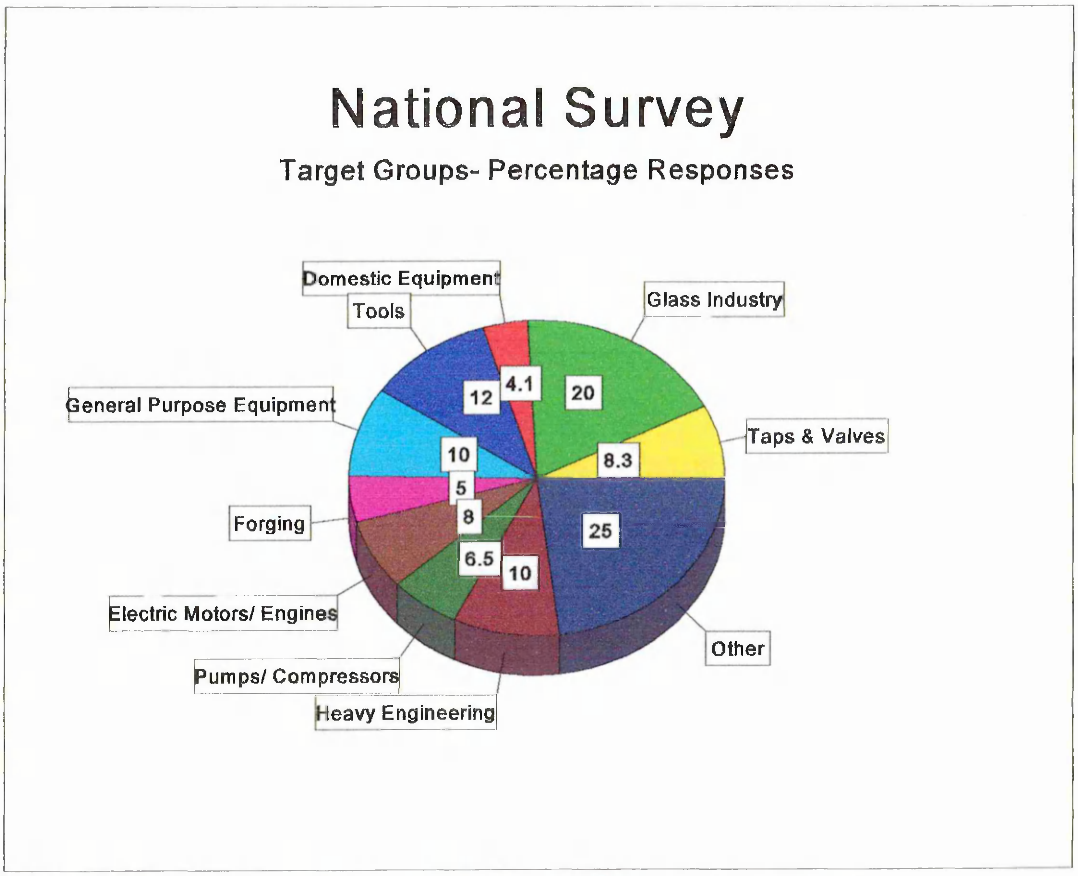


Figure 8.4 Percentage Response Rates to Survey Questionnaire by Different Product Groups

 Original in colour

Derived graphical results from the questionnaire responses are presented in Figures 8.5 to 8.39. However, some of the questions on the questionnaire were open-ended questions which allowed respondents to provide "Literal" responses; ie question 40 "What solutions (if any) were needed to overcome staff difficulties with 3D CAD?" purposely elicited respondents own comments. Results for such literal response questions do not appear within this results section, simply because they are long lists of comments. However, the actual raw comments made by the respondents to such questions, specifically questions 18, 23, 26, 28,29, 37, 39 and 40 are shown in Appendix C and are discussed along with the other results in chapter 9. The numbers appearing down the left hand side of the lists refer to the individual case company number.

8.2.2 Respondents Details

Figure 8.5 relates to questions 2 to 4 inclusive in the questionnaire section **"Your Details"** and present an overview of respondents positions within their organisation, the length of time they have been employed at the company and their academic and training background.

Figure 8.5 General company information

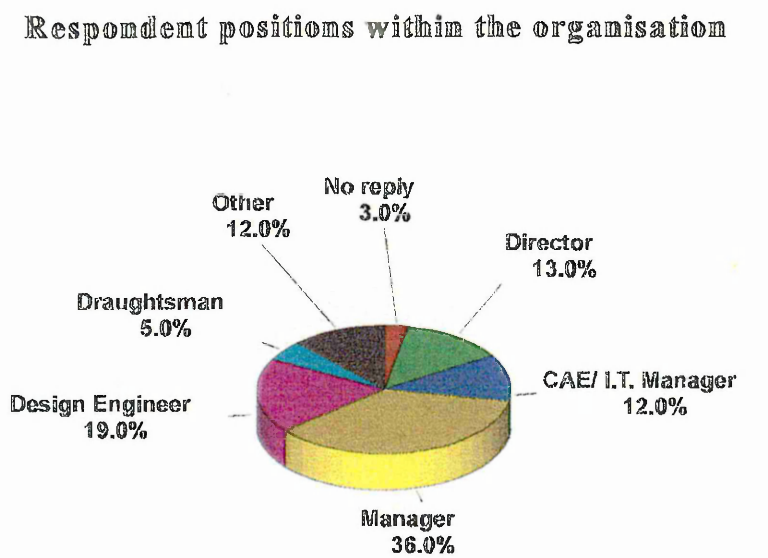


Figure 8.5a Respondents Positions- All Users

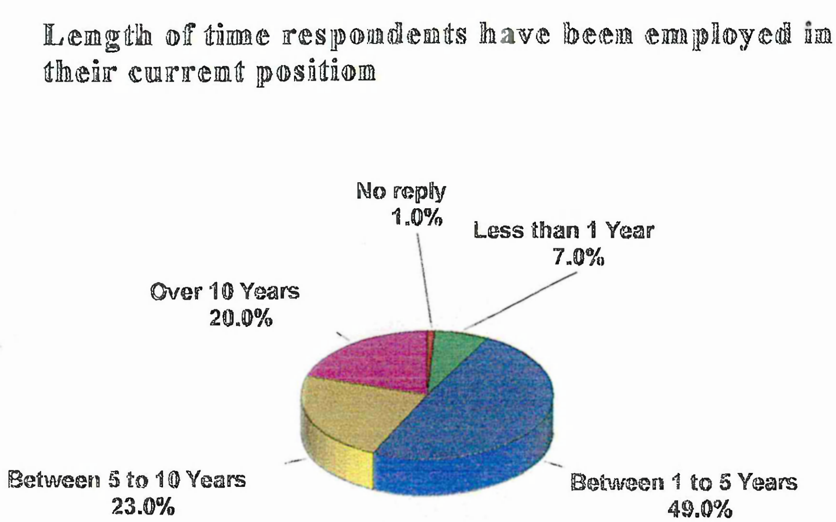


Figure 8.5b- Employment Durations- All Users

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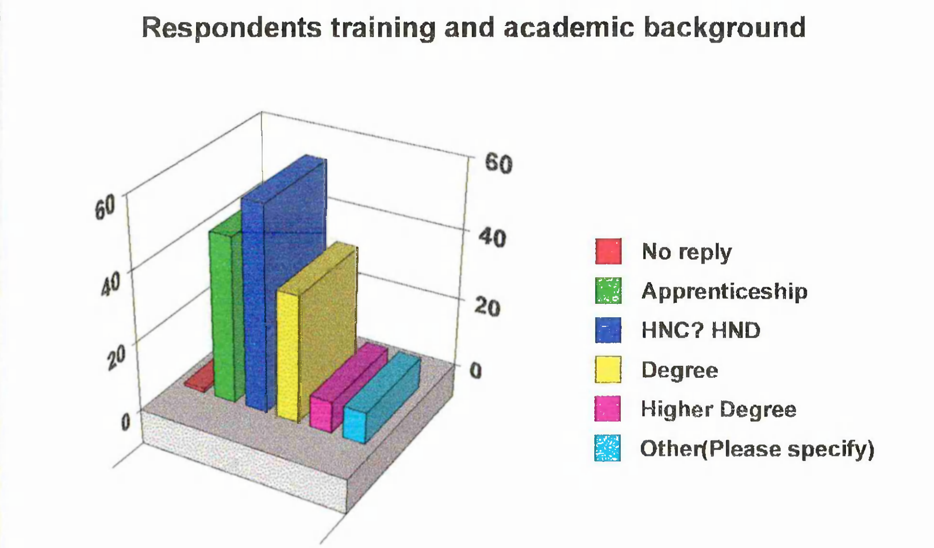

Figure 8.5c Training and Academic Background- All Users

Question 5 on the questionnaire was employed to ascertain if companies employed CAD as a prelude to including the company in the research. As only companies employing CAD have been selected it is not relevant to provide graphical indications of this.

8.2.3 Initial Company Information

Results in figures 8.6, 8.7 and 8.8 relate to questions 6, 7 and 8 on the questionnaire section **"Initial information about your company"**. The figures provide details of products and services offered by the company, the activities undertaken and the organisational structure.

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Figure 8.6 Initial information about companies

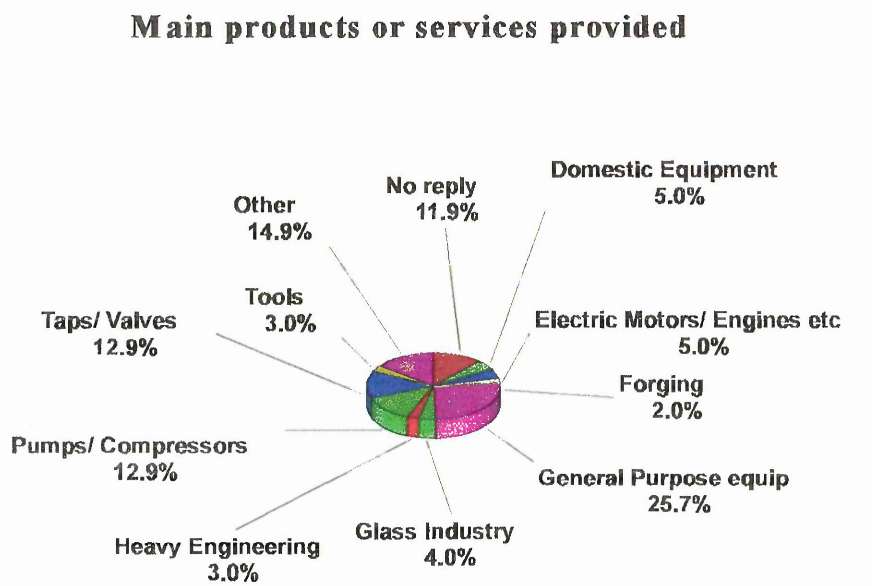

Figure 8.6a All Users

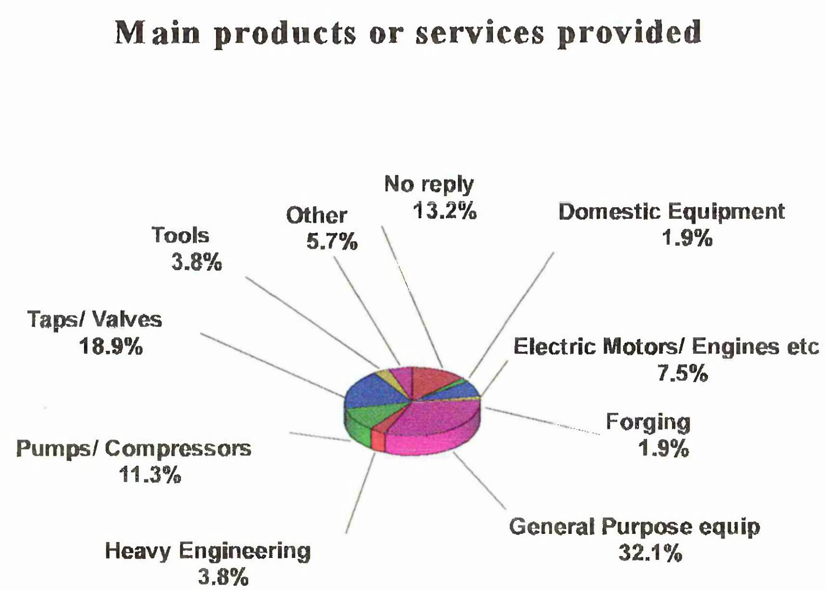

Figure 8.6b 2D Users Only

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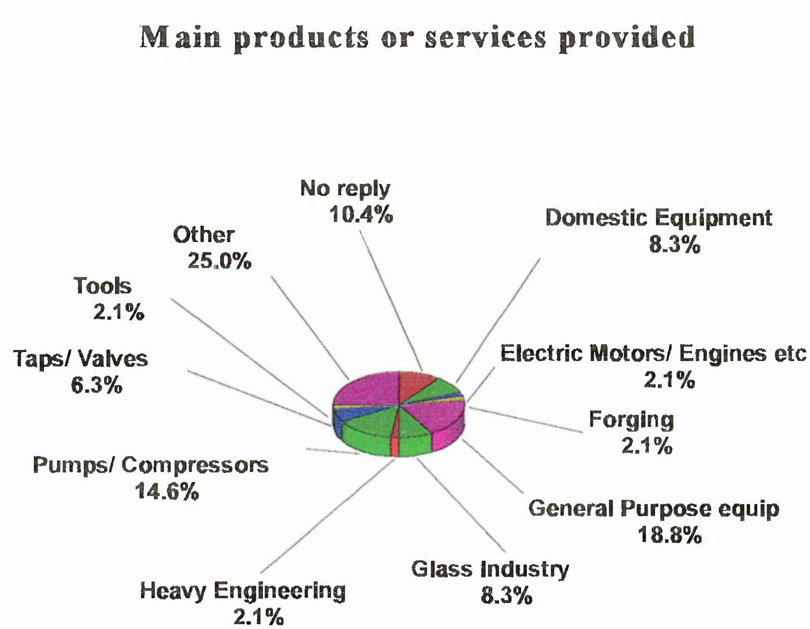

Figure 8.6c All 3D Users

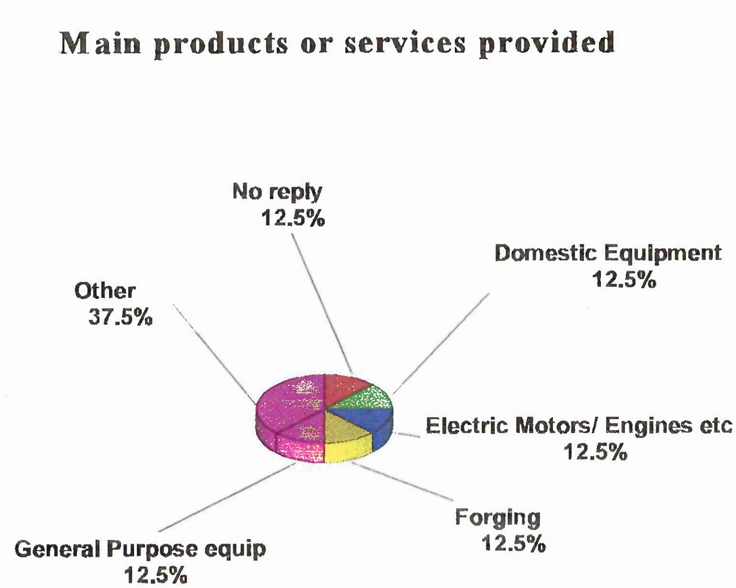

Figure 8.6d 3D Users Only

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Figure 8.7 Range of activities undertaken in CAD user Companies

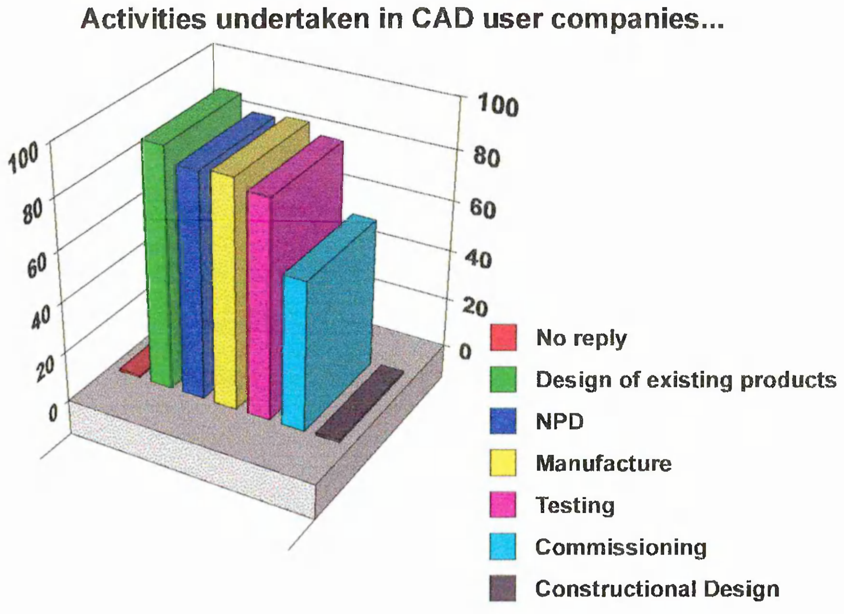

Figure 8.7a All Users

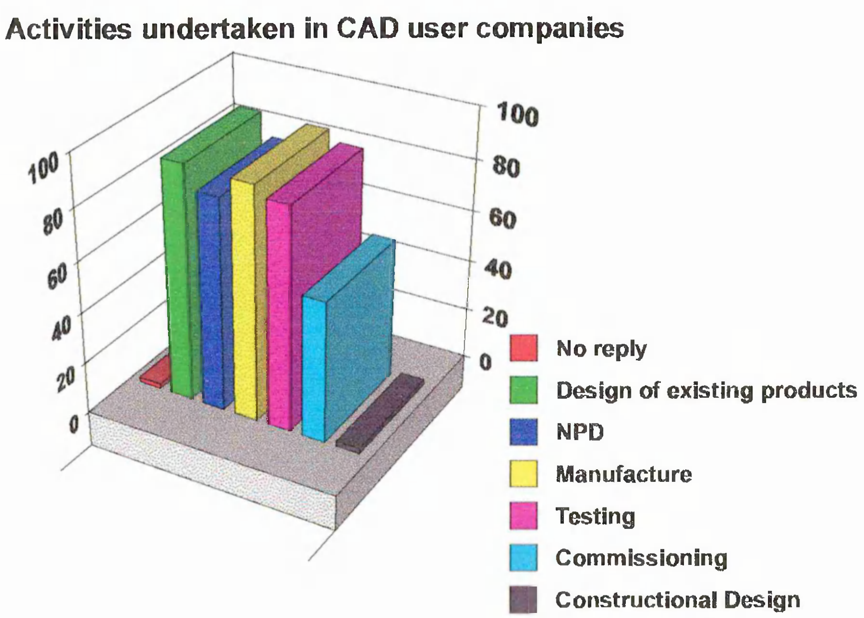

Figure 8.7b 2D Users Only

 Original in colour

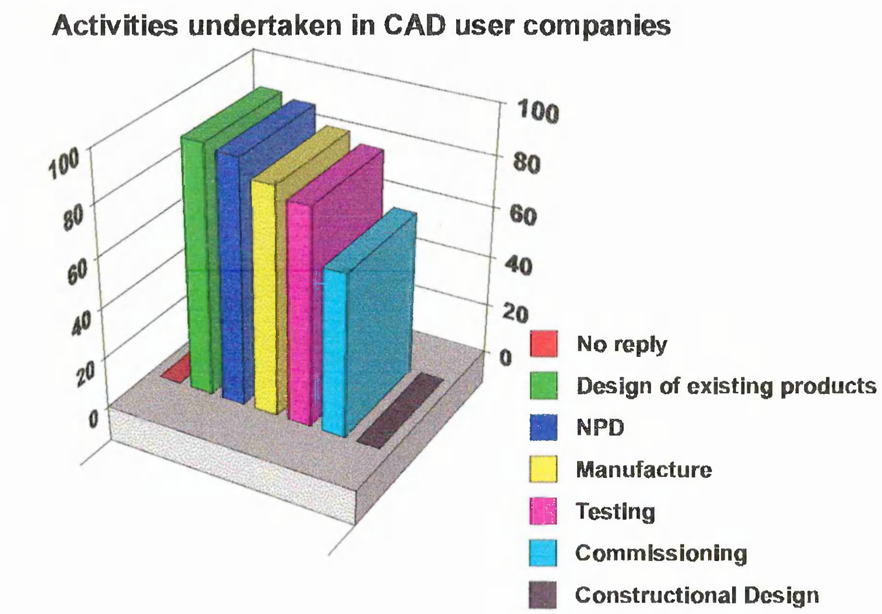

Figure 8.7c All 3D Users

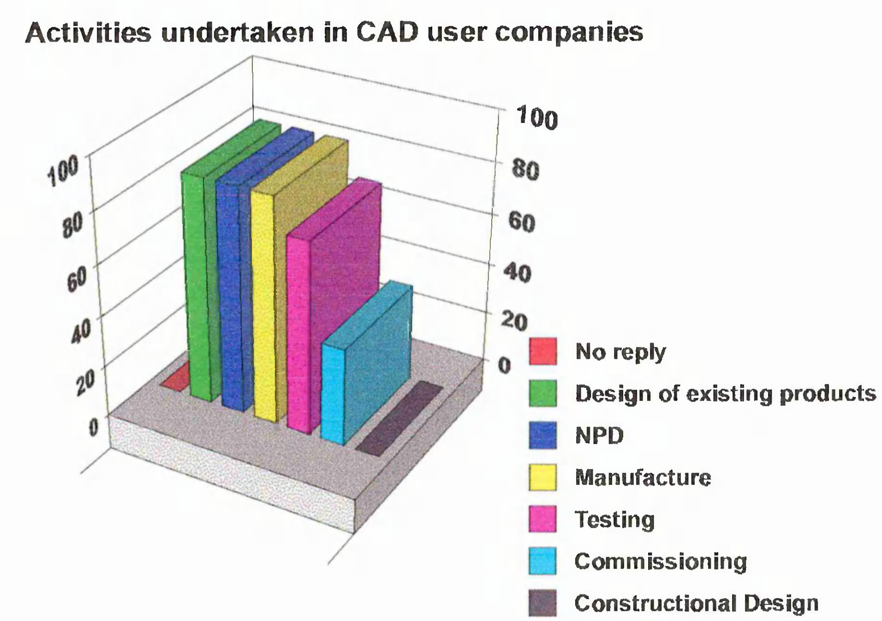

Figure 8.7d 3D Users Only

 Original in colour

Figure 8.8 Organisational structures employed by companies

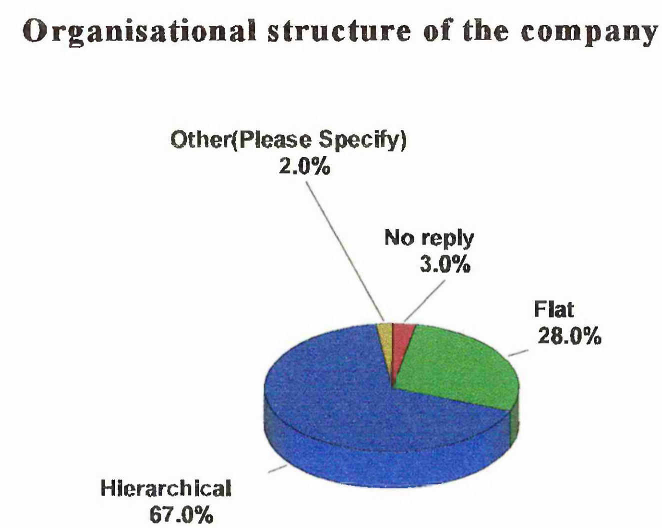

Figure 8.8a All Users

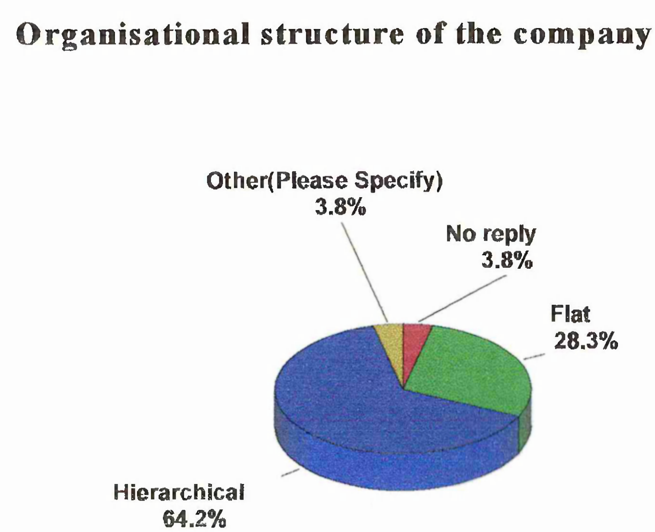

Figure 8.8b 2D Users Only

 Original in colour

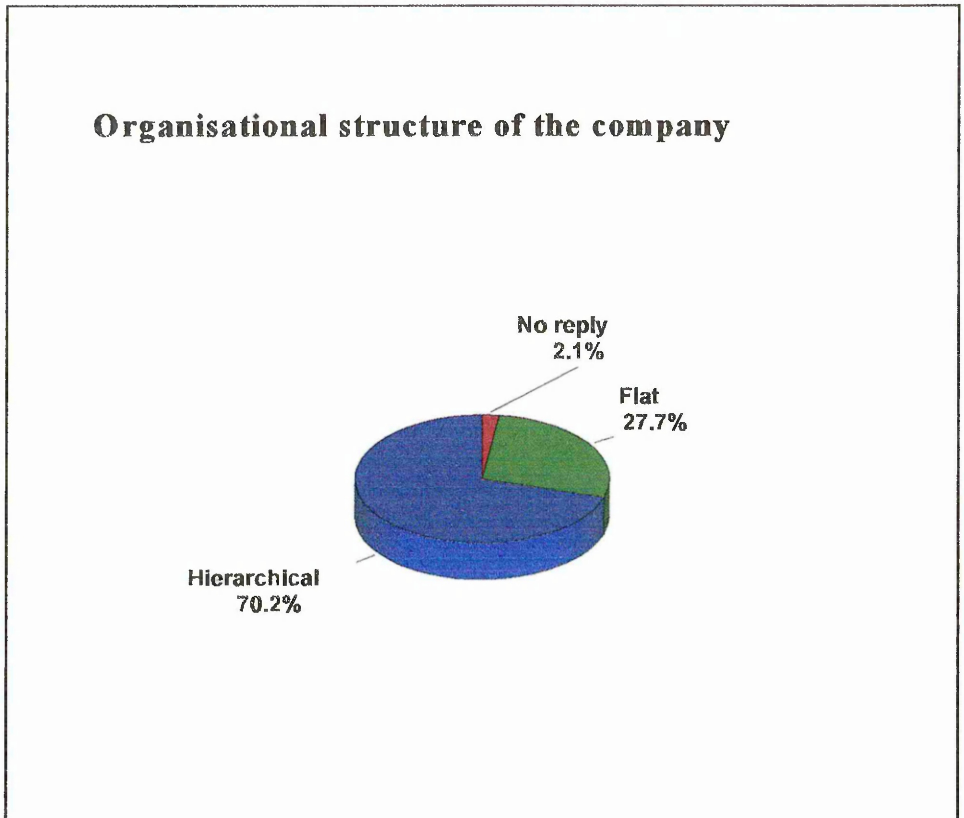

Figure 8.8c All 3D Users

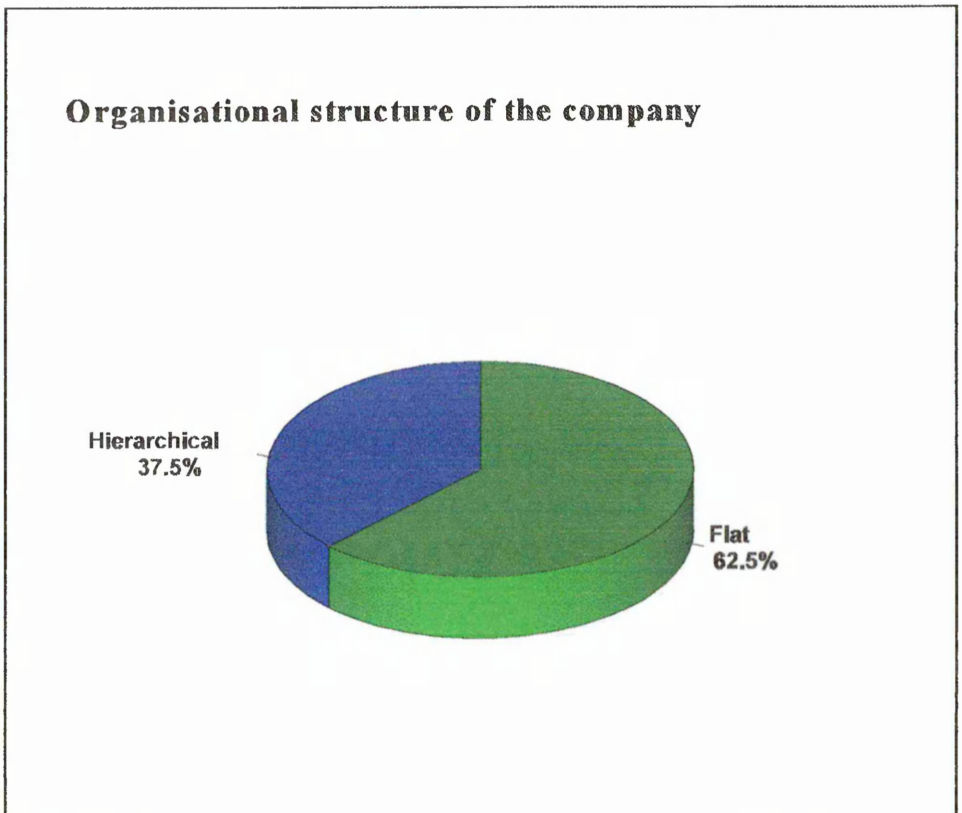

Figure 8.8d 3D Users Only

 Original in colour

8.2.4 The Design Process

Figures 8.9 to 8.13 inclusive, provide information on the "Design process" and relate to questions 10 to 14 on the questionnaire. They present information on the work that designers perform, percentages of work carried out on the drawing board and using CAD, and the numbers of drawing boards and or CAD seats available.

Figure 8.9 Type of work performed on a regular basis

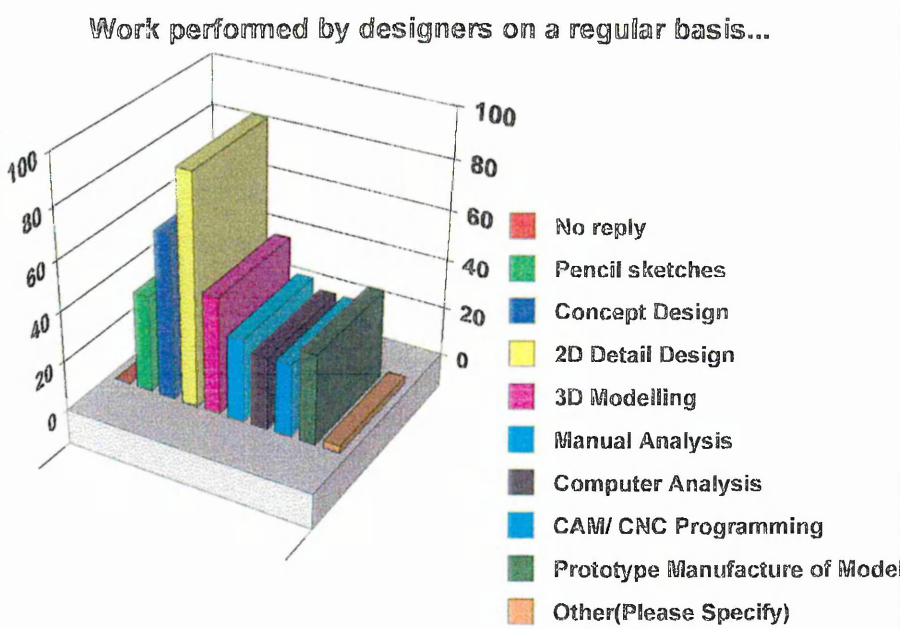

Figure 8.9a All Users

 Original in colour

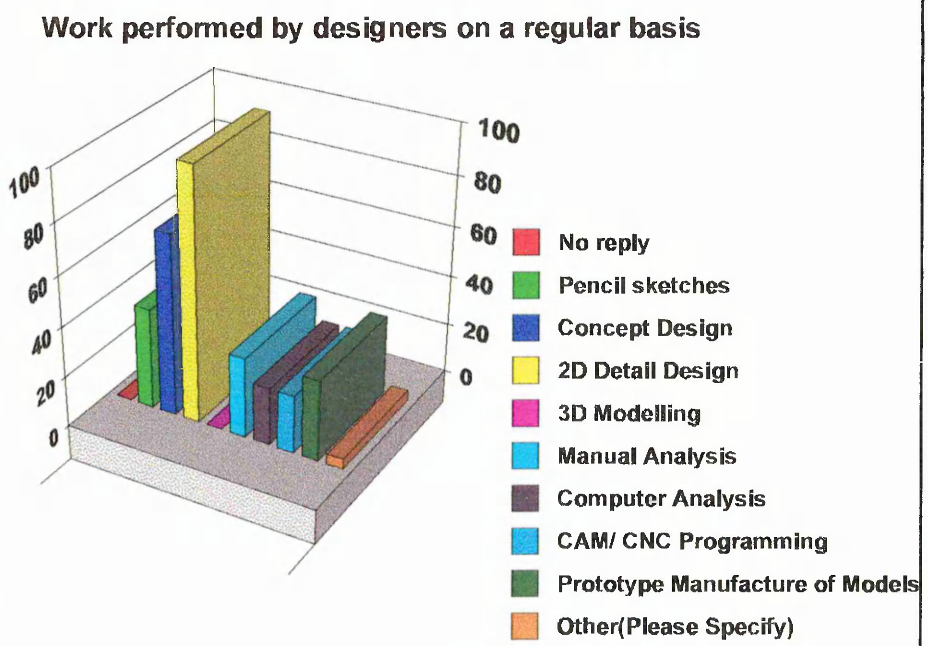

Figure 8.9b 2D Users Only

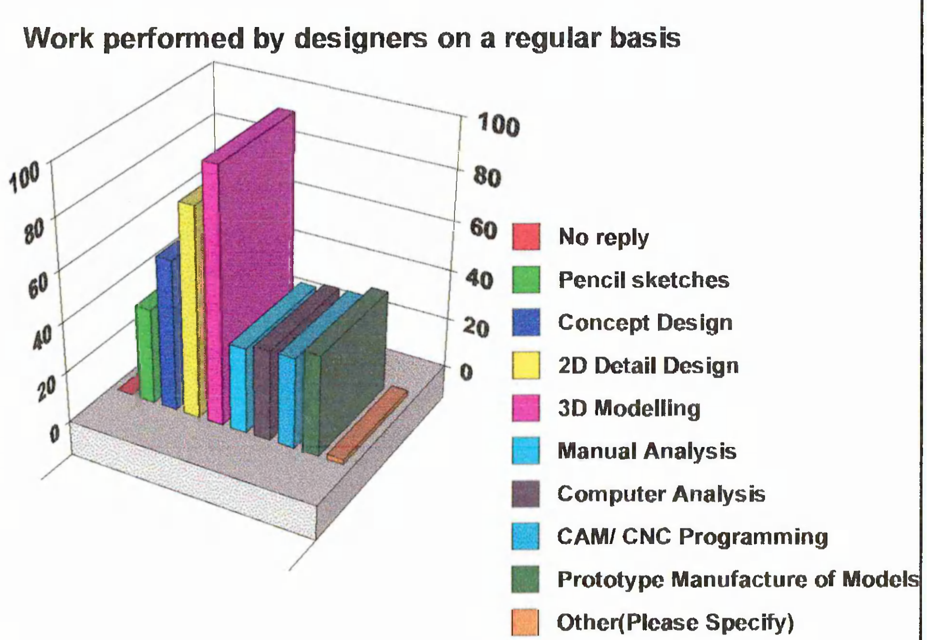

Figure 8.9c All 3D Users

 Original in colour

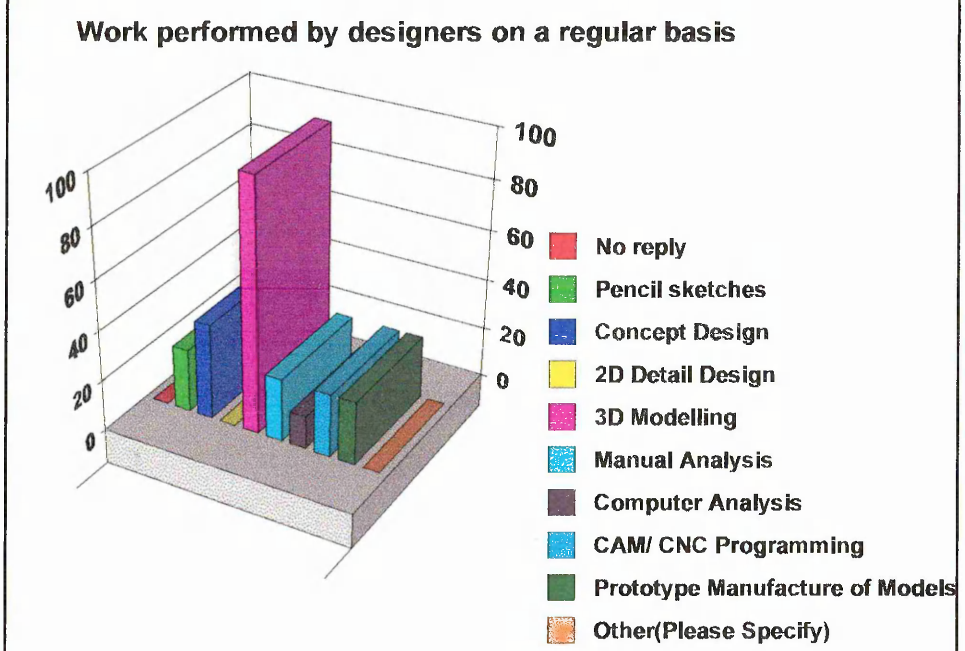

Figure 8.9d 3D Users Only

 Original in colour

Figure 8.10 Percentage of work carried out manually on the drawing board

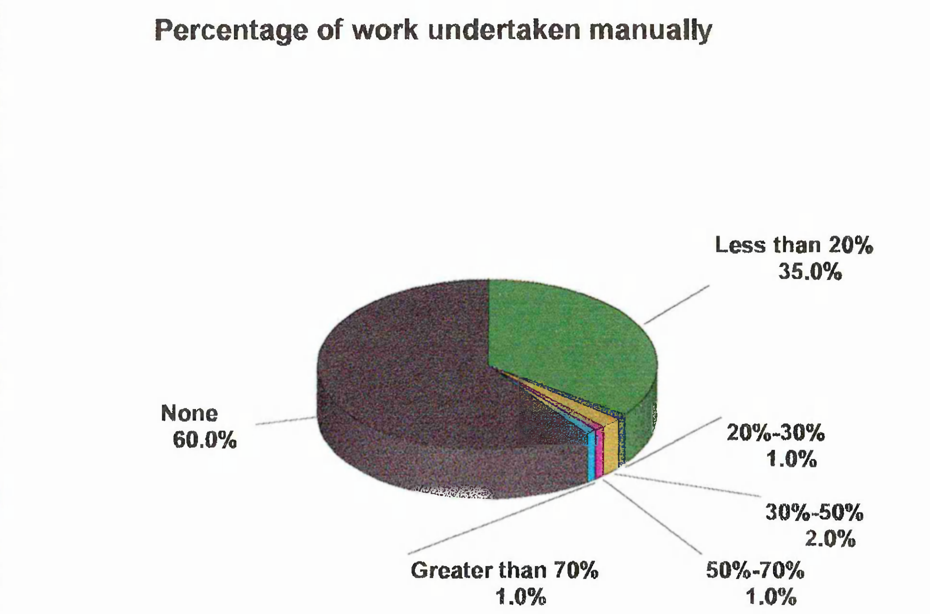

Figure 8.10a All Users

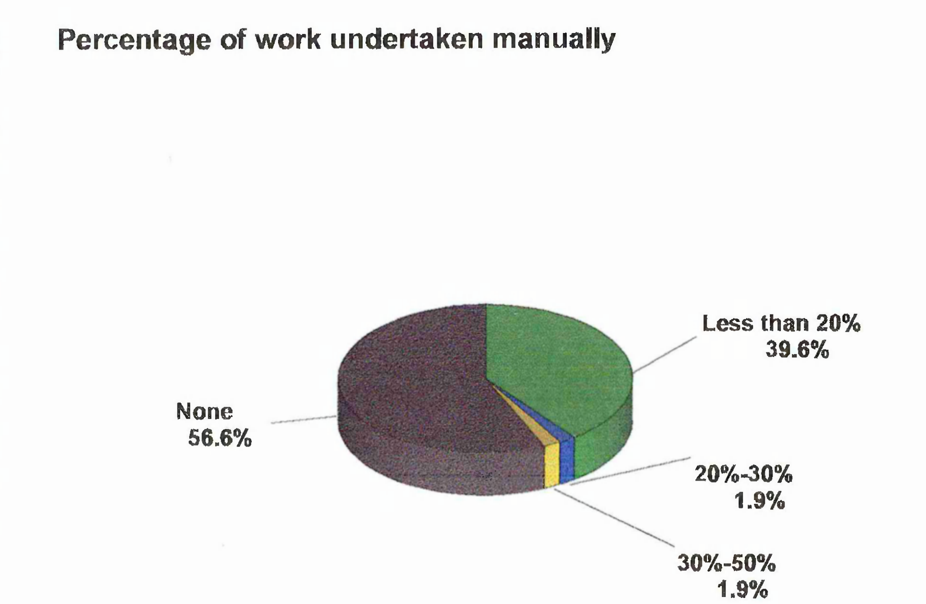

Figure 8.10b 2D Users Only

 Original in colour

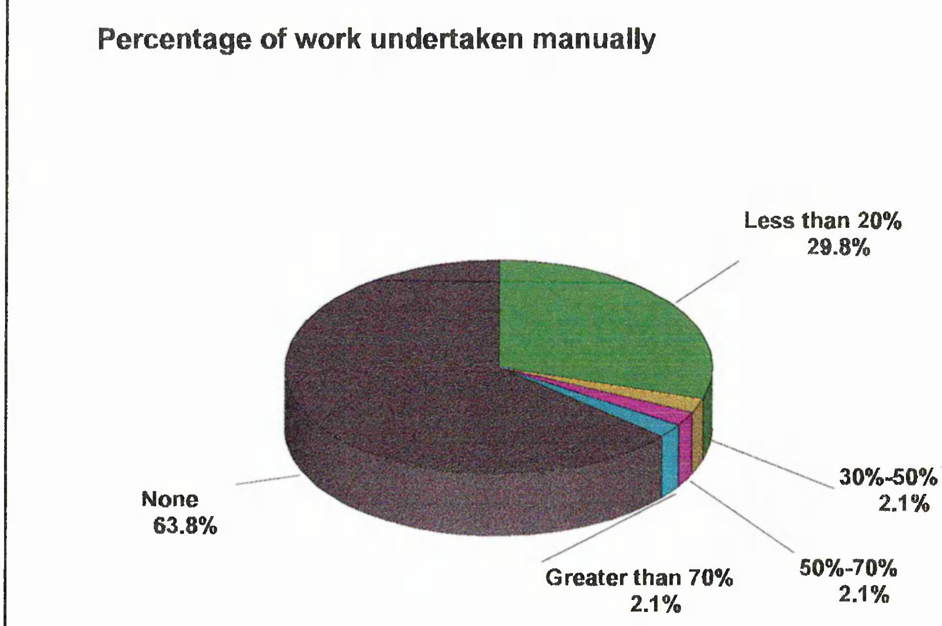

Figure 8.10c All 3D Users

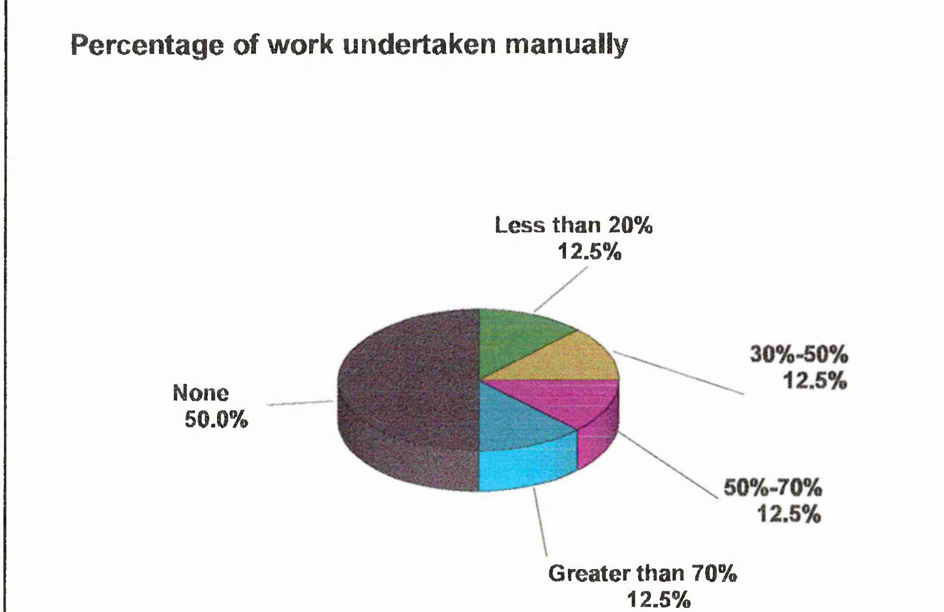

Figure 8.10d 3D Users Only

 Original in colour

Figure 8.11 The design process- number of drawing boards employed

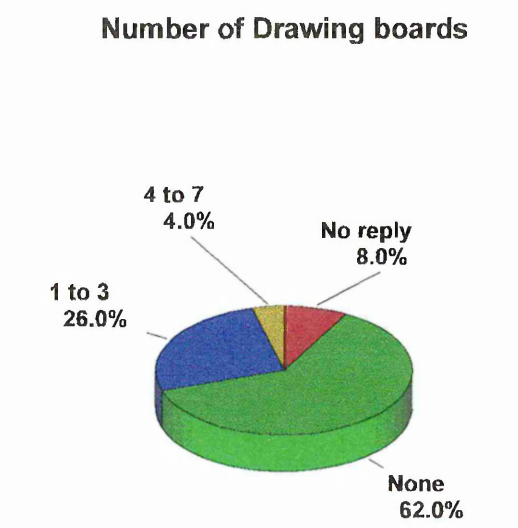

Figure 8.11a All Users

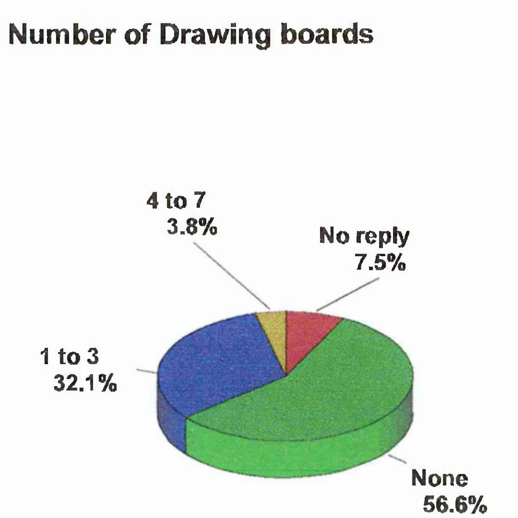

Figure 8.11b 2D Users Only

 Original in colour

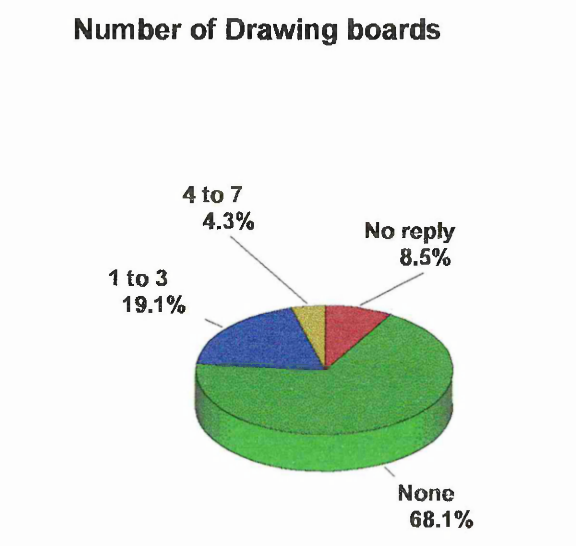

Figure 8.11c All 3D Users

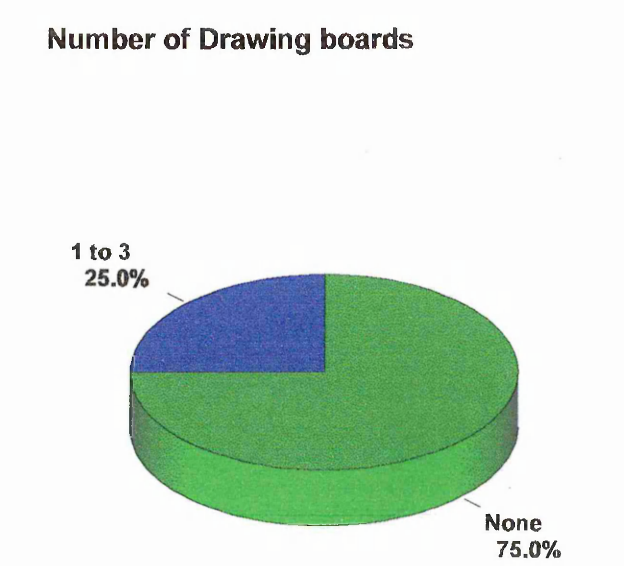

Figure 8.11d 3D Users Only

 Original in colour

Figure 8. 12 Percentage of work undertaken Using CAD

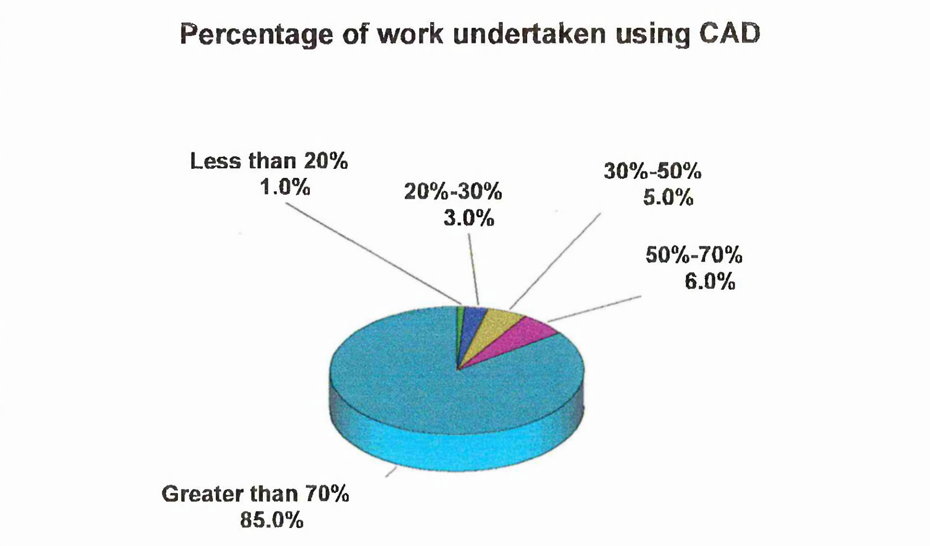

Figure 8.12a All Users

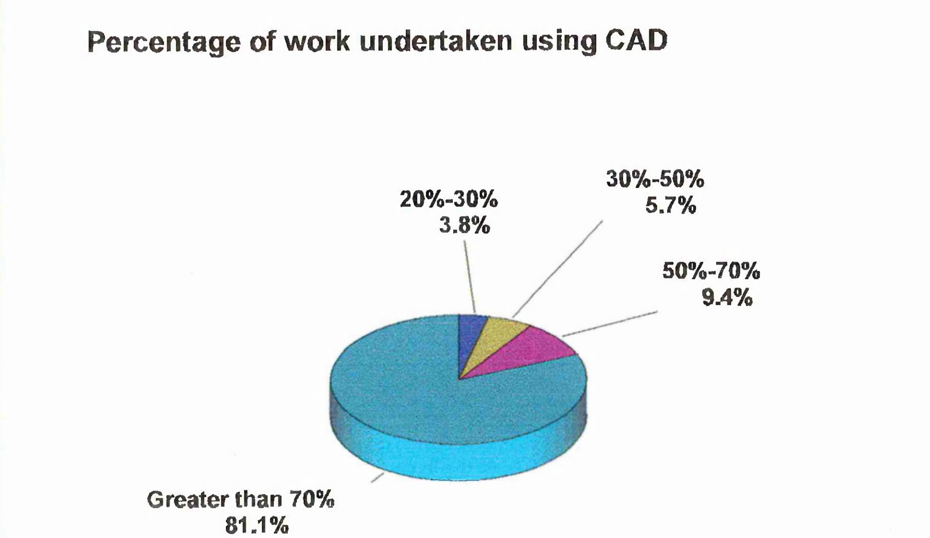

Figure 8.12b 2D Users Only

 Original in colour

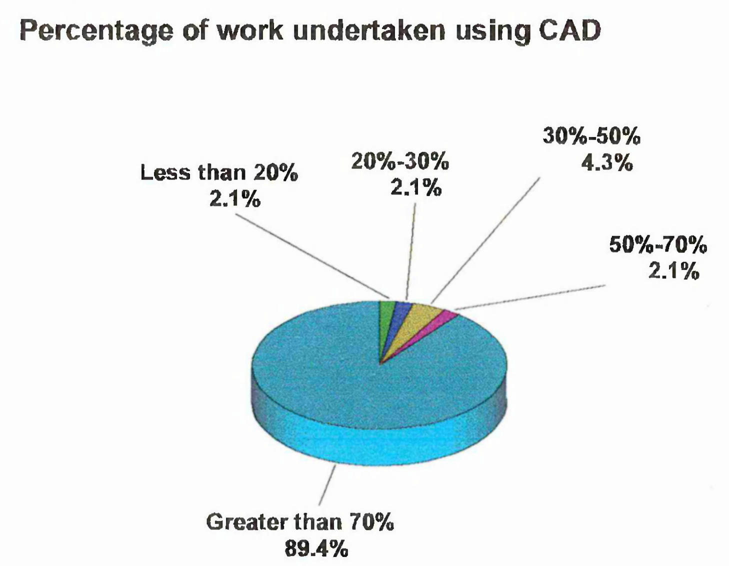

Figure 8.12c All 3D Users

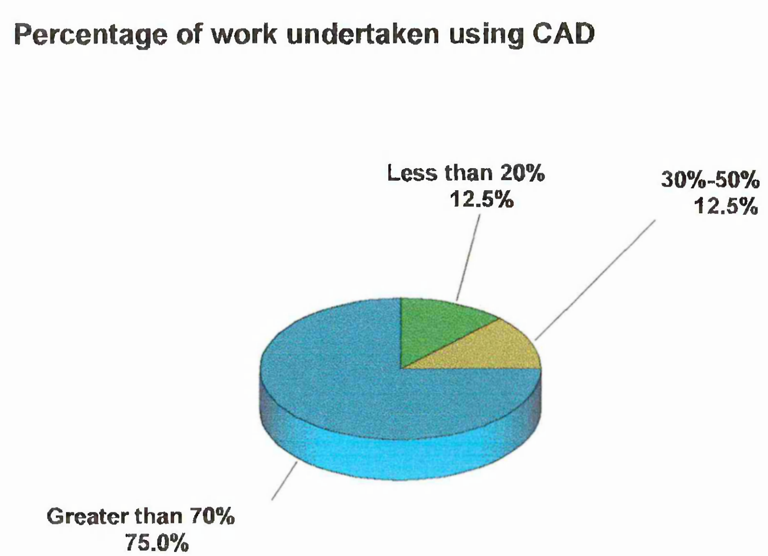

Figure 8.12d 3D Users Only

 Original in colour

Figure 8.13 Investment in CAD- numbers of seats

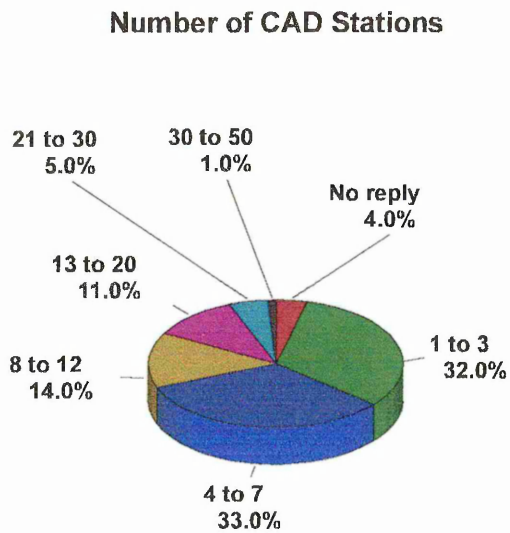

Figure 8.13a All Users

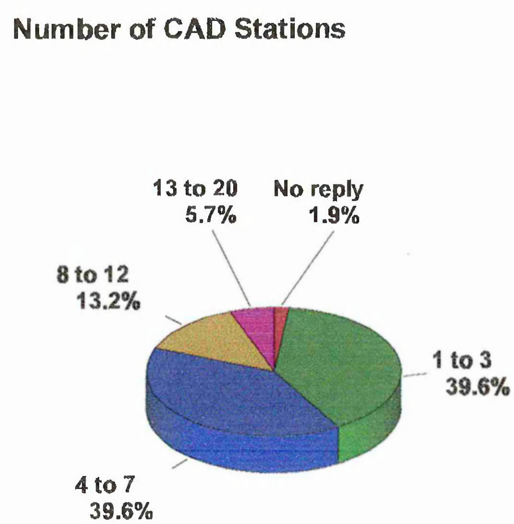

Figure 8.13b 2D Users Only

 Original in colour

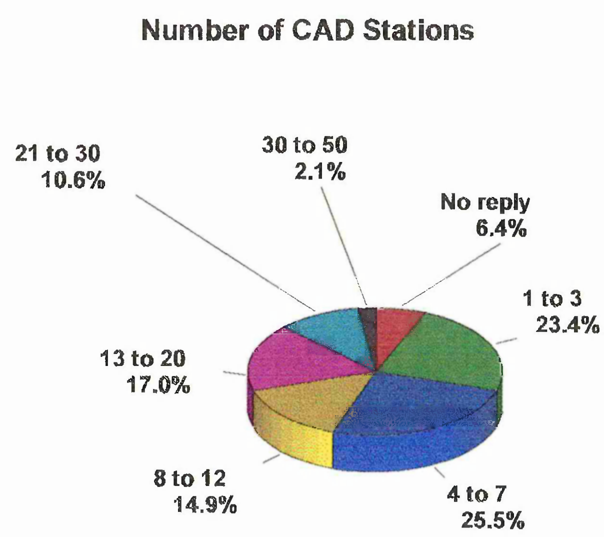

Figure 8.13c All 3D Users

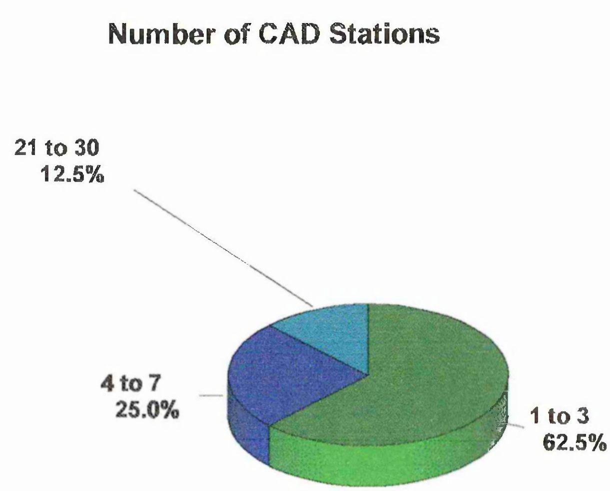

Figure 8.13d 3D Users Only

 Original in colour

8.2.5 CAD Introduction and Development

Figures 8.14 to 8.27 illustrate answers to questions in the questionnaire section covering **"CAD introduction and development".** They provide a view of how long companies have employed CAD, including how long they have been employing their current CAD system. The results also show the types of jobs for which systems are employed, approximate investments in CAD, the reasons CAD was needed and the subsequent organisational changes (if any) together with reasons for these changes and any levels of resistance to the technology.

Questions 18, 23, 26, 28 and 29 on the questionnaire were open ended questions which required literal written responses and as stated earlier, the comments from companies to these questions are listed in Appendix C

Question 20, "Approximate investment in CAD" is indicated in two graphs, figures 8.17 and 8.18. Figure 8.17 shows the diversity of investment in CAD by the various companies in terms of the total capital outlay, excluding training. However, figure 8.18 illustrates this further by relating this total investment to the numbers of CAD seats employed at the companies by presenting derived figures for investment per seat

The responses to question 21 "Rank the original reasons that your company needed a CAD system" are illustrated in six figures, Figures 8.19 to 8.24 inclusive. The figures show percentages of companies ranking a particular need on a scale of 1 to 6, with the highest importance ranking being "1".

Figure 8.14 Length of time companies have been employing CAD

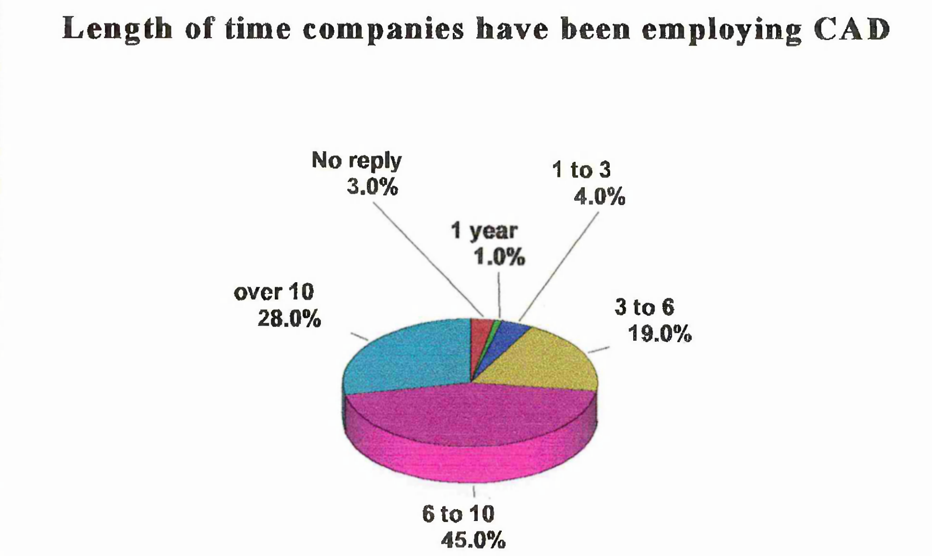

Figure 8.14a All Users

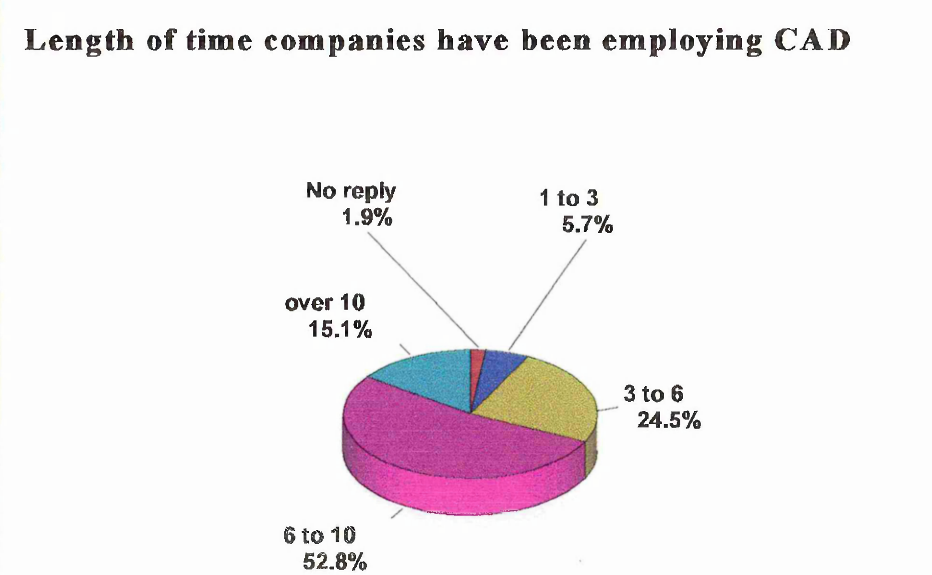

Figure 8.14b 2D Users Only

 Original in colour

Length of time companies have been employing CAD

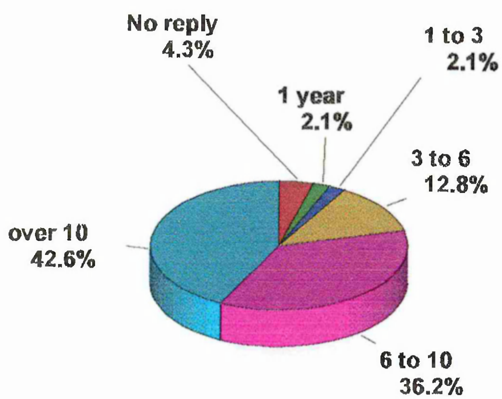

Figure 8.14c All 3D Users

Length of time companies have been employing CAD

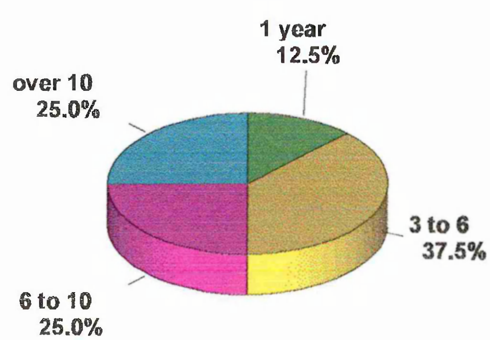

Figure 8.14d 3D Users Only

 Original in colour

Figure 8.15 Length of time companies have been employing their current CAD system

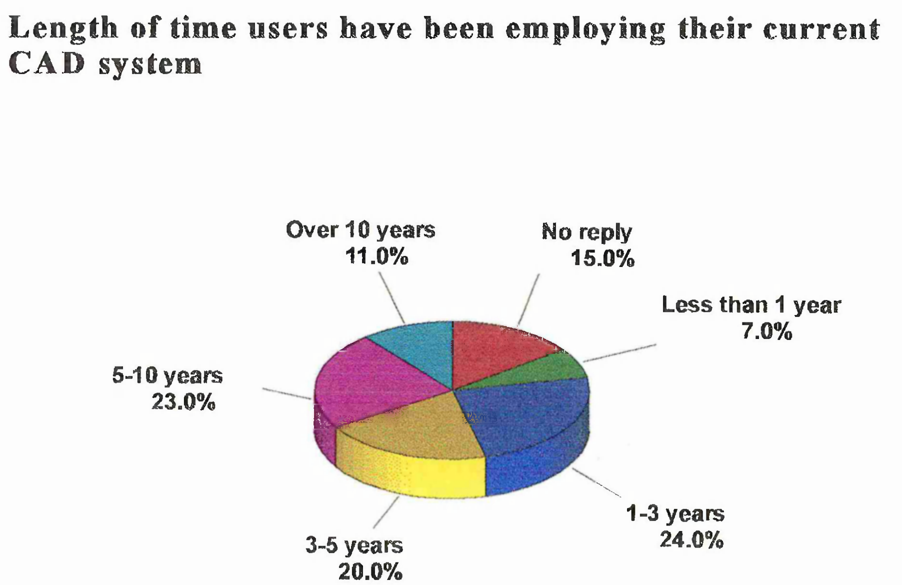

Figure 8.15a All Users

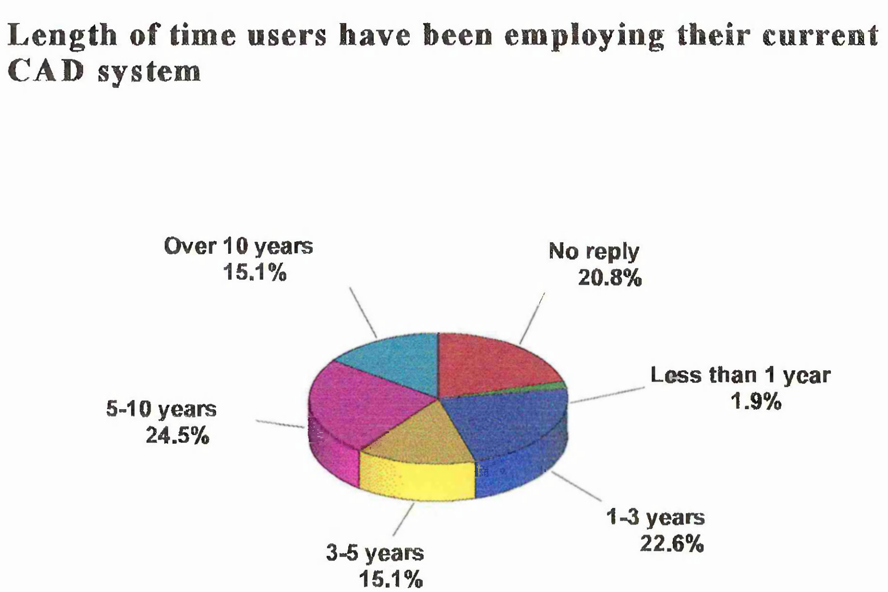

Figure 8.15b 2D Users Only

 Original in colour

Length of time users have been employing their current CAD system

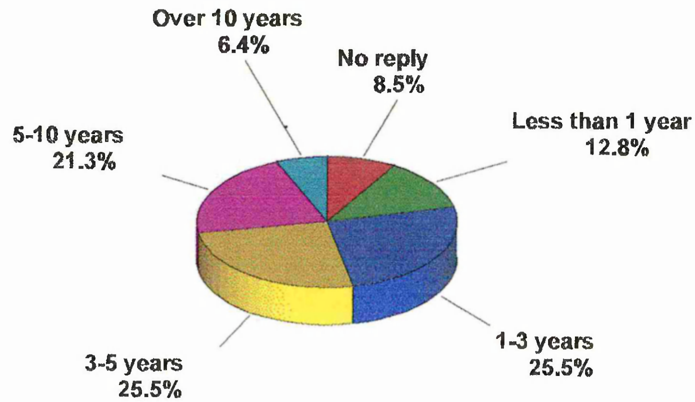

Figure 8.15c All 3D Users

Length of time users have been employing their current CAD system

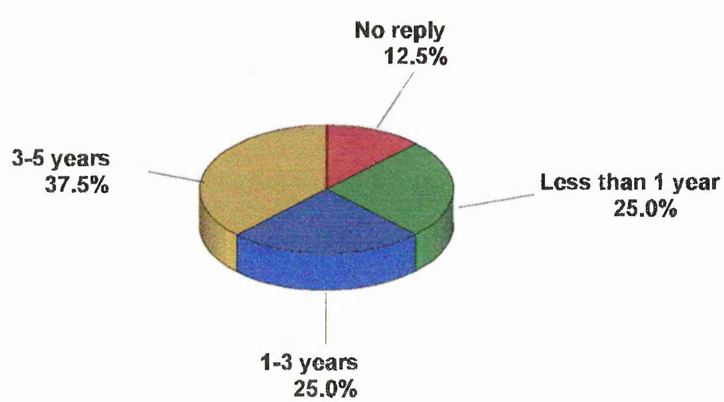

Figure 8.15d 3D Users Only

 Original in colour

Figure 8.16 Jobs for which the current CAD system is used

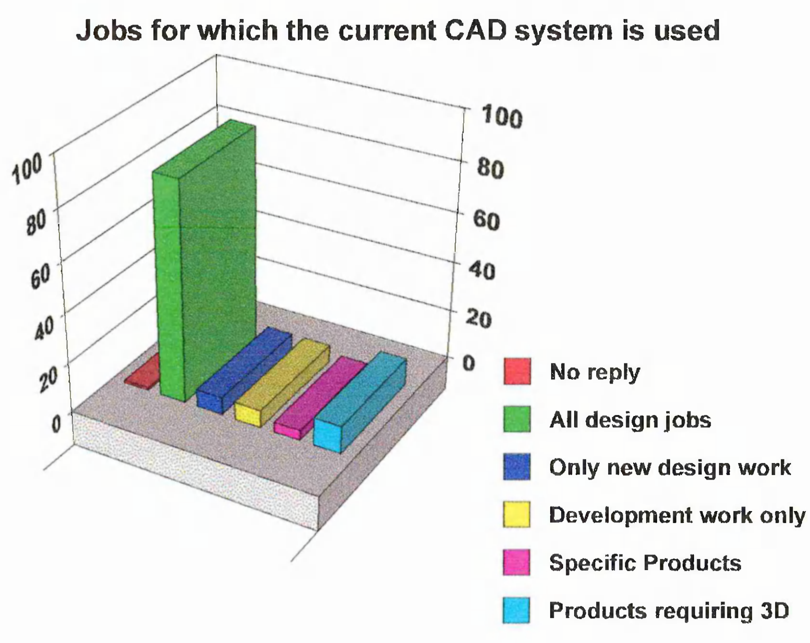

Figure 8.16a All Users

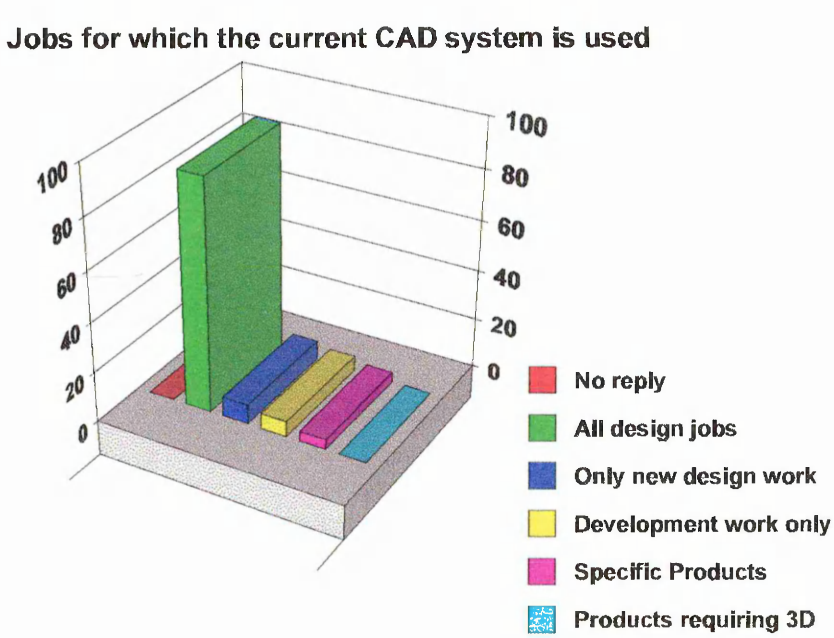

Figure 8.16b 2D Users Only

 Original in colour

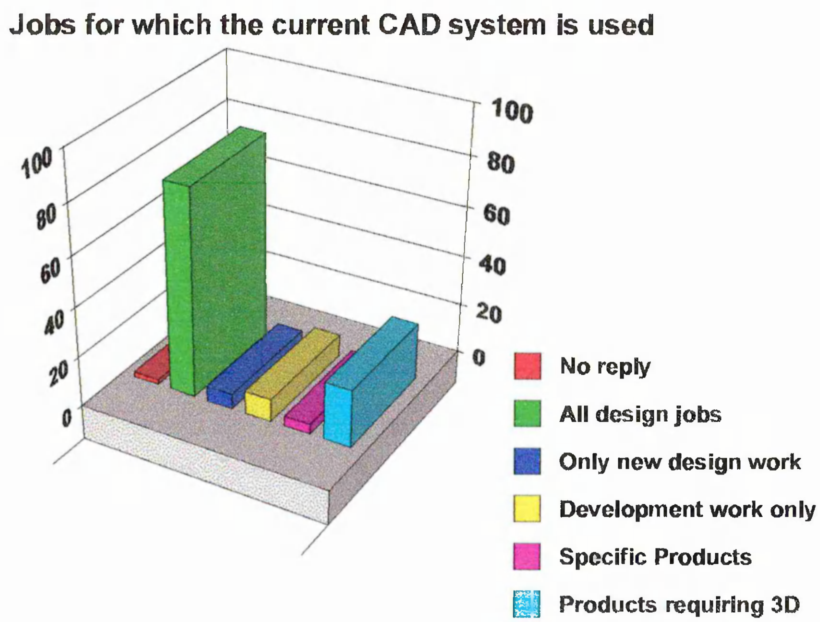

Figure 8.16c All 3D Users

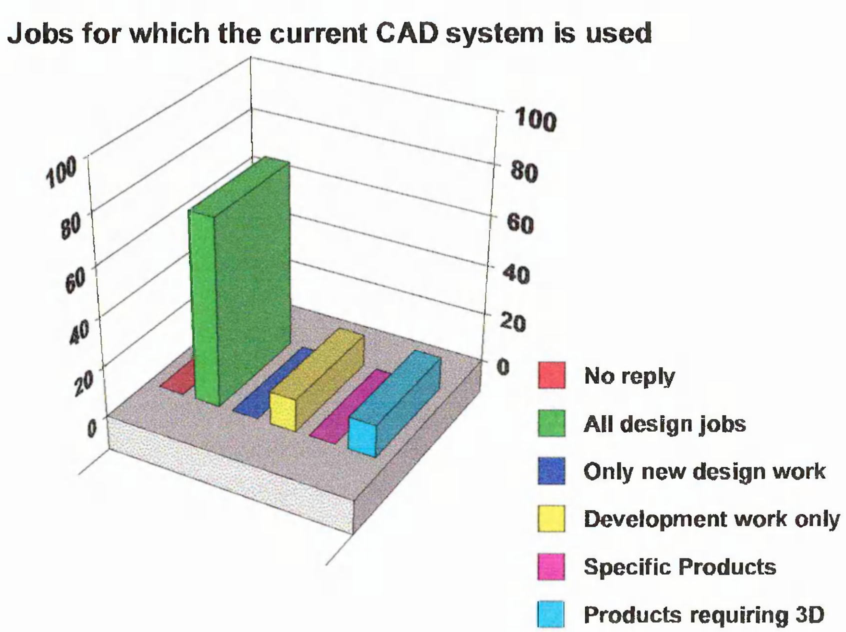

Figure 8.16d 3D Users Only

 Original in colour

Figure 8.17 Approximate investment in CAD (Excluding Training)

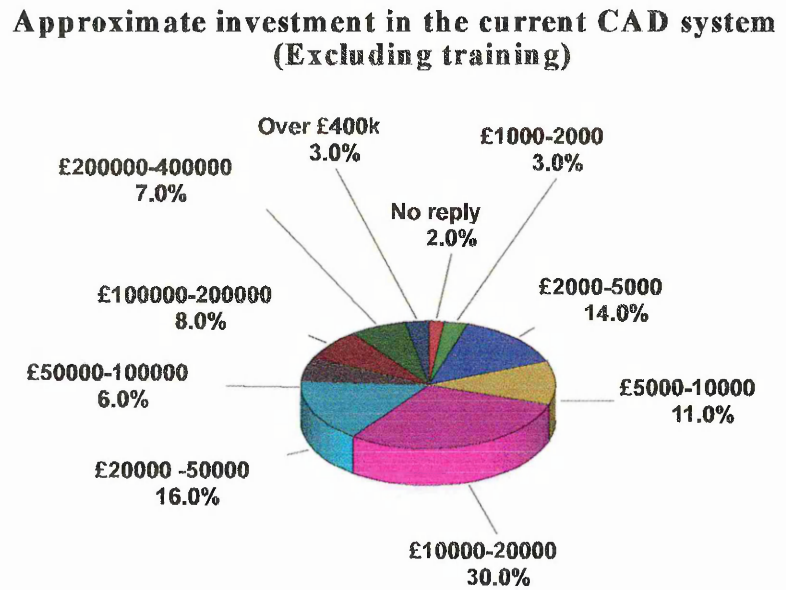

Figure 8.17a All Users

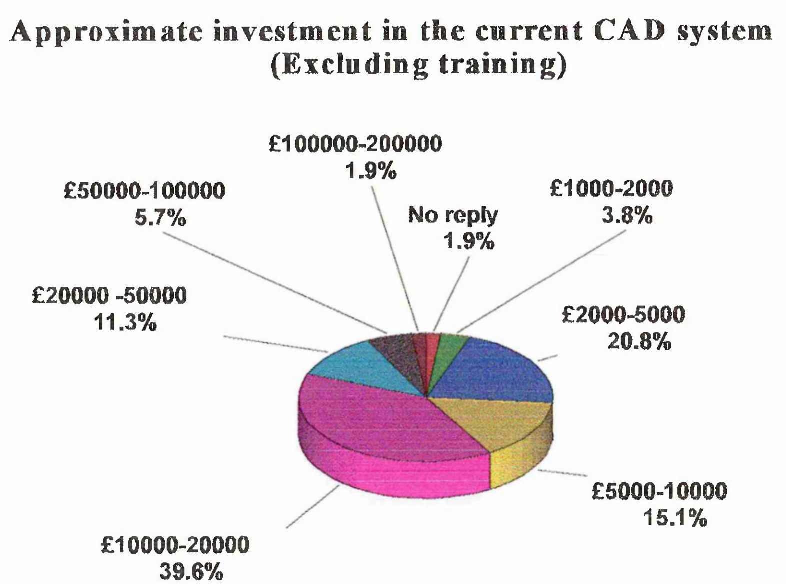

Figure 8.17b 2D Users Only

 Original in colour

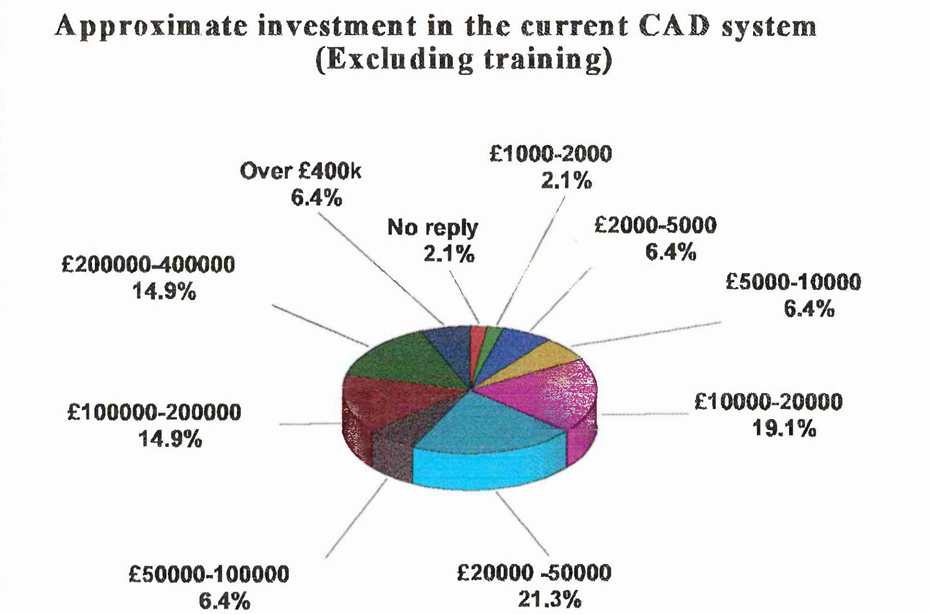

Figure 8.17c All 3D Users

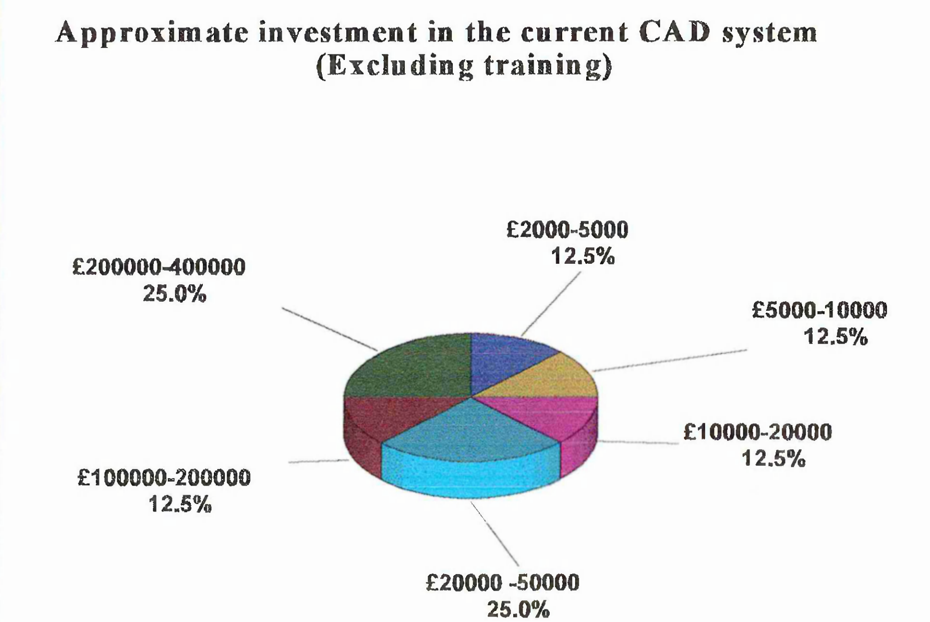

Figure 8.17d 3D Users Only

 Original in colour

Figure 8.18 Average investment per CAD seat

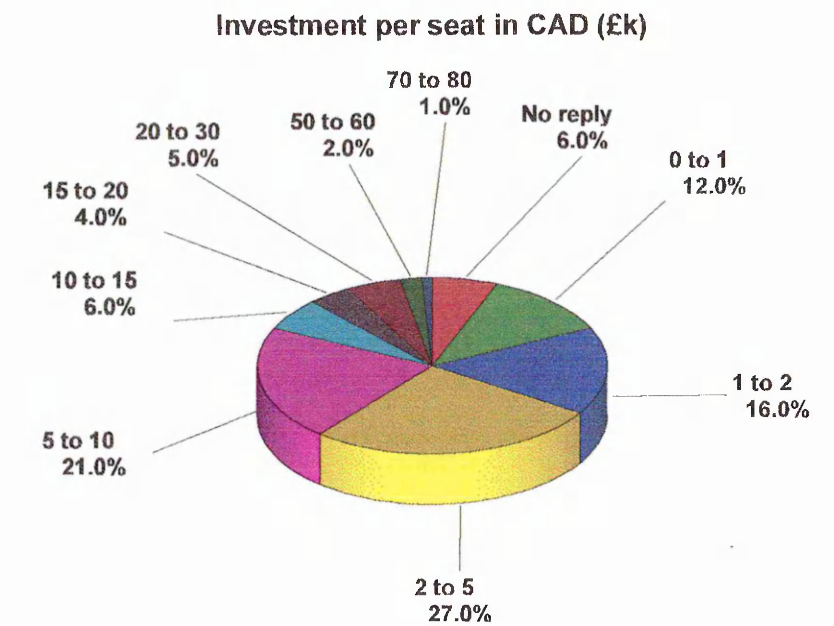

Figure 8.18a All Users

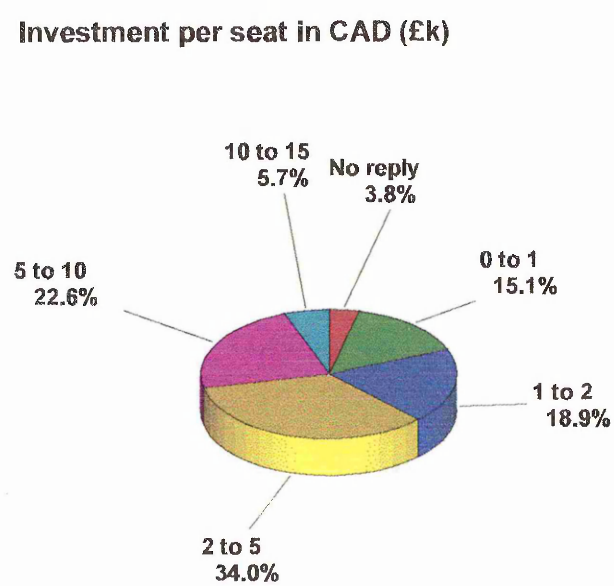

Figure 8.18b 2D Users Only

 Original in colour

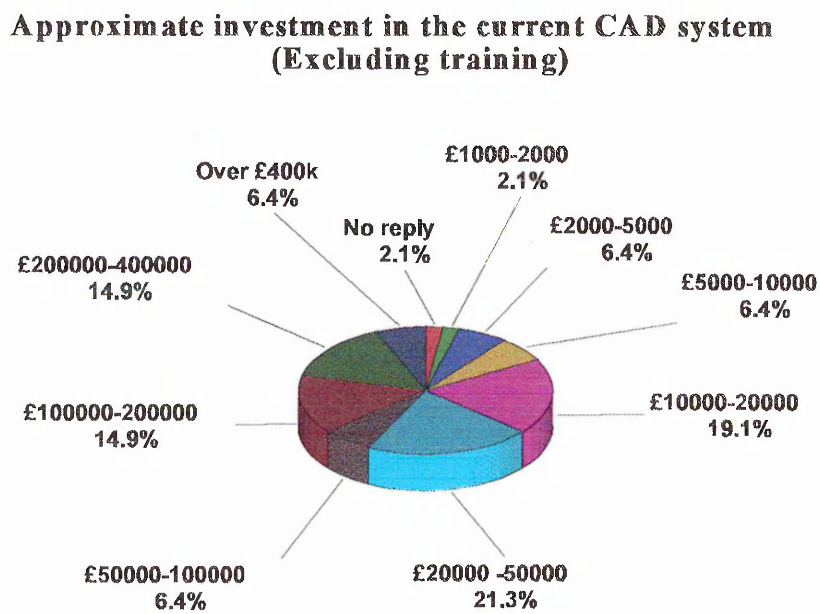

Figure 8.17c

All 3D Users

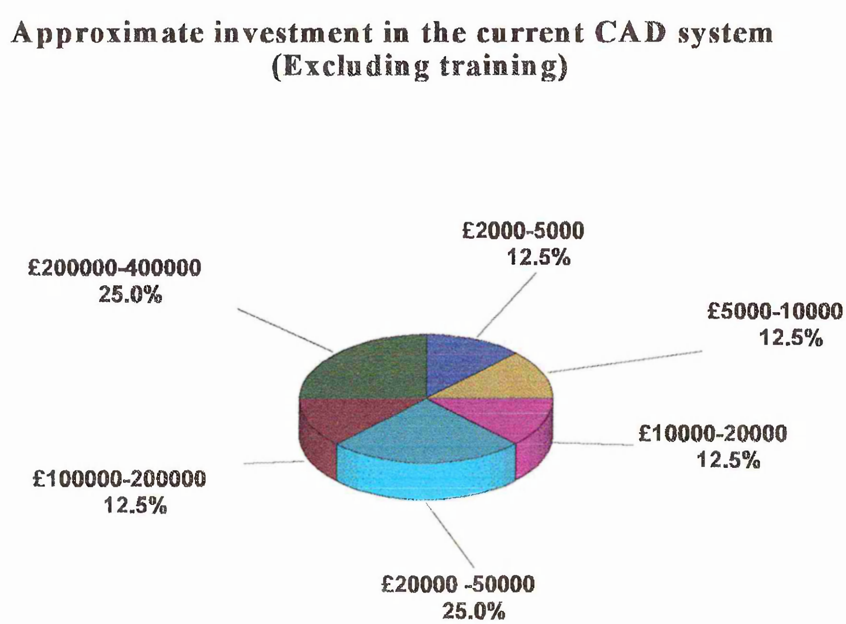

Figure 8.17d

3D Users Only

Original in colour

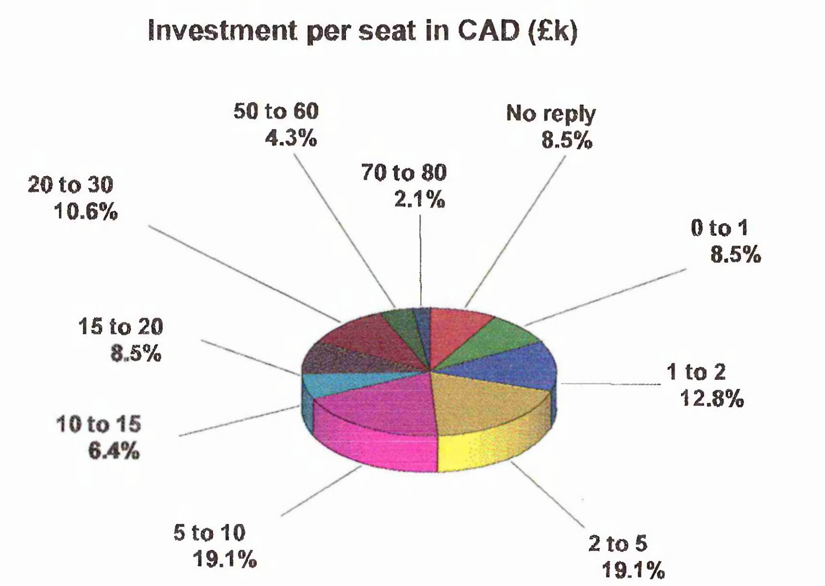

Figure 8.18c All 3D Users

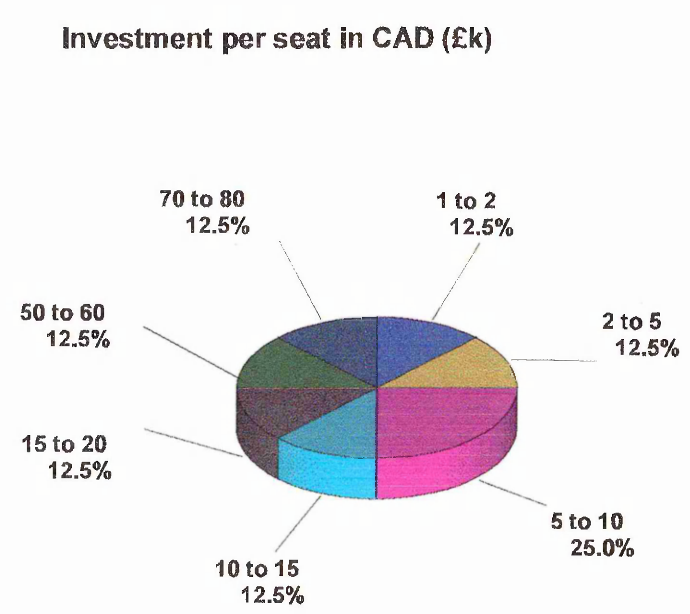

Figure 8.18d 3D Users Only

 Original in colour

**Figure 8.19 Reasons companies needed the current CAD system-
(Productivity)- (Ranked from 1 to 6 with the highest importance ranking=1)**

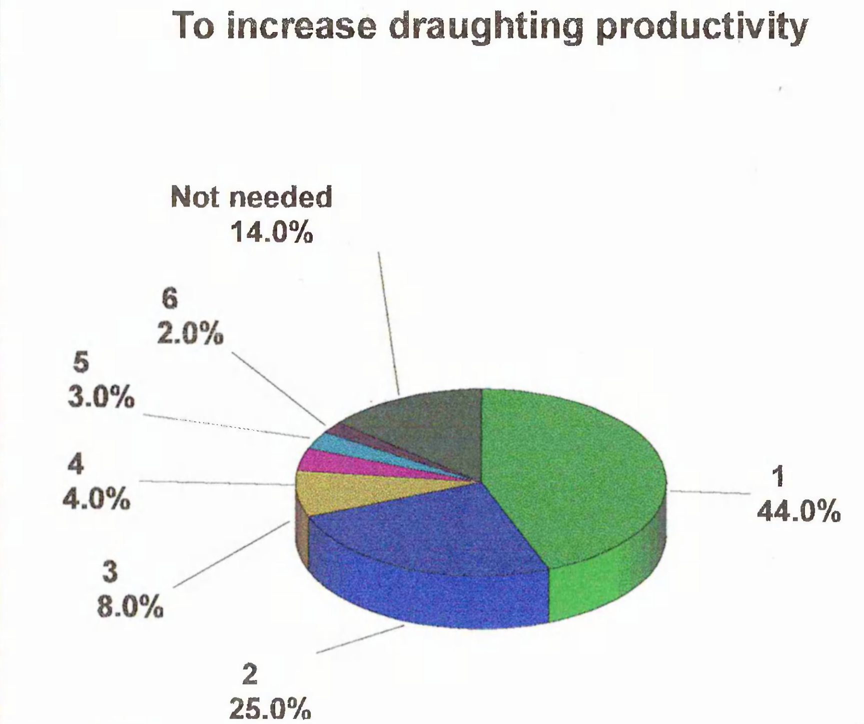

Figure 8.19a All Users

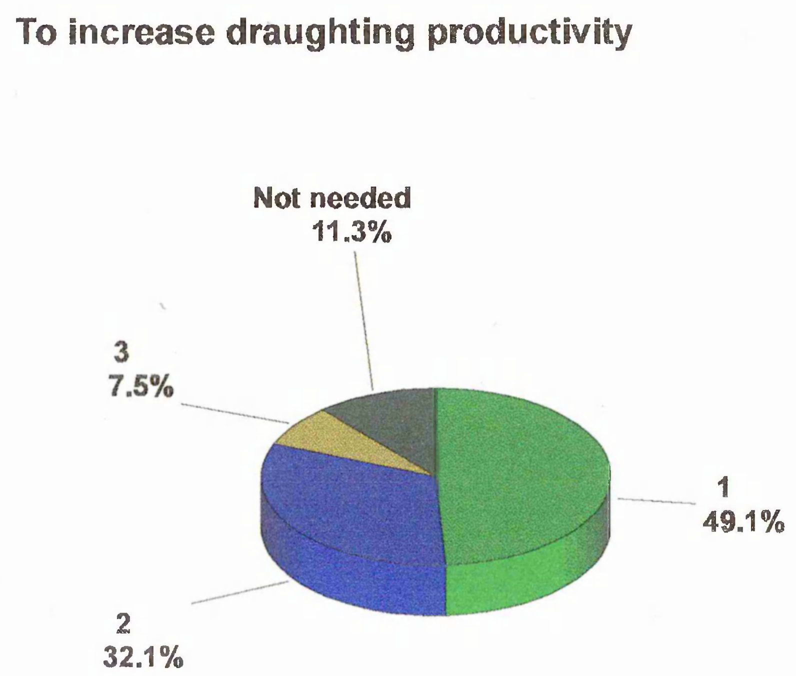

Figure 8.19b 2D Users Only

 Original in colour

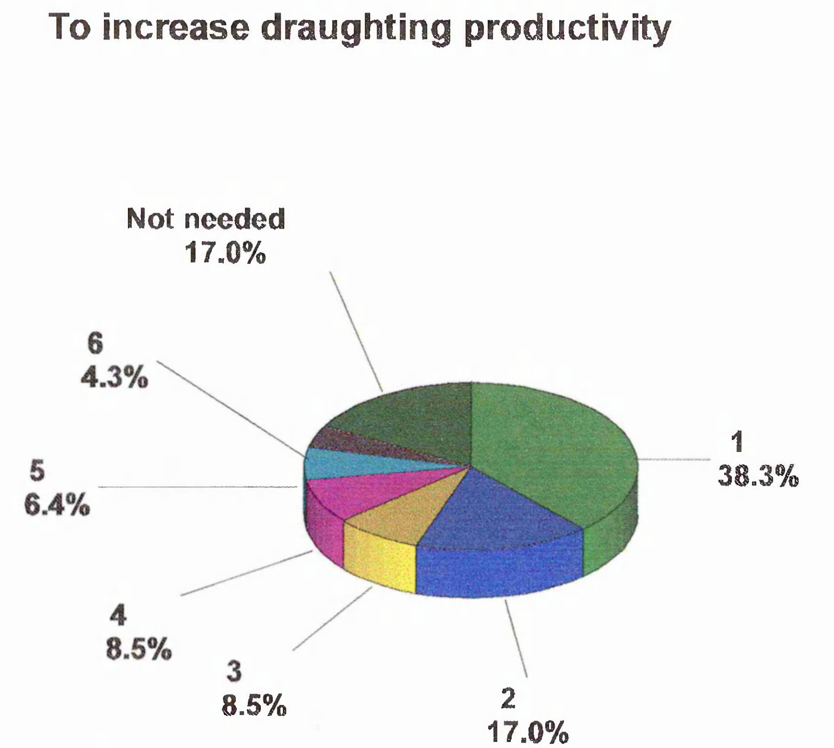

Figure 8.19c All 3D Users

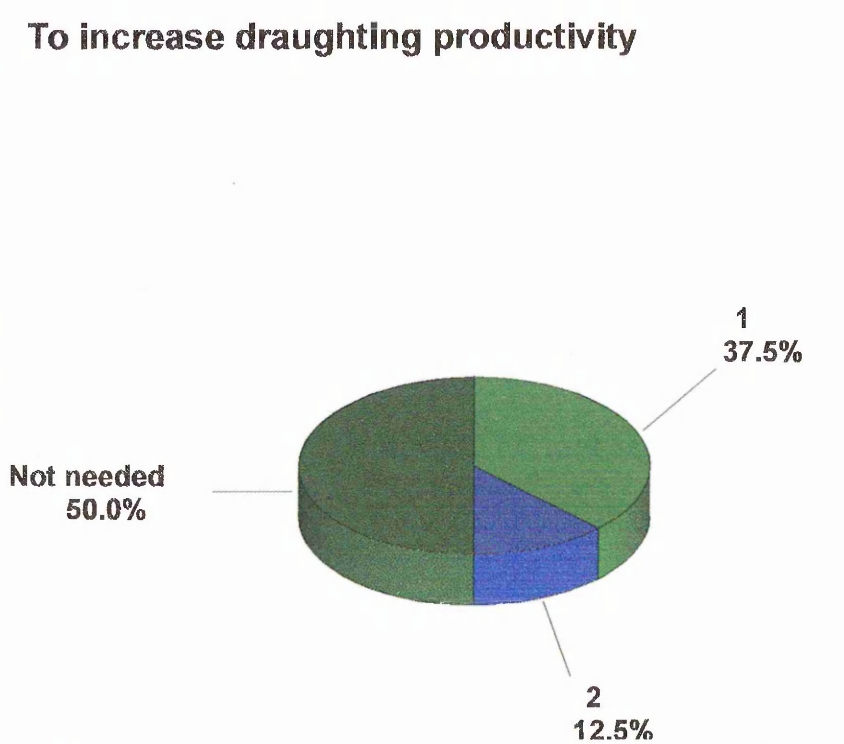

Figure 8.19d 3D Users Only

 Original in colour

Figure 8.20 Reasons companies needed the current CAD system- (New Work)-(Ranked from 1 to 6 with the highest importance ranking=1)

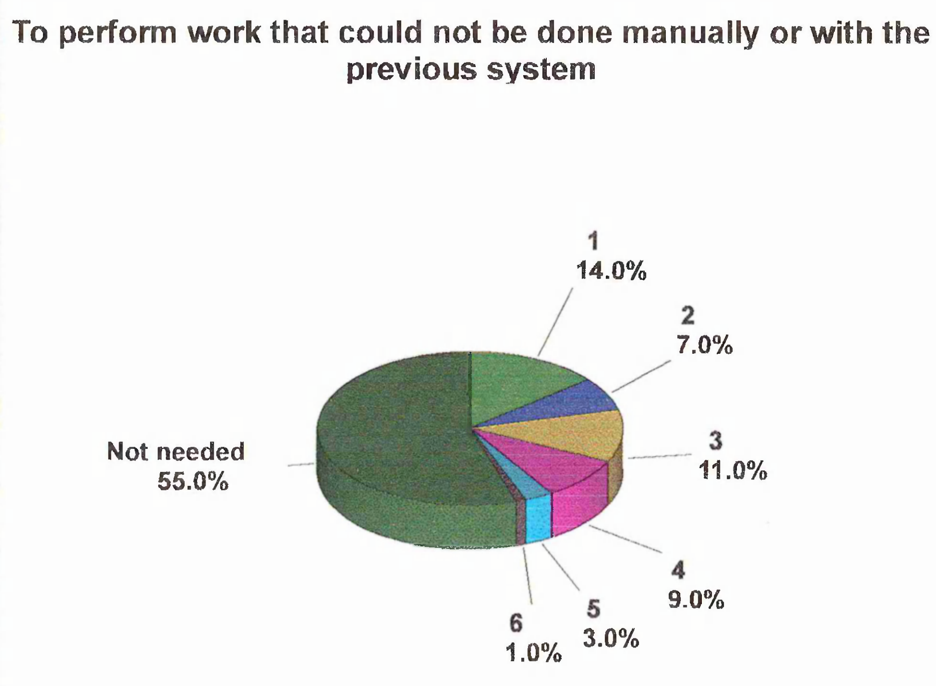

Figure 8.20a All Users

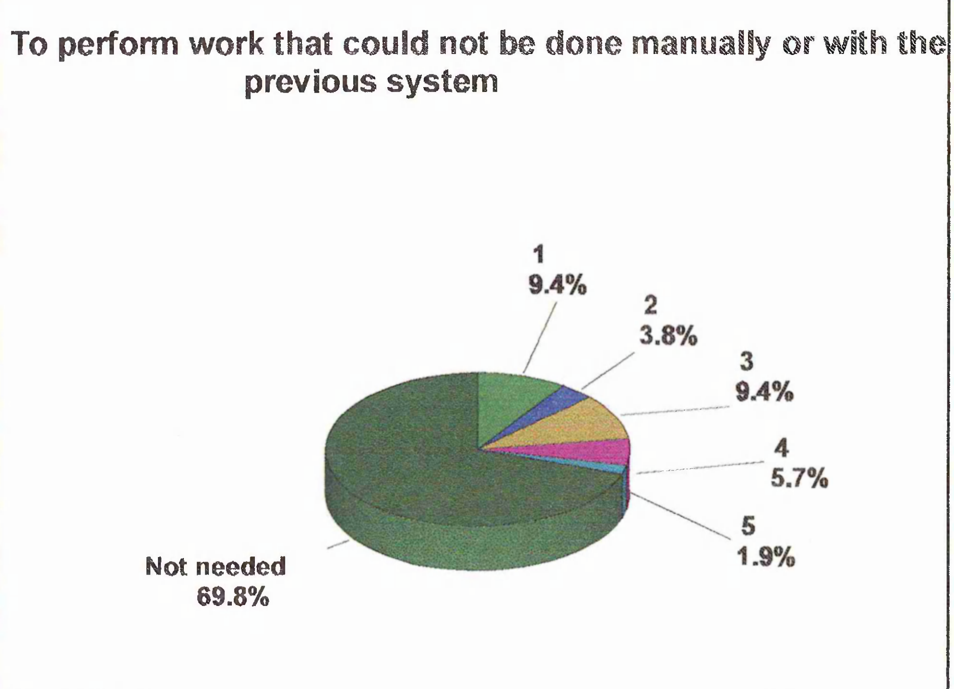

Figure 8.20b 2D Users Only

 Original in colour

To perform work that could not be done manually or with the previous system

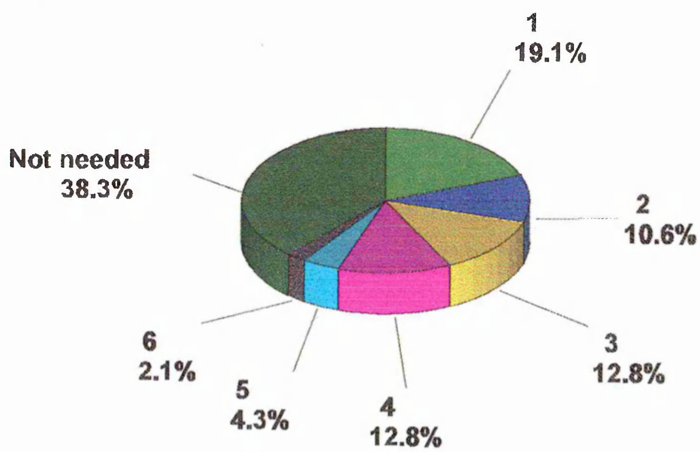

Figure 8.20c All 3D Users

To perform work that could not be done manually or with the previous system

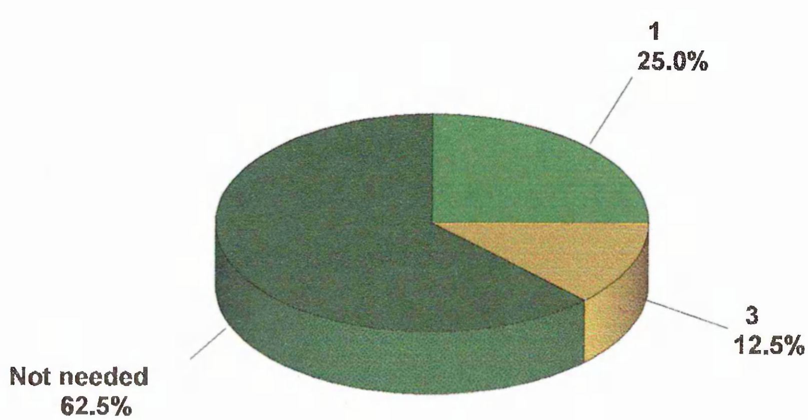

Figure 8.20d 3D Users Only

 Original in colour

Figure 8.21 Reasons companies needed the current CAD system-(Competition)- (Ranked from 1 to 6 with the highest importance ranking=1)

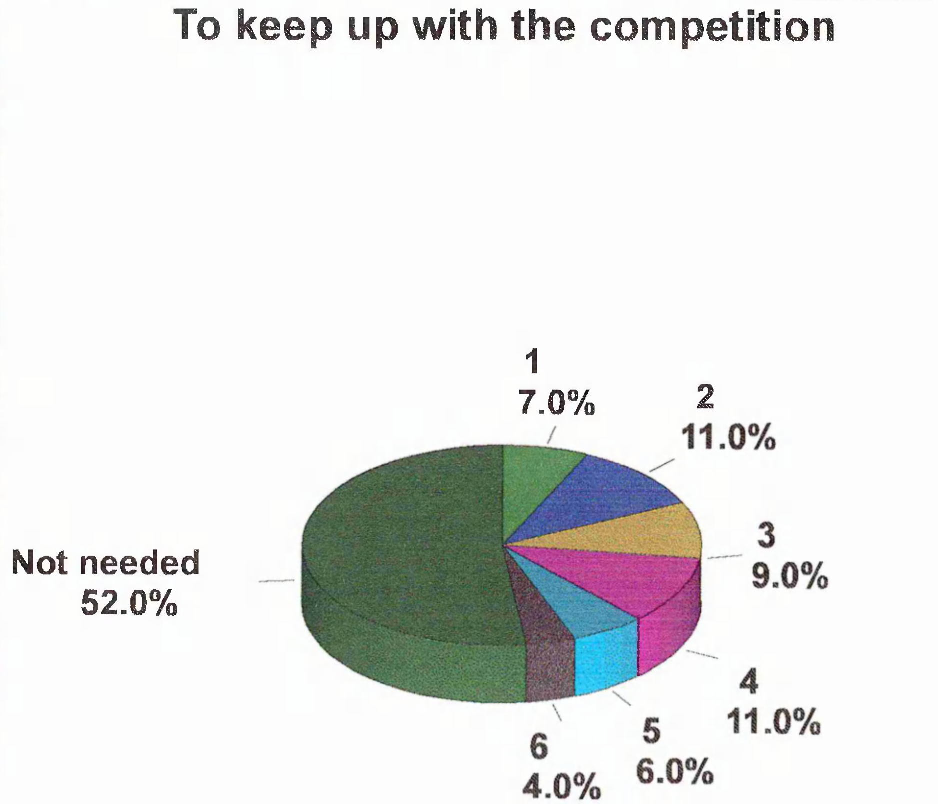

Figure 8.21a All Users

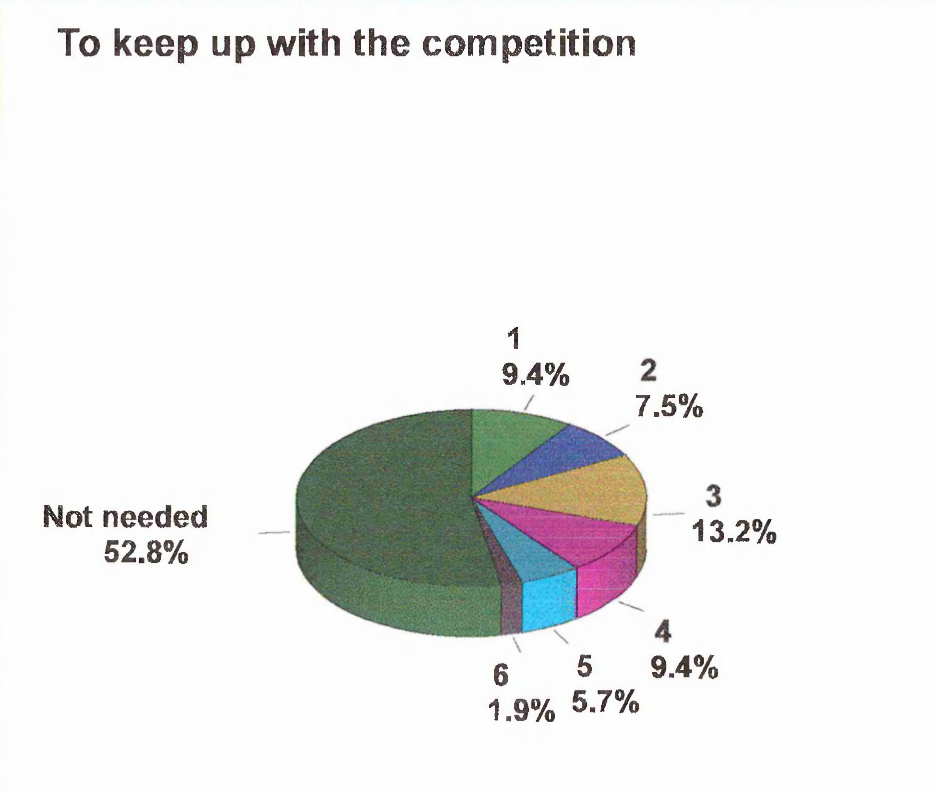

Figure 8.21b 2D Users Only

 Original in colour

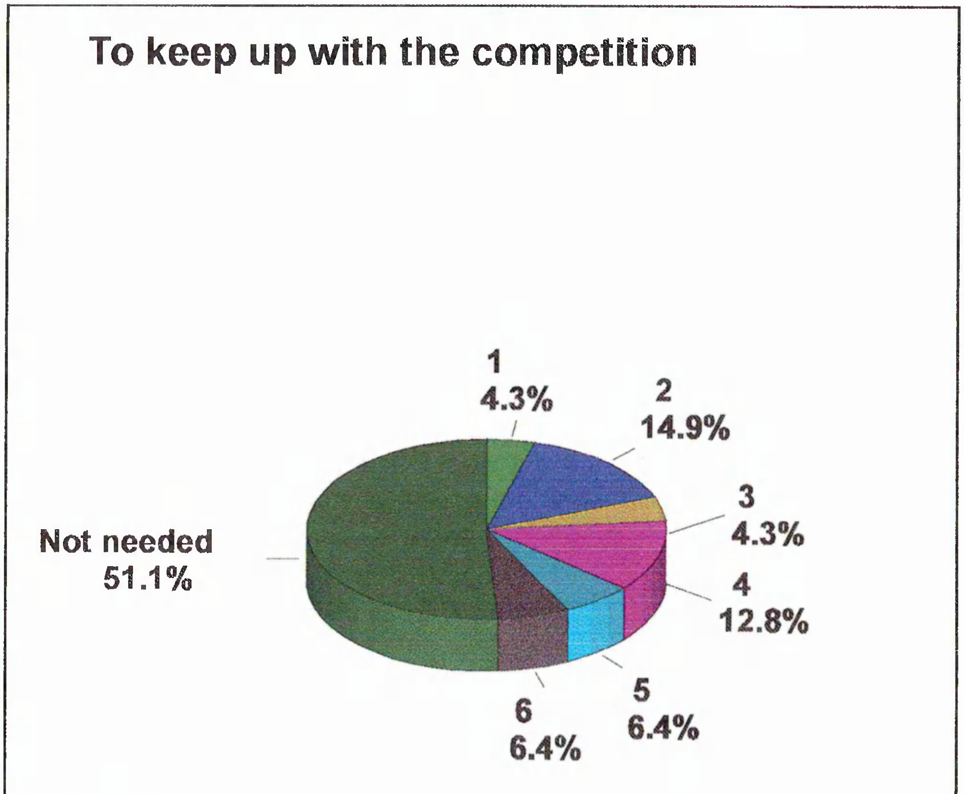

Figure 8.21c All 3D Users

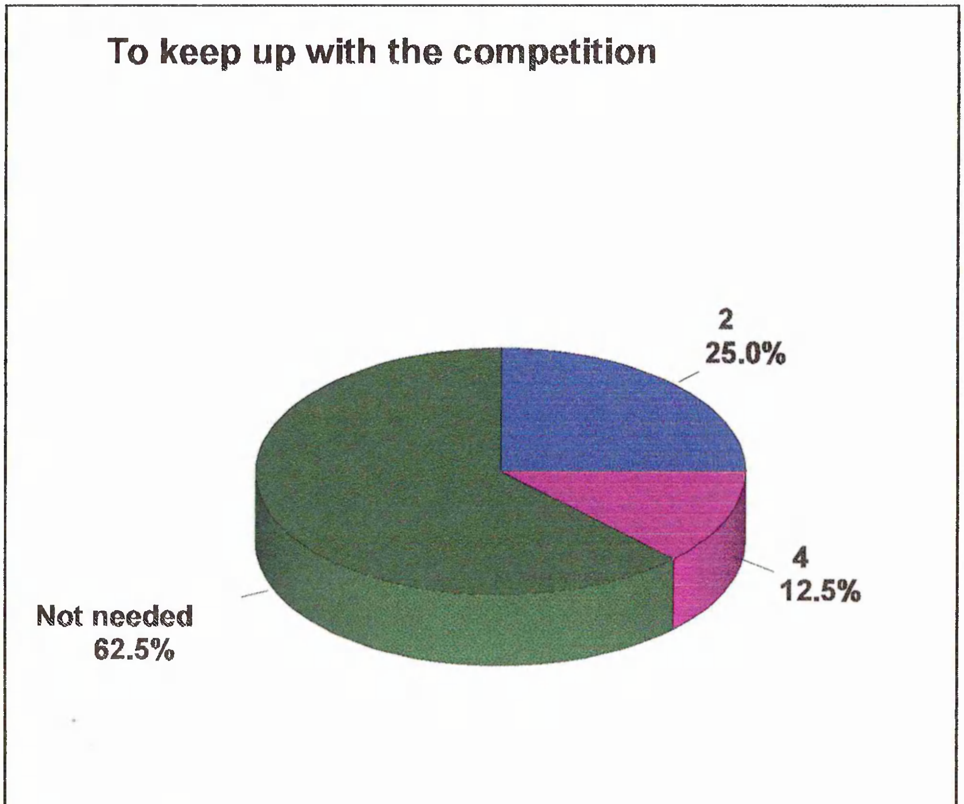

Figure 8.21d 3D Users Only

 Original in colour

Figure 8.22 Reasons companies needed the current CAD system- (Visualisation)- (Ranked from 1 to 6 with the highest importance ranking=1)

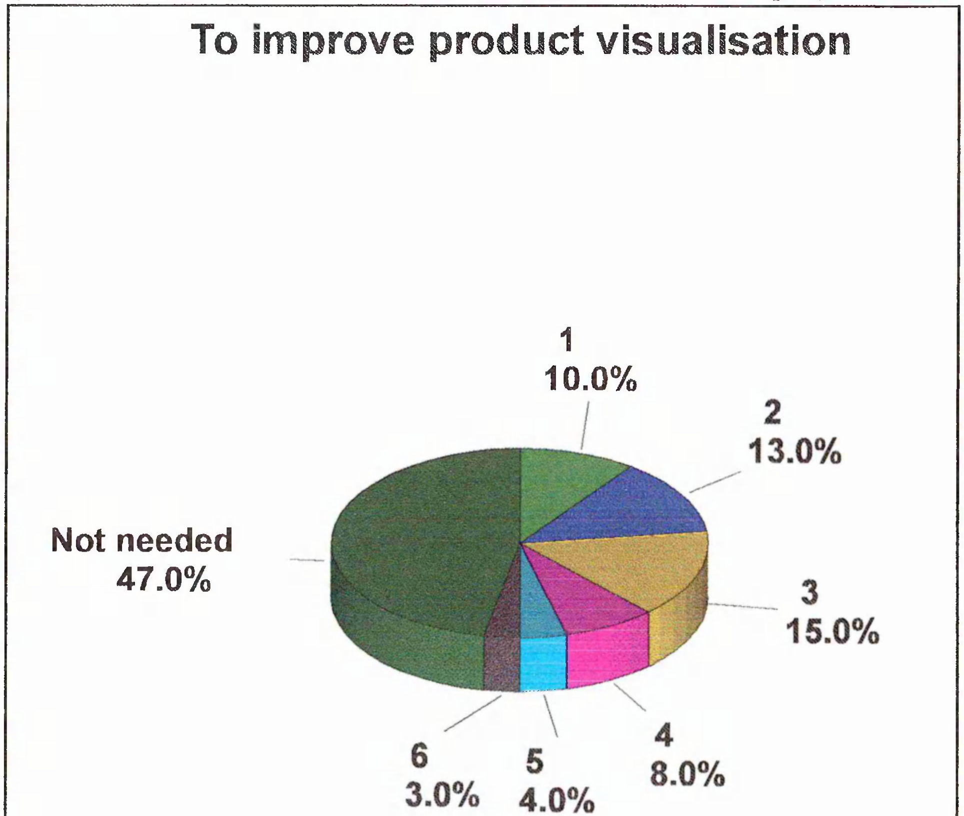

Figure 8.22a All Users

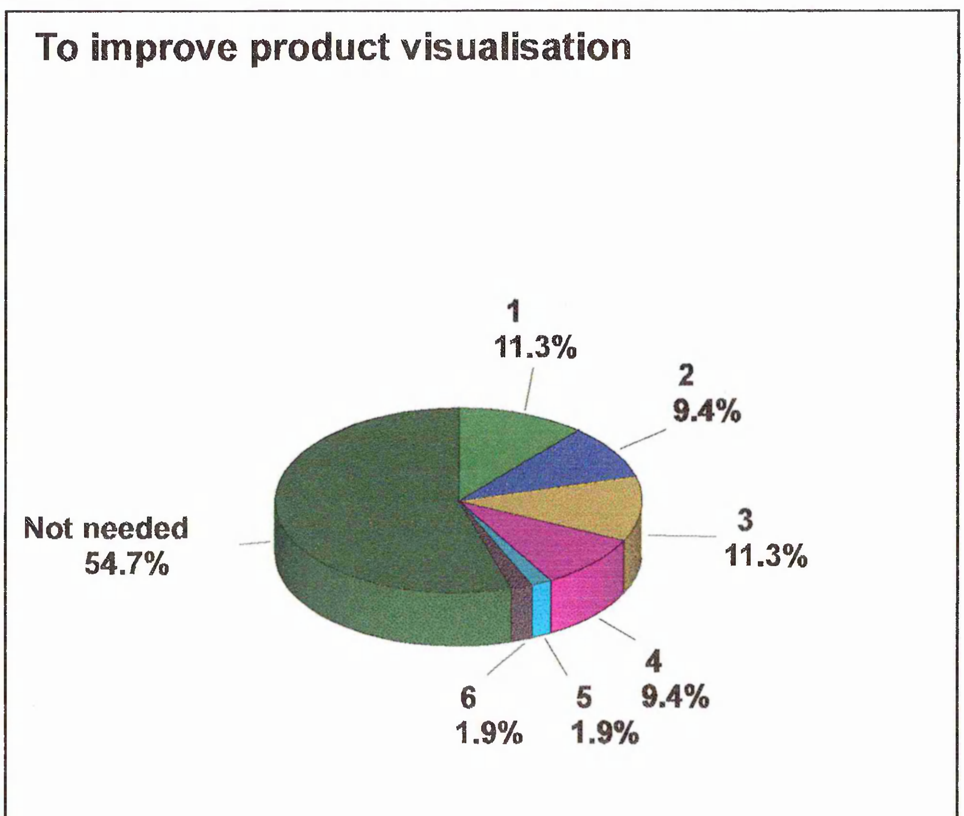

Figure 8.22b 2D Users Only

 Original in colour

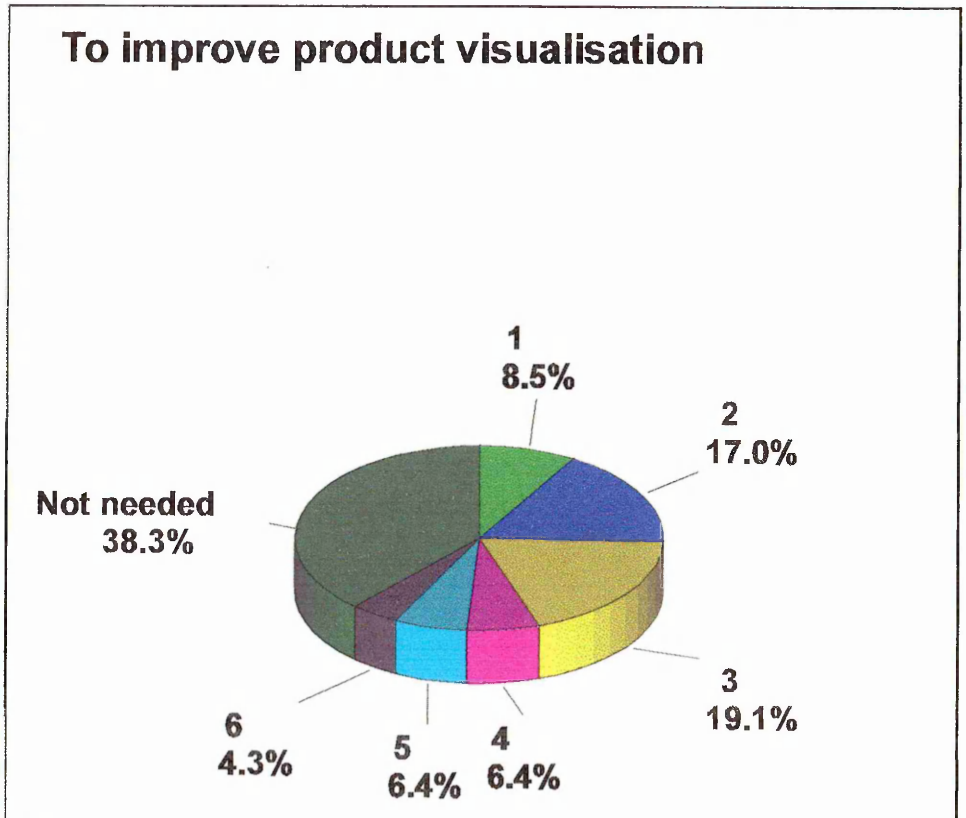

Figure 8.22c All 3D Users

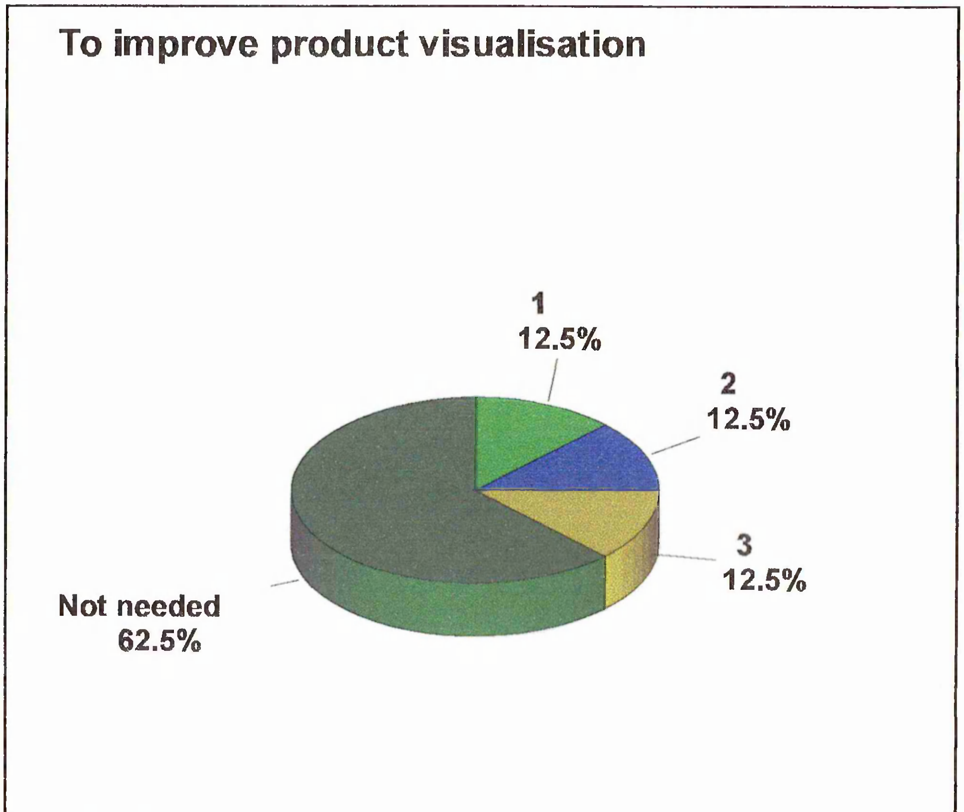

Figure 8.22d 3D Users Only

 Original in colour

Figure 8.23 Reasons companies needed the current CAD system- (Tooling/ Manufacture Times)- (Ranked from 1 to 6 with the highest importance ranking=1)

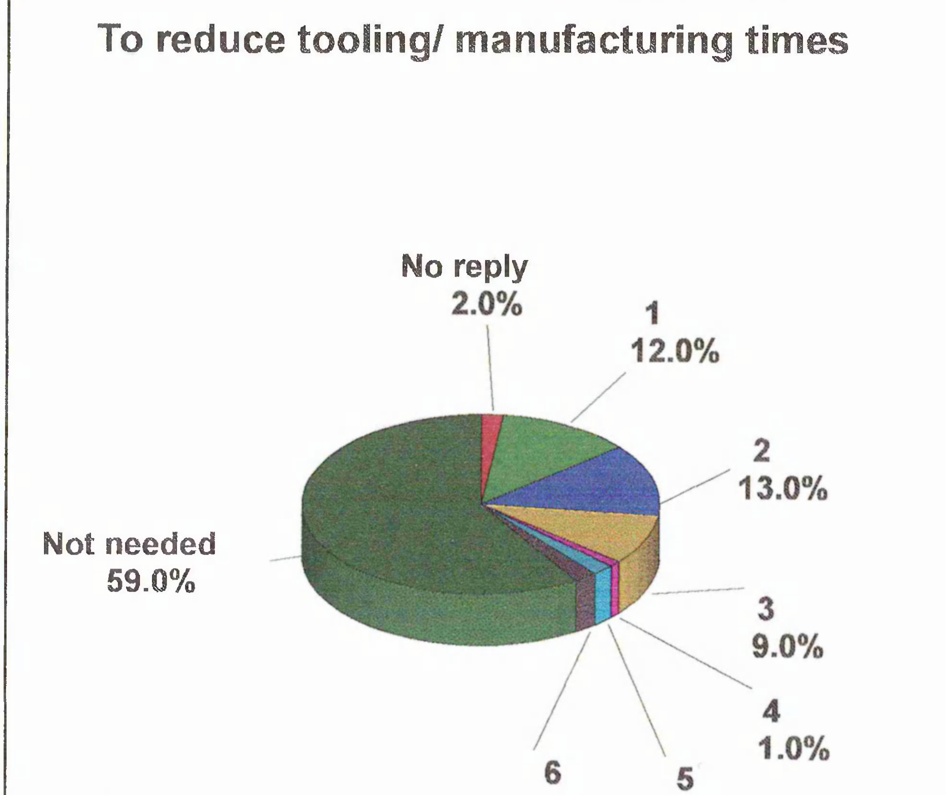

Figure 8.23a All Users

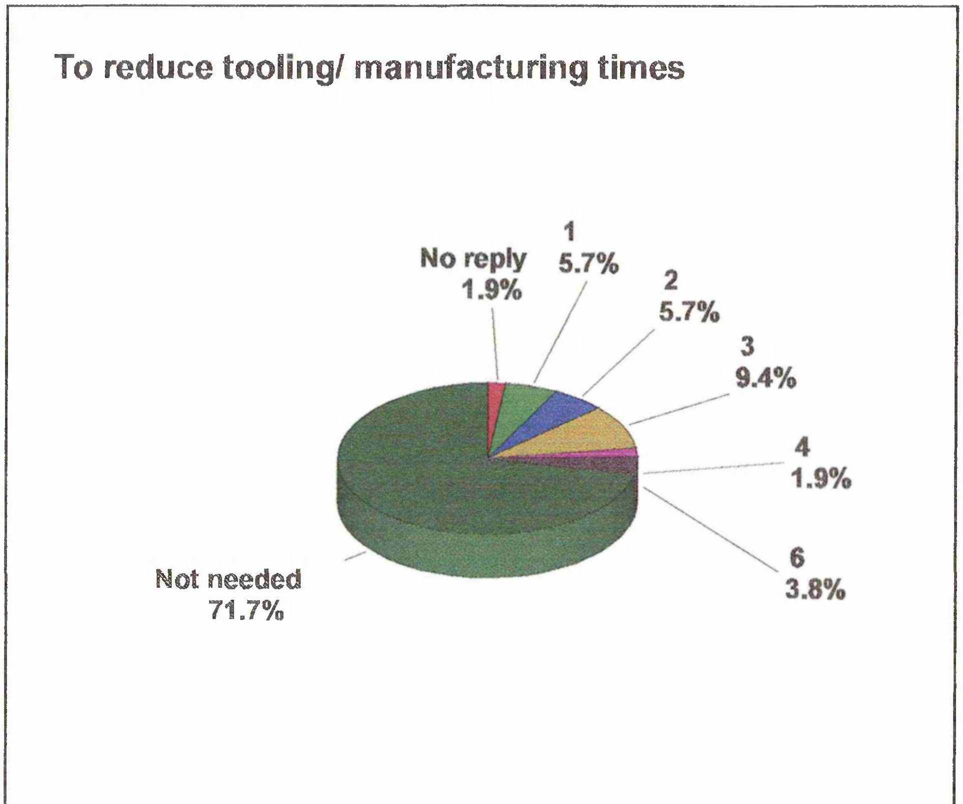

Figure 8.23b 2D Users Only

 Original in colour

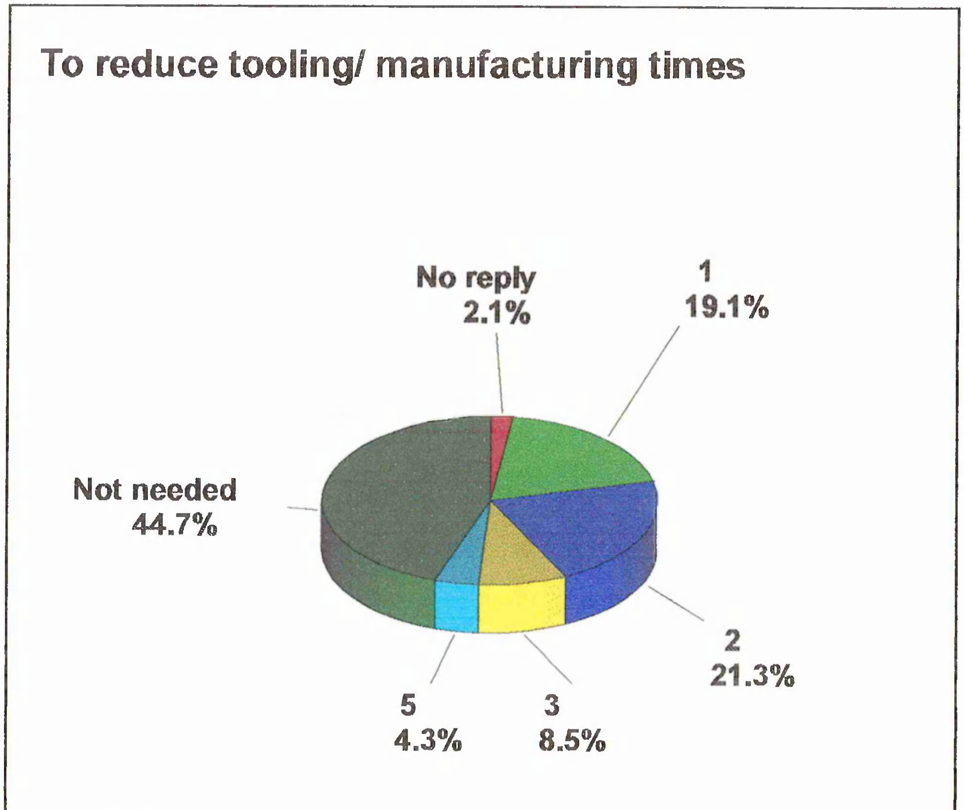

Figure 8.23c All 3D Users

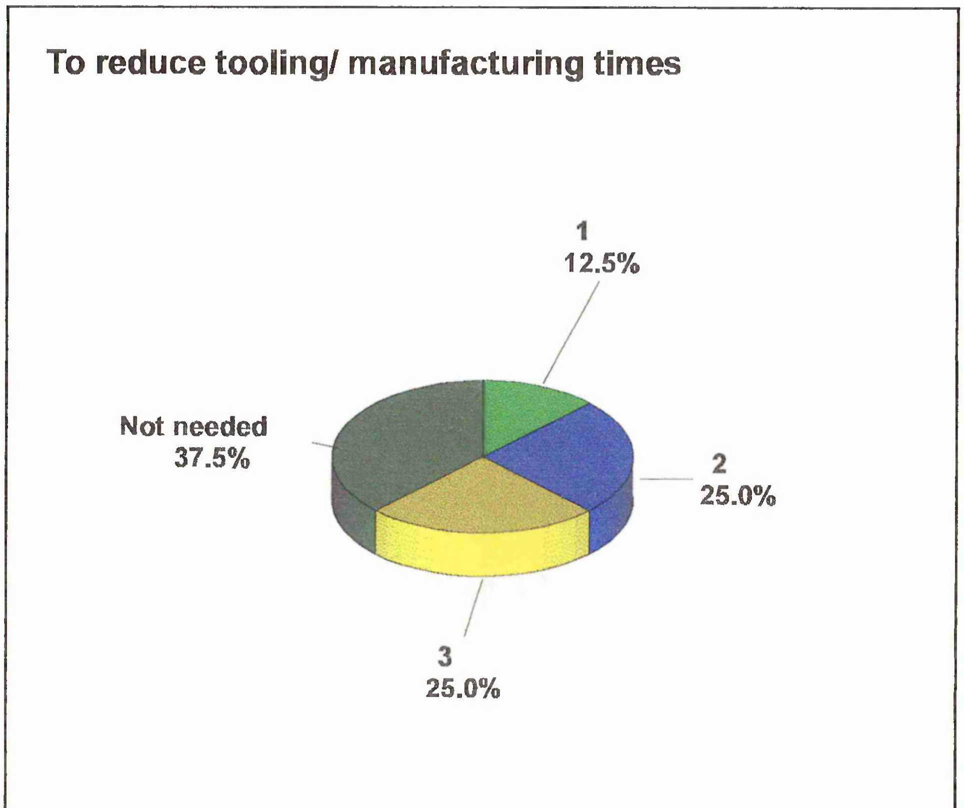

Figure 8.23d 3D Users Only

 Original in colour

Figure 8.24 Reasons companies needed the current CAD system- (Customer Response)- (Ranked from 1 to 6 with the highest importance ranking=1)

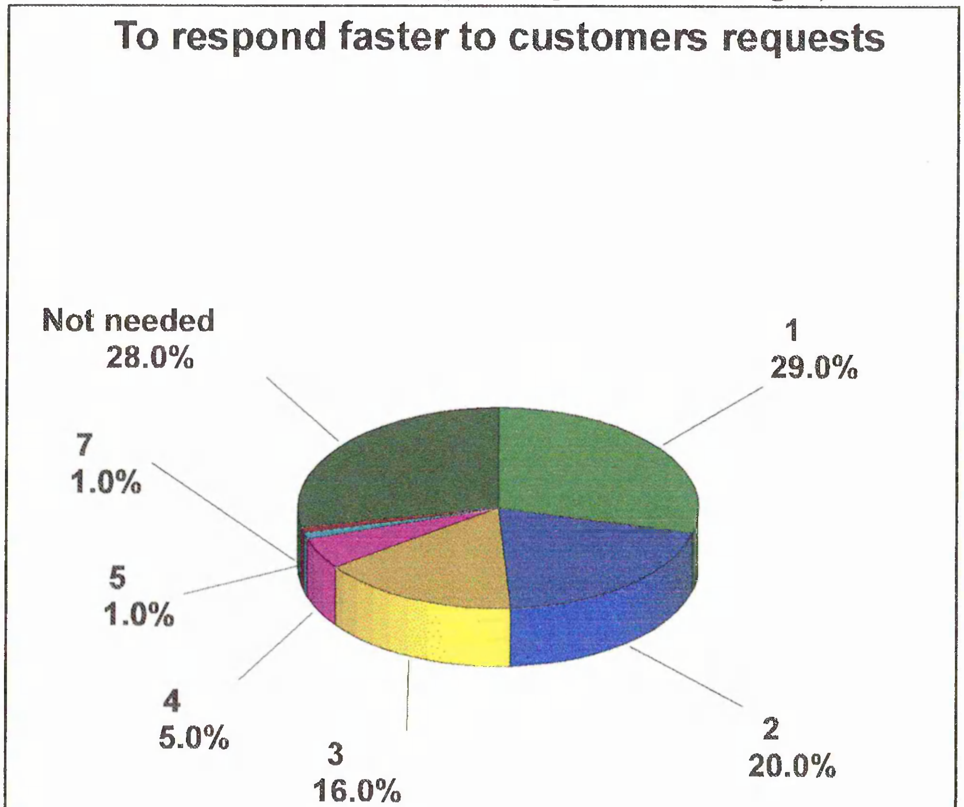

Figure 8.24a All Users

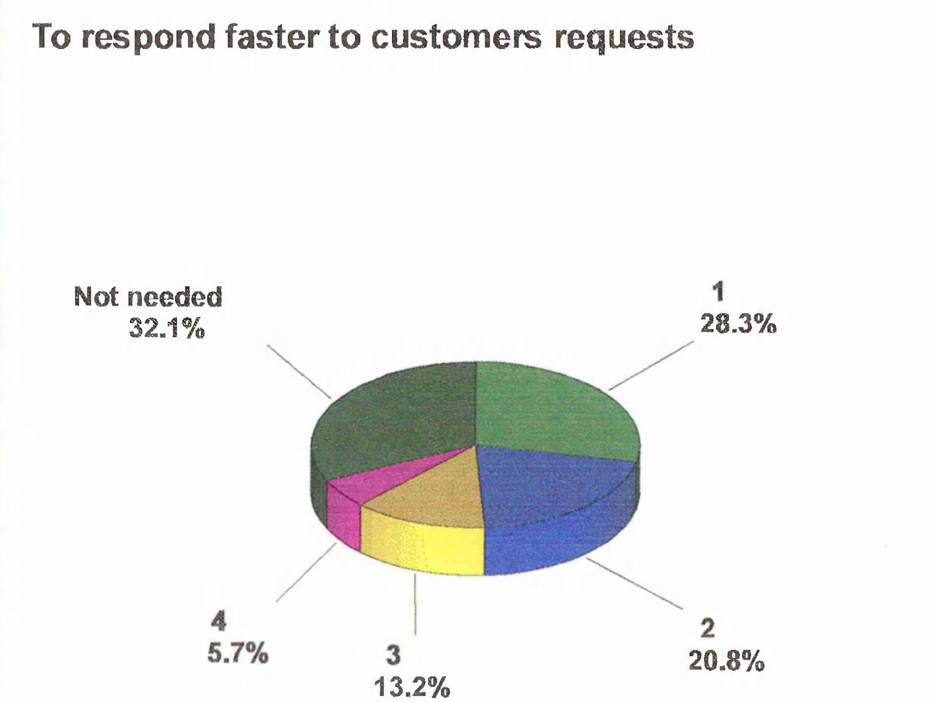

Figure 8.24b 2D Users Only

 Original in colour

To respond faster to customers requests

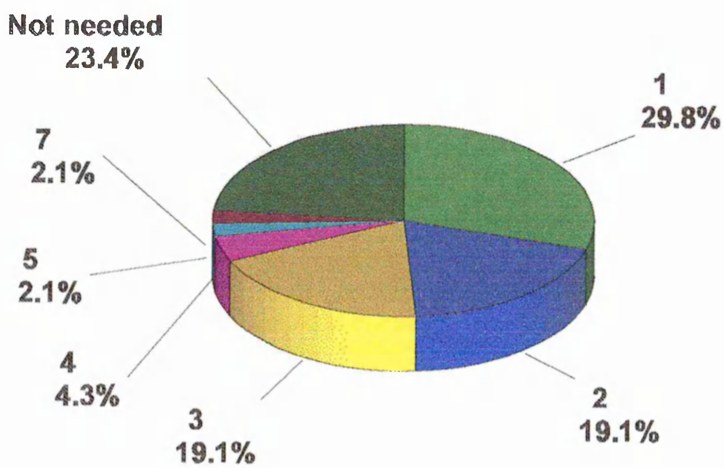

Figure 8.24c All 3D Users

To respond faster to customers requests

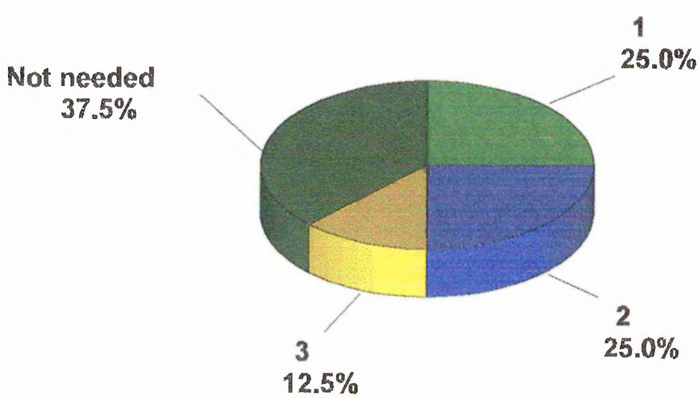

Figure 8.24d 3D Users Only

 Original in colour

Figure 8.25 Organisational structure changes since implementing CAD

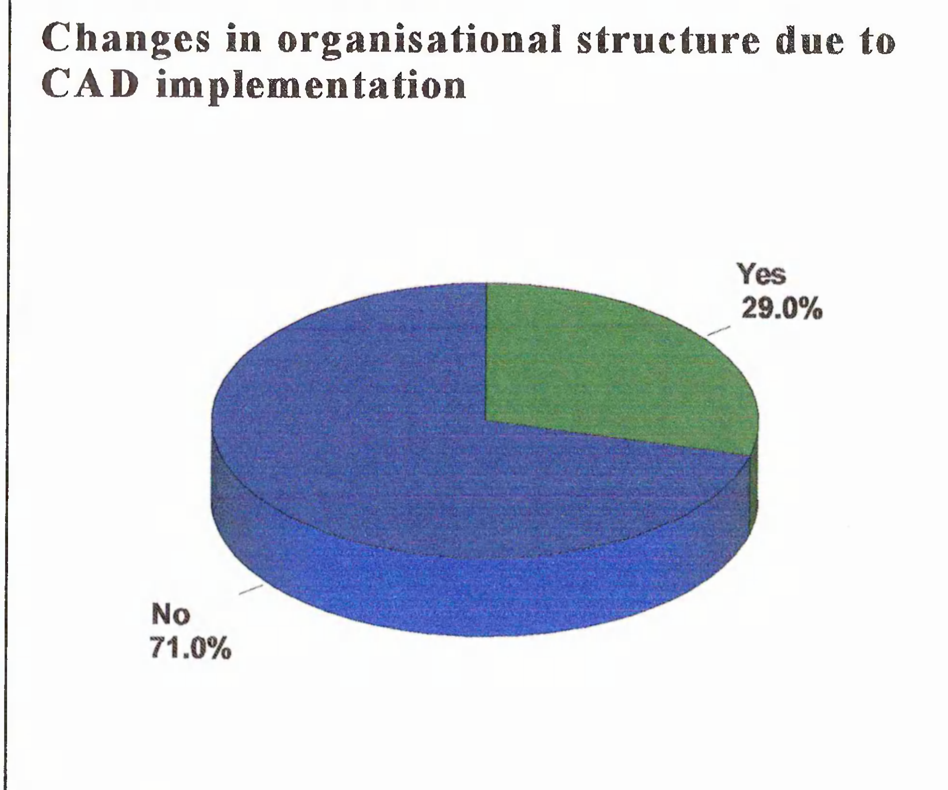

Figure 8.25a All Users

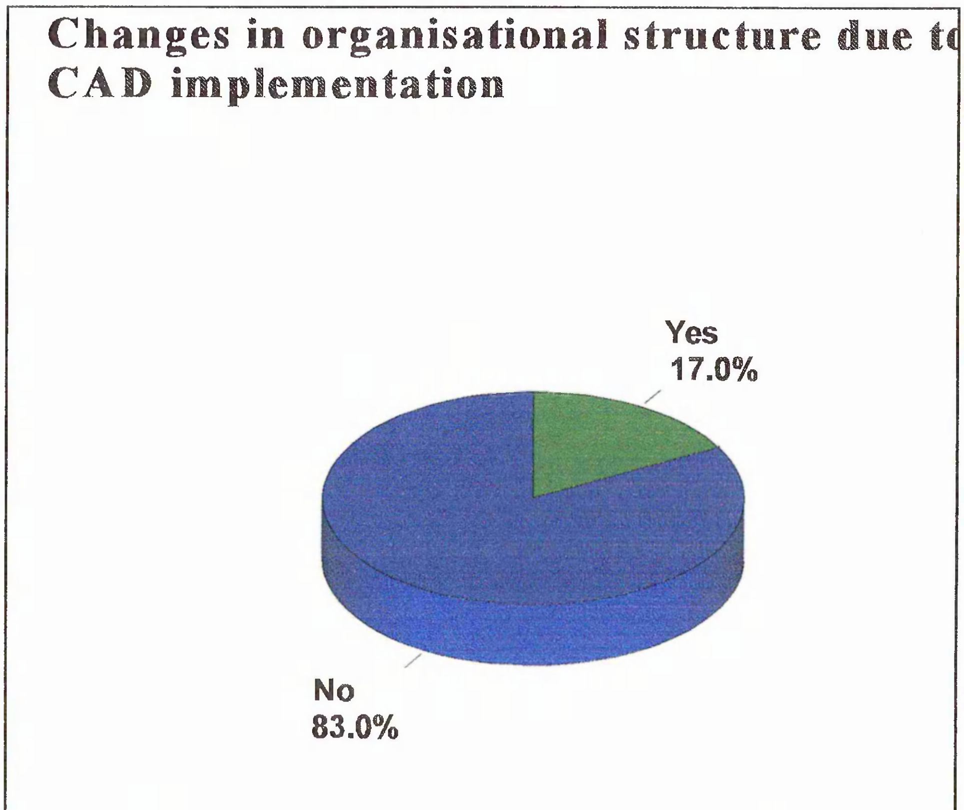

Figure 8.25b 2D Users Only

 Original in colour

Changes in organisational structure due to CAD implementation

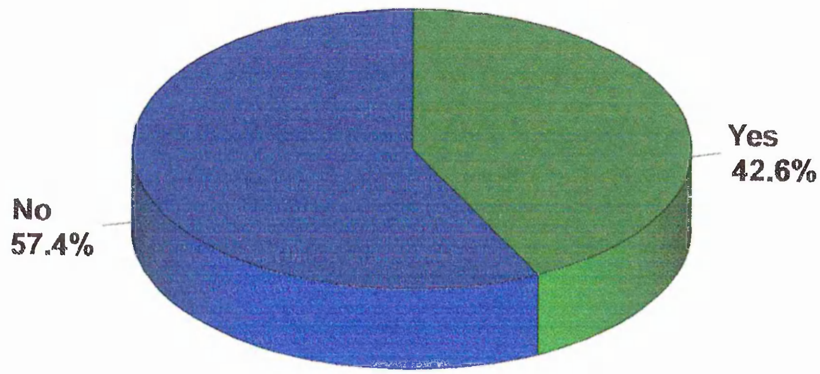

Figure 8.25c

All 3D Users

Changes in organisational structure due to CAD implementation

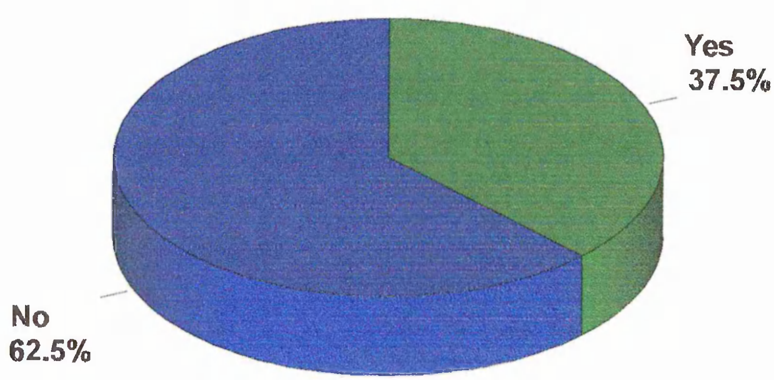

Figure 8.25d

3D Users Only

Original in colour

Figure 8.26 Changes in working practices due to CAD implementation

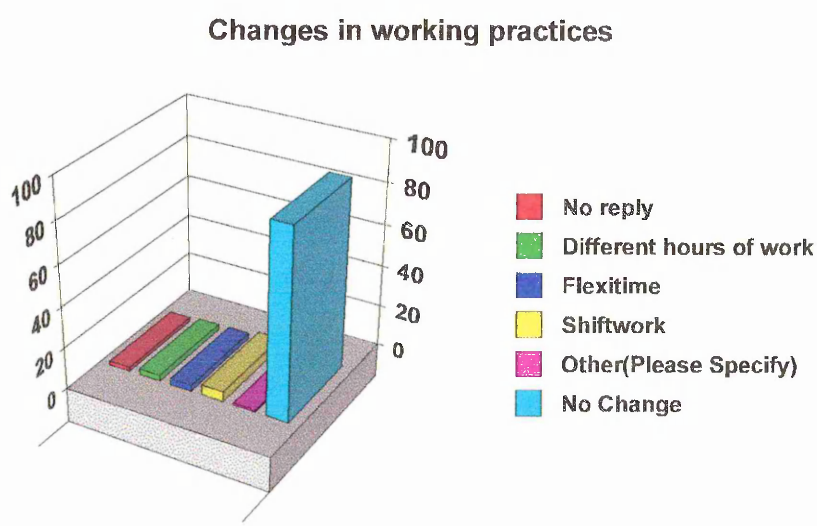

Figure 8.26a All Users

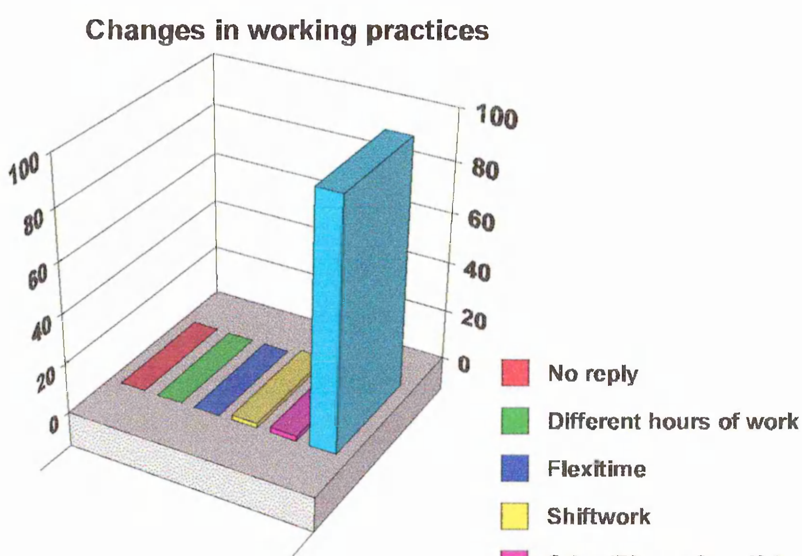

Figure 8.26b 2D Users Only

 Original in colour

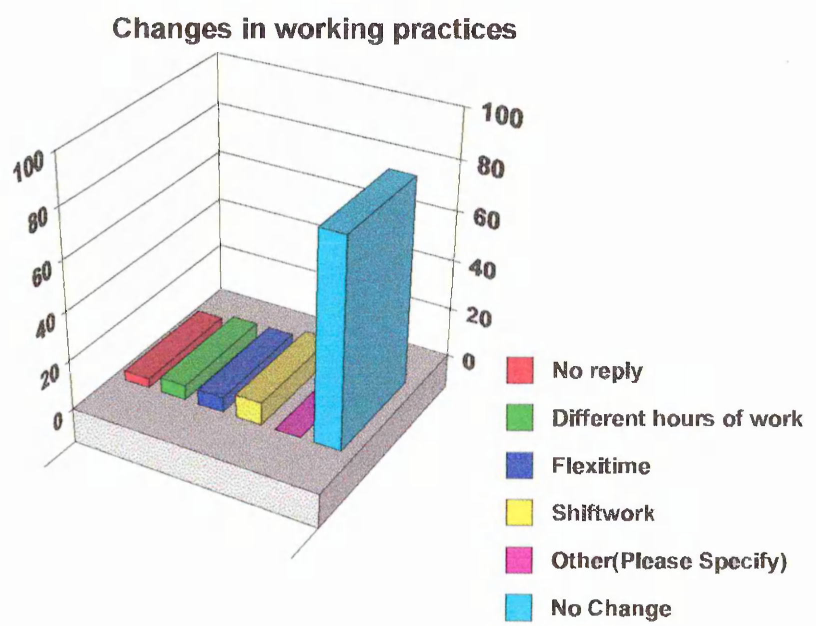

Figure 8.26c All 3D Users

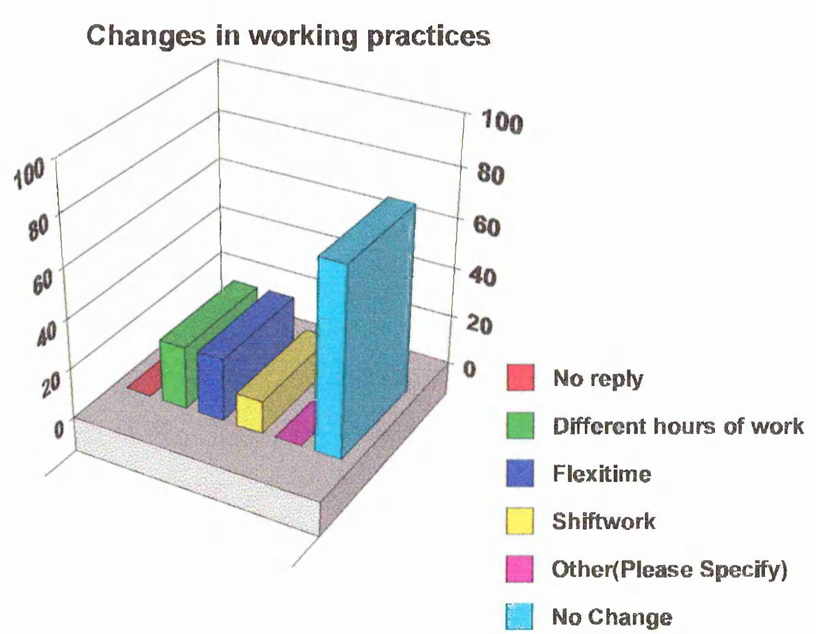

Figure 8.26d 3D Users Only

 Original in colour

Figure 8.27 Resistance to the technology by users

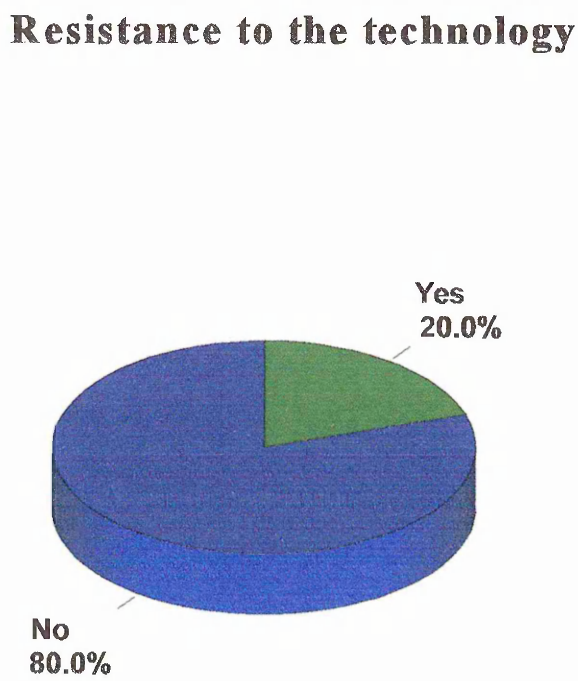

Figure 8.27a All Users

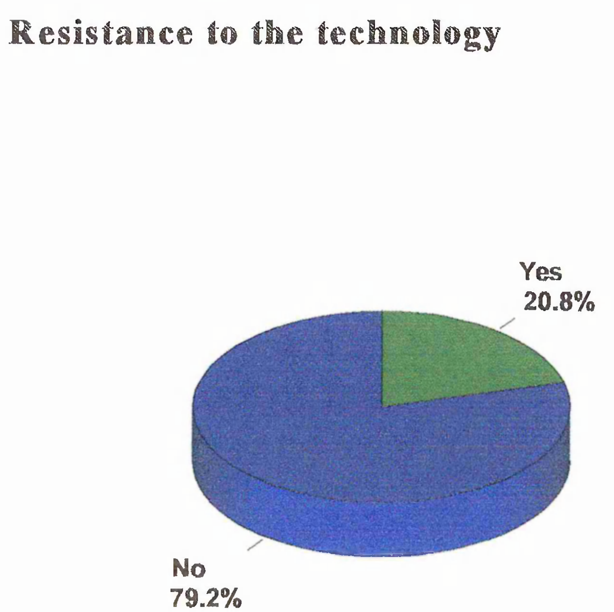

Figure 8.27b 2D Users Only

 Original in colour

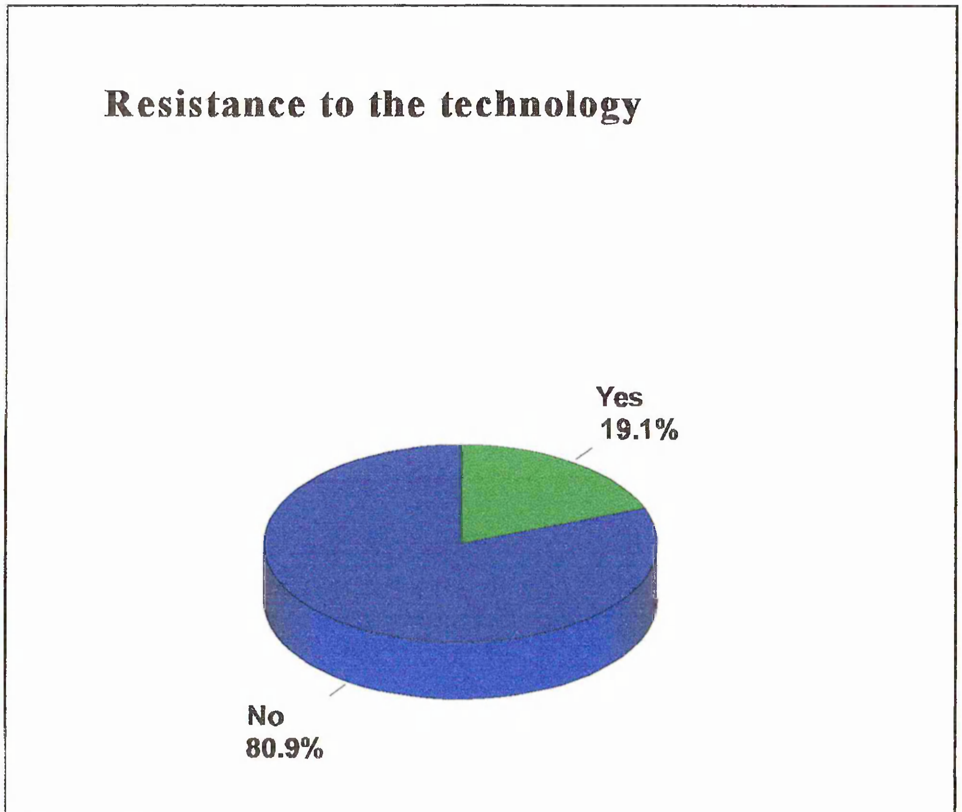

Figure 8.27c All 3D Users

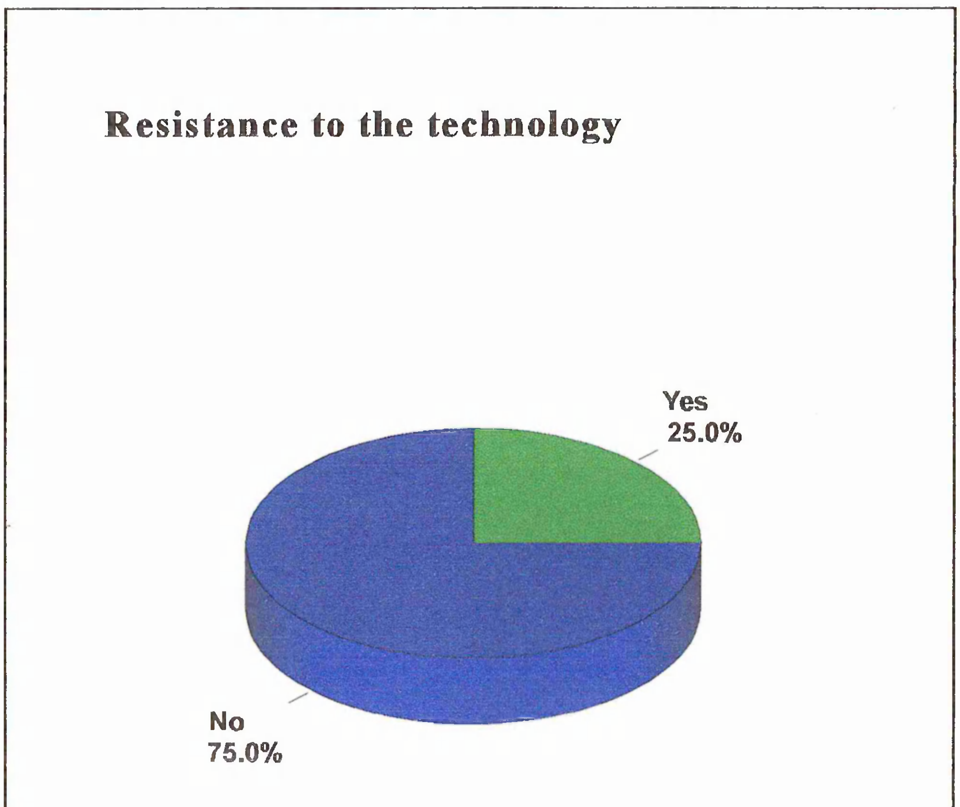

Figure 8.27d 3D Users Only

 Original in colour

8.2.6 Support Structures for CAD

Figures 8.28 and 8.29 relate to the questionnaire section **"Support structure for CAD"** . Figure 8.28 provides information about the types of support systems employed at each company.

For companies who employ internal support such as a CAE department, a separate I.T. department or the support of one person, Figure 8.29 illustrates respondents ranking of various aspects of this support from, Not supported, Poor support, Satisfactory support to World class support. The "x" axis of the graph represents the fourteen support activities listed in question 31a to q31n of the national questionnaire and in the following sequence from left to right:-

- Procedures for draughting
- Implementation of macros
- System configuration
- Data transmission
- Control of upgrades
- Organisational Change
- Solving Problems
- Developing 3D methodologies
- Creation and update of databases
- Training of designers and programmers
- Documentation
- Reviewing and monitoring problems
- Administration and organisation
- Design and analysis packages

Figure 8.28 The organisational structures employed by companies for supporting CAD

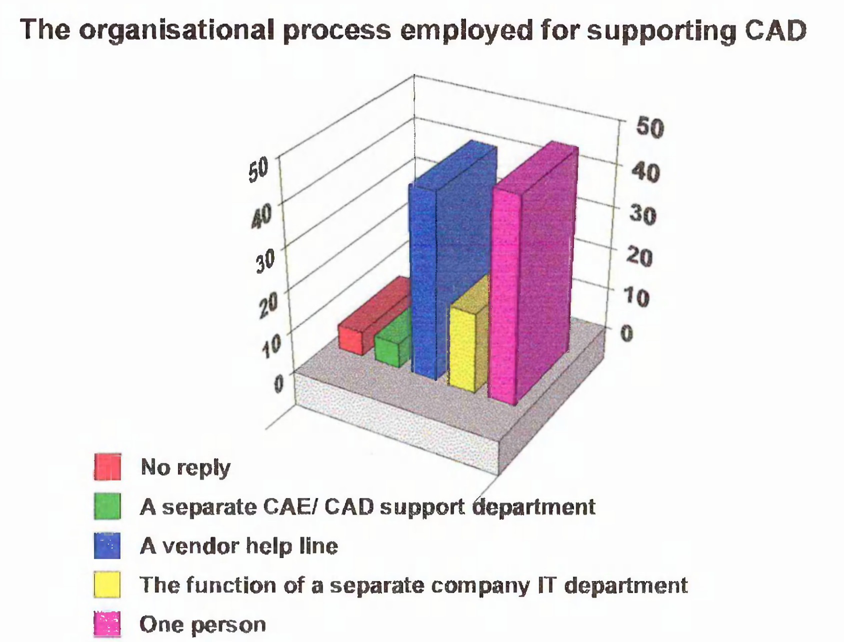

Figure 8.28a All Users

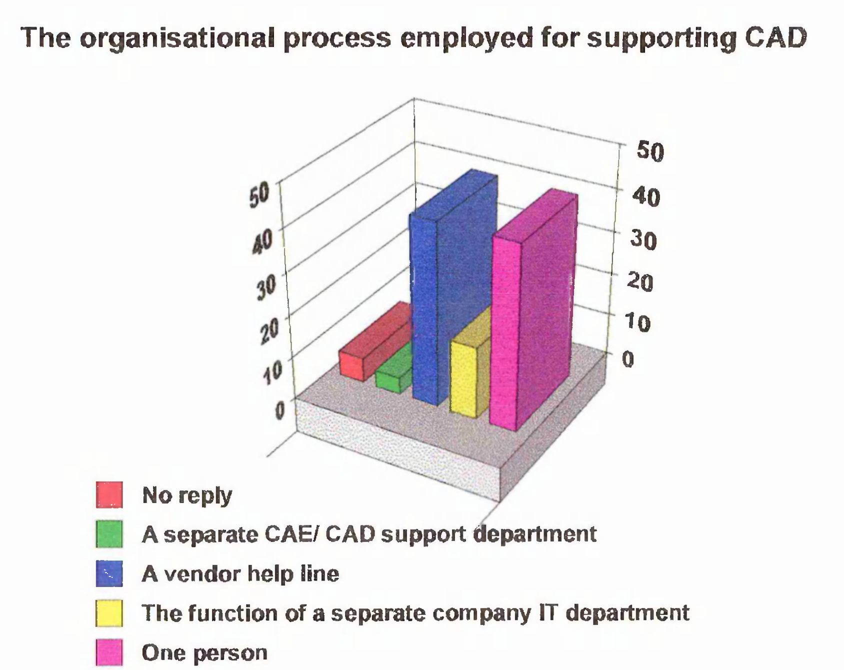

Figure 8.28b 2D Users Only

 Original in colour

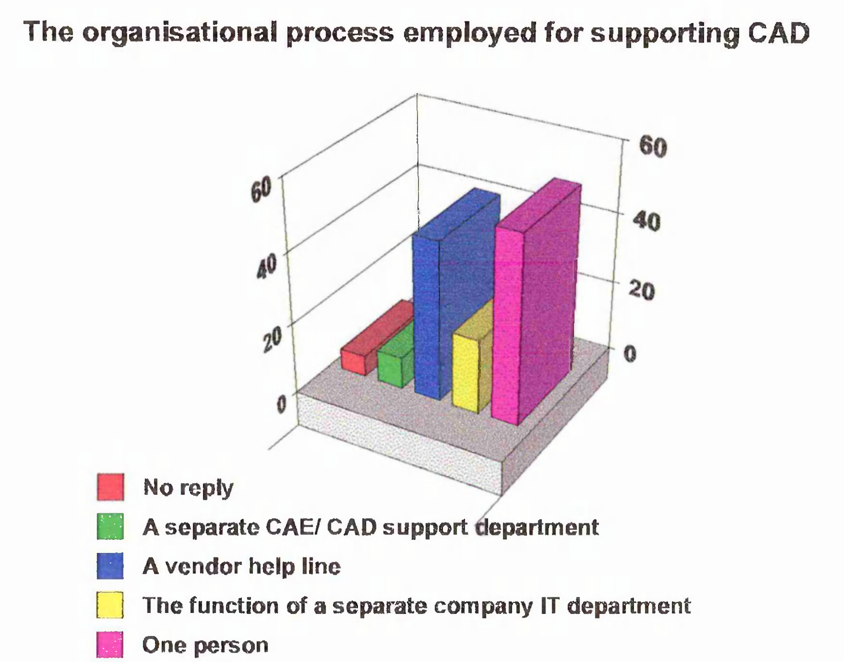

Figure 8.28c All 3D Users

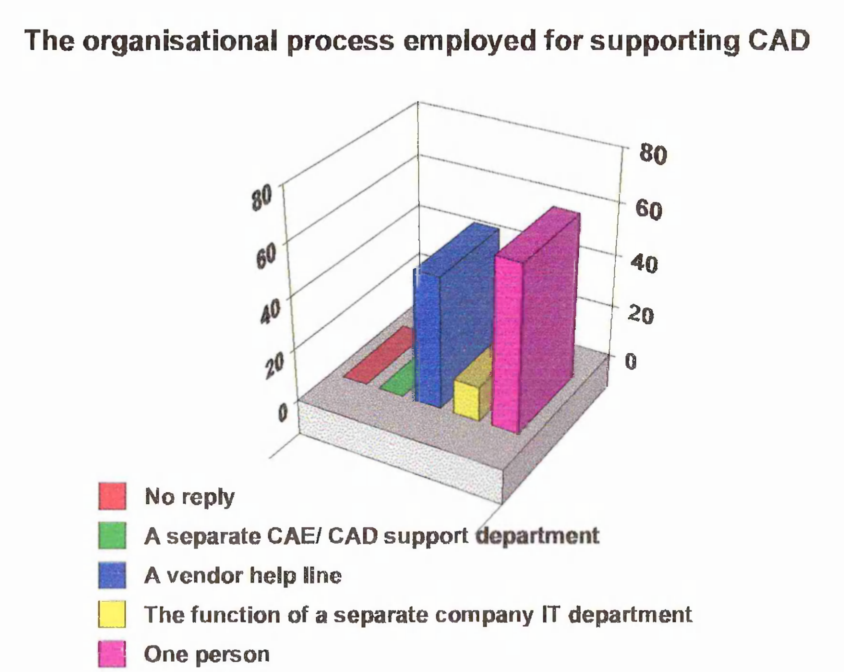

Figure 8.28d 3D Users Only

 Original in colour

Figure 8.29 Company ratings of activities supported by internal support

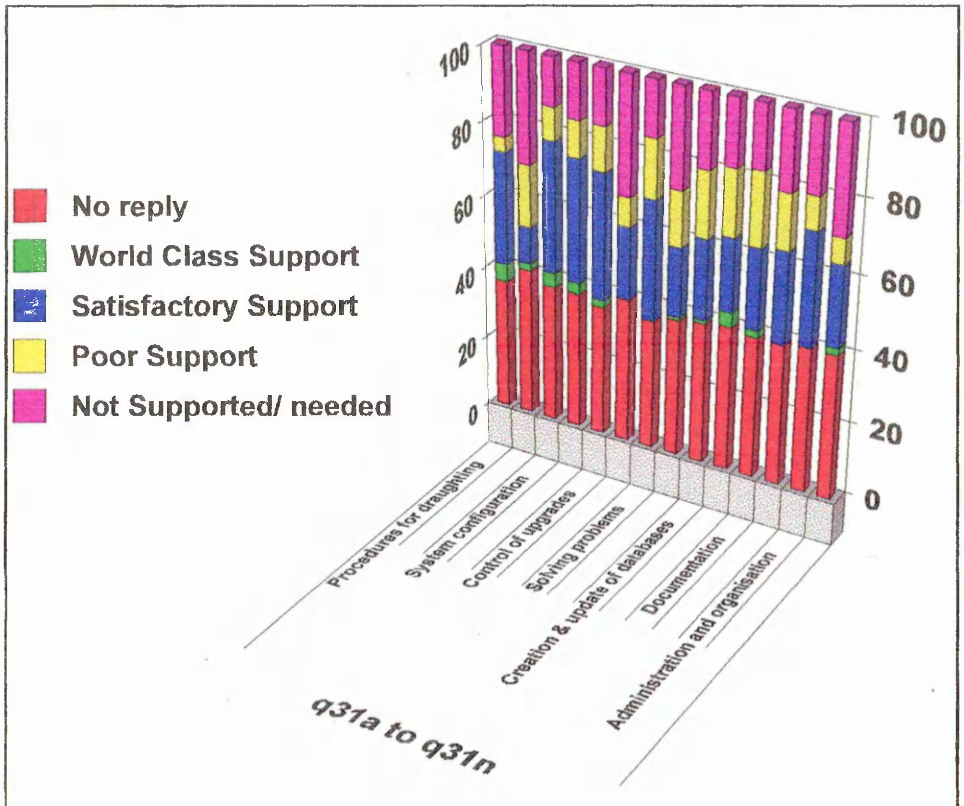

Figure 8.29a

All Users

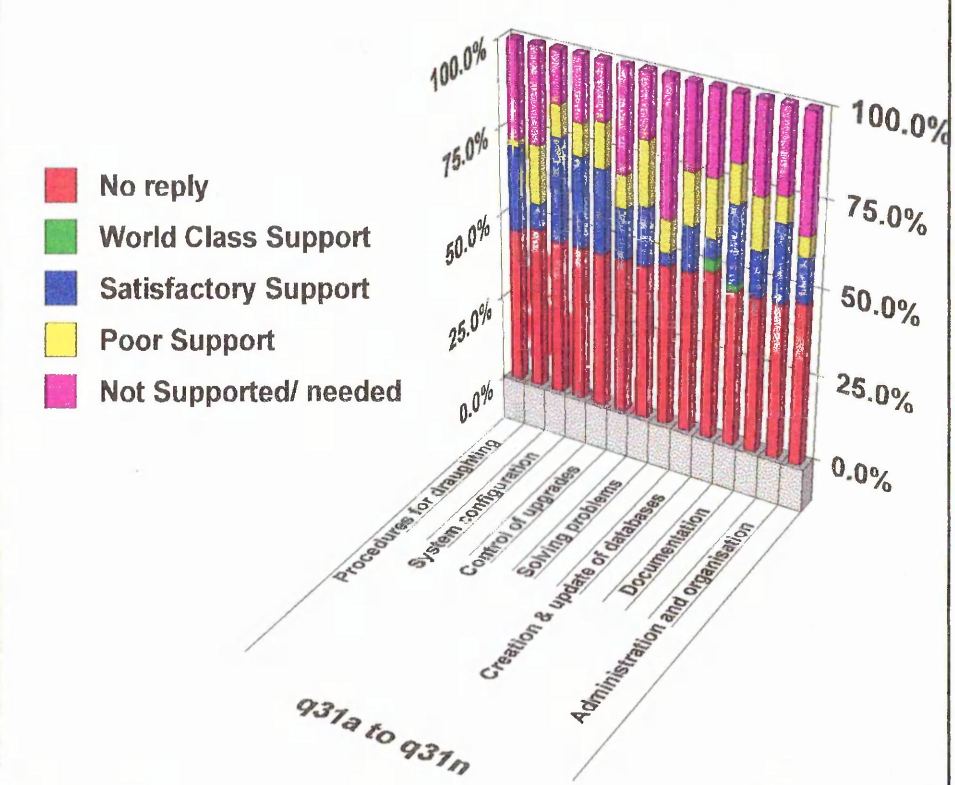

Figure 8.29b

2D Users Only

Original in colour

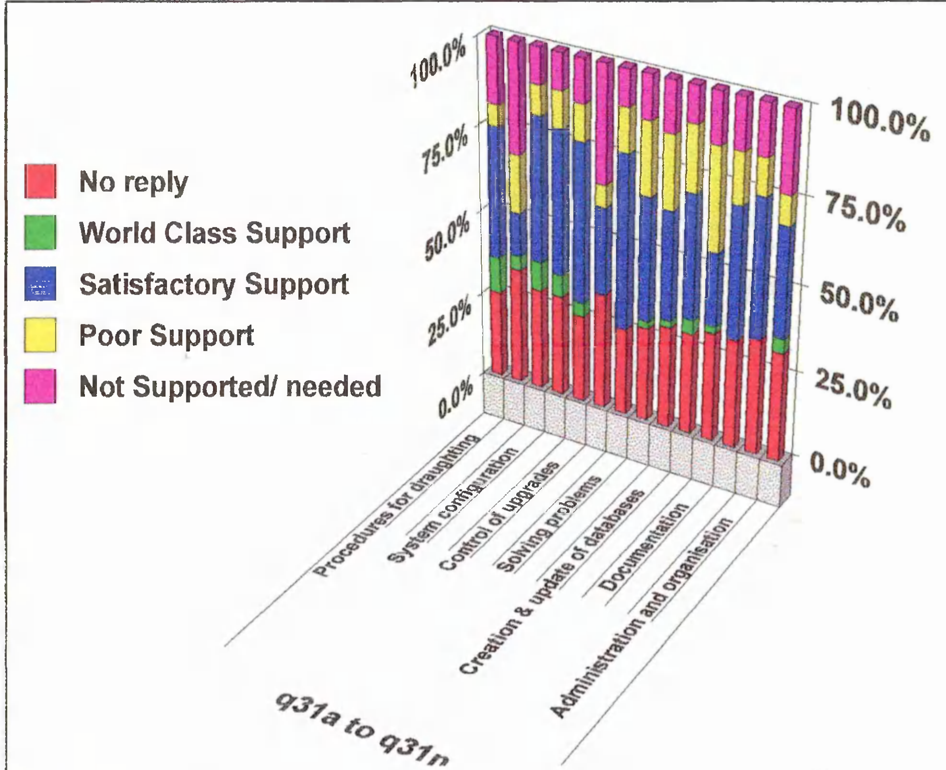

Figure 8.29c

All 3D Users

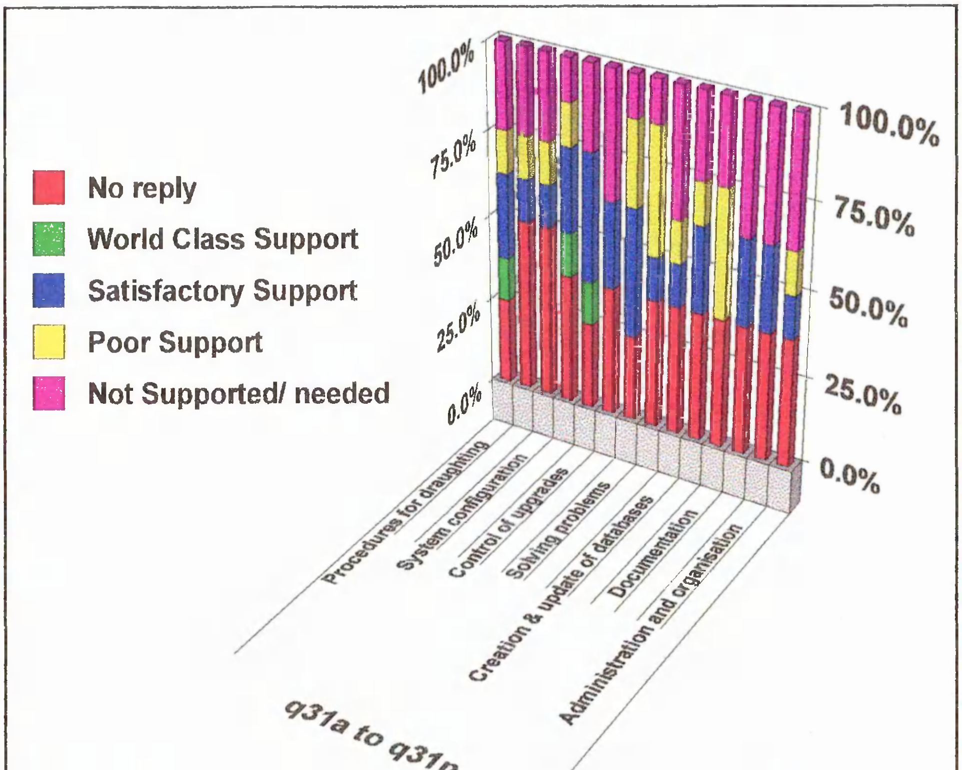

Figure 8.29d

3D Users Only

Original in colour

8.2.7 Training

Figures 8.30 to 8.34 inclusive relate to the questionnaire section concerned with **"Training".** Figure 8.30 shows the distribution of types of CAD training employed by companies from, staff being self taught from manuals, attending basic to advanced internal/ external vendor courses or being supported with in-house training by a company expert. Figure 8.31 shows the percentage of companies adopting a specific amount of time for CAD training (irrespective of the type of training) whilst Figure 8.32 shows the levels of investment provided for training.

Figure 8.33 illustrates how long it took staff to become effective users of the system once initial training was complete. Although the question concerning this provided respondents with a multiple choice answer, there was allowance for respondents to supply a written response if the time taken was longer than twelve months and two 3D CAD users indicated this.

Figure 8.34 presents two graphs for 3D users and indicates how many users were experiencing problems with 3D CAD.

Figure 8.30 Types of training employed by companies

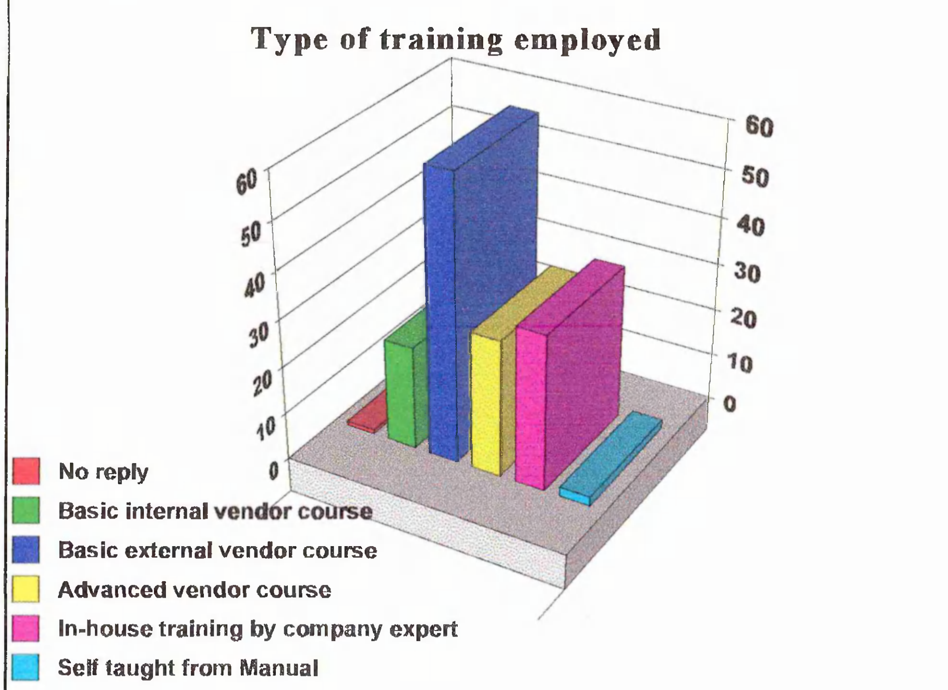

Figure 8.30a All Users

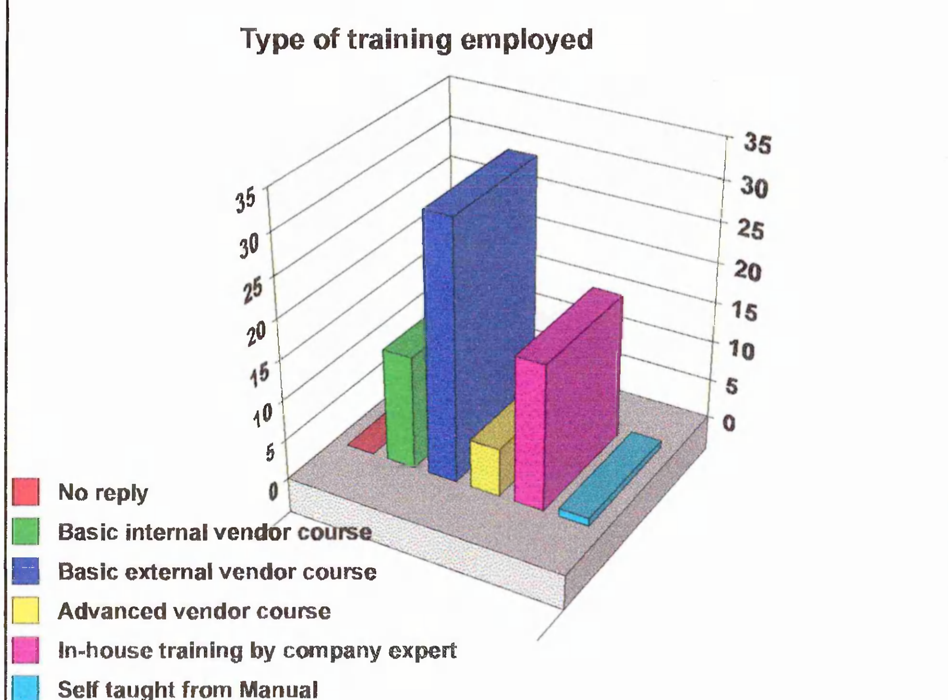

Figure 8.30b 2D Users Only

 Original in colour

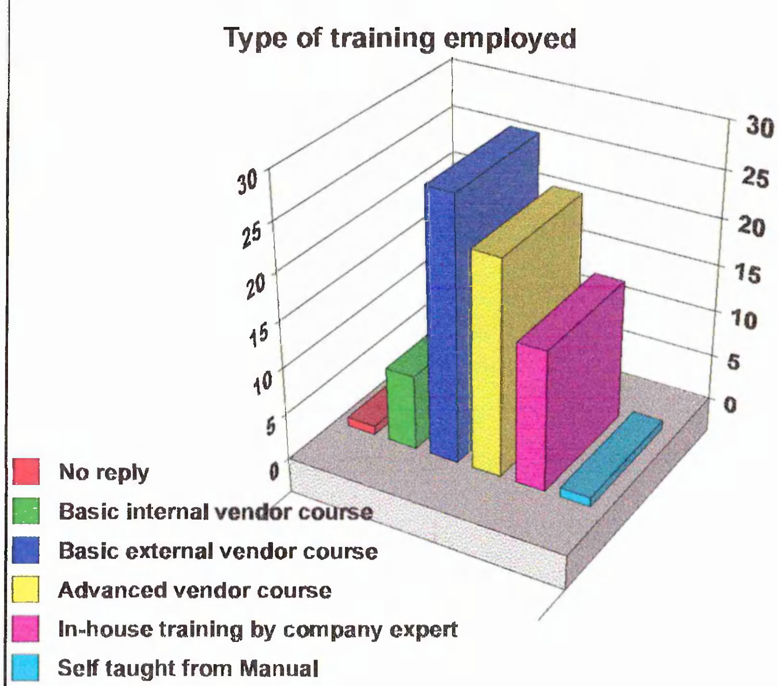

Figure 8.30c All 3D Users

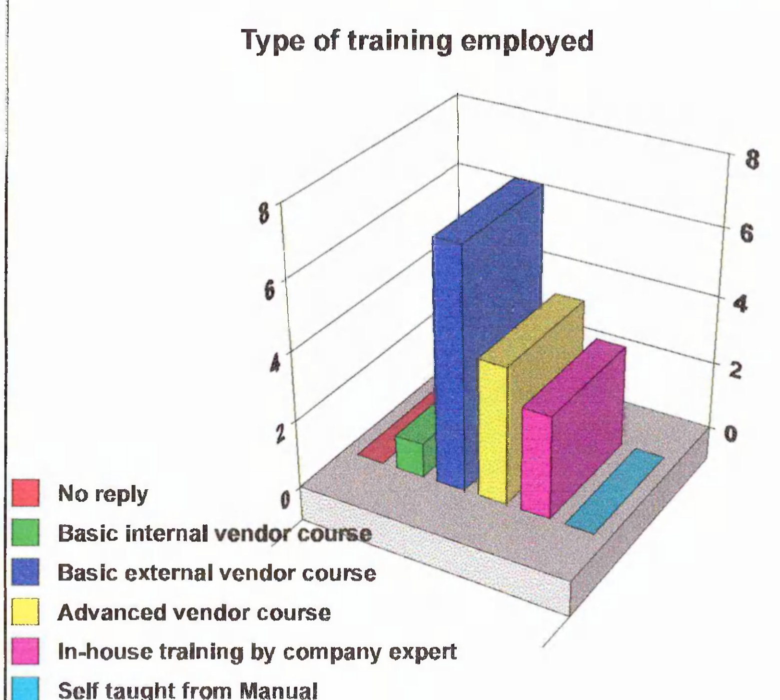

Figure 8.30d 3D Users Only

 Original in colour

Figure 8.31 Amount of time spent on training to use the CAD system

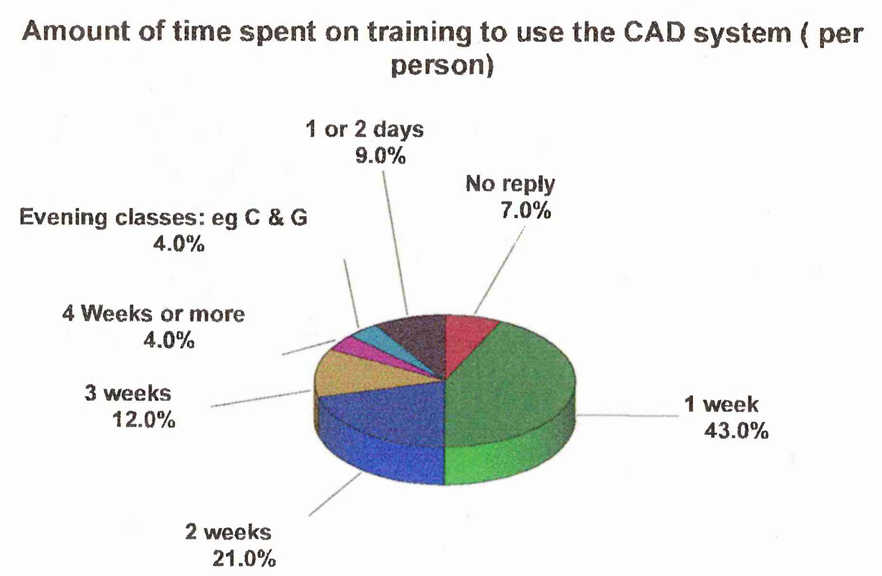

Figure 8.31a

All Users

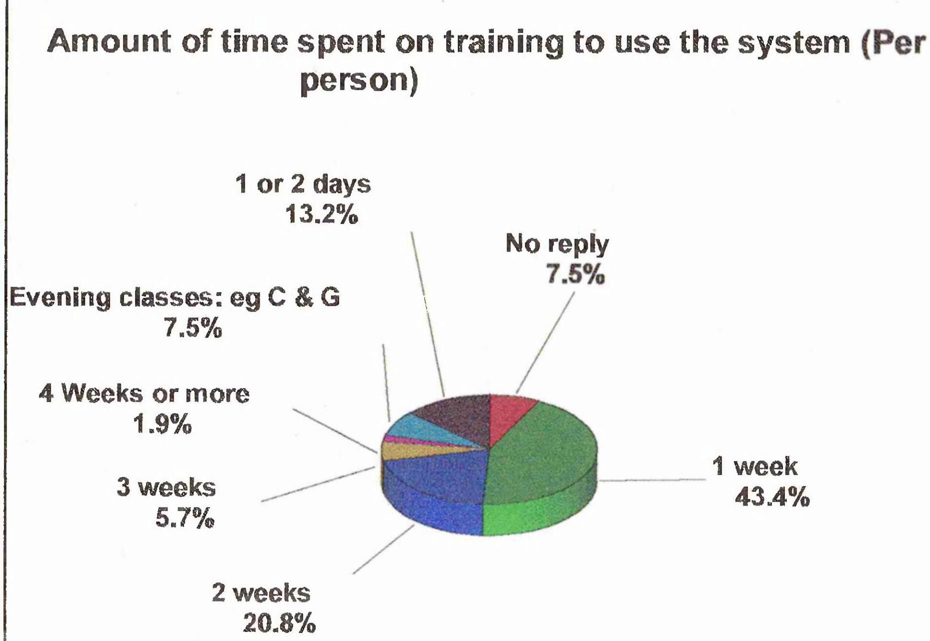

Figure 8.31b

2D Users Only

Original in colour

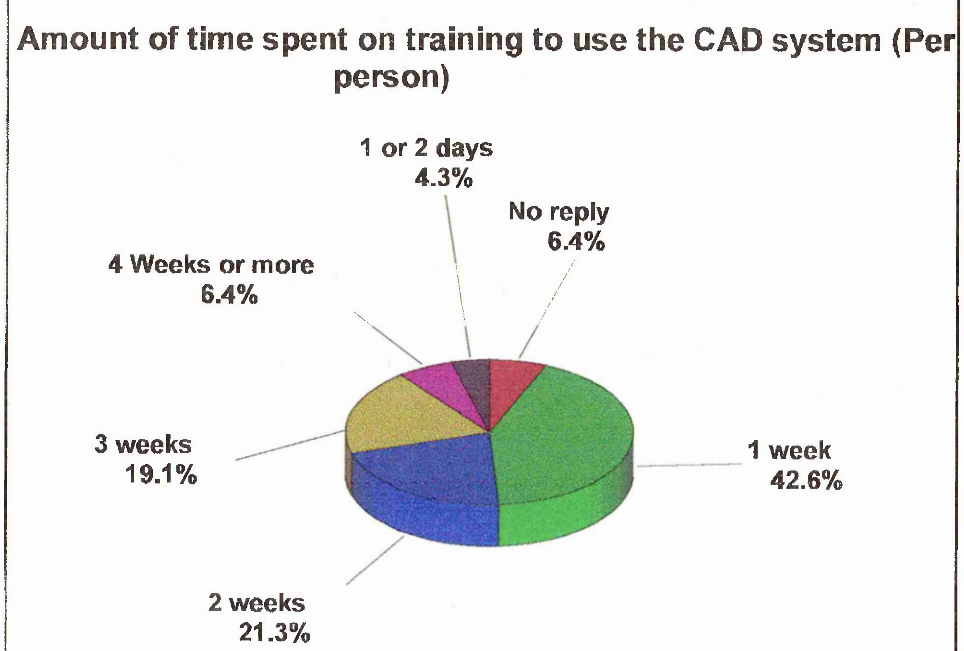

Figure 8.31c All 3D Users

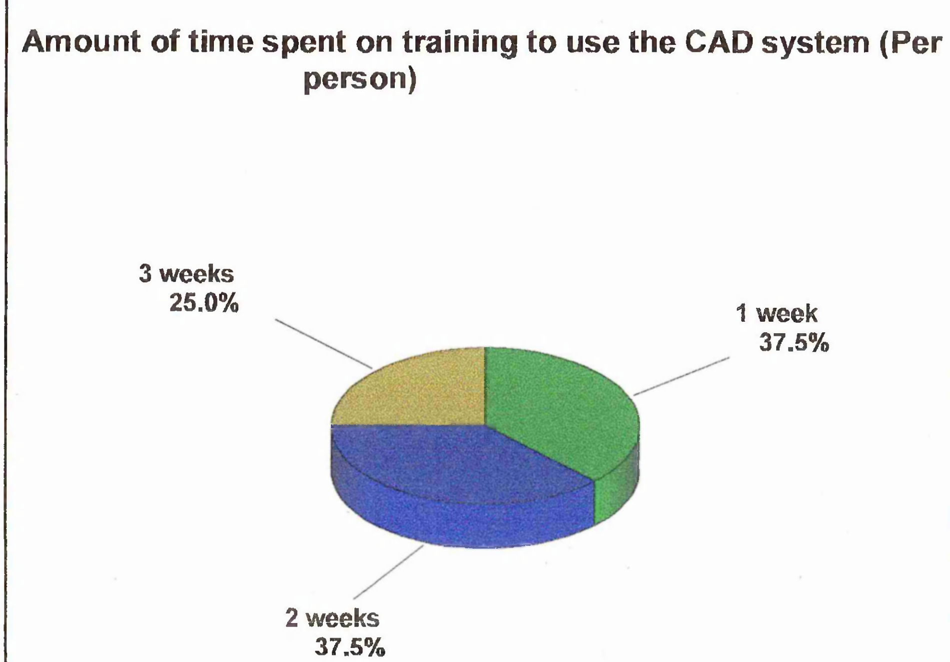

Figure 8.31d 3D Users Only

 Original in colour

Figure 8.32 Amount Invested by companies on training

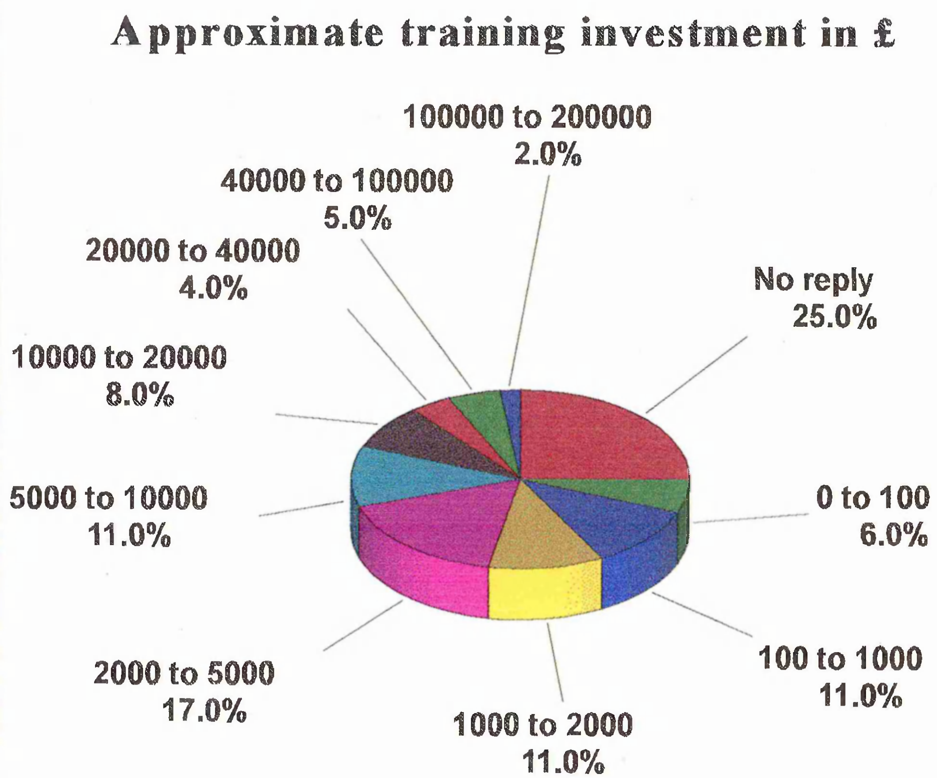

Figure 8.32a All Users

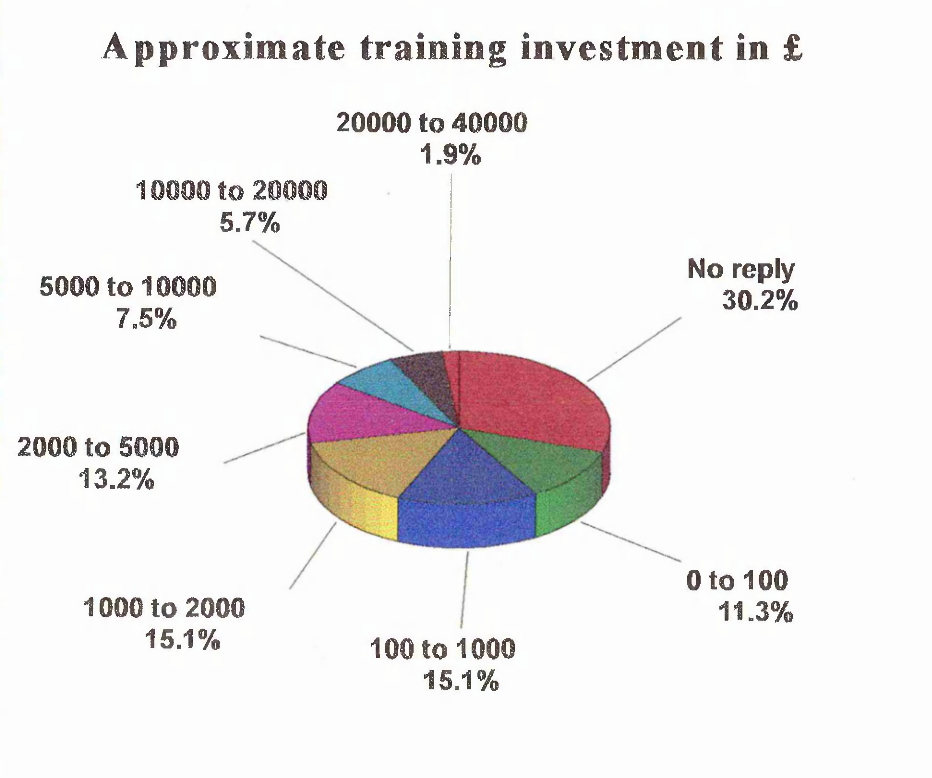

Figure 8.32b 2D Users Only

 Original in colour

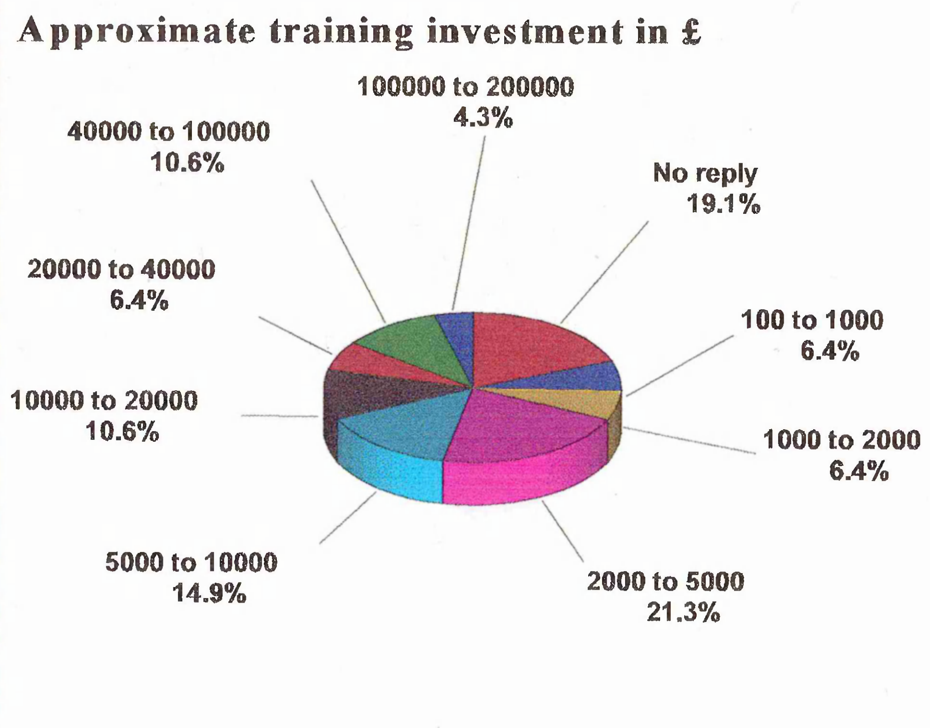

Figure 8.32c All 3D Users

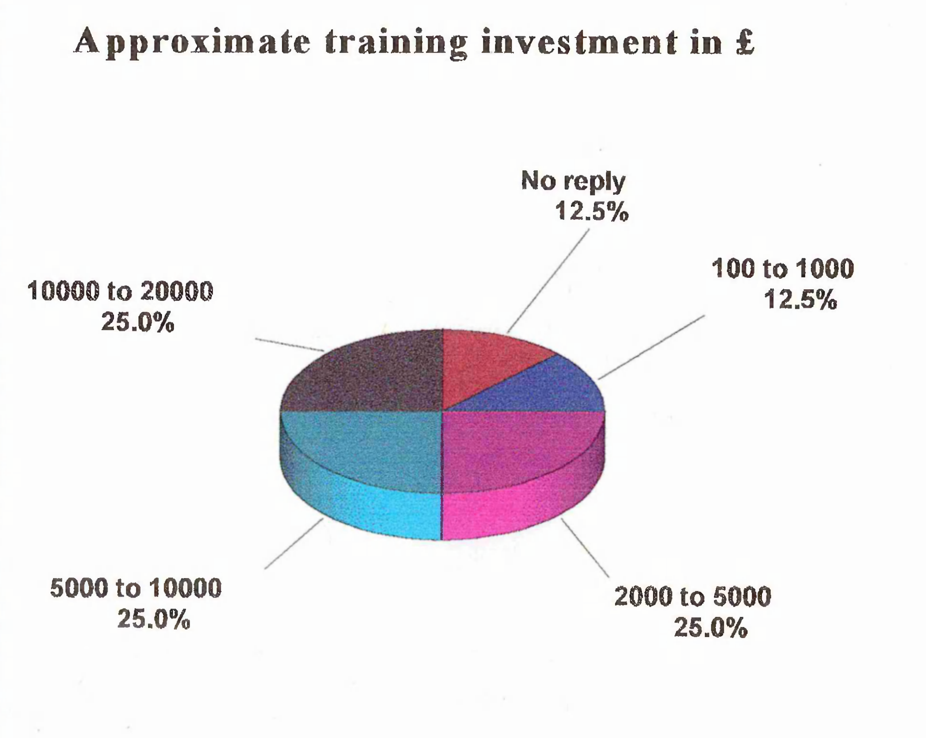

Figure 8.32d 3D Users Only

 Original in colour

Figure 8.33 Length of time after initial training before staff could use the system effectively

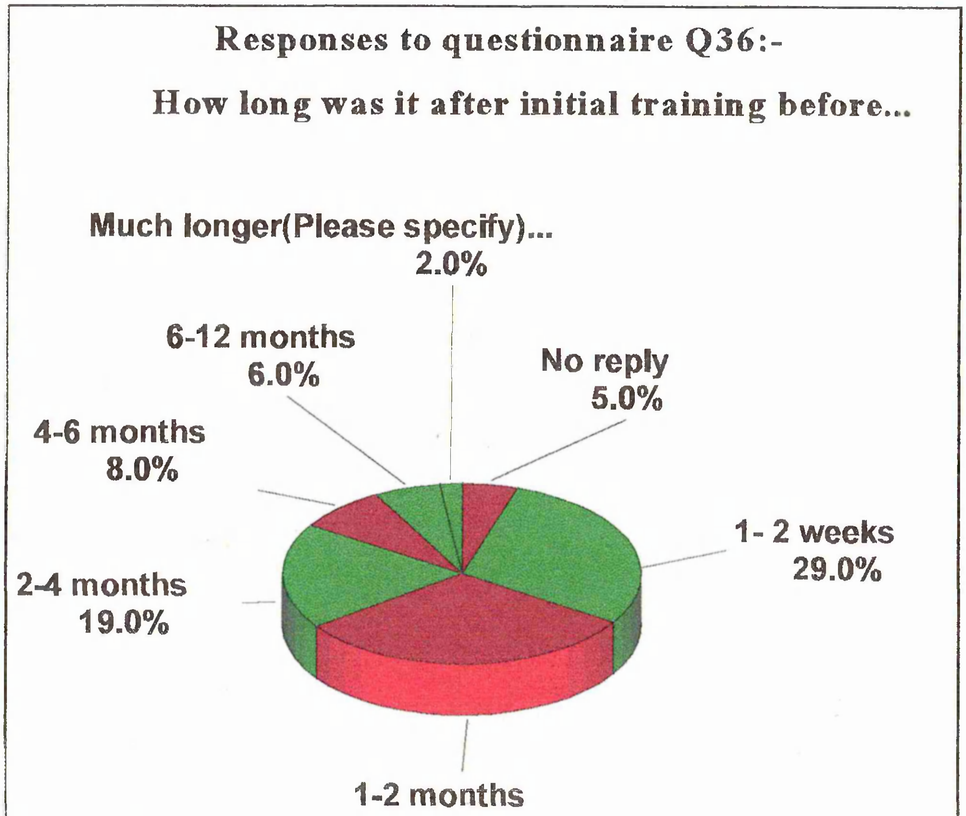

Figure 8.33a All Users

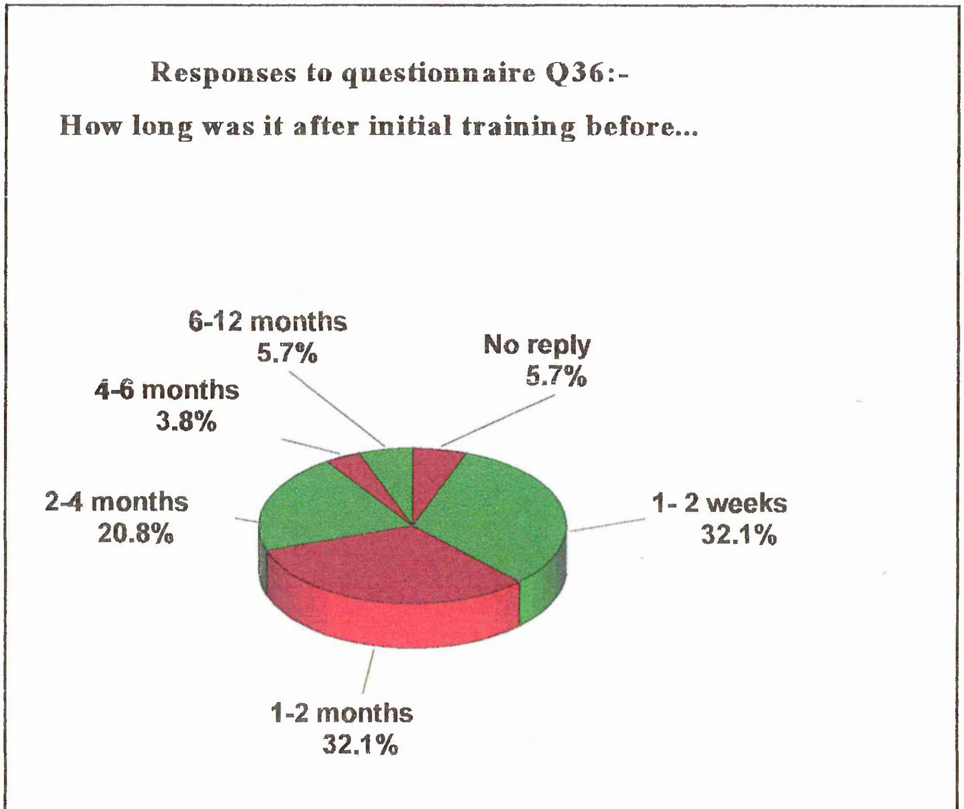

Figure 8.33b 2D Users Only

 Original in colour

Responses to questionnaire Q36:-

How long was it after initial training before...

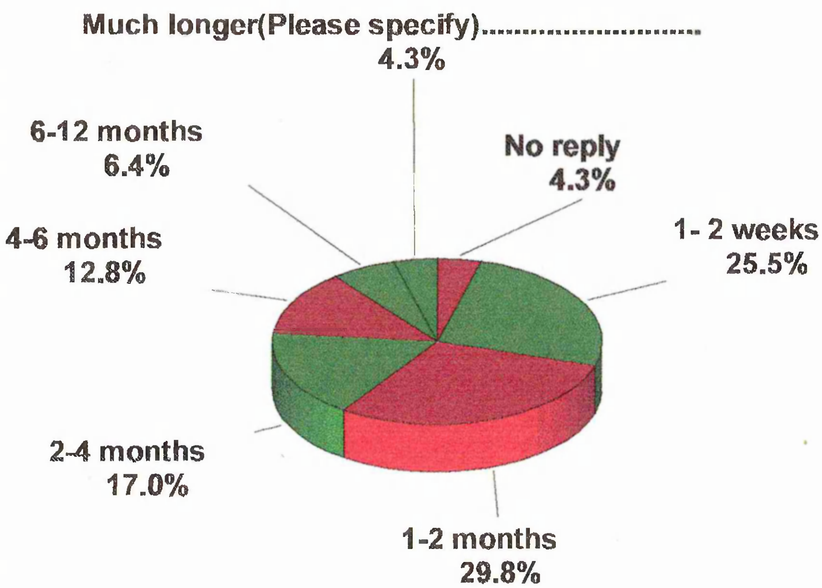

Figure 8.33c All 3D Users

Responses to questionnaire Q36:-

How long was it after initial training before...

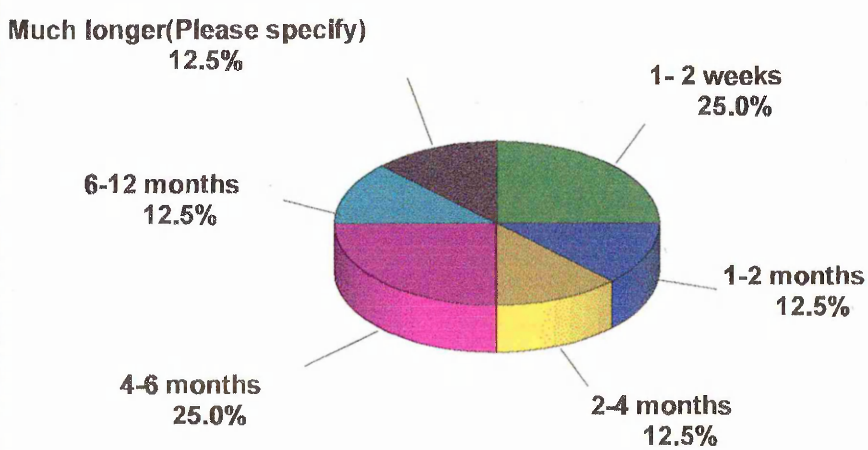

Figure 8.33d 3D Users Only

 Original in colour

Figure 8.34 Percentages of companies using 3D CAD reporting difficulties with the technology

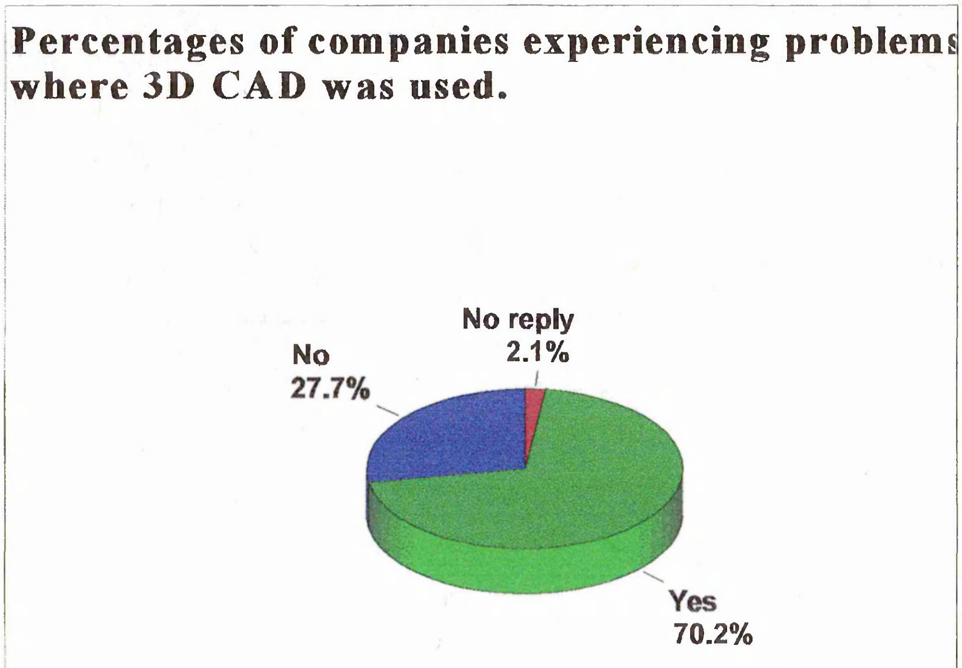

Figure 8.34a ALL 3D Users

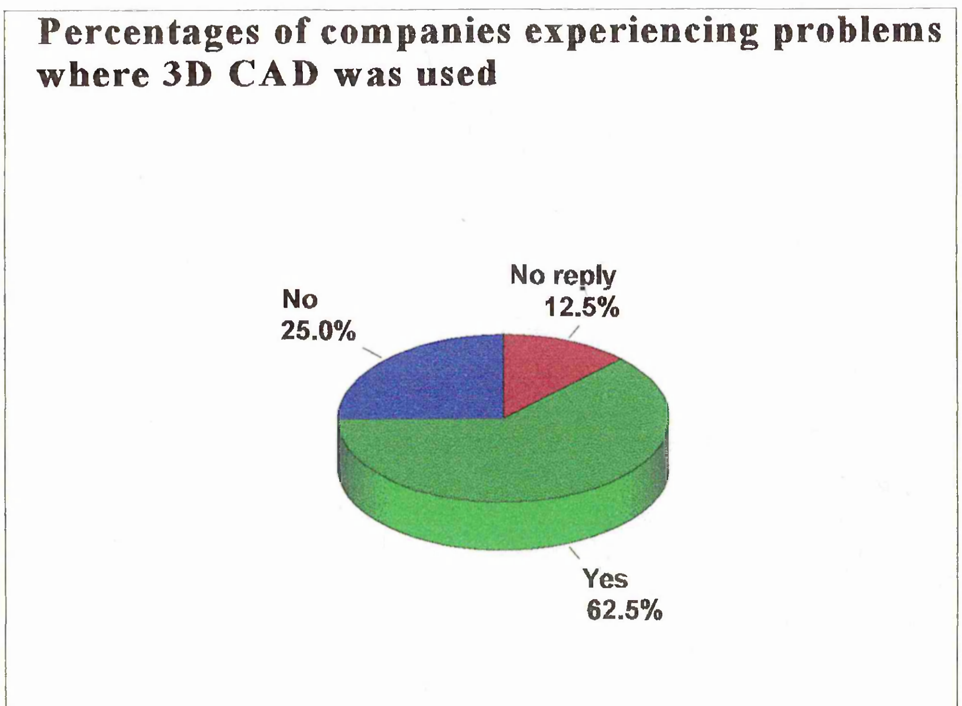

Figure 8.34b 3D Users Only

8.2.8 Impact of CAD on the Company

Figures 8.35 to 8.39 relate to section "G" of the questionnaire, **"Impact of CAD on the company"**. Figure 8.35 shows how many companies are achieving (and not achieving) all they hoped for when introducing CAD.

Figure 8.36 gives percentages to show the perceptions of respondents as to whether CAD has had a significant impact upon company business, is merely satisfactory or whether opportunities are still being sought.

Figures 8.37 and 8.38 show how many new products companies have introduced during the last year and during the last five years as one indication of a successful CAD implementation. This is contrasted further in figure 8.39 which shows the benefits companies are seeing as a direct result of CAD implementation.

Figure 8.35 Impact of CAD on the company- achievement of CAD aspirations

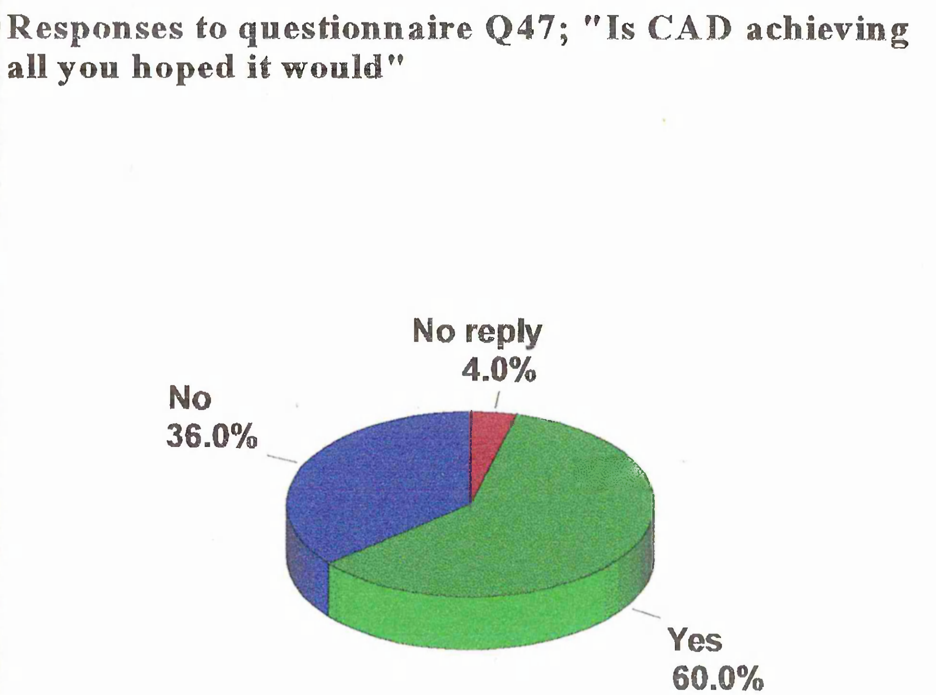

Figure 8.35a All Users

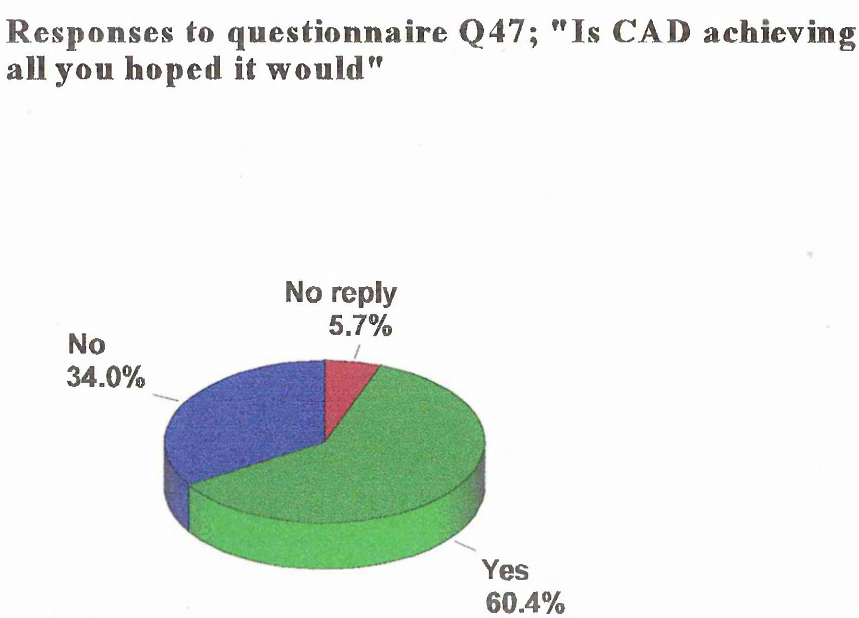

Figure 8.35b 2D Users Only

 Original in colour

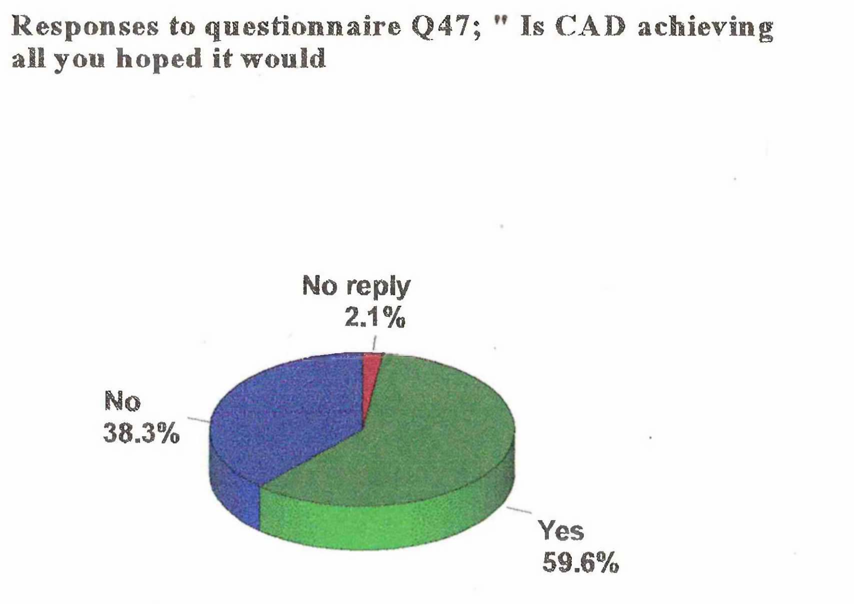

Figure 8.35c All 3D Users

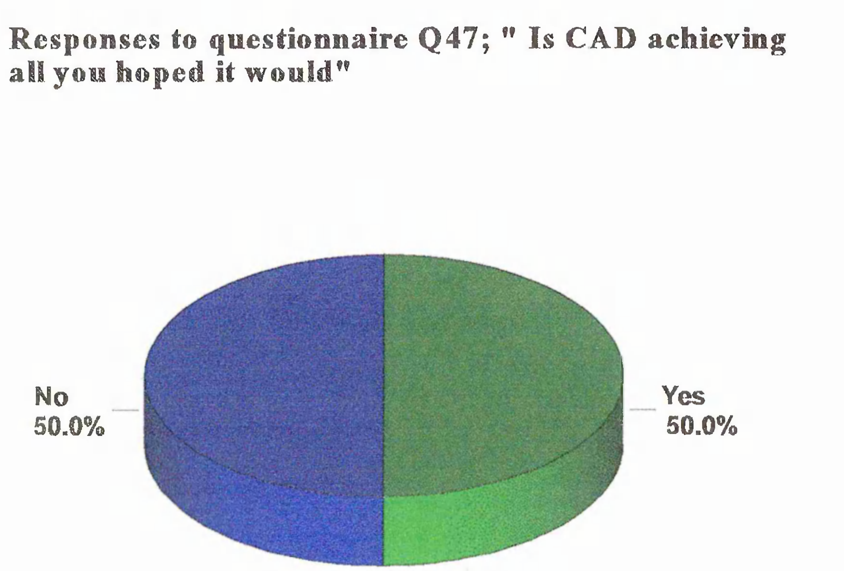

Figure 8.35d 3D Users Only

 Original in colour

Figure 8.36 Impact of CAD on company business

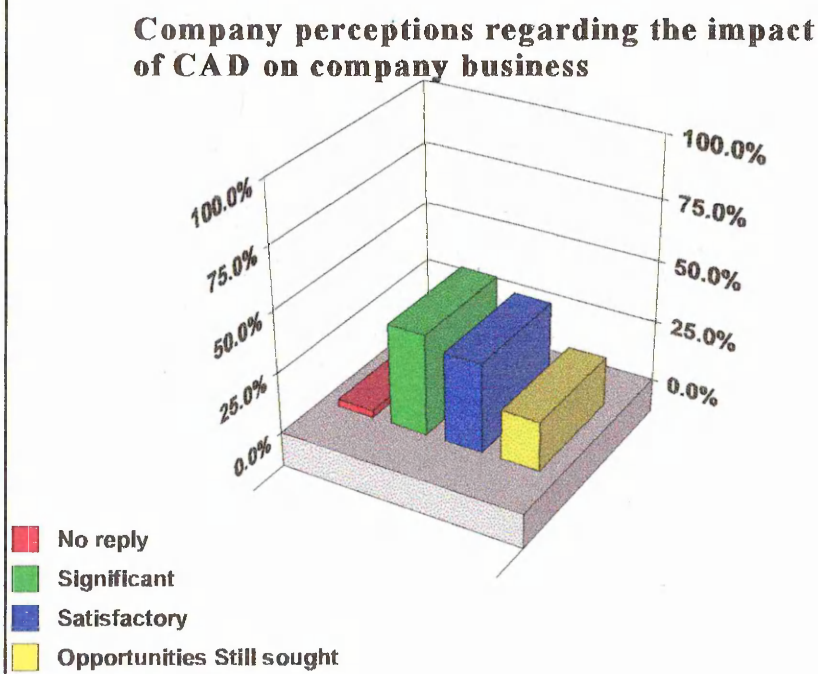

Figure 8.36a All Users

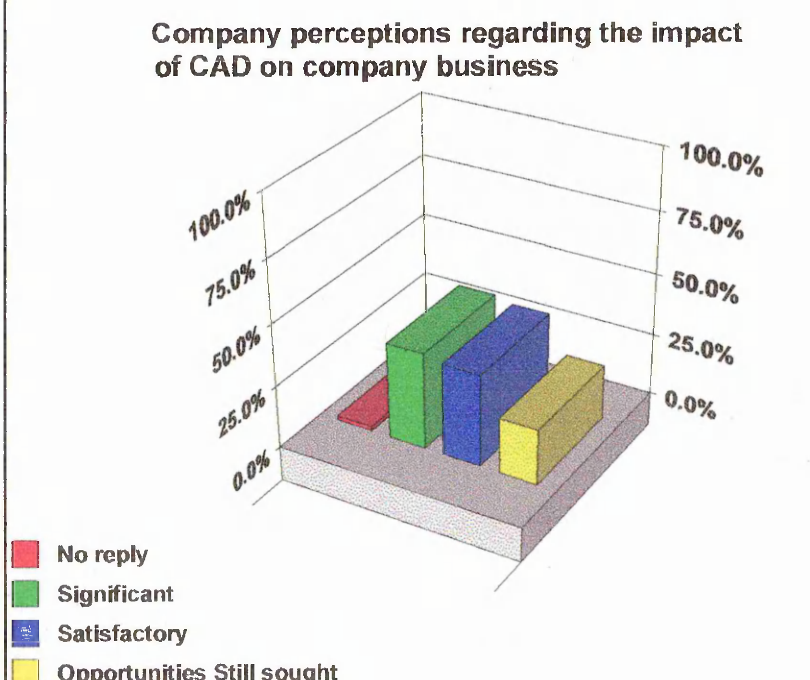

Figure 8.36b 2D Users Only

 Original in colour

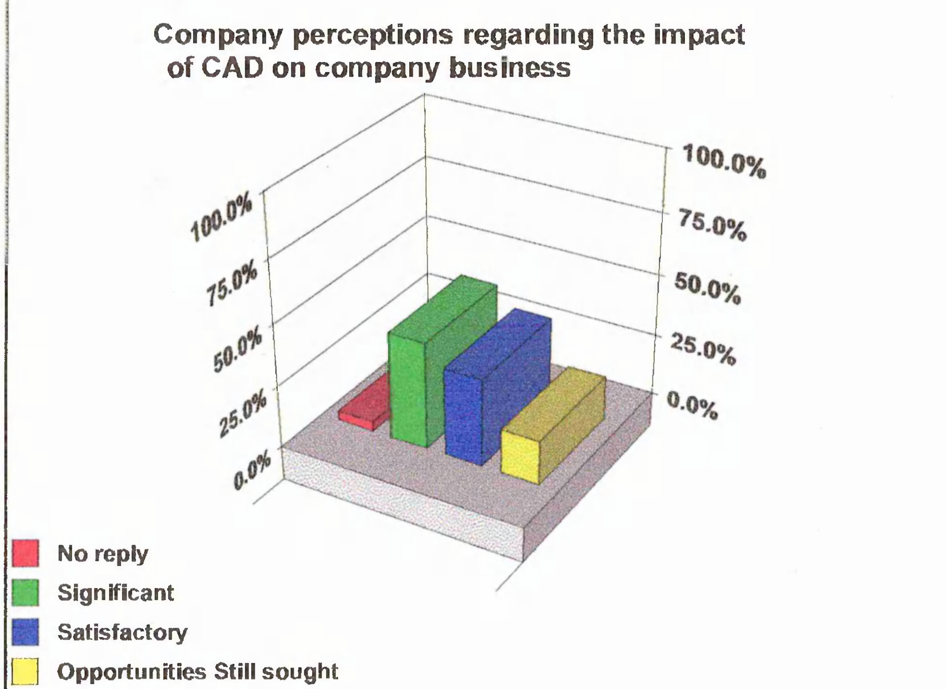

Figure 8.36c All 3D Users

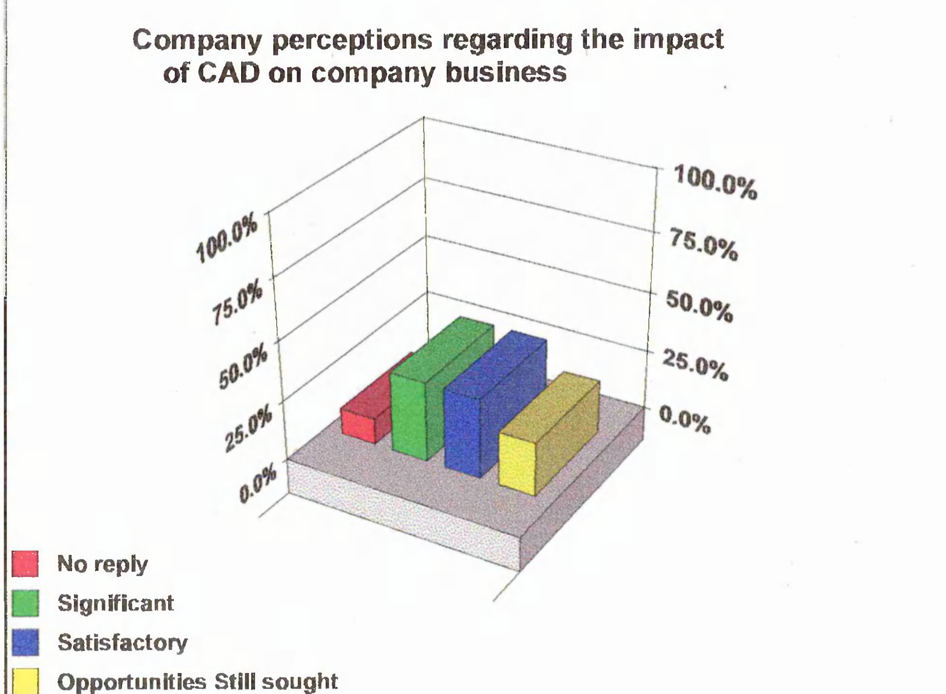

Figure 8.36d 3D Users Only

 Original in colour

Figure 8.37 Impact of CAD on the company- number of new products introduced during the last year

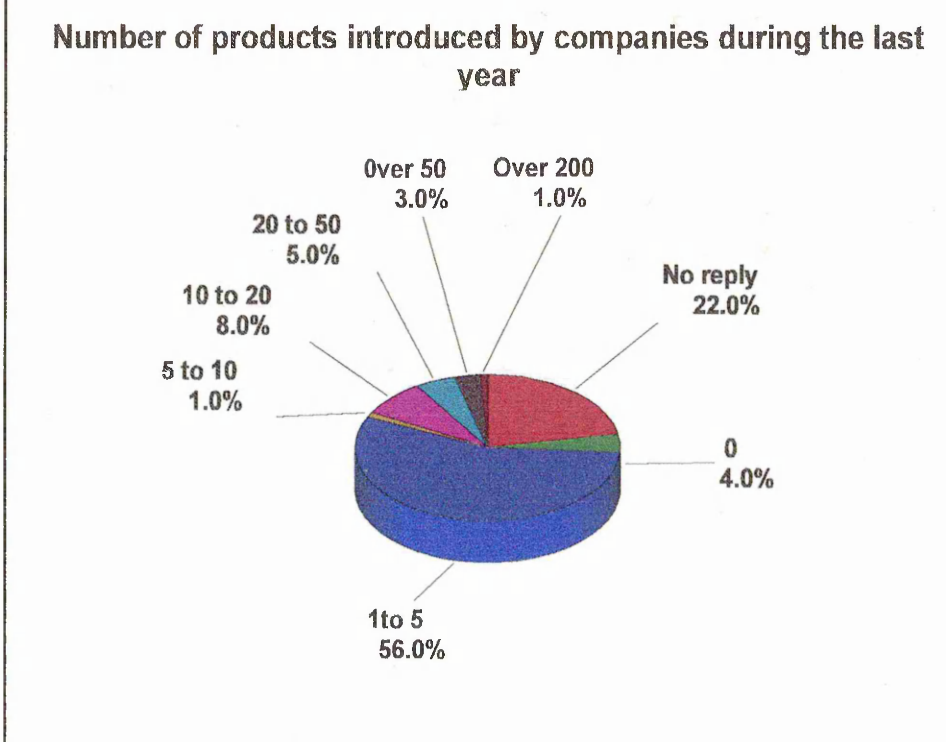

Figure 8.37a All Users

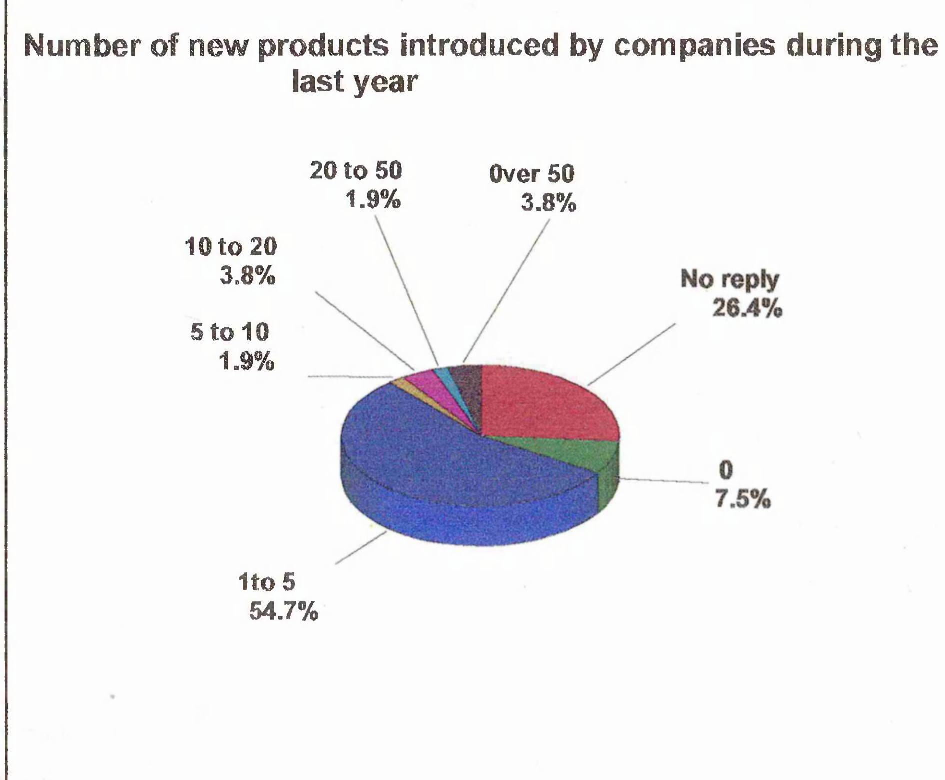

Figure 8.37b 2D Users Only

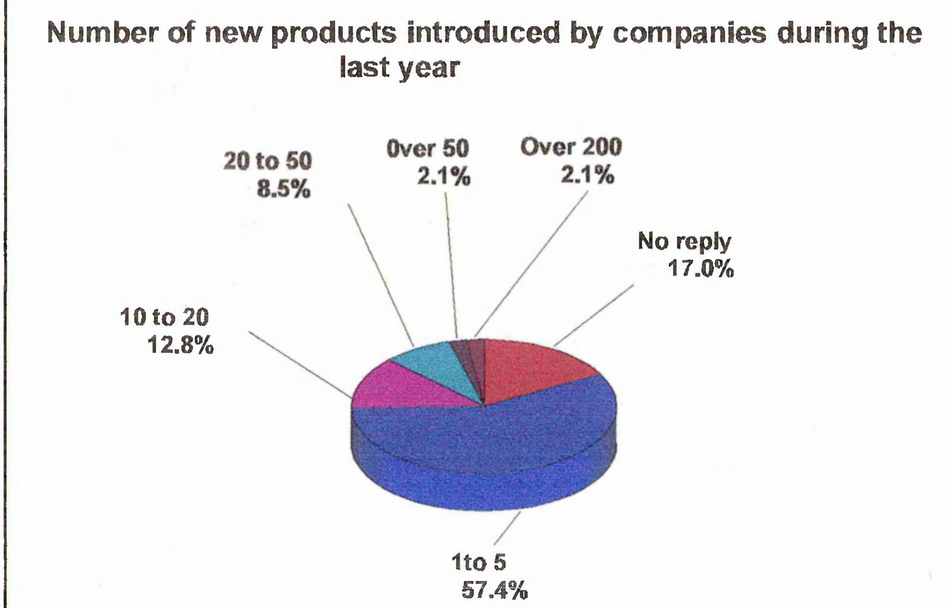

Figure 8.37c All 3D Users

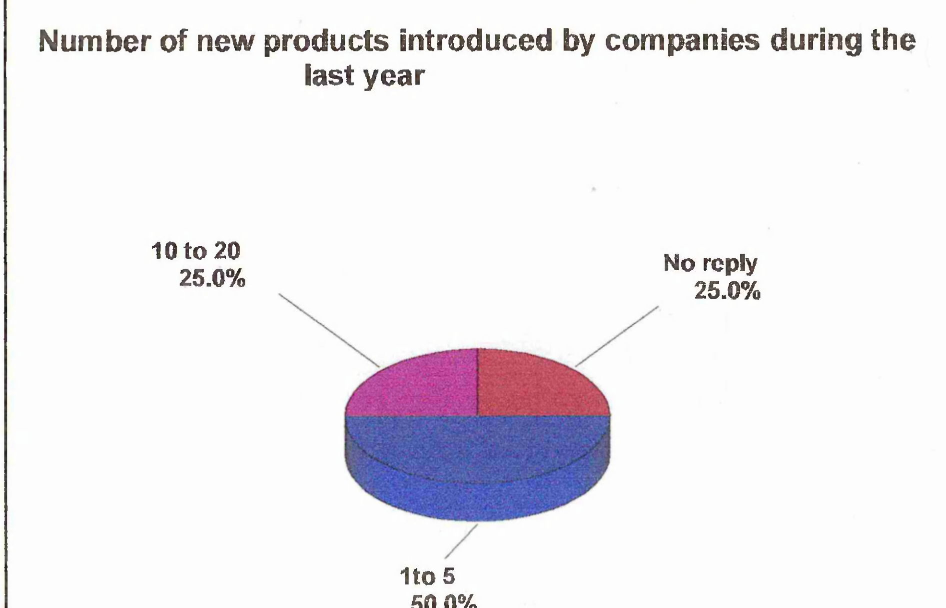

Figure 8.37d 3D Users Only

 Original in colour

Figure 8.38 Impact of CAD on the company- new products introduced over the last five years

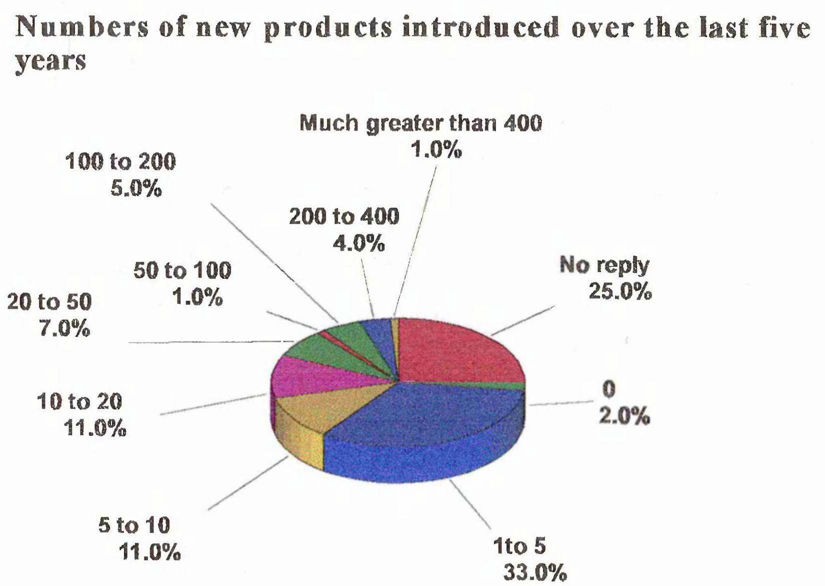

Figure 8.38a All Users

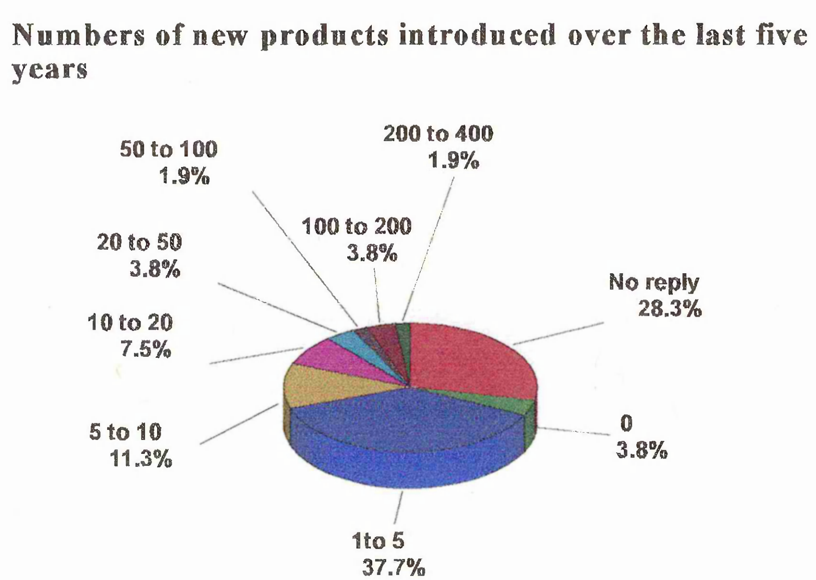

Figure 8.38b 2D Users Only

 Original in colour

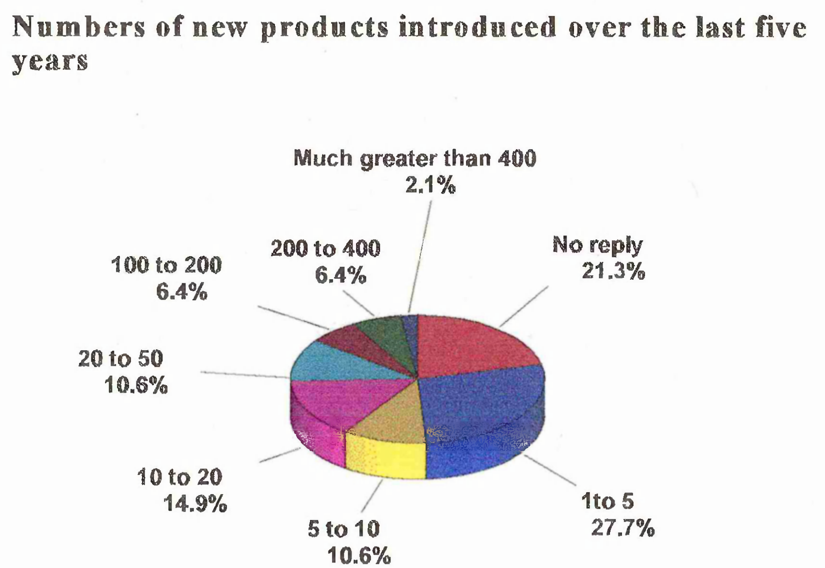

Figure 8.38c All 3D Users

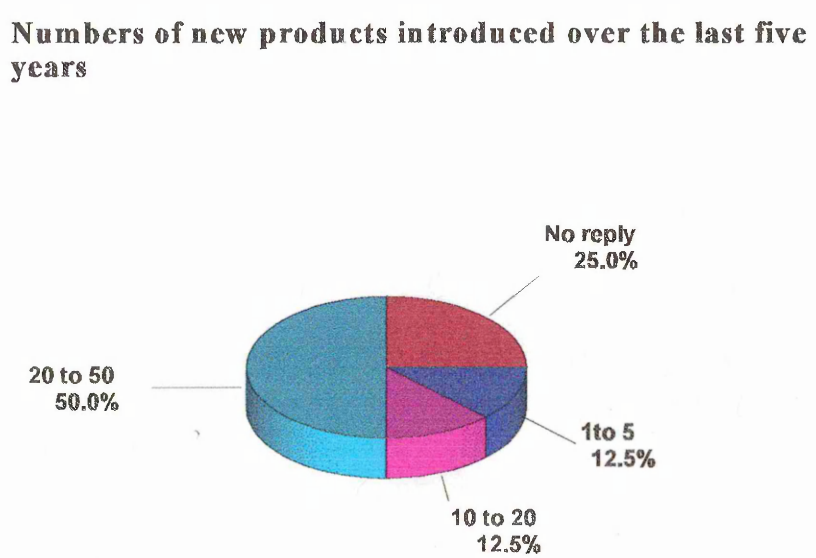

Figure 8.38d 3D Users Only

 Original in colour

Figure 8.39 Operational benefits seen by companies as a direct result of CAD implementation

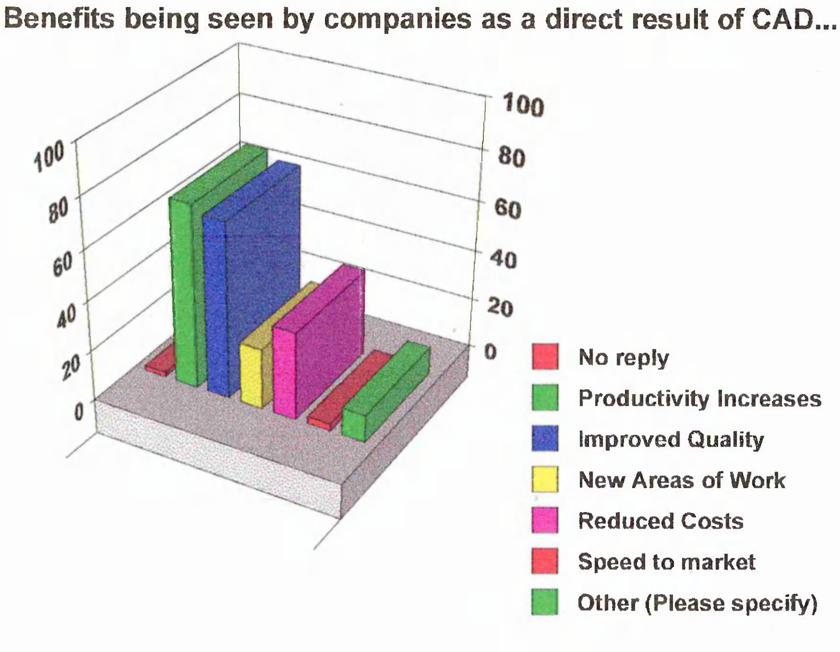

Figure 8.39a All Users

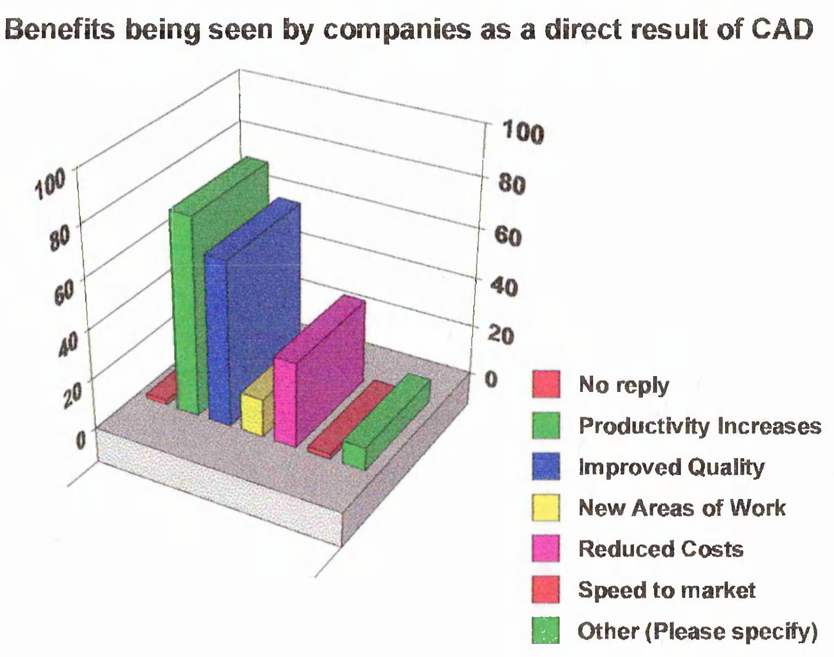

Figure 8.39b 2D Users Only

 Original in colour

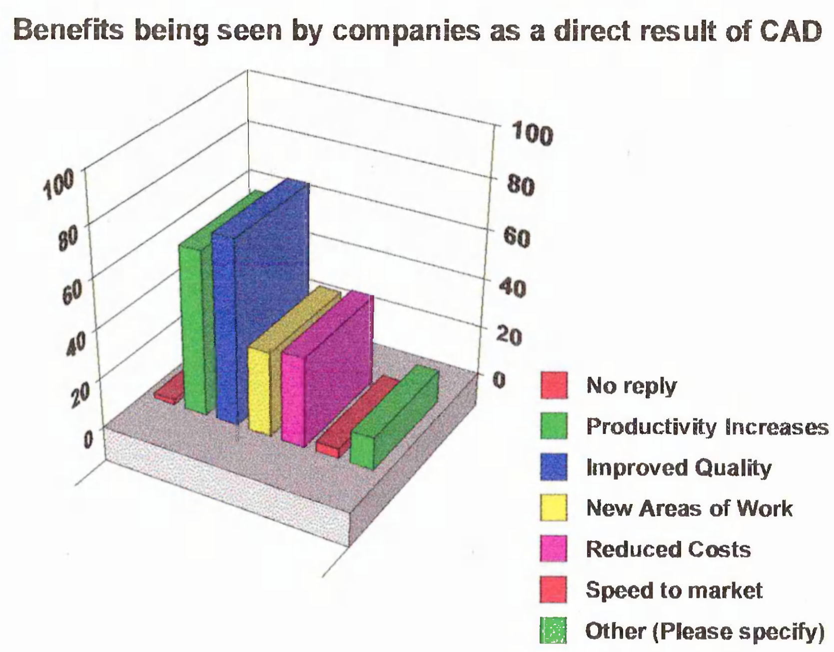

Figure 8.39c All 3D Users

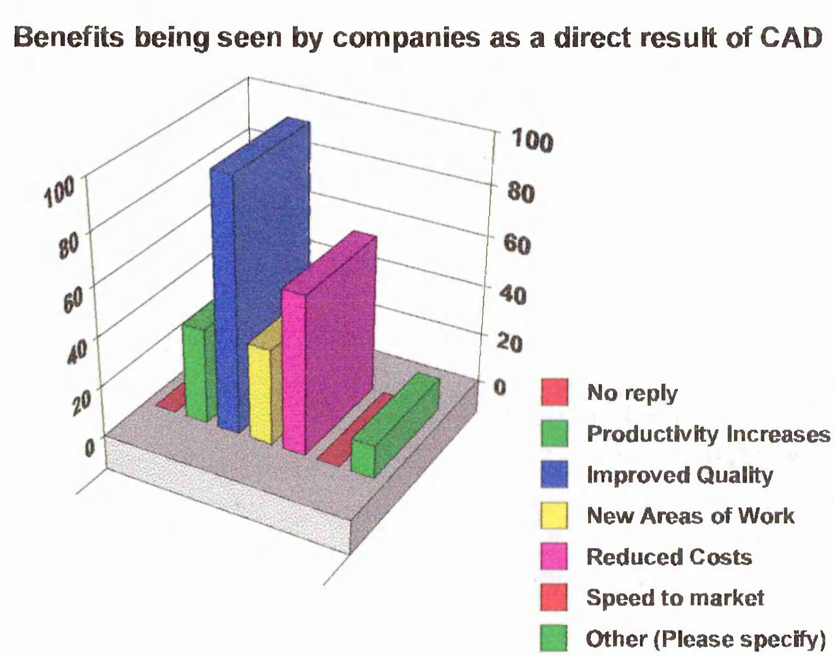

Figure 8.39d 3D Users Only

 Original in colour

9. ANALYSIS OF UK NATIONAL SURVEY RESULTS

9.1 INITIAL INFORMATION ABOUT COMPANIES

General company information is shown in Figure 8.5 on pages 205 and 206.

Important aspects to note are that forty seven percent of the sample had been apprentice trained, that 58% of the respondents were HNC/HND trained and a 45% had obtained degrees (nine of these at higher degree level). Twenty nine percent of the sample were apprentice trained and held HNC/ HND qualifications. Only two of these respondents had been in their current position for less than one year with 14 employed for up to five years and 13 for over five years. Nine percent of the sample were apprentice trained and qualified to degree level and except for one company all had been in their current position for over one year.

Fifty three respondents had not undergone apprentice training but 19 indicated training to HNC/ HND level and 27 to first degree level. Of these respondents only 4 had been employed for less than one year in their current job, 26(49%) for up to five years and 22(42%) for over five years. All respondees were employed in job roles (and for a suitable time period) which made them eligible to provide information regarding the CAD area. Around 35% of the respondees are employed within the design function as CAE/IT Managers, Design Engineers or Draughtsmen and around 45% as Managers or Directors. This data set encourages the belief that the further information will be useful and valid.

Activities Undertaken at the Companies

Figure 8.6 shows the main products or services provided by companies in the survey. Of the 100 companies responding to the survey, 11.9% chose not to disclose their activities, 25.7% are involved in general purpose equipment with pumps/ compressors and taps/ valves each accounting for 12.9% of the product groups. Companies classified under "other" activities account for 14.9% of the respondents whilst the remaining areas, domestic equipment, electric motors, forging, tools, heavy engineering and glass account fairly evenly for the remaining 22%

Activities carried out in user companies is shown in Figure 8.7 and the same relationship of activities exists for 2D and 3D users. All undertake the design of existing products, NPD, manufacture, testing and commissioning. The figures do not quantify the activities in any way, but present the respondents perceptions of activities carried out. Further discussion on the levels of NPD within the companies is presented in section 9.6

The Organisational Structures in Place

There are many texts which describe the organisational structure of companies. Greenberg (150) describes organisational structure as the arrangement of authority, responsibility and tasks within an organisation. He goes on to say that such structures may be defined by:

- Functional tasks
- Product output
- Matrix (both function and product)

Each type may be "hierarchical" with lots of layers of management or "flat" with relatively few layers of management. Authorities on the subject would argue as to the merits of each type but generally the feeling is that fewer layers lead to greater efficiency and effectiveness.

In this survey 67% of all companies claimed to employ a hierarchical structure and the results are shown in Figure 8.8. More than 64% of companies employing 2D only and those companies employing mixed CAD (ie both 2D and 3D) indicated that they operate with a hierarchical structure. However, this is the exact opposite for 3D only users where approximately 62% employ a flat structure and the remainder employ hierarchical structures. The benefits of 3D discussed earlier in section 1.3 transcend traditional over the wall approaches to design and integrate departments creating the need for communication and teamwork and thus a change of organisational approach would be expected.

9.2 THE DESIGN PROCESS

The breakdown of design related activities performed by the total sample of 100 companies is shown in Figure 8.9. Ninety two of the companies engage in 2D detail design of which fifty three only have 2D CAD. Forty seven companies engage in 3D modelling, of which 39 use both 2D and 3D CAD. The remaining eight companies used 3D only.

In terms of the design process 39% of all companies perform pencil sketches. However, this is less prevalent in the eight companies employing 3D only, with only 25% employing pencil sketches.

Concept design is undertaken by 66% of the total surveyed group but this reduces significantly to 28% for those using 3D CAD.

The application of manual and computer analysis appears generally relatively low. Overall only 47% % of respondees report that they employ some form of analysis and this equates to 29% employing computer analysis and 33% manual analysis. Although there is nothing to compare this level of analysis with, one would expect companies involved in design to perhaps employ more analysis. In comparing the types of user, ie 2D or 3D, there is a small variation across software types and this is illustrated in table 9.1

CAD usage	No Analysis	Manual OR Computer	Manual AND Computer
2D Only	55	36	9
Mixed (2D+ 3D)	25	49	25
3D Only	62.5	37.5	0

Table 9.1 Percentages of user groups employing some form of analysis

Clearly 2D only users appear to perform little analysis compared with mixed users and surprisingly the majority of 3D only users also employ little analysis even though those 3D users indicate that they are satisfied with CAD achievements .

Figure 8.9 shows that CNC/CAM is employed by 29% of the total group, with 23% of 2D users employing this function as opposed to 36% of all 3D users.

The manufacture of prototype models is carried out by 36% of companies, 32% of 2D users and a higher proportion, 40% of 3D users.

Reference to Figure 8.10 shows that at least 60% of 2D and 3D users perform no manual drawing on conventional drawing boards. Very few of those employing drawing boards use them very much anyhow, but of those that do, 3D users appear to use the boards more than 2D users. However Figure 8.11 contrasts the number of drawing boards still employed by companies and it is clear that 3D users have tended to reduce their use more than 2D users. This is very probably as would be expected, since a 3D modelling system, used effectively, would eliminate the need to do manual 2D drawings.

There is a small distinction between 2D and 3D users in the percentage of work undertaken using CAD as illustrated by Figure 8.12. More than eighty nine percent of all 3D users perform over 70% of work using CAD compared with 81.9% for 2D only users.

Figure 8.13 shows the distribution of CAD seats for each group of users.

Analysis of these results shows that in the 100 companies sampled a total of 734 seats of CAD are employed and the average number of CAD seats per user equate to;

- For 2D = 5 seats
- For Mixed users (2D and 3D) = 10.5 seats
- For 3D only users = 6 seats

Jobs for which the CAD systems are used

It is clear from Figure 8.16 that the majority of companies use their CAD systems for all design jobs with little prioritisation. The distinction between 2D and 3D users is quite low but there appears to be a more structured approach to job planning with the move to 3D. ie the proportion of companies reporting CAD is used for all jobs is 92% for 2D only users, 83% for 2/3D users and 75% for 3D only users.

Length of time companies have been involved with CAD

Figures 8.14 and 8.15 illustrate how long companies have been involved with CAD and how long they have been employing their current CAD system.

The greater majority of all users (45%) have been employing CAD for over six years with 29% having employed CAD for over 10 years and only 4% have employed CAD for less than 3 years and the remainder for at least 3 years.

Data extracted from figures 8.14 and 8.15 has been used to derive the "average" length of time that companies have been employing CAD and current CAD systems and this is shown in table 9.2

CAD usage	Overall involvement in CAD (Years)	Current System Time (Years)	Percentage of Companies on at Least Their Second Generation of CAD System
2D Only	7	5.58	28%
Mixed (2D+ 3D)	8.52	4.58	56%
3D Only	6.3	2.56	62%

Table 9.2 Duration that companies have been employing CAD and current system

As developments in CAD have come along and companies have become more conversant with CAD and its advantages or limitations, they have obviously changed to a new system. Cross tabulation of involvement time in CAD and duration of use of current systems has identified the percentages of companies having changed to at least a second CAD system; (some companies being on their 3rd or 4th generation of CAD system as indicated by their responses to literal questions on the questionnaire).

2D users have been employing their current CAD system for almost as long as they have been involved in CAD, approximately 80% of this time. Mixed users have had their current systems for around 53% of their CAD involvement time and 3D only users for around 40% of this time.

Summary of Participants

- All respondees were qualified to comment upon their companies use of CAD
- The majority of companies surveyed (52%) employed CAD for 2D work with less than half (46.5%) using 3D CAD
- 2D users have been employing their current CAD systems for around 5.6 years, mixed users for around 4.6 years and 3D only users for around 2.56 years
- In this survey 2D users employed on average five seats of CAD, mixed users 10.5 seats and 3D only users 6 seats

- The emphasis of design is clearly directed towards generating drawings from the CAD system
- Little use is made of manual or computer analysis by 3D only and 2D only users, whilst mixed users undertake up to 12% more
- The use of CNC/CAM and the manufacture of prototype models from CAD is low, again only being employed by a third of the total sample

9.3 CAD INTRODUCTION AND DEVELOPMENT

Types of CAD Systems Currently Employed

CAD systems employed by the companies are shown in Appendix C1 and are listed by 2D, 2D/3D and 3D only users.

Results for 2D users show a proliferation of low end software such as AutoCAD and used essentially as 2D electronic drawing boards; although these systems are 3D systems Systems employed by users stating they employ 3D are on the whole higher end systems and include some of the leading names in 2D/3D CAD.

Total Investment in CAD

The average total investment per user is £62k and the average total investment per user by user group is £19k for 2D only users, £111.8k for mixed users and £105.74k for 3D only users.

The distribution of total investment in CAD (excluding training) by companies is shown in Figure 8.17 . For the companies using 2D only, approximately 80% have systems to £20,000 with around one third of this 80% spending less than £5,000 and a further 20% spending between £5,000 to £10,000.

Companies employing mixed or 3D CAD however have invested significantly more with approximately 80% spending well over £20,000. However, in responding to question 47 of the questionnaire, regarding the impact of CAD on the company and illustrated in Figure 8.35, approximately 38% of 3D users and 34% of 2D users indicate they are not achieving all they wished from CAD.

Investment per Seat in CAD

Figure 8.18 on page 233/234 attempts to put some perspective on investment by comparing average investment per seat in CAD, derived from responses to both questions 14 and 20 on the questionnaire. Understandably 2D users investment per seat is generally lower compared with 3D users. The average investment per seat for 2D users (derived using simple frequency/ average table calculations and ignoring the "no replies") is just £4,000 with 52% of 2D users spending less than £5000 per seat, 74% less than £10,000 and only 5.7% spending between £10,000 and £15,000.

In comparison, the average investment per seat made by mixed CAD users is £9.9k and for 3D only users is £22.5k.

Clearly therefore, there is a significant difference in the investments made between 2D and 3D users and there must also be a significant difference in system capability, complexity and use for the price difference incurred.

Statistical analysis employing the Chi-squared test (described in section 8.1 and appendix E) provide the results for CAD investment per seat, shown in Table 9.3. This suggests that there is no significant link between the amount of investment per seat and achieving company aspirations. ie achievements are not dependent upon obtaining the most expensive system possible, but is influenced by some other factors.

Chi-squared value 3.477

There is no significant relationship

Absolute Analysis % Respondents	Base	Missing No reply	Is CAD achieving all that you hoped it wou... Yes	No
Base	53	3 6%	33 62%	17 32%
Missing				
No reply	2	- -	1 50%	1 50%
Investment per seat in CAD (£k)				
0 to 1	8	- -	4 50%	4 50%
1 to 2	10	1 10%	7 70%	2 20%
2 to 5	18	- -	14 78%	4 22%
5 to 10	12	1 8%	6 50%	5 42%
10 to 15	3	1 33%	1 33%	1 33%
15 to 20	-	- -	- -	- -
20 to 30	-	- -	- -	- -
50 to 60	-	- -	- -	- -
70 to 80	-	- -	- -	- -

Table 9.3a Statistical relationship between investment per seat in CAD by 2D only users and achievements with CAD

Chi-squared value 8.64

There is no significant relationship

Absolute Analysis % Respondents	Base	Missing No reply	Is CAD achieving all that you hoped it wou... Yes	No
Base	39	1 3%	24 62%	14 36%
Missing				
No reply	4	- -	3 75%	1 25%
Investment per seat in CAD (£k)				
0 to 1	4	- -	1 25%	3 75%
1 to 2	5	- -	4 80%	1 20%
2 to 5	8	1 13%	6 75%	1 13%
5 to 10	7	- -	3 43%	4 57%
10 to 15	2	- -	2 100%	- -
15 to 20	3	- -	1 33%	2 67%
20 to 30	5	- -	3 60%	2 40%
50 to 60	1	- -	1 100%	- -
70 to 80	-	- -	- -	- -

Table 9.3b Statistical relationship between investment per seat in CAD by all 3D users and achievements with CAD

Chi-squared value 8.000

There is no significant relationship

Absolute Analysis % Respondents	Base	Missing	Is CAD achieving all that you hoped it wou...	
		No reply	Yes	No
Base	8	- -	4 50%	4 50%
Missing				
No reply	-	- -	- -	- -
Investment per seat in CAD (£k)				
0 to 1	-	- -	- -	- -
1 to 2	1	- -	- -	1 100%
2 to 5	1	- -	- -	1 100%
5 to 10	2	- -	2 100%	- -
10 to 15	1	- -	- -	1 100%
15 to 20	1	- -	1 100%	- -
20 to 30	-	- -	- -	- -
50 to 60	1	- -	- -	1 100%
70 to 80	1	- -	1 100%	- -

Table 9.3c Statistical relationship between investment per seat in CAD by 3D only users and achievements with CAD

Basis of CAD implementation

Reasons for which companies originally needed CAD are presented in Figures 8.19 to 8.24. They identify company ratings, from 1 to 6, in terms of the importance of each separate need and the actual percentages of companies responding.

It is clear from this summary that much of the need for CAD has been primarily based upon increasing productivity ie reduction in the time taken to produce drawings and increase in the number of drawings produced.

For example, Figure 8.19 shows that 77 companies (ie 77%) have ranked productivity as their number 1, 2 or 3 priority. Overall, very few companies based their need for CAD on activities which can have a significant strategic impact on operational and business activities as evidenced by Figure 8.20; eg only 32% rank the capability to perform new areas of work as their number 1, 2 or 3 priority.

The distribution of original company needs for CAD are summarised and contrasted

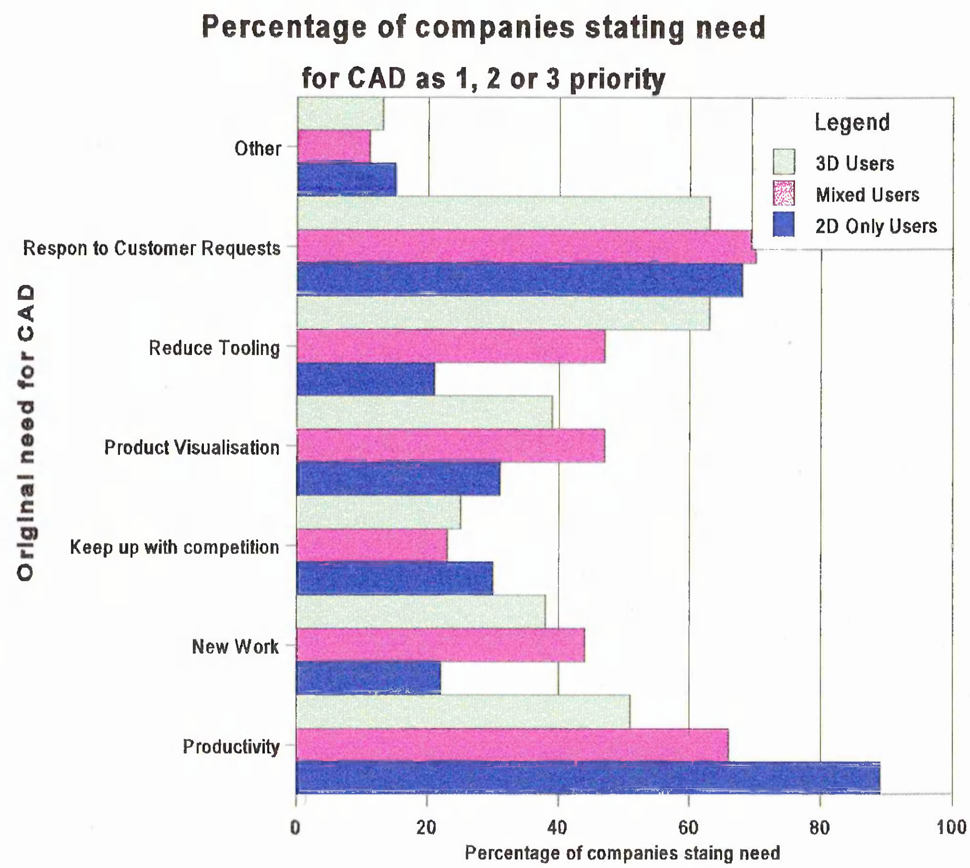

Figure 9.1 Original company needs for CAD

in Figure 9.1 for 2D only, mixed and 3D only user groups and focus on the percentages of companies identifying a particular need as their number 1, 2 or 3 priority.

Within the 2D only user group there is a higher emphasis on productivity (ie 47 companies -89% rating this as 1, 2 or 3) and low emphasis on other needs. In companies where mixed CAD systems are employed, the emphasis of need for CAD still appears to be primarily based upon productivity (39 companies-64% rating

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productivity as 1, 2 or 3). There is a higher percentage of companies in this group reporting needs based upon other activities. eg 43% rate new work and 49% rate reduced tooling / manufacturing times as their 1,2 or 3 priority. In the 3D only user group there is lower emphasis on increasing productivity as an original need for CAD and increased emphasis on other activities. Four companies (50%) rate productivity as their number 1 or 2 reason for originally needing CAD whilst the other four companies state that they did not need CAD for its productivity benefits. Five out of the eight companies (62.5%) rank the reduction of tooling and the ability to respond faster to customer requests as their number 1, 2 or 3 reason for purchasing CAD.

Organisational Change as a Result of CAD

Figure 8.25 illustrates the changes in organisational structure since implementing CAD. Overall 71% of companies have not changed their organisational structure as compared with 29% that have. Interestingly, 17% of 2D only users have changed their structure whilst almost half (42.5%) of all 47 3D users and 37.5% of the 8 3D only users have.

Table 9.4 indicates the levels of achievement stated by companies in relation to changes in the organisational structure. Of those companies that did not implement any change in organisational structure, 65% indicate satisfaction with CAD achievements whilst 30% were not satisfied. In comparison, of the 29 companies that did change their organisational structure to suit CAD, 48% are satisfied with their achievements from CAD but a higher proportion (52%) are not satisfied. Statistically, as indicated in the table 9.4, there is a significant relationship at the 10% level, suggesting that a relationship does exist. An initial look at the results would suggest that a beneficial effect on achievements would be made by not undergoing any organisational change however there may be an alternative explanation as follows.

"Chi-squared value" 3.587030

"There is a significant relationship at the 10% level."

Absolute Analysis % Respondents	Base	Missing	Is CAD achieving all that you hoped it wou...	
		No reply	Yes	No
Base	100	4 4%	60 60%	36 36%
Missing				
No reply	-	- -	- -	- -
Has the organisational structure had to ch...				
Yes	29	- -	14 48%	15 52%
No	71	4 6%	46 65%	21 30%

Table 9.4 Statistical relationship between change in organisational structure and achievements with CAD

The comments from the ten 2D only users and the 21 3D users about organisational changes are shown in Appendix C2.

For 2D users who suggested their organisational structure changed, there was no real commonality of change, since each company appears to have adopted a different approach from reducing staff or closing down departments or re-allocating staff. Only two companies indicated a move to a more multitasking/ team approach and they reported dis-satisfaction with CAD. So overall one might conclude that the changes are non strategic.

Companies employing 3D and suggesting that their organisational structure has changed are clearly focusing more on activities which can have an effect by combining departments and using multifunctional teams. A slightly higher number than the above two(4 companies) suggest the allocation of staff or managers for system administration, development and support.

For 91 of the 100 companies there was no change in working practices as a result of CAD. The changes made by the remaining nine companies however are shown in Figure 8.26 Of these nine companies, one employed 2D, two employed 3D only and six used 3D together with 2D. All nine companies, except three of the 2D/3D reported that they were achieving all they hoped from CAD. Of the companies reporting less than satisfactory achievements two had implemented shiftwork and one different hours of work.

Resistance to the technology

Responses to question 25, " Was there any resistance to the technology by users" yielded a 80% NO and 20% YES response as shown in Figure 8.27. Reference to Table 9.5 shows that there is a significant relationship at the 1% level (ie a very strong relationship exists) between this and CAD achievements.

"There is a significant relationship at the 1% level."

Absolute Analysis % Respondents	Base	Is CAD achieving all that you hoped it wou...	
		Yes	No
Base	100	60 60%	36 36%
Yes	20	7 35%	12 60%
No	80	53 66%	24 30%

Table 9.5 Statistical comparison of CAD achievements with resistance to the technology by all users

Table 9.6 contrasts this for 2D users only and shows a significant relationship at the 5% level ie a strong relationship exists between these two variables.

"Chi-squared value" 6.271701
"There is a significant relationship at the 5% level."
"25% of cells have an expected value of less than 5."

Absolute Analysis % Respondents	Base	Missing	Is CAD achieving all that you hoped it wou...	
		No reply	Yes	No
Base	53	3 6%	32 60%	18 34%
Missing				
No reply	-	- -	- -	- -
Was there any resistance to the technology...				
Yes	11	1 9%	3 27%	7 64%
No	42	2 5%	29 69%	11 26%

Table 9.6 Statistical comparison of CAD achievements with resistance to the technology by 2D only users.

Although Figure 8.27 shows that 20% of companies responded to question 25 on the questionnaire to indicate some resistance to CAD, 22% of companies actually provided written responses to question 26 concerning the format of this resistance. The comments from these 22 companies are shown in Appendix C3 and relate mostly to;

- Fear of change
- Reluctance to learn new skills
- Refusal to use the technology

There is a very slight increase in resistance evident between 2D and 3D users; ie 22% 2D, 25.5% of 2D/3D users and 37.5% of 3D only users report resistance to the technology. However, this has not resulted in any significant increase in absenteeism for example, as only 1 company reported this effect.

Company responses to the questionnaire regarding the effect that CAD has had on morale and relationships in their departments are shown in Appendix C4. Thirty six of the companies report that CAD has had no effect on morale whereas twenty six other companies report "Improved" morale, a further seven report closer interaction, teamwork or sharing of information and twelve companies indicate observing negative aspects on morale.

Of the thirty six companies observing no change in morale or relationships, 16 companies employ 3D and 2D CAD, 19 employ 2D only and one company employs 3D only. Because of the integrating nature of 3D CAD, one would expect that if 3D was being used for strategic company effectiveness, that some change would occur, certainly in relationships within and across departments, but also in terms of morale due to the possible broader scope of work involved.

Of the twenty six companies reporting improved morale, 8 use mixed CAD, 15 use 2D only and 3 use 3D only. Of the seven companies specifically citing closer interaction, teamwork and sharing of information 5 employ mixed CAD and the other two companies employ 2D only.

As stated previously, lists of comments from companies concerning morale are shown in Appendix C4 . However, the particular comments from companies indicating negative effects on morale are re-iterated below.

- Increased dependence by older staff on younger staff — 2D/3D user
- Frustration during the first six months learning period of CAD — 2D user
- Older members felt threatened — 3D user
- Problems between class of users — 2D/3D user

• Older staff have product knowledge not computer skills	2D/3D user
• Increase in abusive language at the software	2D/3D user
• CAD operatives were more likely to suffer from depression	2D user
• Increased pressure to produce drawings faster	2D user
• Adverse reaction	2D user
• One person refuses to use CAD-	2D/3D user
• Reduction in size due to redundancies	3D user
• Disputes over who has use of terminals in the design office	2D user

Summary

- For 2D users investment in capital equipment has on average only been around a quarter of that invested by 3D users and their need for CAD appears to have been predominantly driven by a desire to increase design productivity. Although some 3D users have rated productivity high in terms of their original need for CAD they rate more strategic company needs higher than the 2D user group.

- Just 17% of 2D only users changed their organisational structure as a result of CAD implementation compared with 42% of all 3D users. The 2D only users also appear to restrict the organisational changes whereas a higher number of 3D users report a more multitasking, teamwork approach to change.

- For 2D only users, where resistance to the technology has been indicated there is a clear link between this and companies lack of achievements with CAD.

- Twelve companies observed negative effects on morale and relationships as a result of CAD, seven of whom used 3D CAD and five 2D CAD.
- Thirty six companies reported no change in morale or relationships compared with 26 companies reporting improvements.

The majority of companies in this survey have been employing CAD for a sufficient amount of time to have achieved the following benefits.

- Be attaining the opportunities originally envisaged for CAD and to have recognised what further opportunities exist from its use and development.
- Have addressed organisational changes to their working structures to ensure CAD becomes a much more strategic technology to the company rather than just an electronic drawing board.
- Have recognised that irrespective of whether no change is observed in terms of morale and relationships within the department, that CAD can have a positive or negative effect on this and thus positively address the issues.

However there is no strong evidence to show that the above has been achieved by the majority of companies.

9.4 SUPPORT STRUCTURES FOR CAD

Introduction

During the initial pilot study it was observed that there was essentially a lack of support in all the companies except one. Companies generally reported that there was no real internal support. Mostly they suggested support was the responsibility of the individual designer to himself or of the design team leader/ manager with no time for support. In these cases support tended to be relegated to the vendors of the software when problems were experienced.

The one exception was company "1" which had a specific departmental support structure and employed one person in this role.

During the case studies similar support methods (and lack of support) were observed, however in some cases more formal support structures existed where internal teams of support staff were employed in a CAD support role.

The observations from the pilot and case studies thus provided a structure for defining questionnaire questions in the area of support. Thus companies were asked to clarify their support structure as the responsibility of:

- A separate CAE/CAD support department
- A vendor help line
- The function of a separate company I.T. department
- One person

Using this rubric, the support provided by companies is discussed for each class of user, ie. all users, 2D only and 3D users.

All Users

Figure 8.28 shows the support structures used by all companies. The greater number of users (48%) employ one person in a supporting role followed by 44% employing a vendor help line. Only 19% have support as a function of a separate IT department and even less, 6% employ a separate CAE/CAD support department.

2D Users

The general trend of lack of internal company support is mirrored by the fifty three 2D users.

The majority (43%) use a vendor help line and/ or one person support whilst only 17% employ separate IT section support and only 4% employ a separate CAE department

3D Users

With the increase in complexity and departmental integration that can accrue from the implementation of 3D, greater support is needed and this is seen in the figure. There is a slight increase in the numbers employing separate IT or CAE/CAD department support; 21% and 9% respectively.

However 53% of companies rely on one person to provide support and 45% employ vendor support.

Interestingly, half of the eight companies using 3D only (Not 2D) utilise the support of one person, 3 employ vendor help and only one company uses separate IT support. None of the companies employ a separate CAE/CAD department.

In responding to question 47 of the questionnaire regarding the impact of CAD on the company, 36% of all companies surveyed (ie 34% 2D and 38% 3D users) indicated that they were not achieving all they hoped from CAD whilst 60% indicated that they were satisfied.

Detailed analysis of this 96% of all users (ie 96 companies) has been carried out via manual extraction of data from the questionnaire database to identify;

- Support structures employed by individual companies
- Activities carried out ie 2D or 3D
- What problems the companies were experiencing

Of the above 96 companies, 88 responded to indicate the type of support utilised.

Figure 9.2 derived from the above results, illustrates the number of the 88 companies, using a particular support structure, in relation to expressed levels of satisfaction with what they are achieving from CAD.

Discussions with CAD staff appears to indicate that it is reasonably satisfactory to consider some types of support as being more significant than others. Therefore, for this research, the use of 1 person plus vendor, 1 person or vendor only support is categorised as "limited" support, whilst the use of I.T. or CAE departments, singularly or in combination with other staff and/ or vendors is categorised as "significant" support.

It is clear from figure 9.2 that the majority of users, (66%) rely on one person support or the vendor for all categories of CAD users.

Only around 24% of the sample shown have significant internal support through the use of some form of separate I.T or CAE department.

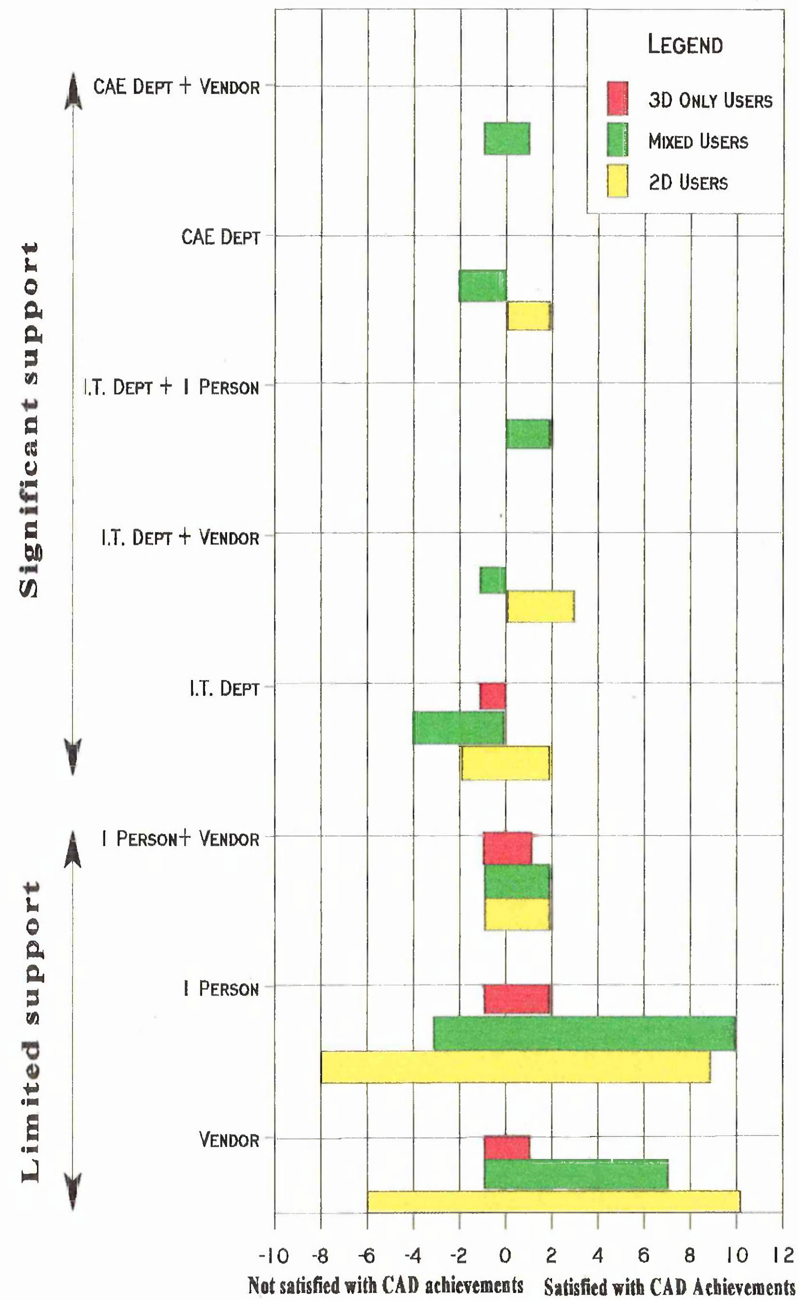

Figure 9.2 Numbers of companies expressing levels of satisfaction with CAD achievements in relation to support structures employed

. Of the 66% of the group employing **"limited support"**, 41% of users are dis-satisfied with their achievements from CAD.

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Of the 24% of the group with **"significant support"**, 52% are dis-satisfied with their CAD achievements. Figure 9.3 further analyses the satisfied/ disatisfied results to illustrate the relationship between support type and CAD usage.

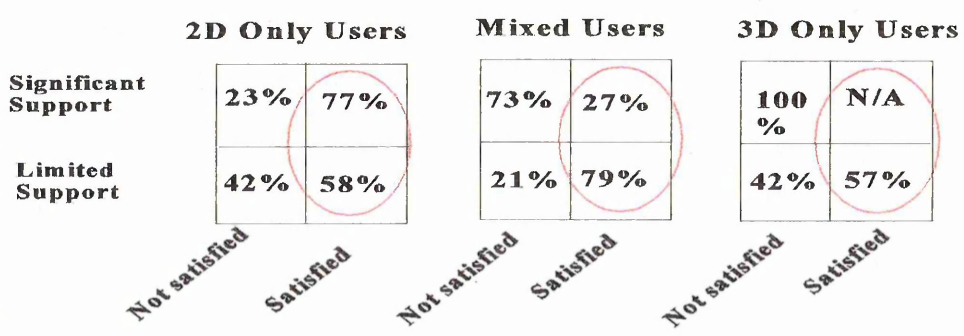

Figure 9.3 Comparison of satisfaction in relation to support type and CAD usage

Ideally companies should be generally satisfied with CAD achievements and this should be evident by the majority of users in each group tending towards the top right hand side of the diagrams in Figure 9.3.

Seventy seven percent of those 2D CAD users with significant support indicate a general satisfaction with what they are achieving with CAD.

Contrasting this with mixed users however (2D and 3D) shows the reverse, with 73% of those users employing significant support structures indicating dissatisfaction with what they are achieving from CAD.

Clearly, for companies using simpler 2D systems with the majority being satisfied with their achievements, then the increased level of support is of benefit.

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It seems though that with the more complex mixed 2D/3D systems there may be an issue with the effect of support structures.

The overall extent of satisfaction or dissatisfaction with support is shown in Figures 8.29a and 8.29b. The figures show the percentages of companies responding with not supported/ needed, world class, satisfactory or poor support for each of the activities in question 31a to q31n of the questionnaire (previously listed in section 8.2.6 but re-iterated here to remind the reader).

A Procedures for draughting

B Implementation of macros

C System configuration

D Data transmission

E Control of upgrades

F Organisational change

G Solving problems

H Developing 3D methodologies

I Creation and update of databases

J Training of designers and programmers

K Documentation

L Reviewing and monitoring problems

M Administration and organisation

N Design and analysis packages

Only a very minute percentage of the total sample of 100 companies report World Class support and even then that is limited to particular support activities, not running across the full spectrum of support activities. For instance, the highest percentage reporting "world class support" for any of the support activities listed above, is 5% of the total sample for procedures for draughting. No one reports world class support for either organisational change, reviewing and monitoring problems, solving problems or administration and organisation.

The training of designers and programmers is reported as world class by only 4% of total respondents and the development of 3D methodologies by 1% of respondents. These results are disturbing, since building world class capability to compete strategically in world markets must start within the organisation at an operational level. Most of the companies report either poor or satisfactory support for activities. However, the situation is slightly different than shown as these figure include the "No replies" and the "Not needed/ supported" responses. Making adjustments for this and extracting only data to focus upon responses concerned with an expression of poor support, produces the data shown in Table 9.7

Support Activities	Percentage of companies indicating "Poor" support for support activities		
	2D Only	**Mixed**	**3D Only**
Procedures for draughting	7	9	25
Implementation of macros	69.2	50	50
System configuration	23.8	11.5	50
Data transmission	26.3	16.6	25
Control of upgrades	35	20	0
Organisational change	38.4	23.1	0
Solving problems	52.6	16	40
Developing 3D methodologies	71.4	29.1	75
Creation and update of databases	53.3	37.5	50
Training of designers and programmers	64.2	32	33.3
Documentation	31.5	50	100
Reviewing and monitoring problems	53.3	30.4	0
Administration and organisation	25	22.7	0
Design and analysis packages	30	15.8	50

Table 9.7 Percentages of companies indicating poor support for support activities

A significant number of the companies report poor support for many of the areas identified in the Support Model in Figure 6.2 on page 174, such as:

- Documentation
- Training
- Creation and update of databases
- Implementation of Macros
- Problem solving
- Developing 3D methodologies

Surprisingly, in spite of the fact that figure 9.3 indicates the majority of 2D users are relatively satisfied with achievements from CAD, the data in table 9.7 indicates that for all but two of the support elements, procedures for draughting and documentation, a significantly higher percentage of 2D users rate the remaining aspects of support as being poor compared to mixed users.

Average support ratings

Using a numerical rating system which scores one point for poor support, two for satisfactory and three for world class support and ignoring both the no replies and activities identified by companies as not being required, an overall percentage support rating was calculated for each company. For instance, by this method a company indicating all fourteen activities were poorly supported could score only 14 out of a maximum 42 points. Thus totally poor support would be represented by a score within the area of 33%. Similarly satisfactory support for every activity would be represented by 66% and world class by 100%. Obviously this is only a guide to the quality of support, since companies could select any of the three rating categories for each activity. However, further collation of the data provides the following ratings for support activities.

	2D Users	Mixed Users	3D Users
Average Rating	56.4	61.1	57.5
Highest Rating	72	78.7	67
Lowest Rating	33.3	33.3	50

Table 9.8 Average support ratings

The relatively small difference in the above ratings does not necessarily convey the influence that support quality has on the levels of satisfaction. However, figure 9.4

shows a definite relationship between increasing levels of support quality rating and the numbers of satisfied companies. Both 2D and mixed uses show higher numbers satisfied than not satisfied as the support quality increases. For 3D only users the trend is however reversed.

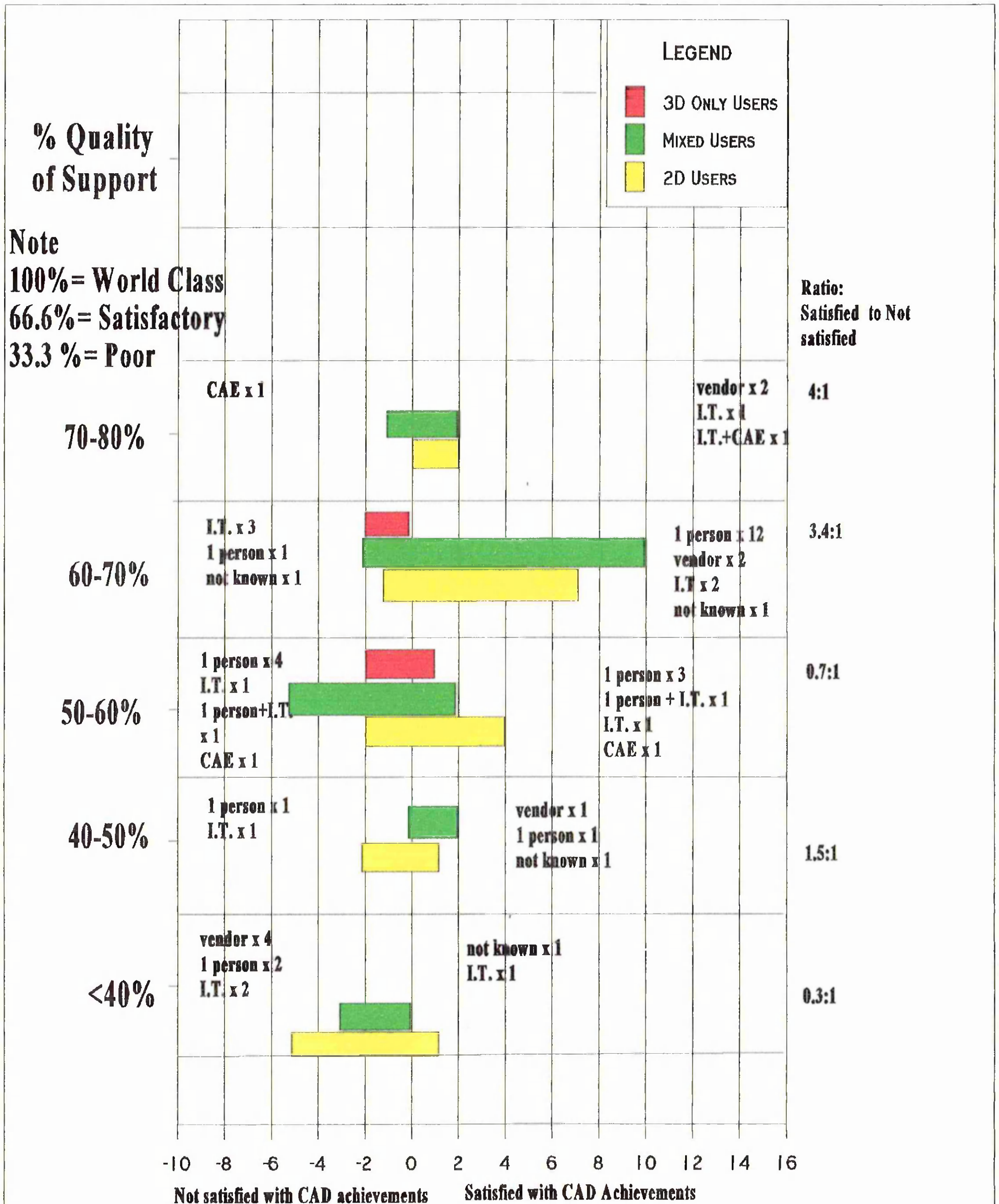

Figure 9.4 Numbers of companies expressing levels of satisfaction with CAD achievements in relation to support quality rating

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For those mixed and 3D only users indicating that they were not satisfied with CAD, the support issue becomes clearer upon further analysis of their responses to question 39 "Where staff experienced difficulties with 3D, what were the main problems".Replies to this question are shown in detail in Appendix C5 and indicate that many are experiencing problems with 3D such as:

- Defining complex models
- Technique problems
- Making the system work to its maximum potential
- New methods of working, file control, storage etc.
- Database management

Average support ratings and the influence of support type

Figures 9.5a to 9.5g illustrate the support quality ratings given by numbers of companies employing each support structure.

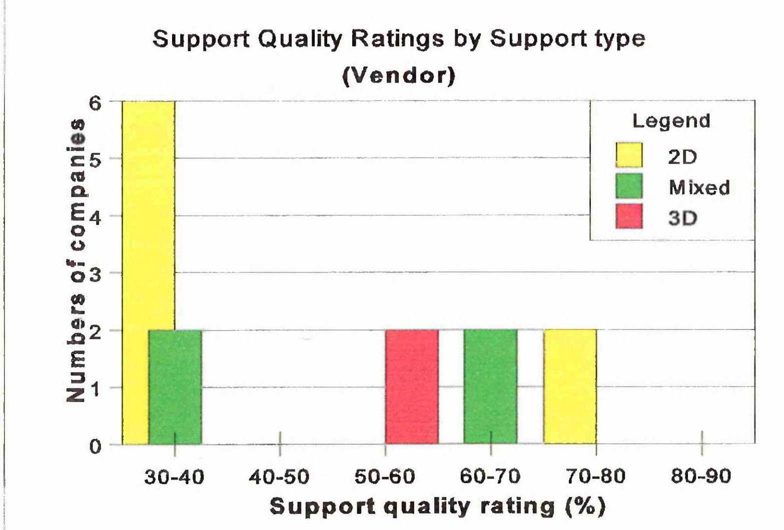

Figure 9.5a Support ratings for vendor support

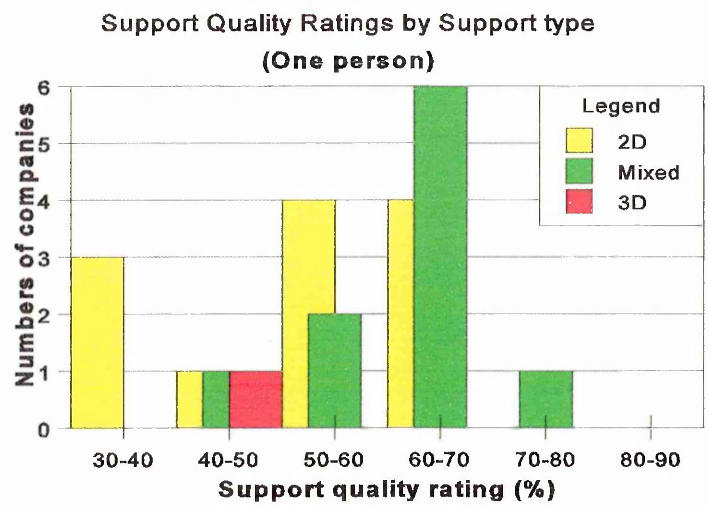

Figure 9.5b Support ratings for one person support

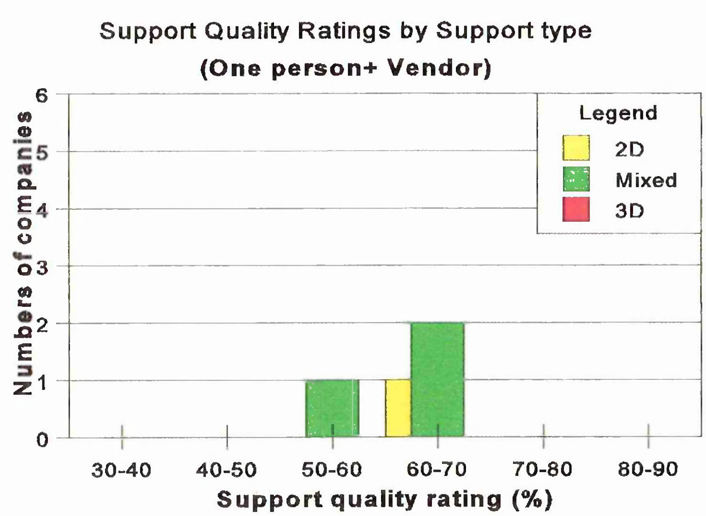

Figure 9.5c Support ratings for one person+vendor support

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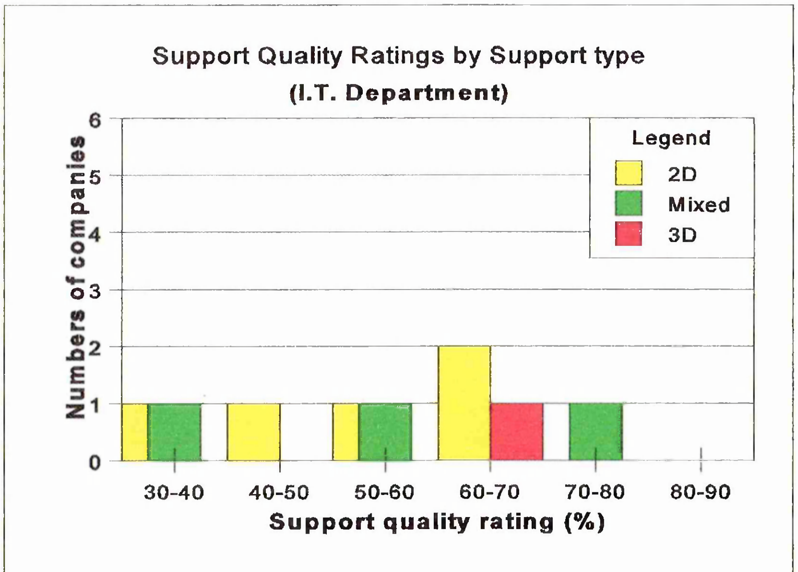

Figure 9.5d Support ratings for I.T.department support

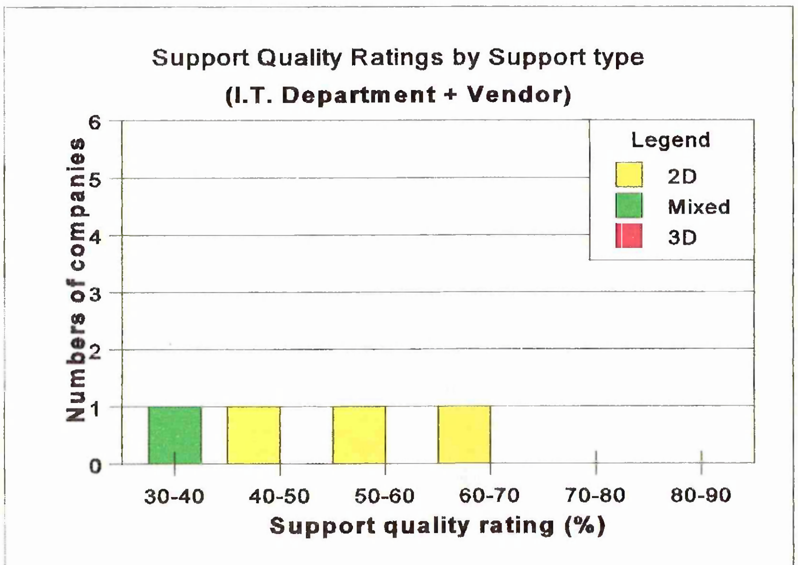

Figure 9.5e Support ratings for I.T. + vendor support

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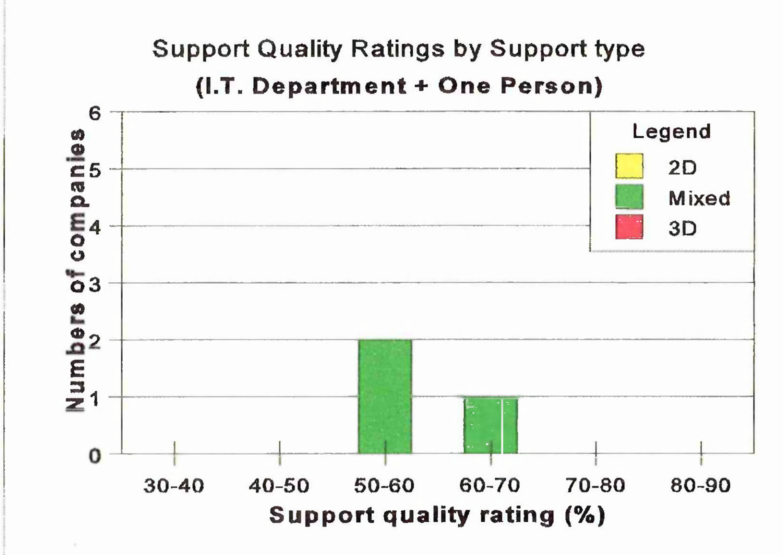

Figure 9.5f Support ratings for I.T. + one person support

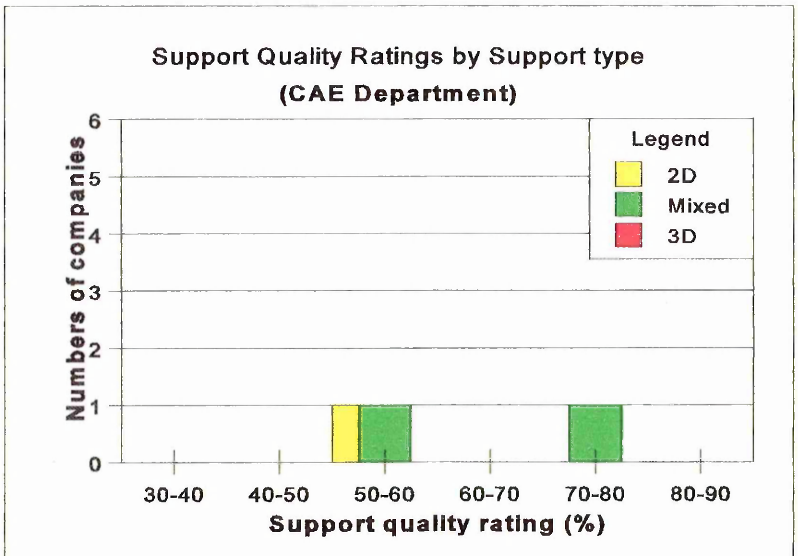

Figure 9.5g Support ratings for CAE department support

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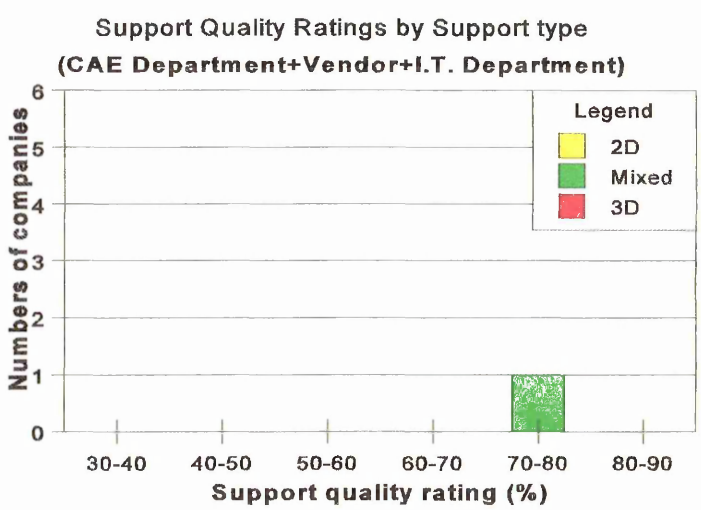

Figure 9.5h Support ratings for CAE+vendor+I.T. support

Summation of the areas on each chart allows the calculation of an average support quality rating for each category of support and provides the following rating figures.

Vendor support-	48.8%
One person-	56%
One person plus vendor-	62.5%
I.T. department-	60%
I.T. department plus vendor	50%
I.T. department plus one person	58.3%
CAE department-	61.6%
CAE department plus vendor and I.T. department-	73.8%

Clearly, vendor only support is rated lowest and CAE department plus vendor and I.T. department is rated highest, but there is sufficient variation between other support types to suggest that the quality of support is more important than the type of support structure.

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9.5 TRAINING

When first implementing a CAD system, (assuming all the relevant decisions have been made about which system and why) one of the first questions will be who will use the system and who should be trained.

Training may for instance be restricted to;

- Just those who will use the system
- Senior designers only
- All designers
- Anyone who is interested

In this survey companies have indicated an almost equal split between training all designers (45 companies) and training only those who were to use the system (46 companies). Two companies reported training senior designers only, 5 anyone who was interested and two did not reply.

This proportion is also almost equally split between users of 2D and 3D as shown in table 9.9

Systems Used	Trained all designers	Trained only those who would use the system
2D	21	26
2D/ 3D	24	20
3D Only	3	5

Table 9.9 Number of companies employing the given approach to training

Types of Training Employed

Results of company comments regarding training are shown in Figure 8.30 and relate to the five approaches listed below, used either singly or in combination.

A Basic internal vendor course (held on site at the company)

B Basic external vendor course (ie external to company)

C Advanced vendor course

D In-house training by company expert

E Self teaching from manuals

In this survey 60% of companies have indicated their use of basic external vendor courses, 22% basic internal vendor courses and 29% advanced vendor courses. A further 33% employed in-house training by company experts and 2% were self taught from manuals. The main differences between the groups of users in respect of training is that around 50% of 3D users employ advanced vendor courses compared with 11% of 2D users, reflecting the increased complexity and difficulty associated with 3D.

Analysis of CAD training in relation to level of achievements obtained by companies is illustrated in Figure 9.6 on the next page.

"Chi-squared value"   2.961162
"There is no significant relationship"
"20% of cells have an expected value
of less than 5."

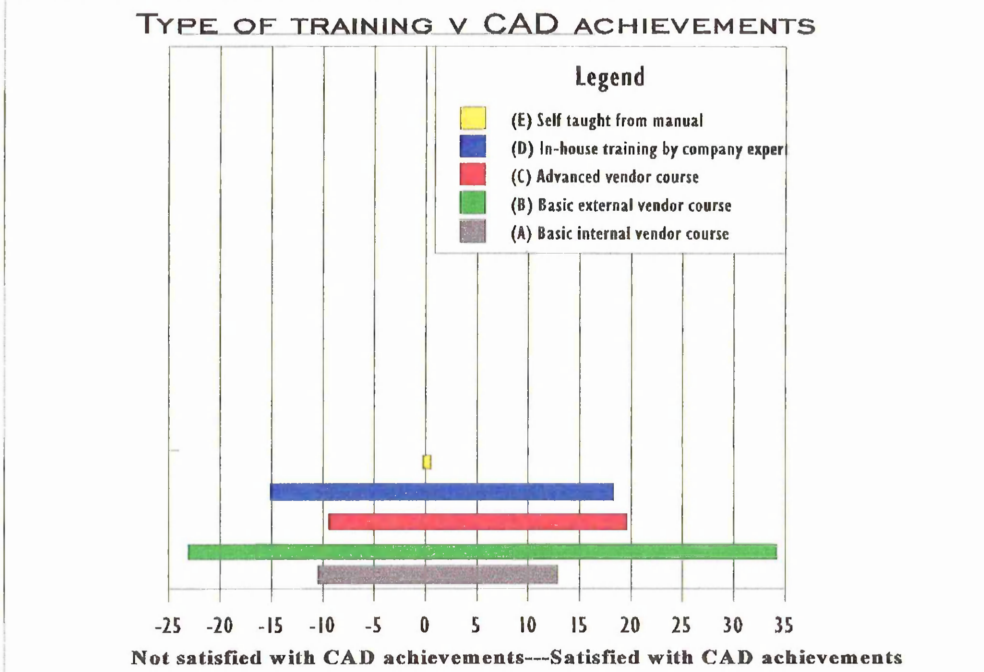

Figure 9.6 Numbers of companies expressing levels of achievements in relation to training methods employed

There is no significant relationship between the type of training employed and companies perceptions of achieving what they hoped for from CAD, either in the total survey sample as illustrated or in the individual sample groups.

Hence the proposition is that perceptions of satisfactory achievements is not a function of the type of training employed and must be the result of activities further down the line of implementation.

Further indication of this is shown in Figures 9.7a to 9.7c The figures contrast the elements of training type, support structures employed and attainment of satisfaction with CAD

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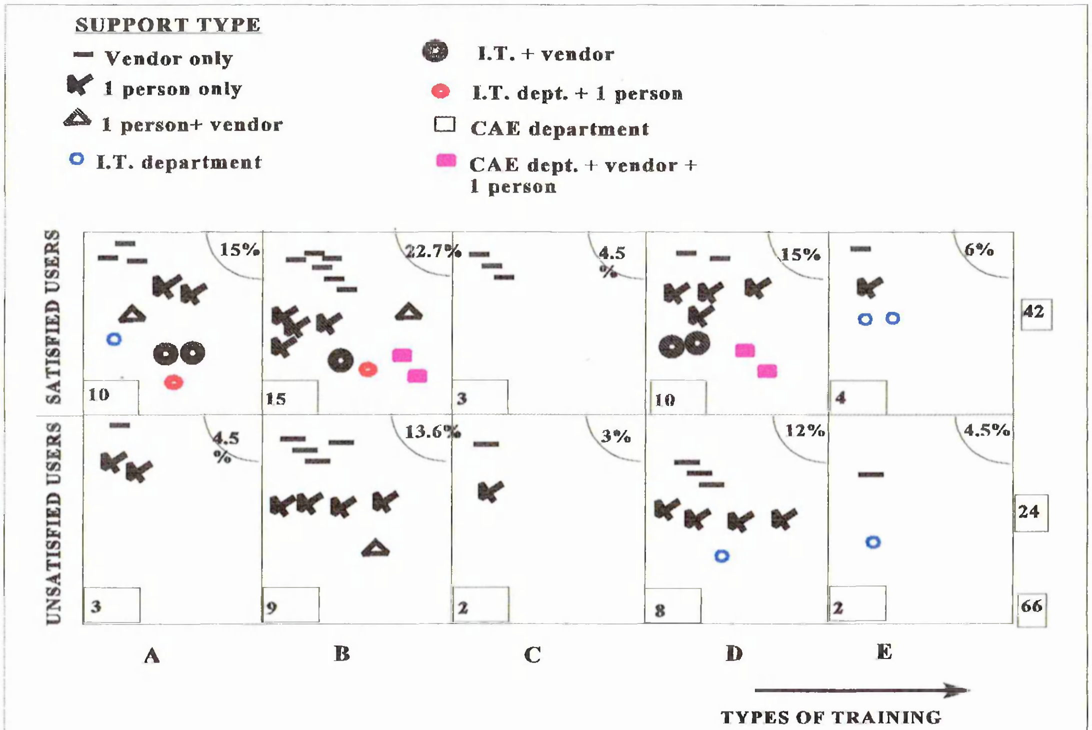

Figure 9.7a Relationship between types of training, type of support and satisfaction for 2D only users

Types of training, A to D have been previously defined on page 313.

In addition to being the most popular, A and B are the most successful training types for 2D users. However for mixed users (shown on the next page) type B and C are more successful as might be expected for this class of user. For 3D only users shown in figure 9.7c, there is no obviously successful training type.

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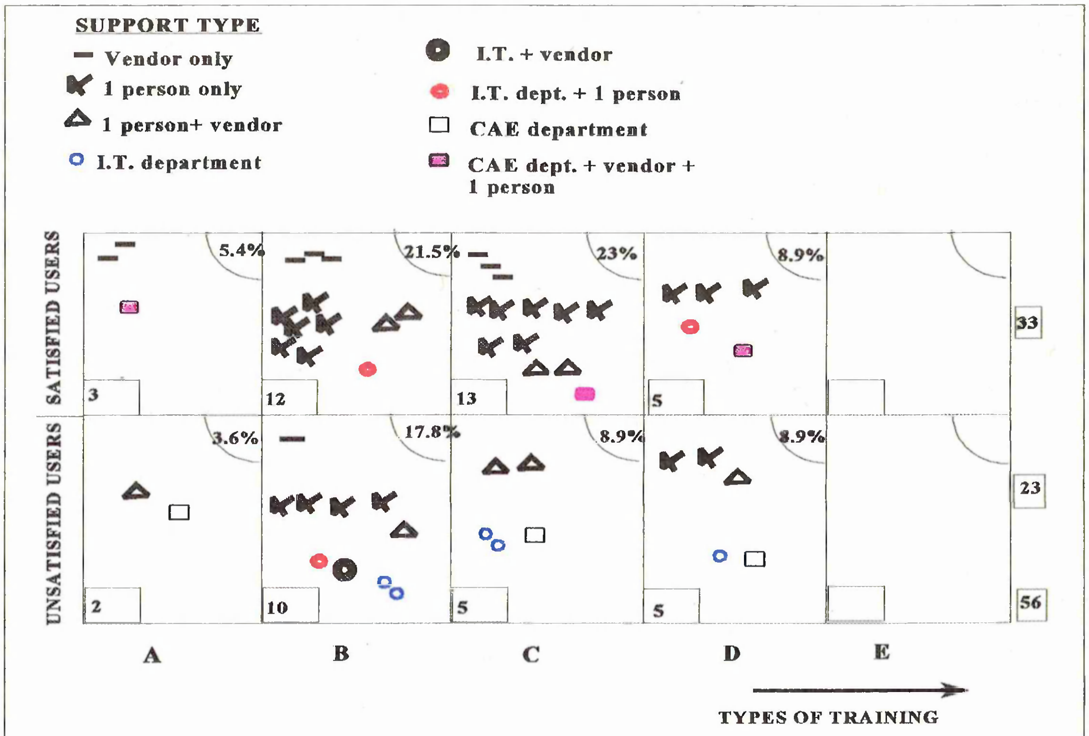

Figure 9.7b Relationship between types of training, type of support and satisfaction for mixed users

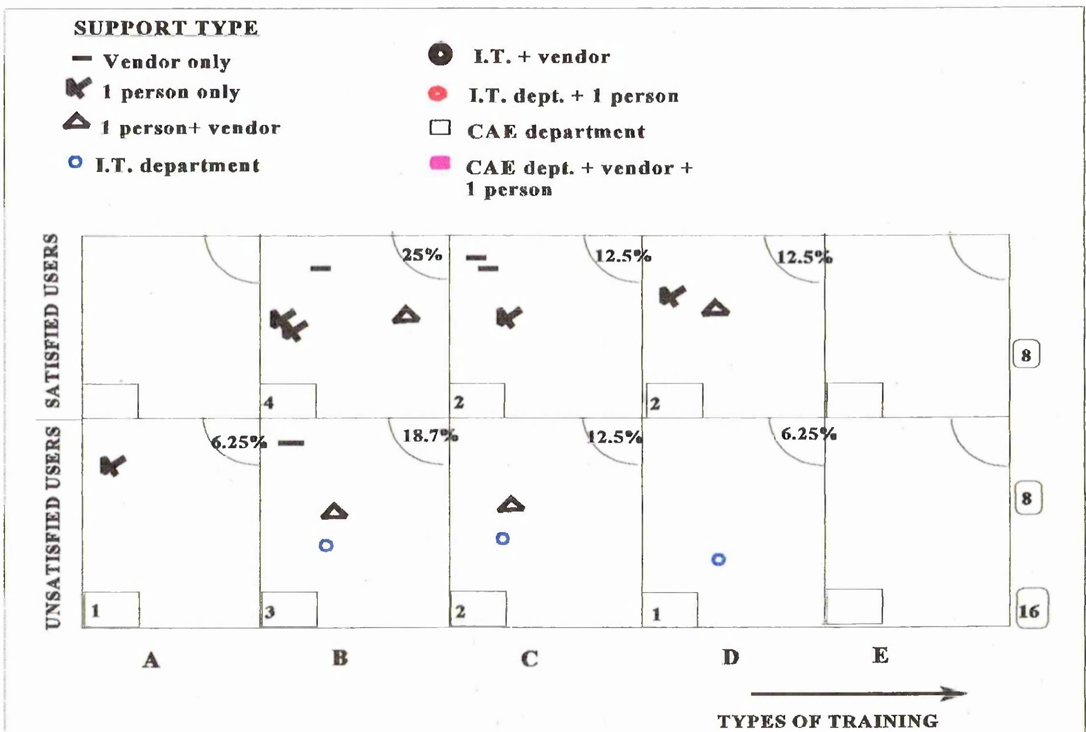

Figure 9.7c Relationship between types of training, type of support and satisfaction for 3D only users

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If the use of vendor only support is ignored (because it is not a form of internal company support) and the number of items in each training category in figure 9.7a to 9.7c are summated, then there is no significant difference between the ratio of satisfied to dissatisfied users for each training approach as shown in table 9.10. ie the training approaches employed have not been a significant factor in producing satisfaction.

Training type	A	B	C	D	E
Satisfied	8	21	11	15	3
Not satisfied	5	16	8	11	2
Ratio of satisfied to not satisfied	1.6	1.4	1.5	1.4	1.5

Table 9.10 Indication that training is not a governing factor in satisfaction

Time Allocated to Training

Figure 8.31 shows the distribution of training time for the four groups in this sample. Just over 40% of users employ one week as the main formal training period. This is the same for 2D/3D users as it is for 2D users, yet as discussed in chapter 1, 3D CAD systems are more complex and difficult to use. Around the same percentage of 2D and 2D/3D users (approx 21%) choose to allow two weeks training . Training of three weeks or more appears to be the province of 2D/3D and 3D only users with around 25% allocating this time as opposed to 8% of 2D users.

Although there is no substitute for effective and efficient training, it is interesting to note that there is strong evidence (shown in Table 9.11) that there is no relationship, in the perceptions of CAD users, between the length of initial training and their satisfaction with CAD achievements.

"Chi-squared value" 0.950903
"There is no significant relationship at the 5% level."
"50% of cells have an expected value of less than 5."

Absolute Analysis % Respondents	Base	Is CAD achieving all that you hoped it wou...	
		Yes	No
Base	100	60 60%	36 36%
How many weeks were spent on training per ...			
1 week	43	26 60%	16 37%
2 weeks	21	13 62%	7 33%
3 weeks	12	6 50%	5 42%
4 Weeks or more	4	2 50%	2 50%
Evening classes: eg C & G	4	3 75%	1 25%
1 or 2 days	9	6 67%	3 33%

Table 9.11 Relationship between length of training and satisfaction with CAD

For example, 60% of users employing a one week training course are satisfied with CAD. Similarly, 62% of users employing a two week course are also satisfied with CAD. This reduces slightly to 50% with companies who used a three or four week training course and increases significantly where users only received a one or two day course or evening class tuition. However, it is highly probable that the depth and length of initial training is such that only surface learning is achieved and consolidation of learning, together with satisfaction, is provided by longer term practice, experience and support.

Investment in Training

Amounts of total money invested by 75% of companies in CAD training are shown in Figure 8.32 and represent some small and large investments. The remaining 25% of companies chose not to reveal this sum. Of the 75% of companies represented however, the various levels of investment produce an almost relatively uniform bell shaped curve over the range (when plotted out as a bar chart in Figure 9.8) suggesting that the sample is unbiased.

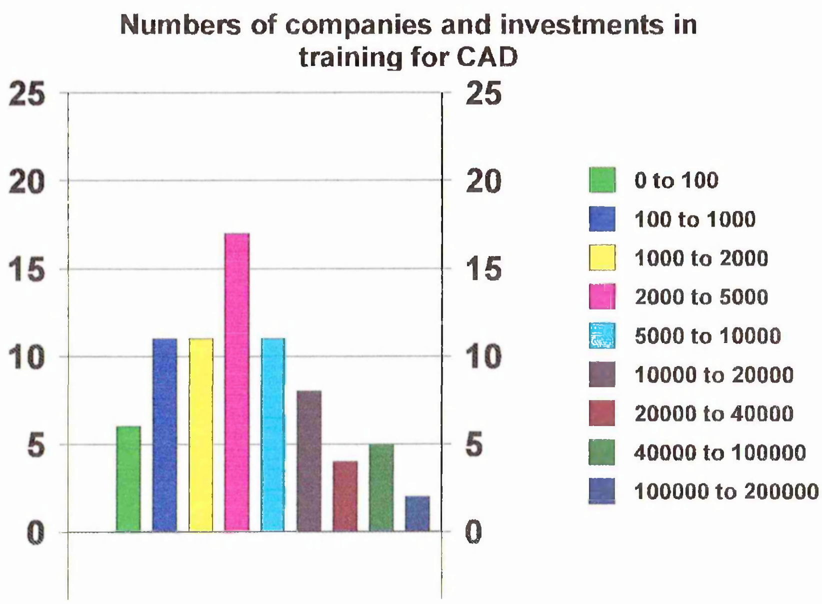

Figure 9.8 Levels of investment in training (£)

Over 41% of 2D users spent less than £2000 in total on training compared with 12%of 2D/3D users and 13% of 3D only users. At this point however 2D users spending more than this decreases rapidly whilst 2D/3D and 3D only users spending more than this increases. eg only 29% of 2D of users indicated that they spend over £2,000 as opposed to 66% of 3D users.

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These figures are contrasted in Figure 9.9 which considers investment in training per seat of CAD in relation to capital investment per CAD seat.

KEY ◆2D ■3D

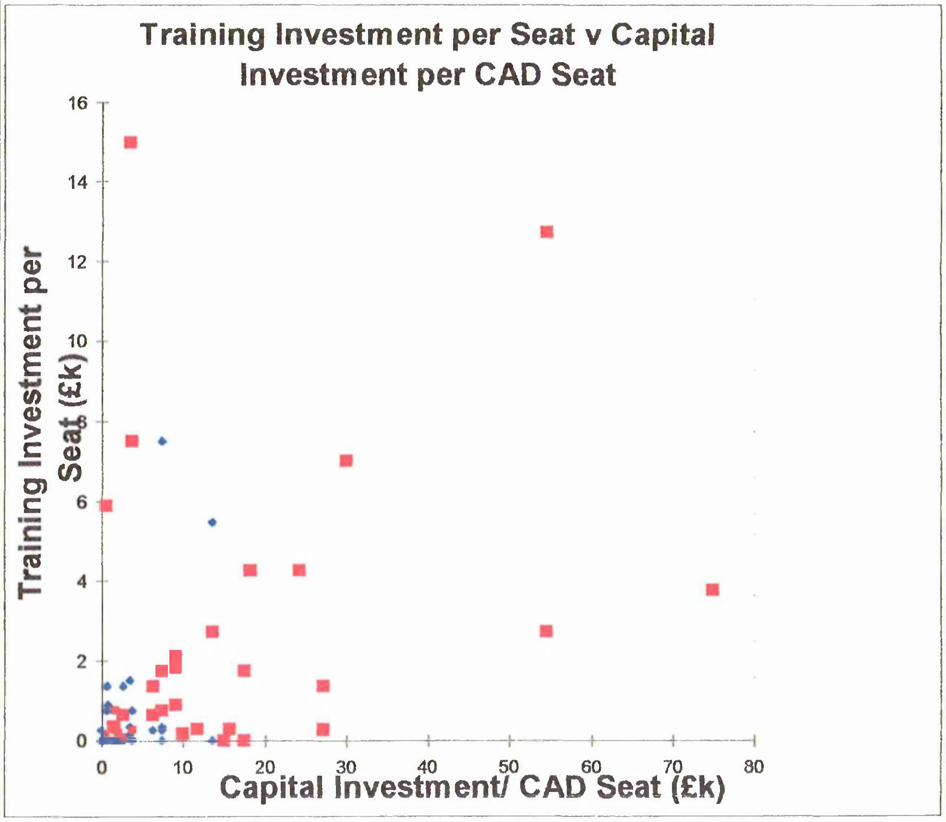

Figure 9.9 Training investment per Seat in CAD in Relation to Capital Investment per Seat

A number of companies have invested heavily in capital equipment, eg. up to £75k, but have only invested small amounts in training to use the system whilst others have clearly supported their capital investment with appropriate and sometimes excessive investment in training.

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The scatter diagram in Figure 9.10 shows the overall picture of company satisfaction along the "x" axis in relation to the training investment per seat of CAD by individual companies (as a percentage of the capital expenditure per seat of CAD) along the "y" axis.

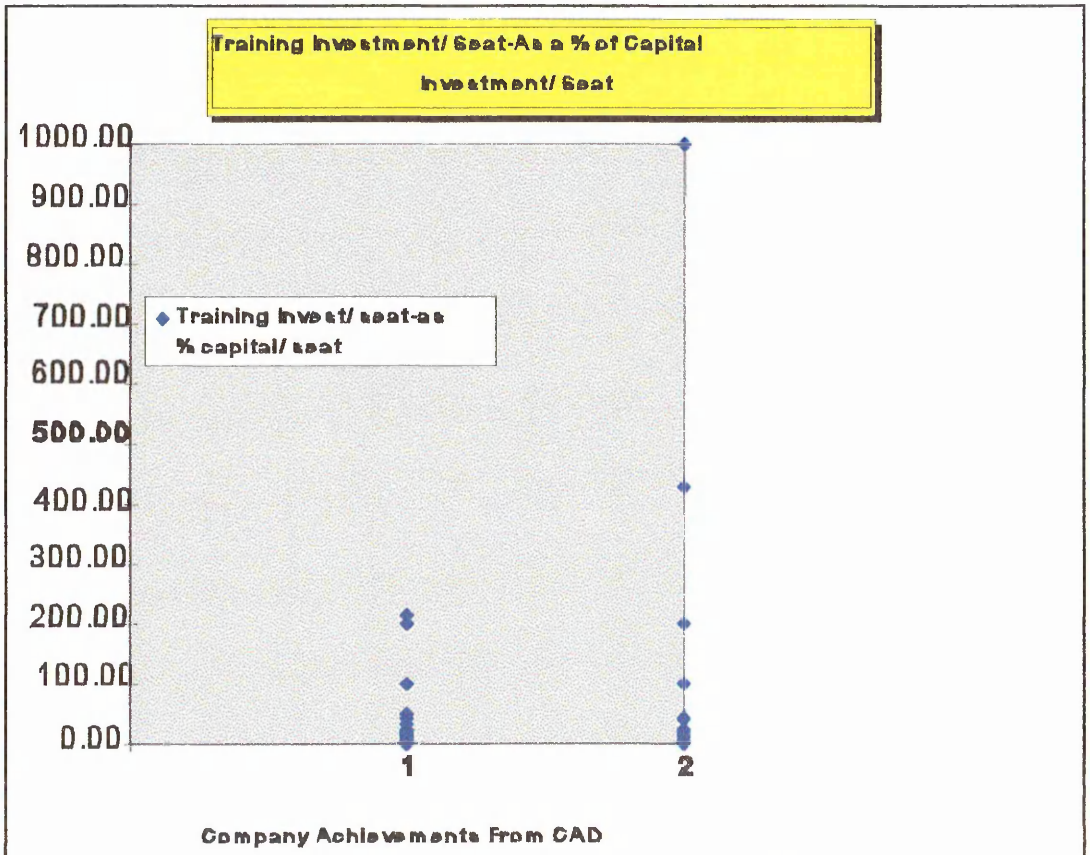

Figure 9.10 Investment in training as a percentage of capital investment per seat in relation to satisfaction with achievements from CAD- 1= satisfied 2= not satisfied

Twenty companies chose not to provide figures for training investment for reasons. Eight companies did not reply to the question, 9 companies suggested they did not know the figures because they had never been calculated and three companies indicated that they did not provide investment in training.

Of the twenty respondents unwilling or unable to provide figures for training 15 were

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employed as managers or directors in the design area and should have been able to estimate the amount spent.

Cumulative figures for the total sample of 100 companies show that 4 invested less than 1% of the capital investment per seat in CAD into training. Eighteen companies invested less than 5% of the capital budget, 24 companies less than 10%, 37 companies less than 15% and 57 companies less than 30%. Nine companies invested between 30% and 50% whilst three invested the same amount in training as in the capital cost per seat. Surprisingly five other companies invested significantly more into training than they invested in each CAD seat; three companies allocating around 200% , one 482% and one other an amazing 996%.

Essentially though, the majority of companies are clustered near the bottom end of the scale having invested relatively small amounts in training. Sixty companies reported that they were satisfied with CAD and thirty six reported that they were unsatisfied. Of the sixty satisfied users, 32 were 2D only users and 28 were 2D/3D users and two of these invested around 200% in training. Similarly for the companies who were unsatisfied, three were 3D users investing respectively 200%, 482% and 996%. The contribution of these five users to the results in this research could tend to skew them somewhat. Therefore ignoring these high values and also ignoring none responses to question 35 regarding investment in training, the average training investment as a percentage of capital investment per seat is shown in Table 9.12

SATISFIED		NOT SATISFIED	
2D	3D	2D	3D
19.2%	21.05%	17%	14.5%

Table 9.12 Average investment in training as a % of capital investment

Where companies are satisfied with CAD, the average investments in training for both groups of user (2D and 3D) are similar. Within the "Not satisfied" group 2D users have invested 2% less than the satisfied group but this is a very small difference. The average investment by 3D users however is 6.5% less than the satisfied group spend. Again this is only a small difference but it could have an impact upon training, understanding and the ability to use CAD effectively.

However, it has been shown that three companies have invested over 200% and have not ensured satisfaction. Thus other factors like effective support to use the system may play a more important part.

Further detailed analysis for 2D users only, indicates the appearance of some relationship between the levels of investment in training and the levels of satisfaction with achievements from CAD as shown in figure 9.11over the page.

Chi-squared value"	10.141204
"There is a significant relationship at the 5% level."
"57% of cells have an expected value of less than 5."

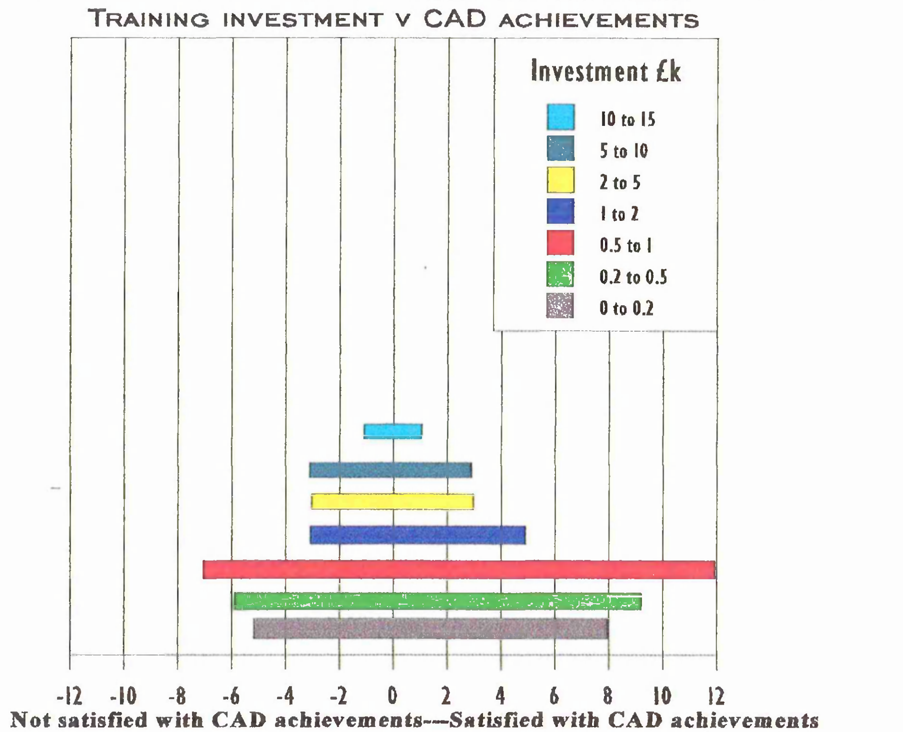

Figure 9.11 Levels of investment in training per CAD seat in relation to levels of satisfaction with CAD

As 2D companies invest larger amounts in training there is a trend for more companies to be satisfied with CAD achievements.

Effective Use of Systems

Figure 8.33 illustrates the length of time taken by companies before staff became effective users of their CAD systems. For 2D users the average time was around eight weeks. For companies employing both 2D and 3D the average time is over ten weeks (Calculation based upon ignoring the 4.3% of companies who took much longer than twelve months). For the eight companies employing 3D only, the average time to

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become effective users is above 13.8 weeks (again ignoring the 12.5% who took more than 12 months).

Comments from all 100 companies (both 2D and 3D users) stating the main problems that staff experienced in becoming effective users are listed in Appendix C6. However, there are a number of common themes running through these comments such as:

- Interacting with an electronic model
- Move to thinking in 3D
- System operation and use
- Training/ Time to practice

Nine companies stated their staff had no problems in becoming effective users. In this group, six companies employed just 2D CAD, two 2/3D and one 3D.

The remaining companies all stated some problems as categorised above, in becoming effective users.

All of these problems can be addressed by the provision of internal company support.

Figure 8.34 shows that over 60% of the 3D users stated that they experienced difficulties specific to 3D and these were discussed in section 9.4 and shown to be related to defining models, technique problems, methods of working and system management.. Reactive solutions adopted by companies to overcome the specific difficulties experienced with 3D are listed in Appendix C7 but are categorised below in Figure 9.12.

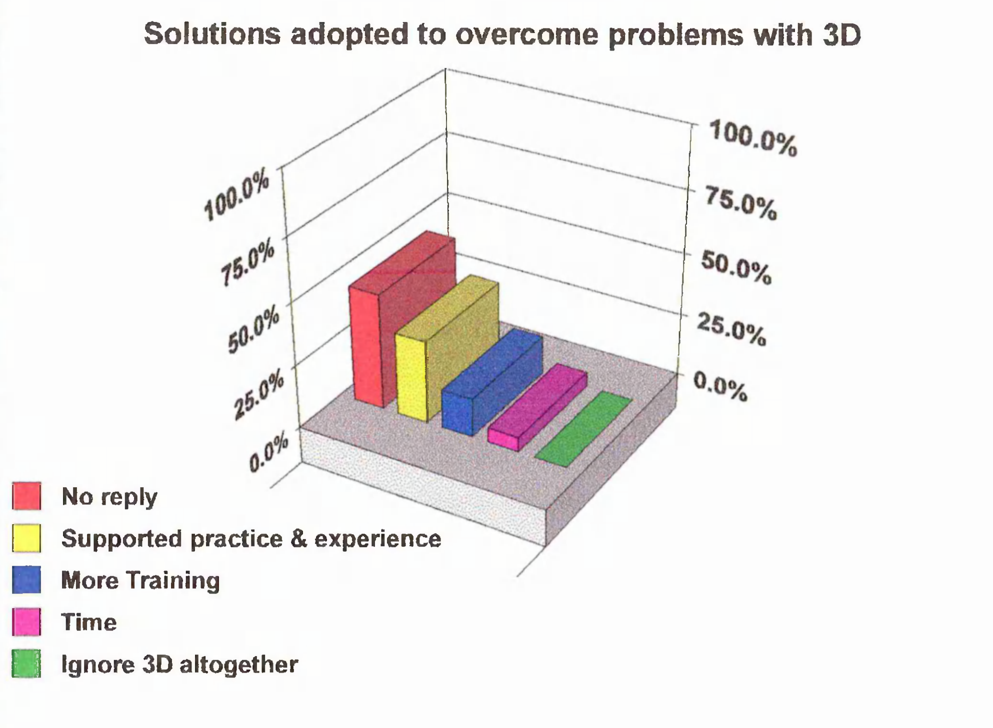

Figure 9.12 Solutions adopted by companies to overcome problems with 3D

If such reactive support was channelled into a strategic support plan both at the beginning of and during a CAD implementation, greater effectiveness would be achieved.

9.6 IMPACT OF CAD ON THE COMPANY

As stated previously, companies perceptions of achievements with CAD are illustrated in Figure 8.35. However, this is contrasted further with their perceptions of achievements in terms of impact on company business as shown in Figure 8.36. Only 25% of users report a significant impact on business. Around 20% of companies in each group of users report a satisfactory impact on business with opportunities still being

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sought by 23% of 2D users, 19% of 2D/3D users and 25% of 3D only users. For world class impact, all the companies need be building their CAD systems capability into a strategy which has a significant impact on business, not just a few minor areas

Figures 8.37 and 8.38 show company perceptions regarding the number of new products introduced during the last year and over the last five years.

Generally the introduction of new products is low, although to some extent this is masked by the categories of responses eg 1 to 5 new products.

Data regarding the number of new products introduced over the last five years was manually extracted from the questionnaire and is summarised in Table 9.13

SATISFIED				NOT SATISFIED			
2D Users		3D Users		2D Users		3D Users	
Over 5 Yrs	Last Year	Over 5 Yrs	Last Year	Over 5 Yrs	Last Year	Over 5 Yrs	Last Year
33	7.7	48	11	5.3	2.2	12	4.4

Table 9.13 Average numbers of products introduced by user groups

Both 2D only users and all 3D users are categorised in the table by their level of satisfaction with CAD and the average number of products introduced by the groups. The figures provide a guide, rather than a strict rigid numerical analysis of the situation. This is simply because in the satisfied 2D group, three companies provided statements that their work involved bespoke one off designs on a continuous basis rather than introducing new products. Within the 2D not satisfied group, four companies indicated bespoke/ special jobs rather than new products and one company just stated "lots" rather than providing a figure.

In calculating the average, these companies were included in the total as were the "no replies", two no replies within the 2D groups and three within the 3D groups. One 3D user in the not satisfied group was ignored because the figures for new products introduced (2500 over five years) were astronomically different to all the rest of the group and would have significantly affected the results.

Over five years, the 2D not satisfied users have only introduced 16% of new products compared with satisfied users and over the last year have on average only introduced 28.5%. The 3D not satisfied users, have introduced more than this but have still only introduced a quarter (25%) of new products compared with the equivalent satisfied group and less than half (40%) compared with the same group during the last year.

It is interesting to note that the benefits seen by companies as a direct result of CAD, shown in Figure 8.39, are clustered around Productivity and Quality with almost 60% of all companies reporting these benefits. Increase in productivity itself is not a significant impact on business rather just the ability to do drawings quicker.

Where companies can gain greater business benefit is with new areas of work, reduced costs and speed to market with existing and new products. However of the total group of companies surveyed, less than 20% report such benefits. 2D users sit below the 20% level for achievement of these benefits whereas 3D users report a slightly higher achievement in terms of new areas of work and reduced costs, but not significantly so.

9.6.1 Problems Experienced by Companies

A survey by the Bostock Marketing Group in 1990 (151) indicated that at that time only

5% of companies believed they had achieved the anticipated benefits from CAD.

Even now, this research work is finding that many companies still have problems.

The perceptions of the main problems experienced by the 36 companies indicating that they were not achieving all they hoped from CAD are listed in Appendix C8.

However, to provide an effective overview of these comments, the main themes/ issues are summarised in figure 9.13.

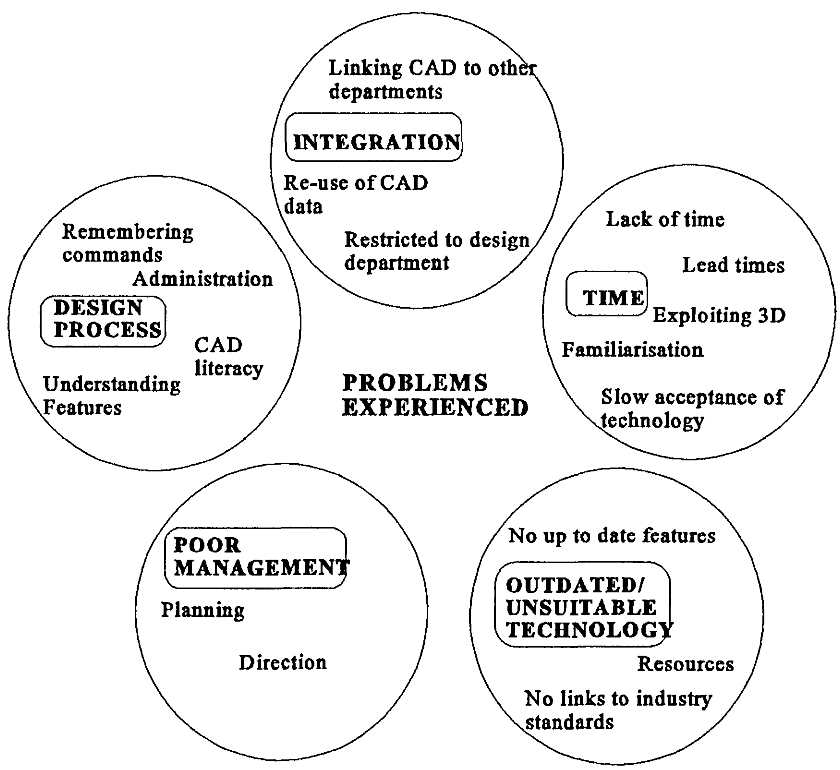

Figure 9.13 Main problems experienced by companies not achieving all they hoped from CAD

Nine companies cited problems with integration, eight with time related issues, six with technology problems, ten with design process problems and three with management problems.

The distribution of these problems by user group 2D only or 3D users also is shown in

Table 9.14

	2D USERS	3D USERS
INTEGRATION	2 (22.3%)	7 (77.7%)
TIME	5 (62.5%)	3 (37.5%)
TECHNOLOGY	5 (83.3%)	1 (16.6%)
POOR MANAGEMENT	1 (33.3%)	2 (66.6%)
DESIGN PROCESS	4 (36.3%)	7 (63.6%)

Table 9.14 Distribution of problems by user groups

Integration appears to be more of a problem for 3D users than 2D users. This is not surprising since it is 3D CAD which can provide the greater opportunity for integration across a company, but which poses the most difficulties in terms of communication interfaces and standards between computer design, analysis and business orientated software such as sales, marketing, stock control etc.

Again more 3D users than 2D users indicate problems with the design process in terms of CAD literacy and understanding the system. . As 3D systems are more complex, becoming proficient in their use takes greater time and training and support and unless companies provide effective consideration in these areas, current and future 3D users will experience problems. Time appears to be an issue for 2D and 3D users both for using the technology and coping with demands for increased productivity.

Since 2D CAD is older than 3D, it is not surprising that for 2D users there appears to be a greater issue with the technology than for 3D users. Five 2D users cite old, outdated or unsuitable technology as a problem compared with one 3D user. Given that two of these 2D users had been employing their system for thirteen years, two for eight years and one for four years it is little wonder that they feel out of date with the advancements that have taken place in CAD, bringing more powerful systems within the budgets of even small companies. The 3D user indicated in the technology category is actually happy that the technology is up to date but unhappy with the amount of investment and cites management vision in this area as at fault.

9.6.2 Moving Forward With CAD

Question 49 on the questionnaire asked respondents to indicate what they needed to do in order to move forward and obtain even greater benefit from CAD, irrespective of whether they were achieving all they hoped from CAD or not.

Of the one hundred companies, thirteen did not reply, eight of these were 2D users and five were 3D users.

The actual comments from companies to this question are listed in Appendix C9. Two 2D users suggested that they did not need to do anything to review CAD, they were happy as they were. One 3D user suggested that a change of culture was required among some staff and three companies (one 2D and two 3D users) indicated that they just need to keep up to date with updates of the software. Analysis of the remaining eighty companies comments are essentially found to relate to the following categories.

- New CAD/ hardware/ software and equipment
- Resources and efficiency
- Integration

New CAD Hardware/ Software and equipment

Forty two of the companies indicated that they needed new CAD hardware/ software or equipment. Eighteen of these were 2D users only who specifically indicated that they needed to implement 3D CAD. Two current 3D users also indicated that they needed to change their system for a new 3D CAD system.

Resources and Efficiency

Eight other current 3D users indicated that they needed further resources , in terms of staff, time, training and support in order to understand 3D CAD better and thus be able to develop models quicker and obtain better use of 3D design data.

A further five 3D users indicate the need for a better data management systems and methodologies to make more efficient use of 3D CAD. This improvement in 3D design efficiency can only take place if the resources are available to assist staff to do this; ie time, training and support.

The need for improvements in efficiency are indicated by four 2D only users. Two of these suggesting the need for more information attached to drawings such as costs, suppliers part numbers etc and two suggesting the need for adequate company policy on CAD or the restructuring of workloads.

Integration

Fifteen respondents, eight 3D users and seven 2D users stated that they needed to integrate CAD with other aspects of the company. For 2D users this is essentially to provide capabilities such as, drawing viewing facilities at other locations in the company or to link to customers CAD systems, linking to other databases for extraction of material and parts lists for purchasing.

A slightly higher requirement for integration is indicated by 3D users with the need to integrate their CAD systems with other areas of the company, but in particular, production and business areas such as sales, marketing, publicity and customers/ suppliers.

9.7 SUMMARY

CAD is a mature technology. Most if not all of the companies that have invested in CAD over the last 10 years should now be using their systems to maximum potential. In this survey 96% of companies have been involved with CAD for over three years and many for over 10 years.

Although upgrades and changes in CAD systems bring along new operational problems, these companies should not be experiencing major difficulties with their systems.

CAD should be having a significant impact upon company business, although evidence from this survey suggests otherwise. Many companies report "satisfactory" or "opportunities still sought" rather than "significant" impact on company business and many have only introduced low numbers of new products during the last five years.

It appears that investment in terms of initial system training time (which ranges from one or two days to between one to four weeks) is not a significant factor in users perceptions of CAD satisfaction. Such satisfaction may be related more to supported practice and experience at users companies.

Generally limited internal support is given for CAD and this support is not rated highly by companies even where a separate CAE department exists. Many of the aapects of the proposed support model are either not supported or are rated as poor. Only 2% of companies responded with "world class" to describe the internal company support provided.. Problems exist, especially where advanced 3D is employed. These include lack of adequate support for the efficient and effective use of CAD. Such problems can easily be eliminated by a focused internal company approach to CAD support

The perceptions of CAD users as to the way forward are reasonably distinct. For 2D only users, a large number see the need to obtain a 3D CAD system. For current 3D CAD users their needs appears to be two-fold. Firstly related to resources such as time, training and support to be able to understand and use the more complex systems effectively and secondly towards integrating the technology across departmental boundaries to obtain the advantages that this can have on both operational and business aspects of the company.

10. DISCUSSION OF RESEARCH RESULTS

10.1 INTRODUCTION

It is widely recognised and stated at the beginning of this thesis that CAD has a significant role to play within the competitiveness of British industry. It has also been illustrated here that CAD is a mature technology and that many companies have been employing CAD for a decade or more.

Chapter 1 has presented the reader with an overview of CAD. In particular it identifies CAD as 2D or 3D and emphasises the increase in complexity of systems with a move to 3D. This complexity is also increased with increase in the complexity of the designed product eg a 3D model of an internal die cavity with bosses, tapers, fillets and radii is more complex than a shaft or plate.

There is a great variety of engineering companies in the UK in terms of size, organisational structure, field of engineering etc. employing one or both categories of CAD. Each has their own product complexities and are using CAD software, purchased from a multitude of different vendors.

The results of the research are therefore taken as indicative rather than extended to industry in general.

Most companies and vendors use the term " CAD Implementation" when considering purchasing and introducing a CAD system. This however implies a fixed time activity which has an end.

This research however considers the "Introduction and Development" of CAD as an ongoing activity. It attempts to understand by exploration and observation some of the key issues associated with introducing and using CAD and how they may or may not have been introduced into a companies implementation methodology as observed in this research.

10.2 DEFINITION OF THE MODEL

The literature review in chapter 2 has shown the critical factors in CAD introduction and development to be:

- An effective implementation plan linked to a strategic business plan
- The simultaneous technical and organisational change directed at obtaining the full benefits
- The degree of training given to staff on technical, organisational, human, social and business factors
- The engendering of a learning culture and the provision of opportunities and rewards

The findings of the literature review are confirmed by the pilot study of six companies whereby the main issues emerging were;

- Maintaining support for systems
- Maintaining Direction- Operational and strategic
- Technical and organisational communication of data

The corroboration of the literature results with the initial pilot study results provides a firm basis for the case study work undertaken. In particular, the research methodology chosen for the case studies, ie the use of "Quality Criteria" which includes leadership, reviewing, strategic planning, teamwork, human development(which also includes satisfaction) and support, focuses strongly upon those issues emerging above.

Since CAD is a supporting technology it will not necessarily lead to new markets (although it can have an impact), rather it will give better performance in existing markets. For this reason the use of quality criteria is justified as a measure of performance.

The in-depth investigations of the three case study companies, A, B & C has identified them as successful companies from which examples of good practice were extracted in relation to the main issues above. These examples of good practice are embedded in the companies "Support Structures" and relate to:

- Strategic Support
- Operational Support
- Training

To broaden the industrial base of the three case studies A, B & C in terms of products, size and geographic location and thus attempt to eliminate any bias, six further in-depth case studies, D to I were undertaken. These case studies provided further evidence of human factor issues from which a "model" for extending a CAD introduction and development could be derived.

Selection of those case studies was based upon the companies having demonstrated success in the use of CAD.

Because of the in-depth nature of the investigation, the use of the nine case studies in total is considered by the author to provide an adequate sample size from which to identify generic themes and to propose them as indicative of companies using CAD. In particular, no attempt has been made to restrict the research to one industry, product area or company size, but rather to explore a broad range of companies and to see what emerged.

Results from the further six case studies indicated that although they were all perceived as being successful, five of those companies had experienced significant problems in the past

with CAD and were still experiencing some problems. It should be emphasised that they were also reaping some benefits from CAD but not to the extent which they felt they should.
Company F and G had experienced drastic failures with the implementation of 3D systems in the past. Company F had may have learnt from this experience but the advent of a new CEO and a much more rigorous and strategic plan for the future NPD within the company together with CAD/ CAM is greatly assisting in overturning the previous failure.
Company G give the impression that they have learnt from this experience but it seems to be from consideration of the technology rather than from a human or organisational aspect.

Ignoring the change currently taking place at those two companies, on the whole it can be said that these five companies did not see the need to provide staff with support for CAD. Support was weak in five of those companies, being relegated to a vendor hot-line in case D and G or basically one person in the other cases.
In the other three cases where one person was designated as the internal support for CAD it is clear that the support did not work as effectively as it should. Company D are not supporting and managing the resistance to the use of CAD by manufacturing and are slow to overcome problems of integration of the system into and between departments and other sites. Company E did not embrace the majority of support issues identified in the model and the administration and organisation of CAD at the company was in confusion. Company H are not using the 3D capability of the system and the support structure is not yet driving this.

Except for one company, the further and extended case studies mostly provide examples of what happens if good practice identified in the three initial case studies is missing.
Together therefore, all nine case studies provide evidence which justifies the "Support

Model" proposed in chapter 6.

The main proposition from the case studies is that where companies have relatively weak support structures they appear to experience more problems and are generally not using the technology to obtain the maximum benefits, either operationally nor strategically.

The model developed has a good fit with the case study companies, but to check its validity and relationship to a wider section of industry the national survey discussed in chapter 7 was carried out. Secondary propositions to the main one were identified in chapter 6 in relation to the expected results from the national survey. The intention is not to repeat those propositions here, but a secondary proposition that was emphasised was that many companies would probably not provide internal support at all.

10.3 NATIONAL SURVEY

The total sample size for the national survey was 1000 companies. The overall response rate was 11.8% with a CAD user response rate of 10% which is a good rate of response compared to other surveys and provides a good basis for the research findings.

The results of the national survey are extensive and provide a broad indication of companies and their use of CAD. There were 49 questions on the questionnaire covering the areas of:

- General information about companies
- The design process
- CAD introduction and development
- Support structures for CAD

- Training
- Impact of CAD on the company

Analysis of responses to the questionnaire (discussed in chapter 9) has followed the above format and has attempted to emphasis the performance and problems experienced by companies in these areas whilst focusing on the influence of support.

The survey confirms the propositions and finds that;

- Many companies do not provide internal support structures for CAD
- Of those companies that do provide internal support, many staff are dissatisfied with the level and quality of support
- Where companies employ 2D CAD the majority of users are satisfied with the limited support which is available to them and the achievements from CAD.
- A high proportion (80%) of 3D users employing separate internal support structures are experiencing problems with 3D, are dissatisfied with what they are achieving from CAD and generally rate the quality of support poorly.

In rating the internal company support, only 2% of companies responded with "World Class" to describe this support, 26% responded with satisfactory, 13% poor and 21% not supported/ needed whilst the remaining 38% did not employ any internal support structure.

Overall therefore the support provided by companies does not appear to be addressing companies capabilities to be world class competitors.

To operate successfully companies must of course maintain financial planning and control and keep a watchful eye on general operating costs and high cost activities. Very often therefore

new ventures and activities which are perceived as being difficult to quantify in terms of contribution to company profits are restricted. In the past, design and particularly development, has been one of the first activities to suffer from such restrictions.
Evidence from the national survey highlights this problem in terms of the low investment in people as opposed to the higher capital investment in technology.
To some extent therefore, it is no surprise that many of the companies surveyed do not provide any support structure (possibly because of the economic constraints) and those that do, only provide restricted support.
However, case study company "I" provides some good examples of how a support structure can be financed and justified based upon "projects" identified to significantly improve the operation of CAD for users and to show a strategic impact on that departments and company business.

For many of the companies employing 2D their perceptions of the way forward is to move towards implementing a new CAD system and for many this is a 3D system. Twenty eight companies (which is almost 52% of the 2D sample group) indicated that the way forward was to obtain new hardware/ software or equipment and eighteen companies specifically indicated purchasing a 3D CAD system.

However, section 9.6.1 identifies problems experienced by 3D users in terms of CAD literacy and understanding. It was illustrated in section 9.6.1 that to move forward with CAD some 3D users indicate the need for more resources in terms of staff, time, training and support in order to understand and make effective and efficient use of 3D design data. They also indicate the need to integrate CAD with many other aspects of the business.

Most of the 2D user groups have little or no experience of real support and this is evidenced within the eighteen companies indicating a change to 3D CAD. Two companies have no support at all, eleven companies rely purely on the vendor, ten companies relegate support to one person and five companies rely on the I.T. department for support.

It will be difficult for them to adapt to the changed requirements of higher quality support needed for 3D without some education and training. Without this education and training companies may well adopt the mind set exhibited by case study G; ie Nothing really will have to change- the support existing at the present will be the same. The point to remember here is that Company G have failed with 3D in the past as have company F.

11. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

11.1 INTRODUCTION

Successful use of CAD is an important contributor to the well-being of the UK manufacturing industry. This research has sought to establish human factor issues affecting this successful implementation.

Inductive methods have been used with fifteen UK companies to establish issues arising from human factors etc. and further explored and validated by a postal questionnaire eliciting one hundred responses from UK companies employing CAD. This methodology encourages belief that the outcomes of the research are valid and can form the basis for future action by companies entering this arena for the first time.

In addition, a framework for evaluating human factor approaches has been developed from a set of criteria originally proposed by Baldridge to evaluate quality matters. Again this set of criteria is recommended to industrial organisations as a useful tool for evaluation of CAD implementation.

11.2 CASE STUDIES

From the case study investigations the following conclusions can be drawn;

- CAD is a tool which aids designers and which can have operational and strategic benefits.
- Companies however, appear to concentrate more on the operational design aid side of CAD for reduced time and better drawings, rather than employing it as a strategic tool.
- Companies must recognise and invest in "staff potential" as a company asset not just the technology.

- Although companies may be perceived as generally successful by external recognition through customers and status in the marketplace, this does not guarantee that they will not still experience problems with CAD and nor does it guarantee that they will reap the benefits of CAD to the extent that they should.
- Human factor issues are important contributors to the success/ failure of CAD implementation.
- Operator support is varied, irrespective of company activity and CAD system used
- Support needs to effectively address a mix of technical, organisational and human issues
- Generally companies do not recognise the need to provide support and often the quality of support provided is limited and weak
- Companies where support is weak, may experience more problems than companies with strong support for CAD
- Companies which employ high quality support for CAD, irrespective of the type of support structure in existence, may find it easier to focus attention on the strategic impact of CAD on the company, rather than employing it as an electronic drawing board
- Companies using 2D CAD may find it easier to achieve business objectives with less strong support structures, whereas 3D CAD requires a greater degree of internal support to achieve business objectives

11.3 POSTAL SURVEY

Many comments received back from company representatives, particularly concerning support for CAD, were quite negative and pessimistic. These pessimistic results are interpreted here as being significant since one would expect most questionnaire returners would be proud of their achievements with CAD and would wish to present the best face of the company.

From the postal survey many conclusions are reportable as follows;

- The achievement of a significant impact on business is not a function of the number of years CAD is employed.
- More than one third of CAD users are not achieving all they hoped from CAD, particularly 3D and mixed users.
- Company benefits from CAD are predominately focused upon productivity and quality rather than more strategic business benefits such as new areas of work, reduced costs and speed to market.
- The majority of CAD users either rely on the vendor for support or an existing draughtsman/ designer.
- Internal company support should be the best possible, but where internal support does exist, it is generally limited and it's quality is not always rated highly. Support focused on the business benefits is necessary for success.
- 2D CAD users have little experience of internal support since it is easier to achieve target benefits
- Many 2D only CAD users perceive the way forward as upgrading to or implementing a new 3D system
- Where advanced 3D CAD is employed , users experience problems with the greater complexity and integration of such systems across departmental boundaries
- The effective and efficient use of 3D CAD is strongly influenced by adequate

internal support for use, training, practice time and experience

- Significant benefits can accrue from the use of 3D CAD, particularly since many products involve complex internal and external shapes.

11.4 A SUPPORT MODEL

From this research it is possible to propose a support model for improvement of CAD effectiveness in UK industry. This would take the form of a specification as follows;

Specification:

A. Companies

Companies who are considering introducing CAD for the first time, currently using CAD with limited or without any internal support and companies considering upgrading to 3D CAD should:

1) Allocate funds and set up a separate internal company support structure for CAD, with emphasis on the quality of support.

2) Develop a strategy for that department which promotes the effective and efficient use of CAD on the three levels of the model proposed in section 6.5.

a) A back-up support level encompassing operational and human support

b) A strategic business level

c) A people level (Continual experience and training)

Continual experience and training should involve in-house training by company/ group experts sat alongside users working on real design jobs

Staff should be provided with "protected" time to learn and develop

3) Develop an organisational structure for reviewing, on an ongoing basis:

a). Staff training and development.

b). Operational problems and system performance.

c). CAD performance in line with the business strategy for the company

The Baldrige quality model has been successfully adapted and applied in this thesis to investigate CAD implementation. It is recommended that this model should be used as a tool which companies use to monitor progress on CAD success.

B. Academic and Research Institutions

Academic and research institutions have a role to play in re-educating industry to the potential gains to be made by employing such positive support.

a) Through the development of awareness training courses

b) By working with individual companies on an informative basis

c) By publicising successful implementations and disseminating examples of good practice

11.5 SUMMARY OF RESEARCH

This research shows that the findings of Stark (24) and also Majchrzak and Salzman (26), that many companies then were not able to report significant effects of CAD on company business, or had not achieved the intended benefits of CAD, is still true for current day CAD users.

The critical issues and barriers involved in current day CAD implementation have been identified and they are generally covering similar areas to those in earlier studies in the late 1980's/ early 1990's by Beaty and Gordon (USA) (27), Fleischer (USA) (63), Mortenson and Nehring (USA) (28), Kratzer and Kratzer (Germany) (29), and Ebel and Ulrich (53) in a study of France, Germany, UK, Hungary, Sweden and the USA.. Most of these of course are not UK based studies.

Beaty and Gordon provide an indication of barriers but do not provide suggestions for overcoming them. Ebel and Ulrich and Kratzer and Kratzer both suggest that the human factor role is of prime importance in achieving effective CAD but they do not provide a model of this for implementation.

Fleischer identifies training and support as important issues to address but again does not provide a model for this. Mortenson and Nehring identify internal support as the most important issue for CAD effectiveness and although they provide some recommendations, these are not in any great detail.

The research herein however, extends the studies done by these earlier researchers and adds to the understanding of how such problems may be overcome. It introduces a support model for current day CAD implementation, based upon internal support and mentoring which focuses on specific issues ie. an internal guru who can lead the way for others.

It provides evidence of problems and difficulties experienced by companies when elements of this support are missing and indicates that greater success is achievable where such a model is employed.

11. 6 RECOMMENDATIONS FOR FURTHER WORK

The indications from this study are that the use of proper internal support as outlined in the proposed model could pay dividends for companies in helping them to tackle and alleviate problems associated with the use of CAD, especially in the areas of 3D CAD. This is particularly relevant to companies currently only employing 2D CAD (essentially with limited experience of supporting staff and the technology) and considering investing in 3D with its subsequent increase in complexity of use and organisation.

Further work is required to provide "live" testing of the support model through collaboration with a number of companies moving to 3D in the near future. Such testing should contrast several issues;

- The differences in problems and levels of success experienced by companies employing high quality support, no support or limited support quality.

- How such support might exist in small companies compared with larger companies with greater resources. Emphasis here should include identifying strategic gains from the technology and its' continued financial review and justification based on CAD projects.

- The research in this thesis allows for bias by selecting companies from different product groups. However a much more rigorous study of the nature and quality of support needed by various product groups and product complexities could help refine and expand the proposed support model.

The results of collaborative work outlined above should provide a detailed enough picture of support problems to enable the specification of support to be developed into an implementation methodology. Such an implementation methodology would not represent a time dependent activity but would be related to the continued use and development of the technology.

A big issue with the development of the support specification as contained herein, or the future implementation methodology, is their take up by the industrial sector. In part this is because research identifies issues concerning industrial performance but there is no clear pathway between findings/ recommendations in academia and the industrial sector. Traditionally, UK companies have not had a culture which emphasised employee support and well being. However, the development of support structures for CAD has implications for a change of culture across the company. Whatever the gender of CAD personnel, they will endeavour to produce excellent results where they are in a contented, secure, pleasant and problem free environment. Especially in an environment where strategic, operational, technical, educational/ training and human factor considerations are predominantly evident and are such that they do indeed enhance successful CAD implementation.
Supporting and investing in staff is likely to be an issue in any new technology emerging in the future and the knowledge, experiences and recommendations arising from investigating CAD implementation may be transferable to other technologies and organisations. However, most companies have limited resources and are too busy to absorb such recommendations without having adequate "support" from researchers to assist them.

This then is a role for academic, professional and government institutions to take on board, to assist companies financially and academically to improve their support structures for the use of the technology

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APPENDIX A1. - PILOT STUDY QUESTIONS

COMPANY HISTORY AND CULTURE

1) When was the company formed, by whom and for what purpose.
2) What were the first products and how many were produced.
3) What sort of market and quality were the products aimed at.
4) Why did the company diversify from one product to another.
5) What mode of technology has been employed throughout the history of the company.
6) Has the implementation of technology been continuous (ie always keeping up to date) or has it been fragmented or step change.
7) What has been the annual growth throughout the history of the company.
8) How has the numbers of employees changed during the life of the company.
9) Has there been a history of resistance to change.
10) How has any resistance to change been approached.
11) What has been the philosophy towards marketing/ publicity of product and how has this changed.
12) What has been the philosophy towards training, employment, education and skill requirements.

Immediate/ Recent History

1) What was the organisational structure of the company prior to CAD and how has this changed.
2) What are the current products.
3) What is the level of complexity of these products/ level of technical input required.
4) What % of current products are new products and what % are 'n' years old.
5) What % of each products are sold.
6) Is there any relationship between the % sold and the age/ innovativeness of the product.
7) What bearing does trade union involvement seem to have had on working procedure, company policy and organisational or management strategy.
8) What advantages/ disadvantages have resulted from trade union involvement.
9)Does the company have a specific strategy for the introduction of new products; What is it and what influences does it have on implementation.
10) What training, experience and qualifications has middle and higher management in traditional and new technologies, business training, human factors and implementation strategies ETC.
11) Does the company have or plan to have a human factors/ human resources management department or unit to actively improve the worklife of employees in terms of opportunities, reward schemes, cultural and social aspects ETC.
12) Does such a unit employ "human factor specialists" or does it rely on engineering/ management staff.
13) What effect do such departments have on the company.
14)Do companies/ staff recognise the link between human factors and business success.
15) Is there a shortage of trained staff in any area.
16)What is the company policy on employing staff in particular areas.
17)Do they employ from outside the company or do they promote from within; moving people across divisional boundaries.
18) Are quality of worklife programs employed.
19) Does the company operate internal professional development schemes to provide

structures for advancement.
20) What organisational structures do the various levels of staff believe they need.
21)What do they perceive the key positions to be and whom do they think should fill these positions and why.
22)Is there a strategy of pre-interview or induction training for new applicants/ staff.

OPPORTUNITIES FROM CAD

1)What opportunities for improving working practices are perceived to exist by different groups/ subgroups for individual, departmental and company functions.
2) Do perceptions of opportunities differ markedly between groups.
3) Where there is a difference in perceptions, what is the order of importance attached to opportunities by each group.
4) Does the order of importance relate to company strategic or operational issues and is this further related to group position in the organisation; eg. culture, social environment ETC.
5) Does the perception of opportunities vary across industries.
6)Do the perceptions of opportunities match up with opportunities specified in the literature survey.
7) Is there a consistency in perceptions and match or mismatch with the literature.

EFFECT OF CHANGE TO CAD ON COMPANY ISSUES

1) What effect has CAD had on issues like;
Design time, lead time to production, quality, flexibility, reduced costs, turnover, available capital, plant expansion ETC.
2) What has been the effect on business; Has the company increased its' business, moved into new competitive markets, increased market share of products ETC.
3) What effects has the degree of consideration of human factors had on implementation.
4) What effect has CAD had on organisation, lines of authority and control ETC.

EFFECTS OF A CHANGE TO CAD ON HUMAN FACTORS

1) What was the age profile of design and other staff prior to CAD and how has this changed.
2) What qualifications and skills did CAD personnel possess prior to CAD implementation and how has CAD changed this for individuals.
3) What traditional modes of engineering education and training in engineering design techniques, system use and company wide business appreciation ETC have staff undergone.
4) What professional qualifications do they hold; eg institute membership ETC.
5) What subjects have staff studied; for how long; what grades were achieved (in both general and engineering education) and at which institutions did they study.
6) What was the mode of study; eg sandwich, part-time, full-time ETC.
7) How does this mode of training compare with Japanese and German education and training.
8) Can the creativity of staff be defined and is there any relationship between creativity and departmental/company success.
9) Have staff undergone training in developing non-technical skills such as group working, information retrieval and presentation, leadership & management and problem solving skills ETC.
10) What training and education has been provided since the planning and implementation stage of CAD and what has been the frequency & duration of such training.

11) What has been the effect on human factors such as;
Job performance, job satisfaction, financial and promotional reward structures, physical and mental health, social standing & status, technical and interpersonal skills ETC.
12) What is the order of priority attached to such effects by staff.
13) Do staff see any need for further training/ education and how important do they feel this is.
14) Do they attach more importance to training once CAD has been implemented.
15) What has been the change, if any, in the turnover of staff since CAD was introduced.
16)How do staff qualifications match up to perceptions and opportunities gained.

GROUP AND INTERGROUP ACTIVITIES
1) How is CAD used to support design.
2) What is the relationship between the design department and other departments in the company and are there clear objectives for their organisation & management relative to the business as a whole. 3) Does the design department employ a design strategy for the management of the design process.
4) Do controls exist to improve and monitor the design process in terms of specification (ie project brief), solution synthesis, evaluation & optimisation of the chosen design.
5) Do you make use of such things as design reviews, skills audits ETC.
6) Where design is undertaken in groups how is the mix of required disciplines & skills determined.
8) How do peoples perceptions vary on group working
9) What competitive elements exist for those working in groups.
10)What incentives have been introduced to motivate staff involved with group/ intergroup problems.
11) What/who are the main influencers of group/intergroup working in CAD (in terms of providing staff with the right conditions, human, technical & organisational for maximum effectiveness)
12) Which of these influencers appear to culminate in problems and can such problems be categorised into various groups with different degrees of effect/seriousness.
13) Which of these problems are the most serious.
14) Are staff aware of the problems and what order of importance do they attach to them.
15) Do management staff know clearly what their jobs are in terms of responsibilities, relationship of their jobs to other areas of the company and external sources such as competition, and how this fits in with efficiency and success.
16) Is the CAD team structure formal or informal. 17) What skills do staff feel team leaders should possess and how does this match up with their perceptions of current team leaders.
18) Are the designers ETC. provided with specific manufacturing constraints eg. design rules for manufacturability, checklists such as numerical rating systems/ actions for improvement .
19)Is there a strategy for limiting materials/ components to certain standard ones.
20) When designing new products do staff recognise the attributes that customers are looking for and are there formal procedures for evaluating this.
21) How are design staff chosen to undertake particular design problems and on what is the use of the CAD facility based.

IMPLEMENTATION STRATEGY

1) What objectives/goals were set when planning CAD and why
2) How was implementation managed and how did the goals change during this time.
3) Were procedures set up for monitoring the "Total" implementation progress; ie technical, organisational and human issues and is this an ongoing exercise.
4) How do the methods adopted compare with other companies methods and is there any relationship between the methods adopted and problems/ successes that the company experiences.

WHAT PROBLEMS HAVE OCCURRED DURING OR SINCE IMPLEMENTATION.

1) What technical, organisational, social & human problems have occurred within the company (and externally with customers, competitors and suppliers ETC.)
2) Are employees satisfied with all aspects of the company and their worklife. Do they feel any particular problems exist and what do they suggest the solution is.
3) Do problems align themselves with the degree of consideration given to human factors at various stages during implementation.
4) Have any problems arisen relative to monetary or other reward systems.
5) Have any hidden problems arisen such as a change in the level of absenteeism or sick leave.
6) What if any has been the change in the number, length, frequency, duration and issues involved with industrial disputes.
7) Which problems were anticipated and which were not.
8) With hindsight which problems should/ could have been anticipated and how

APPENDIX A2.- PILOT STUDY COVERING LETTER

Dear Sir/ Madam,

The attached research issues/ questions have been listed under 7 main headings, with several questions attached to each heading.

These questions relate to information which I hope to obtain from industrial companies to identify the influence that human factors have on effective CAD implementation.

This information will then be used as a basis for carrying out in-depth investigations in a number of companies.

What I am particularly interested in finding out is your views of this work; eg.

1 ***Are the questions relevant to the engineering industry***

2 ***Are they the right questions to be asking; if not, why not and what should be asked?***

3 ***Which issues/ questions are the most important and which are least important. Can they be graded in terms of importance. Can any be disregarded. Are there some issues which must be addressed?***

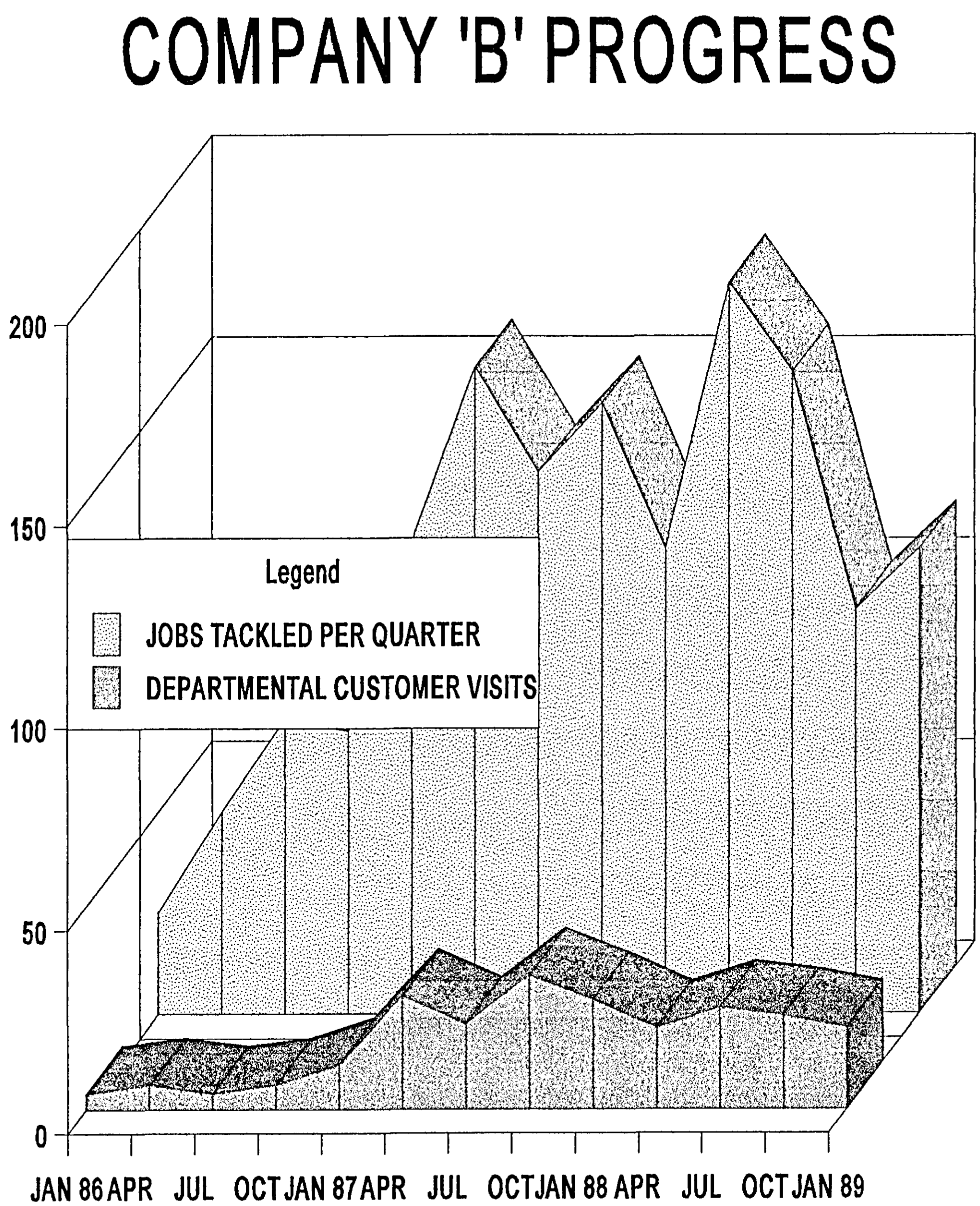
4 ***Have you/ or your company pursued any developments along the lines of the research issues/ questions outlined here and if so, can you comment, with hindsight, on any problems you experienced and activities which have helped overcome the problems?***

I realise that in some cases, you may only be able to make partial comment but I would be grateful for any help you can give.

Yours Sincerely

Chris Short

APPENDIX B:1 COMPANY "B" PROGRESS



APPENDIX B2: INITIAL CASE STUDY COMPANY RATING SYSTEM

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
LEADERSHIP		A	B	C	A	B	C
a) Top down	5	10	5	8	50	25	40
b) Quality focus	3	10	5	10	30	15	30
c) Two way communication	2	10	5	5	20	10	10

TOTAL	100	50	80

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
PLANNING		A	B	C	A	B	C
a) Strategic	5	10	7	9	50	35	45
b) Long term commitment	3	10	5	9	30	15	27
c) Participative	2	10	5	5	20	10	10

TOTAL	100	60	82

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
SUPPORT		A	B	C	A	B	C
a) Reviewing training needs	4	10	7	10	40	28	40
b) Effective Retraining	4	10	7	10	40	28	40
c) Work flexibility & mobility	2	8	7	7	16	14	14

TOTAL	96	70	94

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
REVIEWING		A	B	C	A	B	C
a) Improving performance for;							
Company	2.5	10	7	10	25	15	25
Employee	2.5	10	7	10	25	15	25
b) Recognising key indicators	5	10	7	10	50	35	50

TOTAL	100	65	100

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
PARTICIPATION		A	B	C	A	B	C
a) Working in partnership	5	10	5	5	50	25	25
b) Clearly defined employee involvement	5	10	8	8	50	40	40

TOTAL	100	65	65

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
TEAMWORK		A	B	C	A	B	C
a) Increased employee involvement	4	10	6	10	40	24	40
b) Increased responsibility	3	10	5	10	30	15	30
c) Encouragement/ empowerment	3	10	6	10	30	18	30

TOTAL	100	57	100

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
HUMAN DEVELOPMENT		**A**	**B**	**C**	**A**	**B**	**C**
a) Increasing employee skill/ knowledge	5	10	6	9	50	30	45
b) Increasing well being and satisfaction	5	10	5	5	50	25	25

TOTAL	100	55	70

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
PROBLEM SOLVING		**A**	**B**	**C**	**A**	**B**	**C**
a) Proactive approach	10	10	5	7	100	50	70

TOTAL	100	50	70

CATEGORY	RATING						
	RATING VALUE	MERIT RATING (10)			OPTIMUM RATING		
QUALITY FOCUS		**A**	**B**	**C**	**A**	**B**	**C**
a) In design phase	4	10	8	10	40	32	40
b) On support services	3	10	8	10	30	32	30
c) On response time	3	10	10	10	30	30	30

TOTAL	100	94	100

APPENDIX C1:- TYPES OF CAD SYSTEMS EMPLOYED BY COMPANIES-2D ONLY USERS

CASE	CAD SYSTEM EMPLOYED
2	FastCAD
4	AutoCAD
5	AutoCAD 13
8	AutoCAD R12
12	AutoCAD LT.
13	AutoCAD R13
16	CIMLinc Incorporated, CIMCAD
17	AutoCAD R13
19	Autocad R13
20	Robo CAD 2D
21	AutoCAD
22	Radan- Radraught-Radpunch
24	AutoCAD
25	AutoCAD
27	AutoCAD R13
28	AutoCAD R 10,12,13-PCAD/ Accel Tango
29	AutoCAD R14
31	AutoCAD R14
35	AutoCAD 12 and LT
38	AutoCAD R12 on DOS on PC's
39	AutoCAD R12- CADSTAR 7(Electrical)
41	AutoCAD R14
42	CADRA V10.4
43	CADCAM/ CATIA Drafting
45	Hewlett-Packard ME10
48	ADRA CADRA 10.4
54	AutoCAD LT97
55	AutoCAD R12-2D Draughting
	Finglow & PV Compress for Mech Design
58	AutoCAD R13, Cadpipe
59	AutoCAD R14
61	FastCad 3D
63	RADAN
65	AutoCAD R13 with Genius 13
66	Matra Datavision Strim 100, VERO. Visicads
67	AutoCAD R13
70	AutoCAD R14
74	AutoCAD R11
75	AutoCAD R13 with Genius & Workcenter
76	MEDUSA
77	Converto 2D CAD & CAM
79	AutoCAD
81	FastCAD

82	AutoCAD R13
83	Bentley
84	ATS Supervisions 6800
87	AutoCAD LT; AutoCAD R12
89	CIMCAD 2D running on Unix workstations
90	DesignCAD 2D
92	AutoCAD R14
94	6x AutoCAD LT 97, AutoCAD R14 x1, EasyCAD x 1
95	AutoCAD R14. Electrical Designer
97	AutoCAD 12
99	AutoCAD R13 + Genius

TYPES OF CAD SYSTEMS EMPLOYED BY USERS OF 2D AND 3D

CASE	CAD SYSTEM EMPLOYED
1	SDRC I-Deas Master Series
3	CU Medusa, Unigraphics, SDRC IDeas, AutoCAD, CADPipe- Each system used for a specific task
7	SDRC Ideas, Alias
9	CIMCAD, Unigraphics, AutoCAD
10	Pro Engineer, ME10, AutoCAD
11	ACAD V24, MECHDESKTOP V2(1Yr)
14	AutoCAD 14, Mechanical Desktop
15	IBM Catia
18	AutoCAD R14 and Mechanical Desktop
23	AutoCAD, Promod, Mechanical Desktop
26	CIMCAD 2D_Pro Engineer 3D-AutoCAD 2D
30	Intergraph EMS and Solid Edge
32	3D- Pro Engineer; 2D- AutoCAD R14 + Genius
34	Personal Designer(Ex CV)- AutoCAD-Unigraphics
36	CATIA; AutoCAD
37	Solidworks
40	AutoCAD R14 plus Pro-Engineer
46	CATIA- ANVIL 4000- PANOPLIE
49	AutoCAD R13
50	IDEAS on Sun workstations
51	Pro Engineer
52	Pro Engineer
53	3D Surface Modelling- Graftek
56	AutoCad R13/14
57	Delcam Duct 5, Powershape and Ductdraft
60	RADAN
62	CADLogic ParaCad + 2D Cam; Matra-Datavision Euclid 3D CADCAM
64	Parametric Solid Modelling
68	Bentley Microstation

71	CADDS 5
72	AutoCAD R14
73	Personal Designer(Computervision); AutoCAD R14; SDRC IDEAS
78	IBM RS6000
80	AutoCAD R14; Solidworks 98
86	Intergraph Microstation
88	AutoCAD Mechanical Desk 2.0 + Genius
91	AutoCAD 14 and GTX Raster CAD
93	AutoCAD LT- AutoDesk Mechanical Desktop
96	Intergraph Microstation 5 + EMS

TYPES OF CAD SYSTEMS EMPLOYED BY 3D USERS ONLY

CASE	CAD SYSTEM EMPLOYED
6	3D Solid Modeller, SDRC I-Deas Master series 5
33	NC Graphics (Cambridge)-3D CADCAM
44	Autodesk-Mechanical Desktop
47	Pro Engineer-3 seats: Solid Model 3D
69	Mini CAD (Apple)
85	AutoCAD R14. Mechanical Desktop R3.0
98	SDRC Master Series; IDEAS & C3P
100	Pro Engineer

APPENDIX C2.
COMPANY COMMENTS REGARDING ORGANISATIONAL CHANGES AS A RESULT OF CAD- 2D USERS

CASE	COMMENT
16	Teams went from Product Specific to Multifunctional-Data was more accessible
17	Re-allocation of staff
19	I.T Person employed to oversee/ trouble shoot computer equipment
20	No Change- CAD used as an electronic drawing board
58	Many departments closed down
59	Employed new staff
66	Move to more team approach
89	Employ less people in the technical function-Due to business rather than CAD implementation
94	Full potential of electronic data/ drawing management realised thro major changes to the way drawings are controlled & viewed at different locations
97	CAD literate engineers rather than board designers

COMPANY COMMENTS REGARDING ORGANISATIONAL CHANGES AS A RESULTS OF CAD- ALL 3D USERS

CASE	COMMENT
1	Design & Prod linked together. Admin role created for system
3	Reduction in people and middle management
6	No more Draughtsmen; Manager required to be CAD literate
9	Responsibility for developing CAD/CAM/PDM was allocated
11	Use electronic drawing control because no Drawing office- all engineers multitask
26	Structure originally a drawing office-Now product based
34	Departments split from D.O for all products to teams for total manufacture
46	Multifunctional-cell based teams for co-location with manufacturing
49	Extra staff
50	Draughtsmen replaced by designers
51	Multifunctional design teams now in use from many departments
52	Data management
53	Added CNC programming and System Support
57	Design dept developed to support customers needs-only 1 designer prior to this
60	Design manager required to support CAD etc
62	Should have changed BUT has not
64	Department eveolved from function to team based environment
71	Business reorganisation- CAD was not the driver
93	Drawing Office procedures
100	Reduction of Draughtsmen involved CAD operator status raised close to section leader due to their increase in "Market" value

APPENDIX C3:- COMPANY COMMENTS REGARDING FORMS OF RESISTANCE TO CAD

CASE	COMMENTS
1	Some found 3D very difficult & time consuming
3	Some people thought they were "Too old to learn"
8	The use of computers generally. (Especially employees aged 55 & over)
13	50% of users are aged 50 years plus
19	Reluctance to learn new skills especially with the "Older" persons
20	Refusal to work with it by older draughtsmen
26	Fear of new technology which lasted a few weeks
33	Older members of workforce felt threatened by new technology
34	People thought that there would be job losses
38	Refusal to use system by then sole draughtsman-Moved to another dept and new staff recruited
40	Union opposition ten years ago
46	Fear of change by older staff members, followed by requests for early retirement
51	Fear of the unknown- Easier to stick with existing technology and practices
54	Reluctance to give up pencil & paper-Resistance to change- "I can draw quicker without it"
55	Older staff reluctant to use CAD
60	None
62	Older staff resisted. Overcome with training and 6 months experience
66	Senior managers
74	One draughtsman retired early
90	Staff not familiar with the new system
94	Technophobia and resistance to learn new software
97	Reluctance to take on CAD in Engineering
98	Complaints about Bugs & slow drafting. Note system needed because of customer demand
100	Parts shown on screen would not give true scale

APPENDIX C4:- COMPANY COMMENTS REGARDING THE EFFECT OF CAD ON MORALE AND RELATIONSHIPS IN THE DEPARTMENT

CASE	COMMENTS
1	Improved between Prod & Design- CADCAM is 1 package. They all winge together now!
2	Cannot gauge as only one engineer has worked under both systems. Morale always has been good

3	Very little
4	No effect
5	Improved
6	No effect
7	Very good- High
8	No change
9	Improved
10	No effect
11	No problems
12	
13	Positive-Company perceived to be keeping up with technology-Not forcing down employees throats
14	Increased dependence by older staff on younger staff able to easily adapt to computers
15	Morale improved-Designers and Engineers eager to use new technology
16	Appears to be closer interaction between users
17	No change
18	No real change
19	Personnel became frustrated during the learning period-approximately six months
20	Very little
21	Improved. People like knowing they keeping up to date
22	No reply
23	No reply
24	Improved
25	No change
26	Tends to be more involvement in teams
27	No change
28	Mutual selection of appropriate CAD-Improves team working and levels of commitment
29	Generally morale improved-But it has never been bad
30	No change
31	Not applicable due to number of staff-2
32	Improved-Users feel that 3D has enhanced their skills
33	Older members of workforce felt threatened
34	In time a general improvement. More time for interesting work than repetition
35	Improved morale as employees saw opportunity for self improvement with company support
36	Morale and relationships have improved
37	No change
38	Not at all
39	No effect
40	Problems in early days between CAP & LocS CAP users. ie 2nd class!
41	Good
42	
43	No effect
44	Good

45	Not affected
46	As part of a new suite of systems, morale has improved-benefits are now being seen
47	Improved
48	
49	It hasn't
50	Work more as a team on one model file
51	Younger staff accepted and ran better with technology. Older members had superior product knowledge
52	Increase in abusive language directed at the software
53	Not affected
54	No long term effect
55	
56	
57	
58	Permanent CAD operators were more likely to suffer from depression
59	YES-Increased pressure to turn projects out faster
60	No
61	
62	No change
63	Improved as everyone sees it as a benefit to company & themselves
64	Closer liaison with engineers-CAD added communication with engineers & production staff
65	0
66	Adverse reaction
67	We have a young team who have grown with the CAD system. To them there is no other system
68	Only one person refuses to use CAD. Other employees have never worked on drawing boards
69	
70	Positive
71	No change
72	No effect
73	More shared information- Better communication
74	Designers would not like to move back to hand drawing
75	
76	Not at all
77	Improved
78	No effect
79	No change
80	No change
81	No change
82	Disputes over who has use of terminals in design office
83	Improved
84	None
85	
86	
87	No effect

88	Higher morale-Better relationships eg information sharing improved
89	All staff were receptive to the introduction
90	Morale better except when computer system goes down
91	No change noticed
92	No change
93	No change
94	Increased morale as drawings produced more quickly-ie less paperwork-but overloaded I.T. department
95	
96	
97	Cannot quantify
98	Improved in proportion to capital investment
99	No change
100	Department has reduced in size due to redundancy in 1992

APPENDIX C5:- COMPANY COMMENTS REGARDING DIFFICULTIES EXPERIENCED BY USERS OF 3D CAD

CASE	COMMENTS
1	General lack of confidence. Managers afraid of the system held confident people back.
3	No reply
6	Thinking in 3D as opposed to 2D on paper
7	No reply
9	Complex increase in input requirements compared to 2D
10	No reply
11	3D understanding
14	Strategy for attacking new jobs- Poor mental ability to visualise end product to be able to start
15	Conceptual problems with working in 3D as compared with draughting
18	No reply
23	3D visualisation
26	Lack of understanding of basic concepts at first
30	No reply
32	Adjusting to the idea of creating a "Parametric" model & relationships
33	Manual drawing inaccuracy
34	Seeing/ visaulising in 3D
36	Remembering the commands/ procedure
37	Constructing 3D Models
40	Totally different concept to drawing
44	Everyone found difficulty in changing from thinking in 2D to 3D
46	3D to 2D sheet metal development
47	No reply
49	No reply

50	No reply
51	Understanding the meaning of system generated solid model faults
52	No reply
53	Surface representation- Enclosed volumes
56	Processing times for rendering etc
57	Surface Control (Intersection and blending
60	Learning curve is much greater
62	Overcoming "Technique" problems not taught in training courses. The knowledge Black Hole
64	Logical approach to constructing modell and model manipulation
68	As above-poorly written manuals and inadequate processing power of machines
69	No reply
71	Methodology/ best practice usage
72	Inability to generate Helix forms
73	As q37
78	No reply
80	No reply
85	Familiarisation & Optimisation of use
86	Longer Learning Curve
88	Availability of time to adapt skills and habits from 2D to 3D modelling
91	No reply
93	Lack of Training
96	Only one person can use 3D and well
98	No reply
100	Defining 3D model- Pro Engineer needs exact data to define parts

APPENDIX C6:- COMMENTS FROM COMPANIES STATING THE MAIN PROBLEMS EXPERIENCED BY STAFF IN BECOMING EFFECTIVE USERS OF THE CAD SYSTEMS

CASE	COMMENTS
1	The change to thinking in 3D not 2D- The issue of Modelling everything
2	None
3	Need to build up a database of drawings or components
4	All have moved from other typs of CAD systems and had to adapt
5	No reply
6	Engineers tend to forget basic engineering principles when learning software
7	Doing their jobs as well
8	After training, each user did not have an expert to learn from as it was a new system for all
9	No reply
10	None

11	3D- Understanding the order in which parts need to be built and correct selection of datums
12	No reply
13	None- In House trainer/ designer employed for 6 months
14	Having time to practice in a production environment
15	Moving from perception of drawing as master to electronic 3D model
16	Software requires some interaction with the Unix operating system
17	Time allocation
18	Changing to Windows interface and removal of digitiser
19	None of users were computer literate- Fear of experimenting with various commands and system
20	Older staff had to become familiar with computers
21	None
22	No reply
23	Understanding the higher level functions
24	None Known
25	Practice-Learning curve-Expectations
26	Originally move to 2D was easy-Current migration to 3D much harder because of mindset
27	Using computers
28	Use of computers-especially back-up procedures. Associative dimensioning-maintaining
29	Poor training provision ie formal training-No company policy on such equipment.
30	Getting used to a new method of working. Learning practically how to do things rather than theoretically
31	System not used full time-Use restricted to type of work-No time for staff to "play" with system
32	3D- Learning the new approach to product design thro relationships and parametrics. 2D adjusting to new command sequences
33	No reply
34	Lack of basic computer knowledge and a general reluctance to learn
35	Not being able to see the total design at all times as compared with manual drawings
36	Remembering the command/ procedure
37	Constructing 3D Models
38	Sorting out common parameters-eg Plot,fillet etc-Getting used to tablet/ command structures
39	Directory structures-Filing drawings-General understanding of computer use
40	Computers themselves and visualising large structures
41	Remembering commands
42	None
43	No reply
44	None
45	Keyboard skills lacking-most users not previously used a computer
46	Being trained too early in the programme-Resulting in refresher courses when CAD usage required

47	Becoming proficient users to meet timescales. Initial start was slow
48	Changing from drawing board to CAD techniques-ie labour saving commands-filing system
49	None
50	Management expected immediate results after training
51	Becoming familiar with all available options. System capable of far more than we currently use
52	Takes 1000's of hours to learn "Efficient" modelling for detailing and modification
53	Menu structure familiarity- Surface construction
54	Age. All designers were 50+ and never used a computer
55	No reply
56	People new to the business have a long learning curve due to variety & complexity of product lines
57	3D Modelling
58	No reply
59	No learning time prior to producing live parts
60	Persons not computer literate never fully master CAD
61	Familiarity with the system
62	3D. Long steep learning curveToo much implemented too quickly-staff overloaded
63	If anyone had used AutoCad they had to stop thinking that way
64	Management of database
65	File management; Standardised drawing methods
66	Lack of encouragement from (older) senior managers
67	Becoming familiar with Windows based Icons when upgrading from DOS based version of CAD
68	3D-Due to poorly written manuals/ errors in programme-3D modeller was written for mainframe-does not run that effectively on PC's
69	Time to learn system
70	Learning curve
71	Obtaining consistent periods of use- Dictated by role/ responsibility
72	Familiarity with the software
73	New methods of working-File control and storage
74	No reply
75	Familiarisation with commands and general use of system
76	Learning the "setup" of existing drawings (Sets, layers etc.
77	Lack of understanding in 3D object Manipulation
78	Company Macro's and internal drawing standards
79	Learning commands and features
80	Software Terminology
81	No reply
82	The designers who did not use the system regularly tended to forget much of what they had learnt
83	No reply
84	Poor Manuals
85	Adapting to 3D Modelling

86	No reply
87	New company procedures
88	Availability of time to adapt skills and habits from 2D to 3D modelling
89	Familiarisation with software. Different approach to manual drawings to achieve same end result
90	Getting used to the tools and icons and the user interface
91	None
92	Too many options
93	No reply
94	Identifying the Best way-ie most efficient way of creating the drawing- especially where experience has been on another system or just draughting
95	Knowing easier ways of doing things. Knowing what the system can & cannot do
96	No reply
97	Understanding menu systems and document control procedures
98	Lack of Vendor support
99	Learning user interface
100	System completely different to previous 3D CATIA & 2D CADCAM. Insufficient jobs requiring total CAD usage

APPENDIX C7:- COMPANY COMMENTS REGARDING SOLUTIONS NEEDED TO OVERCOME STAFF DIFFICULTIES WITH 3D

CASE	COMMENTS
1	Consistent pressure from designers to get on and do job. Problems were people not system ones
3	No reply
6	Experience
7	No reply
9	No reply
10	No reply
11	Hard work and information transfer between designers
14	Brain Transplant! Lack of practice ie time limits
15	Training & Support by experienced staff
18	No reply
23	Additional training
26	Training and experience
30	No reply
32	Practice
33	No reply
34	Time
36	Practice at using the system
37	"Fast Learners" helping others
40	Training and patience
44	Practice
46	New G.I.I routine employed

47	No reply
49	No reply
50	No reply
51	More training via consultancy in specific areas
52	No reply
53	Software updates
56	Better organisation to calculate timings & plan accordingly. Faster hardware for network rendering
57	More time to work out the best method of construction
60	Allowed more time to practice and internal user group meetings
62	Specialised site consultancy training from vendor
64	Regular user meetings-shared experience-rapid implementation of standards whilst not overdoing them
68	No reply
69	No reply
71	Best practice workshops
72	Looking at alternative software solutions
73	More familiarisation work through specific cases
78	No reply
80	No reply
85	Training
86	Hands on Experience
88	Allocated time to practice "on the job"
91	No reply
93	More training-eg 2 Days
96	Not yet done
98	No reply
100	Extra advanced training and total commitment to Pro Engineer usage

APPENDIX C8:- MAIN PROBLEMS EXPERIENCED BY COMPANIES WHO ARE NOT ACHIEVING ALL THEY HOPED FROM CAD

1	Push & utilise options available. Hold key personnel to develop work done
2	Spend too long drawing new assemblies-Not been able to exploit 3D as it takes even longer
3	Slow acceptance of changes in technology-2D verses 3D use
6	Better Use of CAD data in total business process
8	Producing parts list and complete set of drawings for a production run from this via laser printer
9	Overhead in implementing 3D CAD
15	CAD system still mainly restricted to Design Departments
16	System is old & lacks up-to-date features. New system imminent-Microstation -3D, FEA, Flow analysis.
19	Reluctance by directors to invest in more up to date software
20	It is only a 2D system- It does not interface well with industry standard

25	Link between CAD and CAM not as effective as it could be
28	Tools need updating.Links needed for ECAD-MCAD-CAM essential in 3D to improve NPD times
35	Always seeking to produce designs in ever shortening lead times. Thus always room for improvement
37	Full benefits of 3D CAD still to be achieved
38	CAD benefits accrue from modifying/ extending BUT we generally make one-offs so do not benefit to the extent hoped
41	Data exchange with suppliers with different releases of software
50	Not enough CAE/CAM in factory. Would like minimal drawings or no drawings at all
51	We are only 2.5 yrs into a 5 yr programme dealing with re-use of design information
56	Methodology in D.O: Do not currently do G.As. Improve data manipulation outside CAD programe- Develop BOM linked to DWG.
59	Lack of time
60	Advancing faster to use 3D to produce more data automatically
62	Poor management planning negates most of the benefits at present. Potential to improve in all areas
63	Only using CAD as a draughting tool and not as we should. Time & labour constraints prevent this at present
64	Modifying cross department interfacing procedures to best employ rapid movement of CAD data thro CAM & eng analysis
66	Lack of direction- Weak and ineffective management
69	More time required to familiarise with software and applications
71	
73	Need better understanding of all feature-many are unused ie sample projects-Generally online help is useless
75	Regular dificulties with Resources incapable of meeting demands due to drawing complexity
81	Constantly tempted back to maual drawing for speed. Difficulty remembering commands-frustration after much work
90	Lack of procedures. Software not up to date. Not got latest tools/ functions. Exchange of drawings with other companies
96	Getting the system performing to its full potential
97	Difficulty to recruit good designers who are CAD literate
98	Integration with analysis packages lags behind- data exchange to customer eg PDGS translators + EDI
99 time	Automation could be taken a lot further to improve the design process
100	3D Complicated system. Every item has to be Modelled to allow interferences to be checked

APPENDIX C9:- COMPANY PERCEPTIONS OF ACTIVITIES REQUIRED TO MOVE FORWARD AND OBTAIN EVEN GREATER BENEFIT WITH CAD

1	Better system admin for more flexibility. More users pushing the system
2	CAD authors best placed to improve draughting speed & enable our

	engineers to become more productive
3	Change of culture among some staff
4	Nothing. We use AutoCAD LT 97 and do not need 3D
5	Look at new CAD programs and hardware
6	Make CAD data available to sales/ marketing, publicity & production .
7	Stay world class with training, equipment and software
8	Looking to move to AutoCAD R14 in near future
9	Reduce lead time using 3D
10	No reply
11	Introduce bolt-on programs-Static/ Dynamic force calculations & possibly FEA. More powerful computer
12	
13	Transfer library of manual drawings to CAD. Enable wider audience to view. Investigate 3D
14	Closer linking with customers using CAD
15	Develop Integration with other functions, especially manufacturing
16	Introduce latest CAD technology- Greater interaction with production required
17	No problems as we are!
18	Implement Document Management. FEA Tools. Tolerance Analysis Tools
19	Invest in 3D solid modelling software
20	Aquire up to date 3D system, implement it properly and train to use it to the full
21	Start to use 3D
22	Implement full 3D working and full information management system
23	More updated 3D imagery
24	No reply
25	Purchase latest version and new training. Invest in better software to link between CAD and CAM
26	More commitment of funds and management understanding of 3D opportunities-
27	Keep hardware and software up to date-Improve training
28	No reply
29	Establish a company policy and stick to it
30	No reply
31	Introduce 3D for visualisation- reduce time to market
32	Greater resources to develop standard generic models quicker; so that we can realise the benefits earlier
33	More CAD stations and more staff with an understanding of 3D
34	Move onto windows orientated software. Improve drawing library. too much repetition
35	No reply
36	Improve the hardware
37	Integration od CAD system into company databases
38	Invest more money in equipment and training to increase productivity and reduce staff levels
39	3D design and training- Update AutoCAD R12

40	Better drawing management database. Scanning and rasterising of non-CAP drawings
41	View capabilities at all computer terminals
42	Retain contact with vendor for updates/ training
43	Obtain 3D upgrade to aid and improve design stage
44	Need better integration betweenCAD/CAM & other CAD related products
45	Move to 3D
46	Generative process method based on expert system & Icons
47	Rapid prototyping to bring complex products within a 1 year time frame from art to part
48	Higher spec PC's and 3D Modelling
49	Keep updated on latest AutoCAD releases
50	Greater vision-More belief in CAD-More CAE/CAM equipment
51	Link design information into more business areas and increase web awareness on/ off site
52	Data management related to change note system and issue levels
53	Invest in new machine tools
54	3D & Modelling may assist marketing, but it is difficult to justify the cost
55	Make profit & increase investment in newer products
56	Review systems and methodologies. Invest in software develpment -make more efficient use of CAD information
57	Invest in designing 6-10 new jobs so we can show customers our creative skils-rather than customers supplying concepts
58	No reply
59	Re structure work loads
60	Extend the use of 3D
61	Invest in more comprehensive CAD package
62	Better management to allow engineers to utilise the available benefits from CAD especially 3D techniques
63	Lock people away to standardise components and create a database. With correct use of parametrics and associativity & modelling the potential is endless
64	More training and allow more movement of CAD/CAM/FEA data rather than use a compromise system to mimic a paper based operation
65	Upgrade to 3D design with CAM links
66	Change the management
67	Use the latest hardware for faster process times; Develop systems to improve hard copy printing processes
68	Keep an eye on new CAM technologies & how Rapid Prototyping is improving and reducing in cost
69	Make more time and training available
70	3D-(Underway now); Further automation
71	Better use of 3D data, post design to achieve better "Value" from the geometry
72	Employ Pro Engineer Integrated System for Design, Manufacture and Marketing
73	More time for individuals to realise potential of software being used.

	Pressure for results in excessive
74	No reply
75	Sadly-spend more money on more powerful hardware-This is the single biggest problem with any CAD system
76	Using the system more efficiently eg macros etc; Change workstation to new one
77	Direct Electronic links with customers CAD systems
78	Reduce lead time on 3D operation
79	Consider the possibility of using 3D CAD
80	No reply
81	1) Need a library of piping components-flanges,elbows, screw threads- to be able to scale & insert. 2) make more user freindly
82	3D modelling for the designers
83	3D
84	System is only used for draughting. New hardware & more modern CAD package- job is just updating existing drawings
85	VDU at shopfloor and goods inward to allow 3D visualisationof the supplied and/ or manufactured hardware
86	No reply
87	More information attached to drawings ie costs, suppliers part number
88	Wider use ie sales engineers to use CAD library(generated in-house) for hydraulic circuits + build modular product customer drawings
89	No reply
90	Get a new CAD system-Upgrade PC's, Drawing procedures. Review of drawing/ filing system/ storage
91	No reply
92	Link CAD to site offices and subcontractors for electronic transfer & printing. Connect CAD to materials take-off & ordering
93	Increase number of stations with Mechanical desktop
94	Create drawing network server. Object link data on drawings to external database linking to specifications etc. setup viewing only stations for drawings
95	No reply
96	YES!
97	Implement 3D and Develop staff
98	Further investment in EDI- Better access to expert help
99	Automation could be taken a lot further to improve the design process time
100	Investment needed for new CAD system limits moves to new CAD-Company has used IBM CADAM, CV 3D, CATIA 3D and Pro Eng 3D

APPENDIX D1: PERCENTAGE RESPONSES TO NATIONAL SURVEY QUESTIONNAIRE QUESTIONS

Sheffield Hallam University

Human Factor Influences on Effective Computer Aided Design Implementation

The successful implementation and development of Computer Aided Design and Manufacture is vital to the continuing competitiveness of UK companies. The identification and dissemination of "Best Practice" in the area is of value to most organisations currently using or considering using such technologies. Please spare five minutes to complete the survey and help us to provide industry with the ability to obtain the maximum opportunities from the technology.

Unless otherwise specified please indicate your responses by placing a tick in the appropriate box

A. YOUR DETAILS

Q1 Please write your name and company below
99%

Q2 What is your position in the company
- Director 13%
- CAE/ I.T. Manager 12%
- Manager....36%
- Design Engineer....19%
- Draughtsman.... 5%
- Other....12%

Q3 How many years have you been in this position
- Less than 1 Year 7%
- Between 1 to 5 Years 49%
- Between 5 to 10 Years 23%
- Over 10 Years....20%

Q4 Please indicate your training and academic background
- Apprenticeship 47%
- HNC? HND....58%
- Degree 36%
- Higher Degree.... 9%
- Other(Please specify).... 9%

Q5 Does your company employ CAD/ CADCAM?
- Yes....100%
- No 0%

If the answer to question 5 is "No"; Thank you for your time; Please return the questionnaire to the address shown on the back page

If the answer is "Yes" then your assistance in completing the remaining questions is extremely valuable

B. INITIAL INFORMATION ABOUT YOUR COMPANY

Q6 Please specify the main products or services that your company provide

Domestic Equipment 5%
Electric Motors/ Engines etc 5%
Forging 2%
General Purpose equip 26%
Glass Industry 4%
Heavy Engineering 3%
Pumps/ Compressors 13%
Taps/ Valves 13%
Tools 3%
Other 15%

Q7 Which of the following activities are undertaken in your company

Design and Development of existing products 95%
New Product development 89%
Manufacture 90%
Testing 86%
Commissioning 59%
Civil/ Constructional Services Design 1%

Q8 Is the organisational structure of the company

Flat 28%
Hierarchical 67%
Other(Please Specify) 2%

C. THE DESIGN PROCESS

Q9 How many of the following staff work in design

	1	2-5	6-10	11-20	>20	None
Mechanical Designers	7%	51%	22%	6%	4%	9%
Electrical Designers	12%	31%	3%	3%	1%	49%
Draughtsmen	16%	39%	6%	3%	2%	33%
Other users (Please specify below)	7%	14%	3%	3%	0%	72%

Q10 Which of the following activities describes the work that your "Designers" perform on a regular basis

Pencil sketches 39%
Concept Design 66%
2D Detail Design 92%
3D Modelling 47%
Manual Analysis 33%
Computer Analysis 29%
CAM/ CNC Programming 29%
Prototype Manufacture of Models 36%
Other(Please Specify) 3%

Q11 Percentage of work undertaken manually on the Drawing Board

Less than 20% 35%
20%-30% 1%
30%-50% 2%
50%-70% 1%
Greater than 70% 1%
None 60%

Q12 Number of Drawing Boards(If used)

None 62%
1 to 3 .... 26%
4 to 7 .... 4%
8 to 12 .... 0%
13 to 20 .... 0%
21 to 30 .... 0%

Q13 Percentage of work undertaken using CAD

Less than 20% 1%
20%-30% 3%
30%-50% 5%
50%-70% 6%
Greater than 70% 85%
None 0%

Q14 Number of CAD stations used

1 to 3	32%
4 to 7	33%
8 to 12	14%
13 to 20	11%
21 to 30	5%
30 to 50	1%

Q15 Which statements describe the design process at your company

Staff work individually on projects	57%
Staff come together in teams	52%
Teams are multifunctional	36%
Teams are product based	22%
Staff sit together in product groups	13%
Other(Please specify)	1%

D. CAD INTRODUCTION AND DEVELOPMENT

Q16 How long has your company been employing CAD

1 year	1%
1 to 3	4%
3 to 6	19%
6 to 10	45%
over 10	28%

Q17 How long have you been employing the current system (if different to the above)

Less than 1 year	7%
1-3 years	24%
3-5 years	20%
5-10 years	23%
Over 10 years	11%

Q18 What type of CAD system is currently being used

100%

Q19 What is the current system used for

All design jobs	88%
Only new design work	7%
Development work only	7%
Specific Products	4%
Products requiring 3D	11%

Q20 What has been the approximate investment in the current CAD system (Excluding Training)

£1000-2000	3%
£2000-5000	14%
£5000-10000	11%
£10000-20000	30%
£20000 -50000	16%
£50000-100000	6%
£100000-200000	8%
£200000-400000	7%
Over £400k	3%

Q21 Rank the ORIGINAL reason the company needed the current CAD system (1 being the highest)

	1	2	3	4	5	6	7	Not needed
To increase draughting productivity	44%	25%	8%	4%	3%	2%	0%	14%
To perform work that could not be done manually or with the previous system	14%	7%	11%	9%	3%	1%	0%	55%
To keep up with the competition	7%	11%	9%	11%	6%	4%	0%	52%
To improve product visualisation	10%	13%	15%	8%	4%	3%	0%	47%
To reduce tooling/ manufacturing times	12%	13%	9%	1%	2%	2%	0%	59%
To respond faster to customers requests	29%	20%	16%	5%	1%	0%	1%	28%
Other(Please specify)	11%	1%	1%	0%	0%	0%	0%	87%

Q22 Has the organisational structure had to change since CAD was implemented

Yes..29%

No...71%

Q23 Please describe how the structure changed and for what reason

31%

Q24 Has the implementation of CAD meant there had to be a change in working practices such as:

Different hours of work .... 3°

Flexitime 3%

Shiftwork 5%

Other(Please specify)..................................... 1°

No Change 91%

Q25 Was there any resistance to the technology by the users

Yes..20%

No...80%

Q26 If there was any resistance to its use, what form did this take

24%

Q27 Was there any increase in absenteeism after the CAD system was implemented

Yes.. 1%

No...98%

Q28 How has CAD introduction affected morale and relationships in the department

85%

Q29 Has the implementation of CAD resulted in an increase in staff turnover. If so please indicate the approximate % increase

83%

E. SUPPORT STRUCTURE FOR CAD

Q30 Is the organisational process employed for supporting the use of your CAD system the responsibility of:

- A separate CAE/ CAD support department 6%
- A vendor help line 44%
- The function of a separate company IT department 19%
- One person 48%

Q31 If an internal company support structure of some form does exist which of the following activities are supported and how would you rate this support

	World Class Support	Satisfactory Support	Poor Support	Not Supported/ needed
Procedures for draughting	5%	31%	4%	24%
Implementation of Macros	2%	10%	17%	30%
System configuration	4%	36%	9%	13%
Data transmission	3%	34%	10%	15%
Control of upgrades	2%	35%	12%	15%
Organisational change	0%	20%	8%	32%
Solving problems	0%	33%	16%	15%
Developing 3D methodologies	1%	19%	15%	27%
Creation & update of databases	1%	22%	18%	20%
Training of Designers & programmers	4%	20%	18%	18%
Documentation	2%	22%	20%	17%
Reviewing & monitoring problems	0%	25%	15%	21%
Administration and organisation	0%	31%	9%	20%
Design and Analysis packages	2%	22%	7%	29%

F. TRAINING

Q32 Please indicate the approach to CAD training adopted by your company

	All Designers	Senior Designers only	Only those who were to use the system	Anyone who was interested
Initial basic CAD training was for:	45%	2%	46%	5%

Q33 Which type of training was employed

- Basic internal vendor course 22%
- Basic external vendor course 60%
- Advanced vendor course..........................29%
- In-house training by company expert.......33%
- Self taught from Manual 2%

Q34 How many weeks were spent on training per person

- 1 week...43%
- 2 weeks...21%
- 3 weeks...12%
- 4 Weeks or more(Please specify)............................ .... 4%
- Staff supported to attend evening classes for the package eg C & G......................... 4%
- 1 or 2 days 9%

Q35 Approximately how much has money in total has been spent on training to use the CAD system

- 0 to 100... 6%
- 100 to 1000 ....11%
- 1000 to 2000 ....11%
- 2000 to 5000 ....17%
- 5000 to 10000 ....11%
- 10000 to 20000 .... 8%
- 20000 to 40000 .... 4%
- 40000 to 100000 .... 5%
- 100000 to 200000...................................... 2%

Q36 How long was it after initial training before staff were able to use the system effectively

- 1- 2 weeks...29%
- 1-2 months 31%
- 2-4 months 19%
- 4-6 months 8%
- 6-12 months 6%
- Much longer(Please specify)......................... .... 2%

Q37 What were the main problems staff had in becoming effective users of the system

86%

Q38 Where 3D CAD was used, did your staff experience any difficulties

- Yes...37%
- No 19%

Q39 Where staff experienced difficulties with 3D what were the main problems

39%

Q40 What solutions (If any) were needed to overcome staff difficulties with 3D

35%

Q41 Indicate which other courses design staff have had the opportunity of attending during the last 2 years

	All Staff	Most Staff	Individual Staff	No Staff
New Product Development	0%	5%	27%	62%
FMEA	3%	5%	23%	61%
Design Methods	3%	3%	15%	72%
Project Management	1%	3%	30%	60%

Q42 Approximately how much money is spent per year. per member of staff on training courses (Other than CAD)

- 0 to 50 .... 18%
- 50 to 100 .... 3%
- 100 to 300 .... 10%
- 300 to 600 .... 13%
- 600 to 1000 .... 4%
- 1000 to 2000 .... 8%
- 2000 to 5000 .... 3%
- 5000 to 10000 .... 1%
- 10000 to 20000 .... 1%

G. IMPACT OF CAD ON THE COMPANY

Q43 Please indicate your view of the success of your CAD system in terms of its impact on company business

- Significant Impact on Business 41%
- Satisfactory Impact on Business 39%
- Opportunities For Increasing Business Still to be Attained 17%

Q44 How many new products has your company introduced over the last 5 years at your site

- 0 .... 2%
- 1to 5 ....33%
- 5 to 10 ....11%
- 10 to 20 ....11%
- 20 to 50 .... 7%
- 50 to 100 .... 1%
- 100 to 200 .... 5%
- 200 to 400 .... 4%
- Much greater than 400 .... 1%

Q45 How many new products has your company introduced over the last year at your site

- 0 .... 4%
- 1to 5 ....56%
- 5 to 10 .... 1%
- 10 to 20 .... 8%
- 20 to 50 .... 5%
- Over 50 .... 3%
- Over 200 .... 1%

Q46 From an operational viewpoint which of the following benefits is the company seeing as a direct result of CAD

- Productivity Increases 73%
- Improved Quality 70%
- New Areas of Work 24%
- Reduced Costs 35%
- Speed to market 3%
- Other (Please specify) 11%

Q47 Is CAD achieving all that you hoped it would achieve

- Yes 60%
- No 36%

Q48 If the answer is "No" What are the main problems you experience

36%

Q49 Whether you answered "Yes" or "No" to the above questions, What does your company need to do to move forward and obtain even greater benefit from CAD

87%

Q50 Is the company

- Very small 13%
- SME 37%
- Large 16%
- Very Large 17%
- Not Known 2%

Solutions adopted to overcome problems with 3D

- Ignore 3D altogether 2%
- More Training 9%
- Supported practice & experience 18%
- Time 3%

Trend in Performance Over the Last Five Years:
Profit as a Percentage of Turnover

- Increasing 0%
- Relatively Stable..................................... 0%
- Mildly Unstable 0%
- Decreasing.. 0%
- Wildly Unstable....................................... 0%

Q55 Investment per seat in CAD (£k)

- 0 to 1 ....12%
- 1 to 2 ....16%
- 2 to 5 ....27%
- 5 to 10 ....21%
- 10 to 15 .... 6%
- 15 to 20 .... 4%
- 20 to 30 .... 5%
- 50 to 60 .... 2%
- 70 to 80 .... 1%

Q56 Investment in training per CAD seat (£k)

- 0 to 0.2 ....13%
- 0.2 to 0.5 ....16%
- 0.5 to 1 ....19%
- 1 to 2 ....10%
- 2 to 5 .... 6%
- 5 to 10 .... 7%
- 10 to 15 .... 2%

e again, thank you very much for taking the time and trouble to complete the questionnaire. As d in the covering letter all responses will be treated in the strictest confidence and no reference to pany names or individuals will be made in drawing conclusions from the research

ase Return the Questionnaire to
hort (Subject Group Leader)
ool of Engineering
ffield Hallam University City
ıpus Pond
et Sheffield S1
B

ceive a summary of the research findings please ensure you return the questionnaire, preferably your E-Mail address (or company address)

ail Address..

pany Address..

APPENDIX D2. COVERING LETTER FOR NATIONAL SURVEY

Chris Short CEng, MIMech E, MIED
Subject Group Leader for Design
School of Engineering
Tel 0114 224 3457
Fax 0114 225 3433
E-Mail C.Short@SHU.AC.UK

26th October 1998

The CADCAM Manager

Dear Manager,
I am a senior lecturer within the School of Engineering and also Subject Group Leader for the Design Group of ten academic staff.

We are very active in industrial research into various aspects of design; One aspect being the implementation of New Technology. From our research we have proposed a model for "Effective" CAD/ CADCAM Implementation and ongoing Development. The model promotes the Human and Organisational aspects of implementation, allowing companies to achieve the maximum benefits for themselves and employees.

Currently many companies perform well with CAD/ CADCAM but there are still many others that are not obtaining the maximum benefits. Our "Model" for effective CAD is based upon in depth case studies of nine industrial companies within a range of engineering sectors.

As your company and products relate to one of the above sectors, your assistance in substantiating the research findings by completing the enclosed questionnaire is extremely valuable.

Please could you take the time to answer the questions in as much detail as possible, since without your help we have no model.
Your comments will be treated in the strictest confidence and will not be disclosed to any third party; they will only be used for the purposes of this research.

The completion of the questionnaire will only take a few minutes of your time; However, it will allow you to influence the dissemination of Best Practice in the area of CAD Implementation and Development across the UK.
Please make every effort to return the questionnaire to the address shown as soon as possible and help with this important area of research. Also please ensure that you complete your name and company details and we will send you a summary of the research findings.

Yours Faithfully

Chris Short
Sheffield Hallam University, School of Engineering
City Campus, Howard Street, Sheffield S1 1WB

APPENDIX D3. HOW "SNAP" BUILDS TABLES OF RESULTS

Specifying a Produce Results Operation

FIELD	DESCRIPTION
Title:	Specify a title for the table(s) or chart(s) to be produced from this instruction.
Form:	Specify the required form as Table or Chart.
Style:	Specify the style for the table(s) or chart(s) . All default and saved styles will be available. The Browse option can be used to locate saved styles.

Analysis Specify the Analysis for the table(s) or chart(s).

For example: Q1to produce a table or chart of Q1
Q1 TO Q11to produce individual table(s) or chart(s) of each question within the range Q1 to Q10.

Apart from the method of specifying more than one table or chart within one instruction, the Analysis is specified in exactly the same way as it would be for an individual table or chart in the Results Definition window.

BREAK: Specify the Break for the table(s) or chart(s).
For example Q10 to produce table(s) or chart(s) with a break of Q10
Q9 to Q10 to produce one set of tables as specified in the Analysis by Q9 as the break and another set by Q10 as the break.

Apart from the method of specifying more than one table or chart within one instruction, the Break is specified in exactly the same way as it would be for an individual table or chart in the Results Definition window.

Filter: Specify a filter for the instruction if required. The filter is expressed either as a LOGICAL FORMULA (e.g. Q1=1) or as simply a VARIABLE NAME (e.g. Q1). If a variable name is given, results will be successively filtered by each code value of the specific variable to produce multiple sets of tables. If no filter is required this field should be left blank and every case will be included.

Weight: Specify a weight if required. Results may be weighted by specifying a numeric formula of up to 60 characters in length. This
would usually be a variable or a weight matrix. If no weighting is required this field should be left blank whereupon each case will count as 1.

Score Specify a Score if required. Analysed results may be rated and mean scores produced be specifying a weight matrix or variable name. If no rating is required this field should be left blank in which case mean scores will not be calculated. A
standard error value can be included or excluded, depending upon the setting in the menu

option Tailor- Analysis.

Cells This controls the type(s) of cell values to be shown in the specified table(s). The selection available will depend on the type of analysis being produced.

ABSOLUTE %	Show actual cell values.
TOTAL %	Show percentages of the table total (base).
ANALYSIS %	Show percentages of the Analysis totals.
BREAK %	Show percentages of the Break totals.

EXPECTED Show expected values for each cell as calculated for CHI-SQUARE and related statistics. This option is only available for tables with a row and column axis.

INDEXED Show indexed cell values to give a measure of relative cell values. This option is only available for tables with a row and column axis.

Options This controls the presentation of cell values for the specified tables. Two options may be selected for any one instruction.

ZEROS SUPPRESSED To exclude rows and columns consisting entirely of zeros.

ROWS ORDERED To present table or chart rows in descending order.

CHI-SQUARE To show the result of the CHI-SQUARE Test and related statistics. This option is only available for certain tables.

TRANSPOSE To change the table or chart axes so the Analysis variable becomes the Break variable and vice-versa.

APPENDIX E1:HOW CHI-SQUARED WORKS FROM "SNAP"

The chi-squared test compares observed (actual) and expected (theoretical) values in order to establish whether there is a significant relationship between two variables in a table. To calculate the chi-squared and related statistics for a crosstabulation or grid table, click , having built a table.

The statistics window gives 7 items of output:

1. The Chi-squared value is calculated as: Sum of (O-E)2/E where O is the Observed (actual) value, and E the Expected value for each cell.
2. The Expected values are calculated as Row Total multiplied by Column Total divided by Table Total (Base). They represent the values that would be expected in each cell of the table if the row variable was not influenced by the column variable or vice-versa (The Null Hypothesis). Expected values can be shown on the table by selecting the Expected Values option in the Results Definition dialog box.

3. The number of Degrees of freedom relates to the number of choices that can be made in fixing the values of the Expected frequencies. It is calculated as (the number of Rows minus 1) multiplied by (the number of Columns minus 1). The above is a 5 by 5 table, and therefore has 16 degrees of freedom.
   A statement of the result indicates the strength of the relationship (or non- relationship) between the row and column variables. Comparison of actual chi- squared values from tables of different dimensions or sample sizes is meaningless. The statement produced here resolves this problem.

4. The Phi coefficient is calculated as (X2/N) where N is the number of cases. For 2 by 2 tables Phi always lies between 0 and 1. If one dimension is greater than 2, Phi can be greater than 1. Phi can be used to compare tables of the same dimension but different sample sizes.
5. The Contingency coefficient is calculated as (X2/(X2+N)). It will always have a value between 0 and 1. Tables of different dimensions cannot be compared.
6. Cramérs V can be used to compare tables of different dimensions and different sample sizes. It is calculated as (X2/N(k-1)) where N is the number of cases and k the smaller of the number of rows and columns. Its value always lies between 0 and 1.

7. The final warning message only appears when a large number of cells in the table have small expected values. It is generally recognised that the reliability of the chi-square value of a table reduces as the proportion of cells with small expected values increases. To indicate this, a message is generated to that effect if more than 20% of the cells of a table have an expected value of less than 5.
   The interpretation of the CHI-SQUARED test result follows a seven point scale scale and categorises the certainty of a relationship (or non-relationship

APPENDIX E2:- RESEARCH PAPERS PUBLISHED

Human Factor Influences on Effective Computer Aided Design Implementation
IMechE International Conference- Design to Manufacture in Modern Industry, Bled'93, Slovenija, 7-9 June 1993
C. Short, G. Cockerham

Human, Technical and Organisational Influences on the Operational Effectiveness and Strategic Stance of a Company
IMechE Conference on Effective Technologies for Engineering Success, IMechE, London, November,1993
C. Short, S. Marriot

Maximising CADCAM Performance Through Effective Infrastructures
Manufacturing Excellence Conference, NEC, Birmingham, UK, October 1995
C. Short, G. Cockerham

Human Factor Issues Affecting CAD Implementations; Paper presented at the 1st International Conference on Advanced Engineering Design, CTU, Prague, June 1999
C. Short, G. Cockerham

Human Factor Issues Affecting CAD Implementations, Acta Polytechnical, Journal of Advanced Engineering Design, Vol. 40 No.4/2000, Czech Technical University, Prague, May 2000. **C. Short**, G. Cockerham