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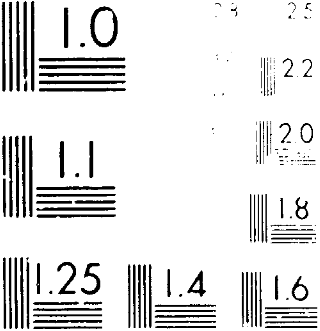
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THE IMPACT OF ELECTRONICS ON THE INTERNATIONAL ECONOMIC SETTING - THE CASE OF COMPUTER-AIDED-DESIGN*

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Prepared by the
Global and Conceptual Studies Branch
Division for Industrial Studies

UNIDO Working Paper on Structural Change

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FOREWORD

This study was undertaken in the framework of UNIDO's research programme on industrial redeployment and structural change.

A major area of research within this programme is devoted to an assessment of the impact that the latest technological breakthroughs will bear on the international division of labour in general and on structural changes in particular. The present study is concerned with one of the most recent of these technological innovations, namely computer-aided-design; an analysis of the sector is presented and its foreseeable impact on the current international economic setting outlined.

The ultimate aim of the study is to contribute to an elucidation of the major factors affecting the pace and direction of the international restructuring of industry thus increasing the awareness of policy-makers as to future developments.

This study was prepared by Raphael Kaplinski, Institute of Development Studies, University of Sussex, United Kingdom, as UNIDO Consultant, in co-operation with the UNIDO Secretariat. Mr. S. Boluda assisted the Secretariat.

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1. INTRODUCTION

Literature on the extent and nature of benefits brought about by electronics-related technologies is sparse. The present report attempts to contribute to the elucidation of these issues.

CAD technology - basically the use of computers for design and draughting purposes - has been chosen as an example of electronics technology. This sector is particularly well-suited for it exposes copious links with the rest of the technologies in the field of electronics. Further, CAD has been recognized as giving rise to a synergistic effect leading to the automation of other production sectors. Lastly, it is reckoned that due to the role CAD plays in the production process it is bound to have a significant impact on the comparative advantage of numerous manufactures.

The present report hopes to increase the awareness of policy-makers about the benefits stemming from the adoption of CAD technology and other electronics-related technologies.

To this effect, this study has been divided in five sections. The first and the last being the introduction and the conclusion, respectively.

Section 2 outlines the technological background of CAD and describes the main different types of CAD systems.

Section 3 is concerned with the CAD suppliers. The major US Turnkey CAD vendors and their performance and policies are reported. An account is also given of the barriers existing among suppliers preventing the free flow of manpower or of technological information, and those encountered by candidates wishing to join the handful of CAD suppliers. The growth prospects for the sector are examined and the main trends identified.

Section 4 deals with the CAD users. The diffusion rate of CAD equipment to users as well as the current price of this equipment are indicated. Some major applications and the operational skills necessary for them are then discussed. Finally, criteria for the efficient utilization of CAD equipment are given and an assessment of the benefits derived from the use of CAD is made.

Section 5 assesses the current international economic setting and derives some policy implications from this assessment and from the facts and arguments presented in the previous sections. The specific impact of CAD on the comparative advantage of both developing and developed countries and on the redeployment process is examined and the current development of a CAD production capability by developing countries is briefly reviewed. Further, a few major constraints hindering the introduction of CAD technology in developing countries are identified and policies aiming at overcoming these constraints are put forward.

2. CAD TECHNOLOGY AND MANPOWER

2.1 What is Computer-aided-design (CAD)?

Basically, CAD is the use of computer technology for design and draughting purposes. CAD equipment enables engineers or draftsmen to make precise, elaborate and detailed drawings of any piece of machinery or industrial product to be manufactured (aircraft, circuit boards, shoes, garments, industrial plants, etc.), by interacting between an alphanumeric keyboard and a changing display on the screen. They can simply draw free hand with an electronic pen right on the screen, and the computer gives the rough shapes, the precise tolerances requested, even rendering them in three dimensions or creating solid forms, thus allowing the CAD operator to examine the drawing from any angle; three-demensionality is the main advantage of computer-based drawings as compared to paper-based ones.

With the help of CAD, designers can enlarge details, apply colours, change shapes, test them under mathematically simulated conditions and edit and modify them. When the work is finished the computer then stores the results in its memory, which can be retrieved later on a touch of a button and brought back to the screen for subsequent examination or revision, thus eliminating tedious and costly repetition for designers and draughtsmen.

CAD technology, hardly known ten years ago, has now become one of the fastest growth areas in the computer industry.

2.2 Historical Sketch of The Origin of CAD

CAD, as the first word of the acronym reveals has to do with computers. The use of computers from the mid-1950s began to have an increasing impact upon the pre-electronic organization of factory production comprising three major subdivisions, namely design, (i.e., drawings, parts lists, illustrations), information control (e.g., inventories, marketing, financial control, wages, etc.), and production and distribution (See figure 1).

Their earliest use was in the design phase where the number-crunching capability of early mainframes allowed for the consideration of more complex design alternatives. This initially occurred in the defence-related aerospace sector but rapidly spread to other mechanical, civil, structural, electrical and engineering uses. The next major step occurred from the early 1960s when mainframe computers began to be used for information control in large enterprises, particularly in relation to payrolls and stockcontrol, and gradually diffused to smaller firms and other users. The thir phase from the mid-1960s onwards, saw the development of numerical control (NC), at first in paticular types of machine tools and then in the control of production. Computer-aided design or rather computer-graphics-aided design which is really what the CAD sector provides, is the most recent development in the electronification of manufacture.

CAD was originally developed for the electronics industry to help design the increasingly complex microchips and printed circuit boards. The interrelation between the CAD and electronics sectors was vital to the development of both with the electronics sectors providing experienced manpower and the CAD sector providing in turn a market and a new technology.

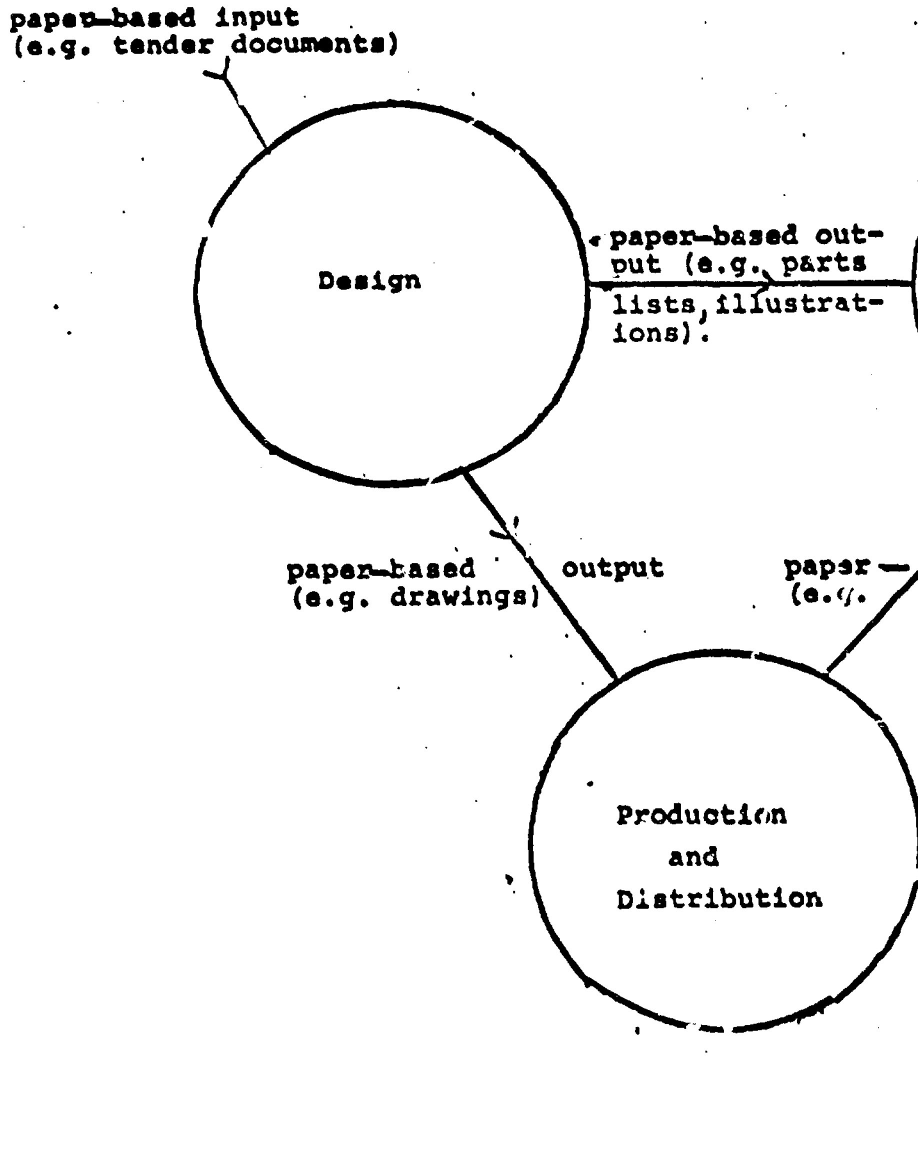
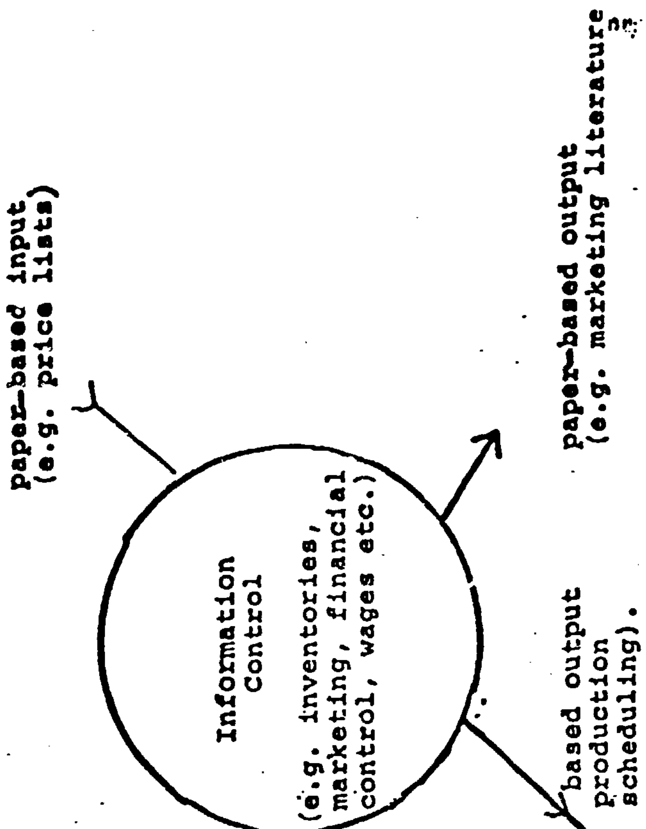

paper-based input
(e.g. tender documents)
Design
paper-based output (e.g. parts lists, illustrations).
paper-based output
(e.g. drawings)
paper —
(e.g.
Production
and
Distribution

FIGURE 1: PRE-ELECTRONIC ORGANIZATION OF FACTORY PRODUCTION



General Motors instigated the first industrial application of CAD with its Design-augmented-by-Computers (DAC) programme, beginning in 1959. This was followed shortly afterwards by similar groups in Lockheed and McDonnell aircraft firms. These three pioneering firms provided over the years a cadre of trained software writers who were instrumental in the formation of many of the major turnkey CAD vendors in the 1970s, as well as in the development of the basic graphics software which these firms used.

2.3 The nature and role of design

CAD, as the acronym implies is chiefly computer technology applied to the field of design. It is therefore fitting to examine the nature of design and the role it plays in the overall production process.

The production process, as already mentioned, is generally dissociated into three different sub-divisions, namely design, production/distribution and information control. Design itself comprises in turn four major sets of activities. Initially, the design-problem has to be specified. Thereafter, the application of design principles to the problem in question results in a solution or a series of alternatives, which then have to be evaluated in relation to factor inputs and output prices to determine whether production will be profitable. Often the best available alternative needs to be redesigned.

The communications between the three production subdivisions have been predominantly from design to information control and from design to production/distribution and have traditionally taken the form of paper-based drawings, a function performed by draughtspersons. CAD is increasingly substituting these paper-based systems of communication, and, by utilizing a single unitary data base, is inducing a reorganization of the production process through the transfer of tasks formerly undertaken in the production and information control phase to the design phase.

The design phase plays an overriding role in the whole productivity process, for although design costs are on average estimated to be only 15% of total costs, the design determines the performance achievements of the product.

2.4 Nature of CAD - hardware and software

In essence a CAD system involves four different sets of hardware. Of primary importance is the computer. Data then has to be fed into this computer, and here there are two major types of workstation; the first is the digitiser board which converts designs to numerical co-ordinates (i.e., binary code), and the second is the visual display unit (i.e., a television-like screen) which allows the designer to see the design and to proceed with it or amend it interactively. Once the design has been completed it has to be communicated; in paper-based systems this may take the form of drawings produced on various types of plotting devices[2/], while in automated systems, the design is transmitted in the form of numerical co-ordinates, often on paper-tape. The final set of hardware is the add-on-memory, since most computers in the market do not possess sufficient core memory of their own; this core memory generally takes the form of discs or tapes

On its own this hardware is useless since it requires a series of operating instructions - that is, software - to operate. Basically, there are two different elements of software which are necessary for draughting; the first of these is the operating system which specifies in fact the way in which the computer executes its tasks - all computers require an operating system. But to produce drawings it is also necessary to have basic graphics software, which is the ability to construct lines, circles, arcs, rectangles, mirror-images, etc., on the screen and subsequently on paper or paper-tape. The software required for graphics is relatively simple and is now relatively widely available. The use of the CAD system for design purposes, however requires specific and more complex software termed "applications software".

The distinction between these three variants of software must be taken into account when assessing the dynamics of market structure, the benefits arising from the use of CAD and the skills involved.

The development of software is the key to the future of CAD technology. The present overall cost ratio of computer software to hardware is about 70:30 and if the current trend continues this ratio will be 90:10 by the end of the 1980s.

2.5 Technological Development

The evolution path of CAD hardware has been earmarked by the following developments:

- interactive refresh and light pen graphics tube in the 1950s.

- the introduction of the storage tube (for screens) in 1970 by Tektronix. The storage tube has the major advantages over the refresh screen of not flickering (and therefore being easier to use) and of lower price. Its major disadvantages are that it is slower to use (since every interaction requires the screen to be "repainted") and requires subdued lighting.

- the development of the minicomputer in the early 1970s and the microprocessor in the late 1970s.

- the improvement in the most recent period of a television-type video screen (raster) which is quick to use, is cheap and allows for the incorporation of colour in applications software. Its major disadvantage at present is poor detail; but the technology continues to improve in this regard.

CAD technology is evolving at a very fast pace. It is necessary to identify and structure the present and forseeable future user needs so as to put technological progress at the service of the latter.

The influence of technological development however, though still important, seems to decline. Technological know-how does no longer suffice; knowledge of the market, well organized systems of distribution and quality of servicing have equally become determinant factors for the success of a CAD firm.

2.6 CAD software manpower

Suppliers employ a large overhead of software writers. These software writers are in general divided into three groups. The first is committed to the development of operating systems. This is a particularly critical task for Computervision which alone manufactures its own computers and employs over 100 programmers in this area, but all vendors continually need to update and improve their operating systems. The remaining software writers are divided between a small number who upgrade and maintain existing applications programmes and the larger number who are involved in developing new applications programmes.

As with the semiconductor industry itself (Forester (1978)), the CAD industry was stimulated by the rapid turnover of manpower. The most significant of these in the early years was a group of specialized software writers who establised themselves on the US West Coast in the early 1970s and constituted a firm called 'Systems Science Software' whose activities were instrumental in the development of all of the existing minicomputer-based CAD suppliers. They provided, through a series of complex alliances with, in turn, Computervision, Gerber, MCS and Calma, the basic software for mechanical applications for almost all the existing software packages now available. In the most recent (post 1978) period a new phenomenon has begun to emerge of small firms, often producing dedicated, microprocessor-driven systems, begun by ex-employees of the major turnkey vendors.

Due to the seemingly ever-increasing expansion of the CAD sector, the supply of software manpower is hardly keeping pace with demand. This shortage of software writers is one of the main constraints of the sector.

2.7 Types of CAD Systems

There are a fairly large number of firms supplying both packages of CAD systems and/or individual hardware and software components; most of them provide a wide range of options. Intergraph, for example, (currently ranked No. 3 in sales) offers 50 alternative terminal configurations. These options however, fall within three groups corresponding to the three main types of computers used, which in turn define the three segments of the CAD market. These three alternatives are:

(i) Microprocessor-based systems. Their scope is rather small and their terminals are not very powerful. Basically they are suitable as pure draughting aids - a sort of draughtsman's word processor - although some are also able to undertake elementary processing programmes such as laying out the electrical circuits on a printed circuit board. Microprocessor-driven CAD systems are aimed at users of matured applications programmes, of which basic graphics capabilities is the most obvious. From the vendors point of view the software needs little attention and the system can be sold at a price which is close to its marginal cost, that is the cost of the hardware input.

(ii) Minicomputer-based systems. These are more powerful and more flexible than microprocessor-based systems and form the basic processing capability for all of the existing turnkey systems. Their strength relative to the small dedicated systems is that they are powerful enough to be able to undertake a large number of applications programmes as well as function as a draughting tool; each minicomputer is also able to drive between three and eight terminals, depending upon the particular suppliers' software and the use made of it by the user.

(iii)Mainframe-based systems. These are partly used for graphics and partly for information processing and analytical testing. The power of mainframe computers provides two major advantages to users. The first is that these systems are powerful enough to undertake the more taxing requirements of partricular software applications (e.g., finite element modelling in mechanical engineering), and to process data-bases (e.g.,parts, lists, payrolls, etc.) for which minicomputers are not suitable. And the second is that the power of the mainframes allows large users (or those using them on a time-sharing basis) to reap economies of scale in unit terminal costs.

Systems in each of these three main computer types could be made available by turnkey suppliers, selling complete systems of hardware and software, or by specialized software vendors which provide software alone. However, the running so far over the past decade has been made almost entirely by the minicomputer-based turnkey systems, with the exception of IBM[3/] whose presence has hitherto largely been limited to very large companies using a relatively large number of graphics terminals with the processing mainframe also being used on a batch-basis for additional heavy-analytic and data-processing activities.

FOOTNOTES

1/ This figure can be higher depending on the type of product. In civil aircraft for example, design costs generally constitute around 25% of the R&D costs which in turn account for about half of the total launch costs; hence design accounts for about 121/2% of the launch costs. Nevertheless, this figure represents only about 1% of the selling price. (See Jacobs (1980) p.178)

2/ The main variants of which are flat-bed plotters and drum-roll plotters (both of which are what they seem), hard copy devices (similar to xeroxing) and electrostatic printing (the most modern variant producing the fastest and best quality copy).

3/ However, IBM only markets its mechanical software. Its electronic software is not marketed outside of affiliates since IBM is concerned that this would divulge proprietary information regarding components, integrated circuits and computer architecture.

3. THE CAD SUPPLIERS

3.1 Profile of Major Turnkey Suppliers

The dominant firm in the industry is Computervision, which was established in 1969 producing CAD systems as well as equipment for the manufacture of semiconductors. Over the decade the CAD division became increasingly dominant and the semiconductor division, Cobilt, was sold off in early 1981.

Traditionally strong in the electronics sector, but moving rapidly into mechanical engineering and other fields is Calma. Established in 1964 this firm was largely dormant until the early 1970s. It was then purchased by a large telephone firm, United Telecoms, in 1978 and after a repeatedly increased offer, taken over by General Electric in 1980.

Intergraph, based in Alabama near NASA Headquarters, is the most rapidly growing CAD firm and is currently trying to broaden its products out of the mapping sector and into mechanical and electronic applications. It delivered its first system in 1973 and has profited enormously from it's proximity to NASA (which provided a steady stream of software writers) and from software contracts with the Department of Defence.

Auto-trol has traditionally been the other CAD supplier with an expertise in mapping, although it too has been moving into other applications areas in recent years. It was established in 1962, but remained small until it was taken over by venture capital in 1973.

Unigraphics, now the subsidiary of McDonnel Douglas Aircraft, responsible for sales of turnkey CAD systems, was an early entrant. It was established under the name of United Computing in 1961 to develop software for numerically controlled machine tools. This explains its strength in mechanical engineering applications which was reinforced when it was taken over by McDonnel in 1976. McDonnel is also beginning to sell - in a largely independent operation - a mainframe-based CAD system called CADD.1/

Gerber was an early entrant to the CAD/CAM market, having bought in the basic mechanical software from Systems Science Software in 1973, and having invested over 70 person years of software to upgrade it by 1979. In 1979 Gerber Systems Technology (now the CAD division) became separated from Gerber Scientific. The Gerber Corporation has a long experience in plotting technology which was strengthened by its subsequent development of a computerized garment cutting technology in which it is the world leader; it has recently taken over its main rival, a subsidiary of Hughes Aircraft Corporation. These strengths led it into CAD applications where it has developed a particular capability in relation to mechanical engineering applications, with considerable experience in the aerospace sector.

Finally, the only large mainframe-based supplier is IBM. For this TNC, CAD is currently a minute sector, representing around 0.003% of turnover. Nevertheless, it began to give more serious consideration to CAD after 1974 for it needed CAD/CAM applications to keep abreast of competition within its own sector. Further, CAD also provided the opportunity to extend sales growth in the face of declining hardware prices with the result that it now occupies the second rank after Computervision Corp. The enormous size of IBM and its comprehensive range of capabilities make it a very powerful competitor in the CAD sector.

3.2 Sources of finance and controlling shareholdings

In the earliest period, when the low levels of software development enabled easy entry, capital was often provided by the entrepreneurs themselves, (as was the case with almost all the major turnkey vendors). But the explosive growth of the industry required extensive working capital; in the case of Auto-trol and Applicon it meant recourse to venture capital, and in the case of United Computing and Calma, to takeovers by larger firms - United Computing was purchased by McDonnel Douglas in 1976 and changed its name from United Computing to Unigraphics, and Calma was acquired by United Telecom in 1978 and sold to General Electric in 1981.

Another source of finance was the stock market; five firms offered part of their stock to the public - Computervision (various share placements have been made since it first went public in 1973), Auto-trol (raising $6.5 m in 1979 and $11 m in 1980), Applicon (selling 31% of its equity in 1978), Integraph (raising $27 m from the sale of 13.2% of its equity in 1981) and Gerber (raising $7.1 m from the sale of 20% of its equity in 1981). All of these turnkey vendors were forced into both long and short term debt[2/] to finance their expansion and to repay extensive accumulated debt. Current Controlling Shareholdings are summarized in Table 1 below.

TABLE 1: CONTROLLING SHAREHOLDINGS OF MAJOR US TURNKEY CAD SUPPLIERS

	CONTROL	OTHER SIGNIFICANT
Applicon	Original founders	General Electric owns 28%; will divest due to purchase of Calma.
Auto-trol	Hillman Foundation (c75%)	25% public + employees
Calma	General Electric (100%)	
Computervision	Founding president and vice president (22%)	Institution
Gerber	Gerber Scientific (80%)	Public (20%)
IBM	Public 100%	
Intergraph	Eight directors and employee fund (a) (40.6%)	Public (13.2%) Employees (46.2%)
Unigraphics	McDonnel Douglas (100%)	

(a) voting rights of employees fund held by founder and his wife.

3.3 Market shares

Currently seven US firms dominate the turnkey market[3/] - the shares of these individual firms for the period 1976-1980 are shown in Table 2 below. The most significant factor which emerges from this tabulation is the growing dominance of the market by Computervision whose share grew from 28.1% in 1976 to 33.2% in 1980, at the expense of all the other turnkey vendors except Intergraph. It is significant that the extraordinarily high growth rate of the industry means that despite a 78.4% annual growth in sales between 1979 and 1980 a firm like Auto-trol was faced with a declining market share, or that Gerber, with a 31.4% p.a. growth rate over the same period[4/], must be seen as struggling for survival.

TABLE 2: MARKET SHARES (%) OF MAJOR US TURNKEY CAD SUPPLIERS

	Market Share (%)				
	1976	1977	1978	1979	1980
Applicon	14.5	15.1	10.9	9.	8.8
Auto-trol	10.	11.4	13.	10.6	8.9
Calma	14.3	15.5	16.	13.61	3.8
Computervision	28.1	25.6	25.8	32.63	3.2
Gerber	3.6	1.3	2.6	3.2	4.1(a)
IBM	21.4	18 2	13.6	12.7	12.2
Intergraph	8.2	8.3	12.	9.3	9.8
Unigraphics			3.3	2.4	2.3
Other					6.9

(a) Excluding estimated sales of PC800 dedicated electronic systems sold by a different division, Gerber's share falls to 2.3% in 1980.

3.4 Geographical Distribution of Sales

CAD equipment began to be sold in the USA; it was only after 197' that sales spread to Europe and Japan.

Table 3 below shows the geographical distribution of sales for various companies. The figures quoted indicate that over two-thirds of total sales by the eight major turnkey vendors - all from the US - are absorbed by the US market. The proportion of foreign sales, however, is increasing. The proportion of US sales for Auto-trol and Computervision for example, fell from 96.2% to 77.1% between 1975 and 1980 for the former and from 84% to 68% between 1971 and 1980 for the latter. Sales growth is highest in Japan with a rate of over 100% p.a.

TABLE 3: GEOGRAPHICAL DISTRIBUTION OF 1980 SALES (%)

<table>
<tr><th></th><th>USA</th><th>Europe</th><th>Japan</th><th>Other</th></tr>
<tr><td>Applicon</td><td>70.</td><td colspan="3">30.</td></tr>
<tr><td>Auto-trol</td><td>77.1</td><td>17.3</td><td colspan="2">5.6</td></tr>
<tr><td>Computervision</td><td>68.</td><td>22.4</td><td colspan="2">9.6</td></tr>
<tr><td>Gerber</td><td>60.7</td><td>23.4</td><td colspan="2">15.9</td></tr>
<tr><td>Intergraph</td><td>79.8</td><td>16.2</td><td colspan="2">4.</td></tr>
<tr><td>Unigraphics</td><td>80.</td><td>20.</td><td colspan="2">0.</td></tr>
</table>

SOURCE: Annual Reports and Interviews

3.5 Past and Projected Volume of CAD Sales

The eight major US vendors mentioned in this study had sales of around $575m in 1980 to which must be added the sales of European (which are particularly strong in sales of software rather than in sales of turnkey, packaged systems), and Japanese firms (of which little is known), as well as those of animation and business graphics systems which are specialized subsectors of CAD.

Additional systems of an unknown value have been installed within turnkey firms themselves; the most significant of these is probably IBM electronics CAD software which is not marketed externally. In the light of these observations it would be surprising if the value of global CAD systems was much less than $1 b in 1980. This is a significantly sized market and compares, for example, with the estimated value of colour TV sales in the USA of $3.6 b in 1980.

On the basis of the above observations it is possible to make some estimates of the size of the CAD market that US suppliers will cover.

As can be seen from Table 4 and figure 2, by 1984 the market for these turnkey CAD systems is likely to exceed $4b per year, and if the market continued to expand after 1984 at 20% p.a., then the annual market for CAD equipment in the 1990s might exceed $12 b. Combined global sales could exceed $5-6 billion in 1984 and $15 b in 1990. As a point of comparison the current annual global market for robots is around $350 m and this is expected to rise to only $2 b by 1990[5/]; further the projected annual sales of colour TVs in the US for 1984 is set at around $4b only, and that for semiconductors at $12b.[6/] By all counts, therefore, CAD is a very large sector of activity.

TABLE 4: Estimate of Future Sales of CAD Equipment by Major US Turnkey Vendors, and of Sales of Colour TVs in USA ($m)

	1980	1984
Actual	575.05	
High Estimate (1978-80 rate of 84.6% p.a)		6678
Medium Estimate (1976-80 rate of 69.3% p.a)		4724
Low Estimate (at assumed rate of 40% p.a.)		2209
Estimated US market for colour TVs	3548	4067

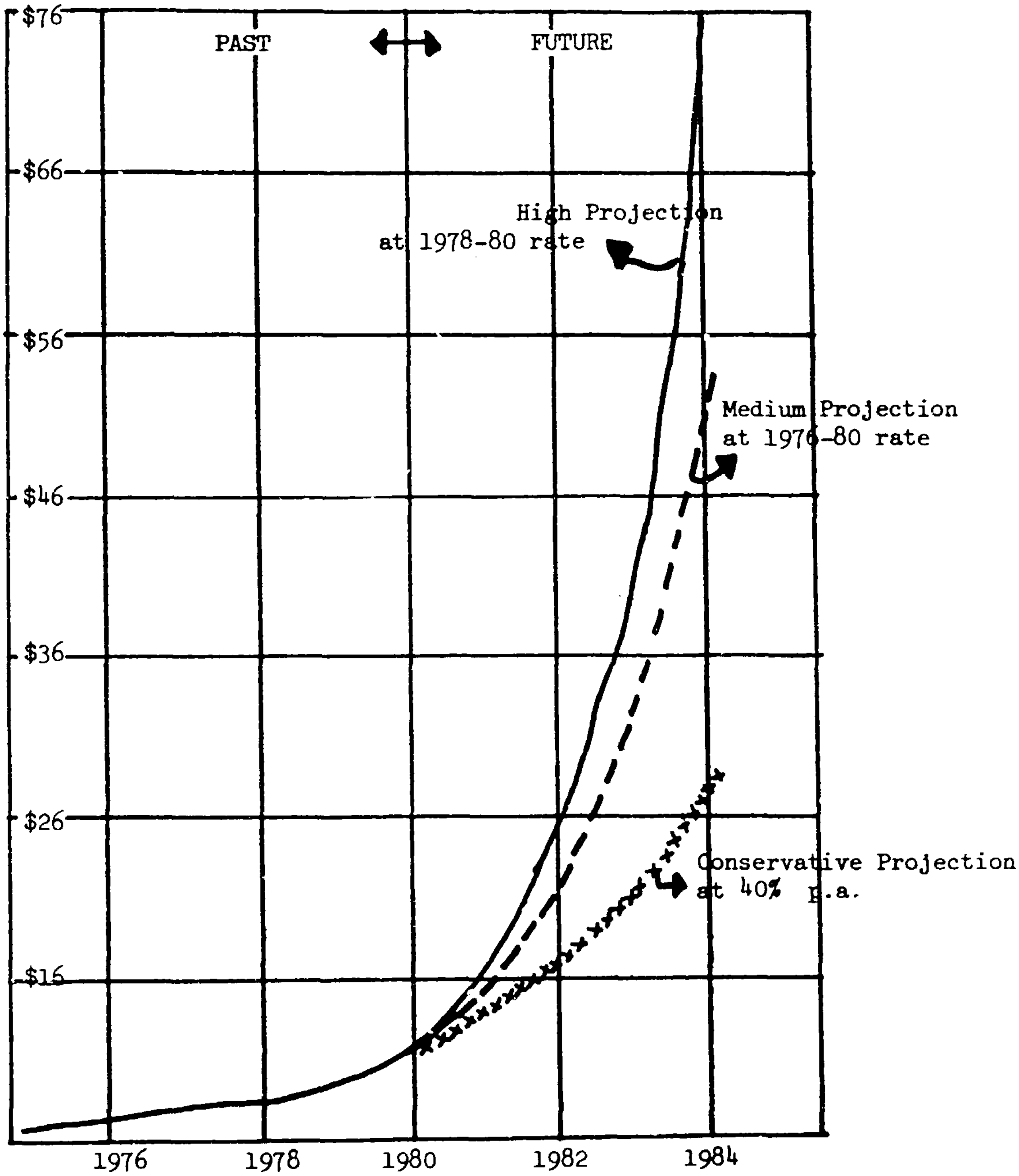
SOURCE: Based upon Table 1 and Electronics International, Jan. 1981

3.6 Marketing Strategies

While the primary realm of competition in the past has been the possession of specific applications programmes which competitors did not have, the growing all-round strength of most CAD suppliers in recent years has led to an increasing tendency towards price competition and to accrued pressure for discounting sales.

Several reasons have been advanced to account for these discounting sales. First, given the difference between average and marginal costs, there is plenty of scope for discounting. Second, some suppliers observed that vendors in particular markets (e.g., currently Australia and Japan) had set aside a predatory pricing fund to inhibit entry by newcomers. A third factor leading to discounting is the policy of particular firms who are facing relatively stagnant markets and aim to increase their market share. The fourth incentive to discounting occurs because companies which are large potential users are an important catch for vendors, since moving to an alternative CAD system at a later state requires new substantial financial inputs.

FIGURE 2: SALES OF US TURNKEY VENDORS - PAST AND PROJECTED



NOTE: 1976-80 annual rate of 69.3%
1978-80 annual rate of 84.6%

Further, the changing nature of CAD users over the past five years - from specialized electronic firms which were familiar with the problems of software maintenance to relatively ignorant users in the mechanical and ACD sectors - has introduced two new elements, namely marketing and servicing, which together with the price, determine competitiveness. Most vendors, particularly in Europe, are expanding their marketing facilities by well over 100% per year. Computervision, for example, currently the major vendor to the mechanical engineering sector in Europe, has been forced to establish a European Productivity Centre as well as a European Service Centre to cope with demands from relatively ignorant users.[7/]

Another competitive stratagem pursued by most vendors is to "oversell" immature software packages to end users. This has three major functions; the first is to "capture" a final user, thus preventing a future changeover to a competitor, for, as already mentioned, the costs of changeover from one CAD system to another are so high as to discourage it. The second is that it is difficult to simulate real operating conditions in the software "laboratory". For example, Intergraph found it difficult to "test" their data-base management system (which is now a major competitive strength for that company) within the corporation due to their relatively underdeveloped data-base; it had to go to a data-base intensive user before it could be effectively debugged. And a third advantage of marketing immature programmes is that the user partly incurs the cost of developing and debugging the programmes.[8/]

3.7 Pricing policies

In order to understand the pricing policies of particular firms it is essential to recognize the distinction between the marginal and average cost of CAD systems. All major turnkey vendors are concerned to extend the quality and range of their software, hence they employ many well-paid software writers. The software costs are fixed, that is they are largely incurred irrespective of the numbers of systems actually sold. Financing these software development costs and providing fixed and working capital to cover sales growth[9/] implies an average system price (i.e., including a provision for software development and growth) which substantially exceeds the marginal cost (i.e., the hardware component) of each system sold.

Without exception the pricing policy of turnkey vendors is to load these costs on to hardware prices; that is to "overcharge" for the hardware in their systems (which, they argue, includes "bundled" software) rather than to charge users for a realistic share of software development costs. Thus, users have to pay significantly higher prices for hardware than those they could obtain if they would unpack the system and buy in the hardware themselves. One user, for instance, could have purchased a disc drive from the original manufacturer for $8,000, whereas the list-price for the identical equipment supplied by the CAD vendor was $75,000.

This pricing policy of on-pricing hardware, rather than charging more realistic prices for software, is an industry-wide practice which vendors justify invoking the following reasons:

(i) Customers are reluctant to pay "high" prices for non-tangible assets such as software.

(ii) If more realistic prices are charged for software it would provide the opportunity for small-scale software houses to supply competing applications programmes.

(iii)Multiple-systems purchasers would object paying each time for software which they have purchased with earlier systems.

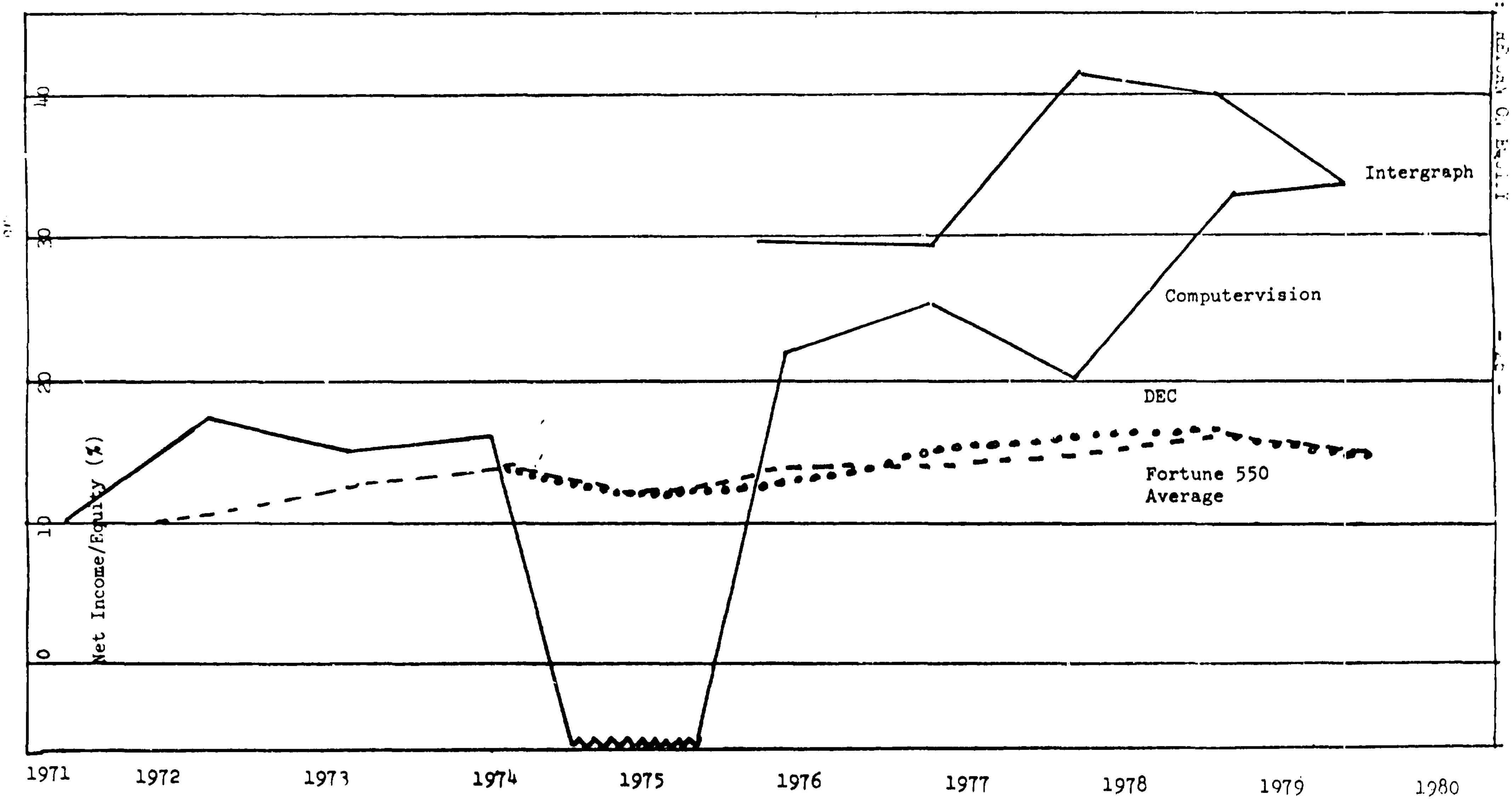
(iv) It inhibits the assembly of unpackaged systems by users trying to copy software for sales to unrelated parties.

For obvious reasons, CAD vendors are anxious to prevent unpackaging, that is the unbundling by users of hardware and software components of the system ; two major stratagems are pursued to inhibit this. The first is the policy of refusing to allow for the maintenance of the software or hardware of any system which contains alien unpackaged hardware; the second is to modify the hardware or coded software in specific sets of hardware, for example the interfacing modules of disc drives, thus preventing the mating-in of independently purchased hardware.

3.8 Profitability

In figure 3 the return on equity of two CAD firms - Computervision and Intergraph - is compared with the performance of DEC, the most successful of the mini-computer firms, and with the largest 500 US firms over the same time period. The comparison reveals that the CAD sector is more profitable than most other sectors.

However, the return on equity is not the most suitable indicator to measure market performance since the CAD sector is still in its infancy and many firms are experiencing heavy development costs. More relevant from the investor's point of view is the appreciation in the value of shareholdings. It is worth detailing some of these gains to obtain a clear picture of the returns to investors.



Intergraph
Computervision
DEC
Fortune 550
Average
Net Income/Equity (%)
0
10
20
30
40
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980

(a) Computervision By January 1981, 3,706 shareholders held 13,347,593 shares, of which the two founders and major current shareholders accounted for around 2,936,470 (i.e. 22%). Given that they purchased most of these shares at the original per value of 5 cents and estimating that their average purchase price was around 50 cents per share, the combined appreciation of the value of their shareholdings has been in the order of $200 m in 11 years.

The value of these shares over the years are shown in Table 5.

TABLE 5: Appreciation in Computervision share prices

DATE	Value of shares ($)	NOTES
Original price (1969)	0.05	
4th quarter 1973 high	19.25	
4th quarter 1974 high	5.13	General Recession in Industry (1974–1976)
4th quarter 1975 high	5.50	
4th quarter 1976 high	5.57	
4th quarter 1977 high	11.40	
4th quarter 1978 high	27.63	
4th quarter 1979 high	56.38	
20th November 1980	50.	
29th January 1981	70.12	

SOURCE: Annual Reports and Merril Lynch reports.

(t) IBM IBM is growing faster than any other CAD supplier; in one year (1981) it has increased its share of the market from 13 to 16%. The company's return on equity however, is expected to go from 21.7% in 1980 down to 19.5% this year (end 1981) . IBM's earnings nevertheless are expected to be up to $6.20 a share in 1981 from last year's $6.10 a share.

(c) Intergraph The founder, J. Meadlock and his wife, together owning 10.7% of total shares and holding the voting rights over the employees-fund holding of 14.6%, paid around $120,000 for their initial holdings. At the 1981 issue price of $18 per share (the per value of these shares are 10 cents each), their appreciation was worth $21.9 m, and at the current share price of $30, the appreciation was $36.5 m.

(d) Auto-trol Auto-trol was purchased by the Hillman Trust in 1973 for $50,000 at 25 cents per share (plus loans at commercial interest rates of $3.1 m). At the 1979 share price high of $33.50, this holding was worth $67 m. In November 1980 the share price was $50, giving their holdings a total value appreciation of around $100 m. But Auto-trol reported a $2 m net deficit on a modest dip of sales in the first six months of 1961.

Exceptions, to this high rate of profits, however, are also to be found. Gerber, for example, presents quite a different picture. Since 1979 Gerber has been struggling to increase its market share both through extensive price-discounting and by widening software applications programmes. But the costs of this have been substantial: just prior to the sale of 20% of its stock to the public in March 1981, GST had accumulated losses (by 31/12/80) of $1.453 m and expected these to increase, and GS had written-off $4 m of debt by GST in exchange for 320,000 shares; further $2.081 m of the expected stock issue of $7.1 m would go to repay additional debt to GS; finally, there was an additional long term debt of $4.5 m. These losses were incurred despite the sale of a technology licence to a Japanese firm, which brought $1m net in advance, plus an annual minimum royalty on sales and a share of its licensee's pre-tax profits.

More recently share values have on the whole slightly depreciated after disappointment over profits. Profits in 1981 for every CAD company except Computervision have been gloomy; Auto-trol, Gerber, Intergraph and Applicon have all reported set-backs.

3.9 Barriers among suppliers

Some CAD firms have taken steps to control software and the movement of personnel to avoid disclosure of proprietary software information to competitors.

Software programmes can basically be divided into two segments - object code (usually referred to as machine code), which is made up of a string of 0's and 1's (i.e., binary code), and source code which is a higher level of programming language, and assembles the object code into less cumbersome bundles of instructions. None of the CAD firms objected to the release of object code to users (since it is an essential requirement for the functioning of their hardware) except for IBM which does not market its electronic CAD software. As for source code, four of the CAD supplying firms had no objection to its release, but one of them observed that the source code itself would be inoperable without a particular item of hardware over which it maintained tight and exclusive control, a second one pointed out that even though it had access to the software of a parent firm which developed its own software and with which it had merged, it took years to unravel it, and a third firm stated that it only released source code if the user entered a "Proprietary Software Agreement". The remaining firms also retained tight physical control over the source code, despite their general observations that they would not feel unduly threatened if their competitors obtained access to it.10/

Software-intensive firms in the electronics industry are increasingly wiring-in sets of software into hardware, transforming in this way the software into firmware which then becomes patentable11/. Moreover, this reduces the input of programming which both saves costs and speeds-up processing time.12/ But as a CAD firm pointed out13/ pattern protection, because of the rapid pace of technological change in the electronics industry, is increasingly becoming less significant than factors such as the knowledge and experience of a company's management and staff and the ability to develop and market its products.

The control of manpower holding firm-specific rather than individual-specific knowledge is an important concern for all CAD firms; a strategy widely used to minimize transfers of manpower is to increase the costs of leaving the company14/. This factor however, is of diminishing importance as the stock of software grows and individual- specific knowledge becomes increasingly differentiated from firm-specific knowledge.

A major method through which CAD suppliers appropriate the individual knowledge of programmers is by insisting on the use of structured programming techniques. These involve the use of standard procedures for software writing which can be easily understood and assimilated by other software writers.

3.10 Barriers for potential CAD firms

The primary factor discouraging potential candidate firms is the scale of software inputs needed to be able to offer a competitive package of applications programmes. This would imply that the longer the CAD industry has been in existence the more difficult it is for new firms to enter the sector.

Table 6 below reveals that compared to US industry in general, the CAD industry invests a very large proportion of sales in research development. This proportion is high even relative to information processing, where the

TABLE 6: R & D AS % OF SALES

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Applicon								11	8.4	12.8	8.9	11.2
Auto-trol[1]						22.8	13	14.6	12.6	15.7	14	12
Computervision	671	28	4.4	6.4	9.7	11.8	12.3	8.9	9.6	8.3	8.8	
Intergraph								6.5	5.7	7.6	10.1	11
Gerber												15.9
All US Industry	2.2	2.2	2.1	2	2	1.9	1.9	1.9	1.9	1.9	1.9	2

1 In 1980, Auto-trol's ratio of R&D expenditure to sales (which at 12% of sales, was the lowest ratio for the firm since 1974) was the fourth highest ratio of the 744 US Corporations surveyed by Business Week; its R&D expenditure per employee was the third highest of the sample.

SOURCE: Interviews, annual reports, Soete (1977), Soete (1979) and Business Week, June editions.

1979 average was 6.1% of sales and the 1980 average was only 2%. Further, Table 7 shows that most CAD suppliers currently employ over 100 software writers per year, expanding these numbers at well over 30% p.a.. Some of the vendors were able to detail in either person-years or millions of lines of code their stock of software - over 1,000 person years in some cases and over 7 m lines of code in others.

But these absolute sunken R&D expenditures are in themselves not a sufficient deterrent to entry. After all, in 1980 prices even Computervision had accumulated less than $80 m of R&D, and some of that was in the development of their own minicomputer; compare this with the $1.5 b profits earned by General Electric in 1980 alone. Rather, the critical factors are that this software development occurs in a relatively specialized sector in the context of a general shortage of software writers and that much of software development is necessarily sequential. Table 7 below reports the number of software writers employed by the eight chief CAD firms and the accumulated years of software in the system.

In spite of the difficulties mentioned, some candidates have succeeded in joining the handful of CAD suppliers. Potential entrants may come from as far afield as the petroleum industry, from a large US industrial firm (as in the case of General Electric or United Telecom[15/]) or even from a European-based firm (such as Schlumberger[16/] or Siemens) or a Japanese-based firm anxious to enter this high technology industry[17/].

Entry may succeed either by taking over an existing supplier or by purchasing a licence on an existing software package and then developing

TABLE 7 1980 SOFTWARE STAFF AND ACCUMULATED PERSON YEARS OF SOFTWARE*

Firm Code	Numbers employed	Accumulated years of software in system
a	40	130 person years post bought-in package in 1974
b	150-200	1000 person years
c	103	n.a.
d	345	n.a.
e	125	n.a.
f	120	n.a.
g	110	600 person years in 2D draughting package plus 400 person years in bought-in mechanical outline
h	88	500 person years of software; 7 million lines of software

SOURCE: Interviews

NOTE: To avoid disclosing proprietary information firm code is not in the same order as in previous tables.

* Exludes personnel on hardware development, but includes those working on operating systems of minicomputers.

it further. The takover of Calma by General Electric is an illustrative example of the first alternative. General Electric is one of the largest industrial corporations in the world with a 1980 turnover of $25 b, and is considered to be the largest user of CAD systems in the world; its various divisions currently use over 100 systems[18/] and it plans to purchase an additional 25 systems per annum. In the face of increasing technology-based competition in all of its markets[19/], the company has made a major decision to upgrade its own technology and in particular, through association between its new semiconductor division[20/], its machine-tool division and its CAD affiliate Applicon (now all grouped in its Industrial Controls Group) to develop the "factory of the future". To this aim, GE tried to increase its 28% speculative holding in Applicon, which had a particularly strong capability in CAD software for mechanical engineering . When this failed it switched its attention to Calma, which was a less attractive proposition since its historic strength lay in electronics applications, and took it over in 1977.

Of the existing turnkey vendors the most vulnerable to a take-over is probably Gerber which continues to struggle in order to retain, let alone increase, its market share; but Computervision with its founders holding only 22% and institutions holding around 38% of its equity, must also be considered vulnerable to takeovers.

As for the second alternative, to licence basic CAD software, it is not without problems. The most important being that sophisticated packages such as AD 2000[21/] have not yet matured. One large scale user undertook a full-length investigation of it in 1980 and concluded that "if he were to procure AD-2000, a staff of 30-50 competent programmers would have to be dedicated to bug-chasing and coding enhancements"[22/].

3.11 Growth prospect

Table 8 assembles the available data on the growth of the eight major US turnkey vendors. The turnover figures for most of these firms are incomplete since only public-owned companies are obliged to publish detailed balance sheets; but with the exception of IBM (where the turnover estimate is based upon interviews) the data in this table are deemed to be sufficiently accurate so as to be reliable. Looking at their turnover since 1976 (from when fairly complete records are available for most firms) the industry's turnover-growth has been explosive. Between 1976 and 1980 the annual compound growth rate was 69.3%, rising to 84.6% between 1978 and 1980. In figure 4 the growth of total sales is compared to what it would have been had the CAD industry grown at the same rate as the world's largest electronics firm - IBM. The growth of the sector is also compared to that of the most successful firm (Digital Equipment Corporation) in one of the most dynamic industries in the 1970s, namely the mini-computer sector. In both sets of comparisons the CAD industry emerges with an astounding high rate of growth.

The major question is whether, these growth rates will keep the present pace for the foreseeable future; the following factors suggest that they will. First, all of the firms visited in the course of this research had order backlogs[23/] which suggested that the 1978-1980 growth rate would be equalled or exceeded in the 1981-1982 period. Second, this order backlog occurred in the context of a global recession causing the electronics and other manufacturing industry to experience very low or even negative growth rates. Third, the cost-reducing and quality-improving benefits arising from the use of CAD technology are likely to be in greatest demand in a

TABLE 8 - GLOBAL SALES OF CAD/CAM TURNKEY SYSTEMS BY MAJOR U.S. VENDORS

	Date of origin	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Applicon	1968								10,183	16,640	18,372	28,469	50,776
Auto-trol	1959						1,447	4,835	6,971	12,549	21,850	33,540	51,000
Calma	1964							9,000	10,000	17,000	27,000	43,000	79,400
Computer-vision (a)	1969	51	724	2,567	5,118	8,510	13,342	14,[illegible]72	19,647	28,188	43,432	103,004	191,000
Gerber	1974								2,500	1,400	4,400	10,200	23,406 (b)
IBM (c)	1974								15,000	20,000	23,000	40,000	70,000
Intergraph (d)	1969	50	270	480	620	920	2,000	3,200	5,718	9,173	20,146	29,518	56,468
Unigraphics (e)	1961										5,500	7,500	13,000
Other (f)											5,000	21,000	40,000
Total (g)									70,019	110,000	168,700	316,231	575,000

(a) Excludes Cobilt - i.e. CAD/CAM only

(b) Includes estimate of 100 sales of PC800 terminals by Gerber Scientific.

(c) Estimate based upon interviews, not balance sheets

(d) Includes sales of non-graphic software to Government which was 6% of turnover in 1980.

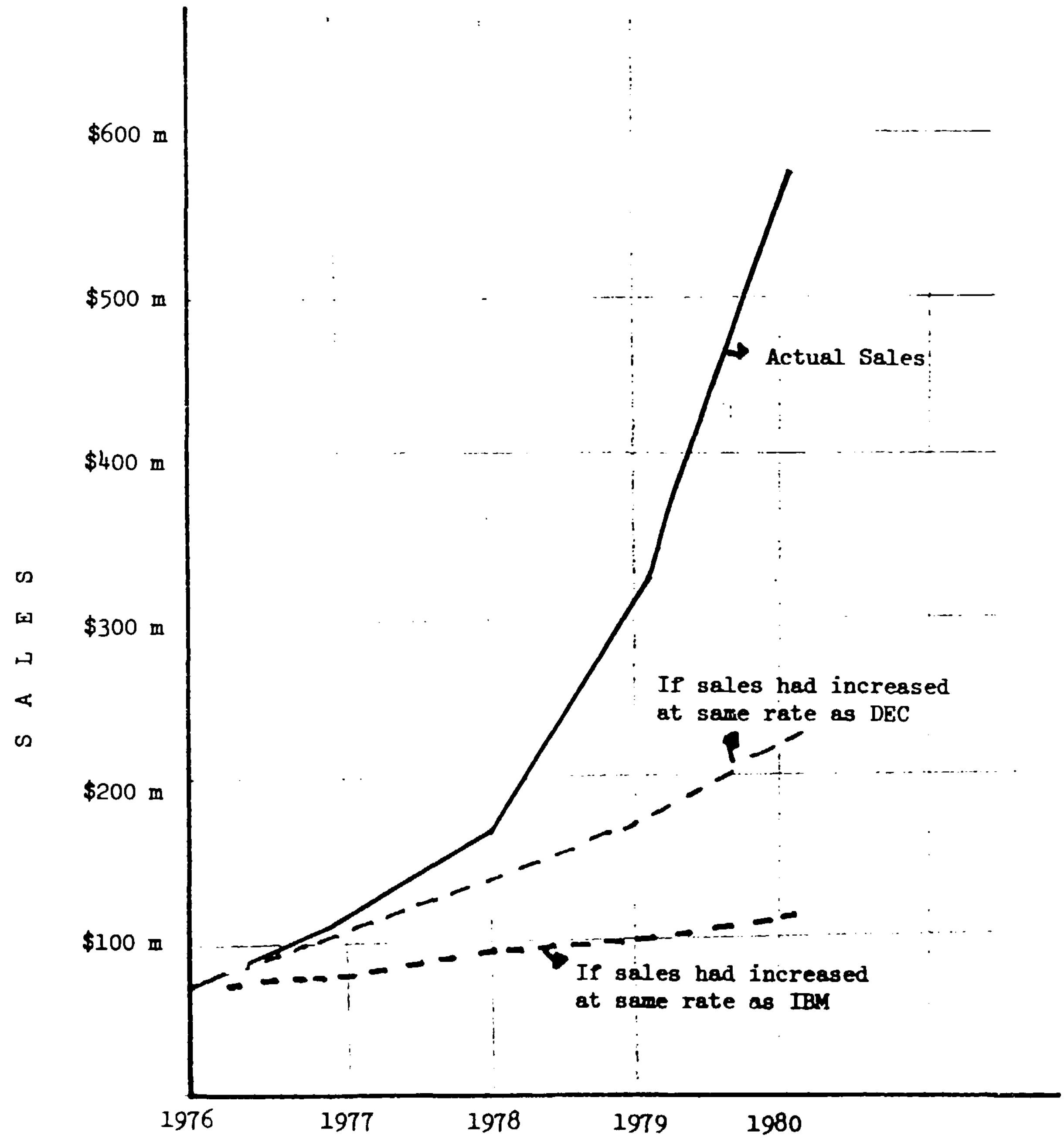
(e) Includes estimate for CADD, excludes sales of UNIAPT.

(f) Based on Kurlack (1980), excluding Unigraphics but making allowance for underrepresentation of small systems.

(g) Excludes animation and graphics CAD; Graphics CAD alone worth around $200 in USA in 1981

Source: Annual Reports and Interviews.

FIGURE 4: COMPARATIVE SALES OF US TURNKEY CAD VENDORS WITH IBM AND DEC.



recessionary period, as it is the case at present. Fourth, one major sector of the market, that of low-cost draughting systems, has only just been opened up.[24/] And fifth, sales of non-electronic CAD equipment have just recently begun.

3.12 Trends

Over the past decade the CAD industry has been dominated by specialized turnkey firms but all these suppliers now recognize that as the market widens, specialisms are dangerous.

Thus, Intergraph, Calma and Auto-trol for example, are rapidly moving towards a suite of mechanical applications programmes to complement their present strength in the particular areas in which they have specialized; the mechanical engineering sector is expected to be the major growth sector for the first half of the 1980s. Further, all suppliers are widening their suite of application programmes for th ACE sector which is regarded as the area offering the greatest growth potential in the second part of the present decade.

Computervision, the dominant firm in the CAD sector, has also decided to manufacture its minicomputer rather than continue dual-sourcing with DEC and Data General Processors. The reasons being, first that the policy of dual-sourcing which was designed to prevent undue reliance on a single supplier and to reduce the incentive to either of them to enter the market, created difficulties in servicing. Second, the technology for these minicomputers was well known; besides, particular parts of their operating system software architecture were suboptimal from the point of view of graphic technology. Third, Computervision's volume (500 systems sold in 1980) was too small to persuade the minicomputer manufactures to wire-in particular "firmware" software instructions. Furthermore, own manufacture increased profitability as it removed the profit margin of the minicomputer manufacturers who were buying in their components from sources equally available to Computervision. These reasons might well convince other suppliers to follow the course initiated by Computervision.

Actually, the CAD industry is currently at a major turning point with respect to the computers used. That is, the industy is moving from earlier 16 bit machines to 32 bit ones which are much more powerful, provide substantially quicker and more accurate processing at a lower unit cost and have also the advantage of allowing for the use of data-processing batch programmes. Currently only one CAD supplier - Auto-trol - offers a 32 bit machine; but all competitors aim to do so within the next 12-18 months.[25/]

CAD firms will also have to face a new challenge as CAD capabilities are being integrated into comprehensive computer-graphics capabilities based on mainframe computers. The reasons for this have been that CAD is too specialized a use - the mainframe manufacturers tend to go for economies of scale in applications packages - and that, in the past at any rate, the market for CAD has been too small to bother about.

Thus, IBM's marketing strategy for CAD systems , for example, is based upon the integration of data processing and analysis. IBM has already provided a computer-graphics-aided-design capability but sees the problem as a more general one - that of developing information-processing capability for the engineering sector, which would include stock and wage control, production planning, numerical control, heavy-analytical programmes, and inter alia, graphics; nevertheless, IBM considers graphics to be a necessary part of any information-processing system and a way of increasing the processing requirements of users. Such heavy data requirements require mainframe processing capabilities, which is IBM's competitive strength. IBM's competitors in this field are not so much Computervision and the other main firms in the CAD sector, but CDC, Honeywell, Hitachi and Fujitsu.

Besides, as manufacturing industry (and the ACE fields) moves towards greater automation, the extent of the market and the pressure for mainframe producers to offer a comprehensive package of applications packages (which include design-graphics) increases. All the mainframe suppliers are therefore being forced to offer CAD software.

Undoubtedly, therefore, the mainframe firms will develop a greater presence in the CAD field in the future. But since these firms thrive on economies of scale, and since their mainframes are suitable for many other uses as well as graphics, they will inevitably have greater appeal for the large-scale users who will, where necessary, be able to develop their own specific applications software or buy-in this software from emergent software suppliers.

Furthermore, there is an increasing number of small firms - estimated at 60 at present - springing up in North America and Europe and offering microprocessor-based systems with basic graphics capabilities and with perhaps one applications programme - often an auto-routing electronics programme[26/]. Many of these firms are started by former employees of established turnkey suppliers who realized that these turnkey firms were overstretched and unable to satisfy the needs of small scale highly specialized users. Indeed, the latter are more likely to purchase a $40,000 terminal for basic draughting only than spend $100,000 for a terminal which is hardly ever used for the analytical work for which it was designed.27/

The existing minicomputer-based turnkey suppliers therefore face the possibility of being squeezed at both ends of the market - from the high end by mainframes and at the low end by the microprocessor based systems. "Squeezed", however, in the sense of the market share rather than in terms of aggregate scale of output, since it is likely that the market for CAD equipment will grow very rapidly in the future.

Most suppliers, however, believed that there will continue to be a role for new applications programmes and these are currently only being developed by the minicomputer-based suppliers. But these suppliers also hold that the role the minicomputer-based suppliers will play will depend upon their ability to provide systems which could also be used by existing and potential mainframe users, and/or could compete with the small-scale mass-draughting market.

Summing up, the CAD sector as a whole is currently witnessing centripetal and centrifugal movements giving rise to the following overall trends:

(1) A growing number of application programmes to satisfy the needs of various industrial sectors.

(2) An expansion of the use of CAD from the design sphere to other spheres of the organizational structure of the firm.

(3) A progressive integration of independent applications into a common data base in order to improve intertask and interdiscipline communications.

FOOTNOTES

1/ Standing for Computer Aided Design and Draughting.

2/ Long-term debt of Intergraph, for example, jumped from $842,000 in 1979 to $6,231,000 in 1980 to finance growth in sales of 53% over this period.

3/ We refer, here to the market for CAD systems in the engineering (electronic, mechanical, civil and structural), architecture, retailing and publishing sectors. Excluded are the fields of business graphics (which according to one source - the Harvard Newsletter on Computer Graphics (Vol. 3, No. 9, May 1981) - was worth $200 m. in 1981) and animation.

4/ Excluding estimated sales of $10 m for the dedicated electronics system produced by an affiliate.

5/ Financial Times, 19 May 1981.

6/ Electronics International, January 1981.

7/ Computervision aims to have in Europe one application engineer providing software support for every eight systems in use, and one maintenance engineer for hardware for every four systems.

8/ This has two sides to it. One US user had developed a simple applications programme, but instead of selling this marketable software, it preferred to give it free of charge to the CAD supplier. The reason for this was that the user did not want to incur the cost of continually upgrading this software to make it compatible with the rest of the system, but it knew that once the supplier sold this software to other users it would be forced to maintain its compatibility to the rest of the systems software.

9/ For example with revenues of only $131.6 m in 1979, Computervision spent in 1980 $31m on capital investment, $22.1 m on Research and Development and increased its working capital requirement over the previous financial year from $43 m to $72 m.

10/ In one of these companies, which employs over 100 software programmers, only 4 people have access to the full store of source-code; in another case a user reported that the CAD suppliers applications engineers came and physically removed the source-code which they had "inadvertently obtained".

11/ Following a recent US Supreme Court Ruling.

12/ Intergraph has a major competitive advantage over its competitors in being able to insert and withdraw information rapidly from its storage discs; the substance of this advantage is wired-in to a separate set of hardware called a "scanner-processor" which Intergraph makes itself under carefully protected conditions.

13/ Hambrecht and Quist (1979) p.20.

14/ One firm, for example, requires its newly appointed European marketing manager to resell his stock to the company if he leaves the company; the latter specifically sees its employee stock option and bonus plans as a way of reducing employee turnover.

15/ United Telecom, following its sale of Calma to General Electrics, has taken over Megatex, a large supplier of peripheral hardware to the graphics industry.

16/ Schlumberger purchased Manufacturing Data Systems Inc. (for $189 m in 1980) which markets CAM software; the next urgent step would seem to be to link this to a CAD capability (beyond the 2D draughting package currently offered by MDSI).

17/ One US CAD supplier remarked that Matsushita alone used 70 of its own terminals and software to design nuclear power plants. Gerber has entered into an agreement with a Japanese firm, Yokogawa Electric Works, which rapidly developed autorouting electronic software which Gerber now offers as part of its system. A third Japanese firm, Dai Nippon Screen, is beginning to diversify out of the printing equipment sector to electronics applications programmes for CAD.

18/ Supplied by Computervision, Applicon and Calma, the latter being a distant third.

19/ See Business Week, Dec. 22, 1980 and March 16, 1981.

20/ General Electric recently purchased Intersil, a semiconductor supplier.

21/ The most readily available set of such software is Hanratty's AD-2000 licensed by CDC and Honeywell. But, AD-2000 is only one of a number of potential software packages which might serve as an entry-point to a newcomer to the industry. Another package-the Pipework Design Management System (PDMS) was developed by a Dutch based firm (AKZO Engineering), the UK government financed CAD Centre and an independent private British firm, Pipework. It is currently unique in being the only full 3D piping package available and has an enormous potential role in the design of process plants. Amongst other things this package automatically calculates whether any two sets of pipes in a complex refinery design interact with each other or with any other piece of equipment. This provides substantial savings in construction, as well as in design.

There are also a variety of solid-modelling 3D systems being generated (such as the EUCLID, financed by the French State, or the ROMULUS package offered by Cambridge Interactive Systems) which have an important future role to play in volumetric design and automated assembly.

22/ Such a task was clearly beyond Tektronix, a manufacturer of CAD graphics screens, which attempted to enter the CAD industry by licensing AD-2000 but subsequently cut its losses and withdrew. It was not however, beyond Auto-trol which has used AD-2000 to establish a suite of mechanical engineering applications programmes Interestingly, Auto-trol originally took out a licence for AD-2000 and later converted this to an outright purchase (for $1 m) for two reasons. First, it was felt that royalty-based fees would prove more expensive in the long-run than buying it outright. And second, Auto-trol had already put in around 70 person years of software into upgrading and debugging AD-2000 and was putting in more effort continually; this was considered proprietary information and Auto-trol was concerned that Hanratty's firm would benefit from its developments.

23/ With the exception of the UK market, where some firms reported that their British sales growth looked likely to decline. In one US survey (Kurlack (1980)), 35% of responding user firms intended to expand their number of CAD systems by more than 100% within 1 year, and another 8% of respondents aimed to expand by 50-100% in the same period. However, in the latter half of the 1980 the increasing incidence of discounts being offered in the US market suggests to some extent a softening market in the face of continued recession (see Harvard Newsletter on Computer Graphics, vol. 3 No. 10, May 1981).

24/ According to one estimate the demand for such low cost draughting systems in the UK alone is around 17,000. Selling at a low price of $35,000 each, this provides a UK market of around $600 m, with a global market of over $10 b (based upon the UK's proportion of global sales in semiconductors.

25/ In his survey of 45 CAD users, Kurlack (1980) found that 40 would have preferred 32 bit machines.

26/ An example of such an entry is a new US systems called Grafcon (see The Anderson Report, Vol. 3, No. 81, April 1981). In 1977 a small architectural firm obtained a contract for wall pattern drawings from a major woodcabin building firm. The initial estimate of 2.5 hours per drawing turned out to be wide of the mark - each drawing took around 10 hours in reality. So a micro-computer was purchased and specific graphics software was written, leading to a CAD turnaround time of 45 minutes per drawing within two months; the system also produced an error-free bill of materials as a bonus. Realizing that it had a viable low-cost draughting tool on its hands an agreement was struck with A.M. Brunning, an old-established graphics equipment supplier, which was anxious to capitalize on a new technology which looked likely to rapidly eat away the market for its established products. In 1980 alone 37 systems were sold (worth around $1.2 m).

4. THE CAD USERS

4.1 Diffusion of CAD Technology

To assess the impact of CAD it is necessary to ascertain its diffusion rate and to identify the sectors most affected by this new technology as well as to determine the degree of penetration of CAD in each particular sector.

If Henwood (1980) is accurate in his assessment that penetration of US industry in 1980 was "less than 5%", and if the penetration rate continues to grow at present levels it is estimated that by 1985 about 20% of the manufacturing industry will be using CAD. Under conservative assumptions, penetration of DC manufacturing industry by CAD will become fairly wide-spread over the coming decade.

The decision favoring the introduction of CAD depends of course, on the benefits it brings. Consequently, it is to be expected that those sectors which stand out to benefit most from CAD will be the most interested in adopting this new technology. CAD equipment is meant to be used as a draughting tool or as design tool; the sectors where draughting or design play an important role are therefore likely to be most receptible to CAD.

The size of draughting and/or design activities and the reckoned benefits brought about by CAD in each of these areas are regarded then to be the two main factors determining the diffusion of CAD technology.

4.1.1. Diffusion of CAD as a draughting tool

Given the use of CAD as a draughting tool and given that the technology represents an optimal choice of technique in Developed Countries, we can expect that it will diffuse through sectors in relation to the proportion of draughtspersons in their labour force.

Table 9 below shows the proportion of draughtspersons in the US labour force in 1960[1/]. It could be deduced from it that CAD is likely to achieve the highest degree of penetration in the sectors of electrical equipment, office equipment, machinery and shipbuilding, and that diffusion to the food, leather, agricultural, fisheries and apparel sectors will be minimal. This hypothesis is corroborated by the actual high rates of diffusion in the various sectors ment oned.

4.1.2. Diffusion of CAD as a design tool

In determining the diffusion of CAD as a design tool, we need to make an important distinction between design intensity and design sensitivity. While in the former case CAD can once again be seen as a choice of technique (i.e., to reduce design costs by savings on design inputs), the sensitivity of a product to a particular strategic design input need bear no necessary relationship to the products' design intensity.

TABLE 9: DRAUGHTSPERSONS AS A PROPORTION OF THE LABOUR FORCE: USA IN 1960(1)

High intensity		Low intensity	
Electrical equipment	2.08	Agriculture	0
Office equipment*	2.00	Fisheries	0
Professional and scientific equipment	1.94	Leather*	0
Machinery except electrical	1.92	Leather footwear*	0
Railroad equipment*	1.82	Leather products	0.01
Shipbuilding*	1.77	Apparel	0.02
Fabricated metal products	1.53	Tobacco products	0.04
Petroleum and gas extraction*	1.53	Textile mill products	0.04
Aircraft*	1.37	Miscellaneous manufactures	0.05
Durable manufactures	1.21	Canning, preserving, freezing*	0.05
Transport equipment	1.18	Food products	0.06
Farm machinery and equipment	0.97	Printing and publishing	0.12
Manufacturing - total	0.47	Coal mining*	0.14
Motor vehicles*	0.74	Non-durable manufacturers	0.15
Construction	0.65	Cement products*	0.15
Furniture and fixtures*	0.48	Non-metallic mining*	0.18
Petroleum refining and coal products	0.48	Wood and Wood products	0.23
Chemicals and allied products	0.46	Stone, clay, glass products	0.24
Primary metal products	0.38	Synthetic fibres*	0.27
Paper containers*	0.36	Drugs and medicines*	0.27
Blast furnace and steel products	0.34	Plastic products	0.30
Forestry	0.34	Metal mining*	0.30
Rubber products	0.33	Pulp and paper*	0.31

Median

Paper and allied Products 0.32

(1) Based on ISIC two digit classification, except for those subsectors marked with an * which are at the three digit level and are therefore subdivisions of the two digit branches already represented in this table.

SOURCE: Calculated with data from the US Department of Labour (1969).

4.1.2.1 Design intensity

Table 10 is drawn up on a similar basis as table 9 except that it reflects the proportion of engineers, kindred technicians, and architects in the labour force. To the extent that design intensity is an indicator of the path of diffusion, then we can expect CAD technology to penetrate economic sectors in relation to the ratios expressed in Table 10.

The ranking of the sectors by design intensity largely coincides with the previous ranking by draughting intensity.

4.1.2.2 Design sensitivity

Design sensitivity, as already pointed out, need not correspond to design intensity. The design of shoes, for example, is probably the most decisive factor in market growth, yet this sector has a very low design intensity. It is an enormous task to order sectors according to design sensitivity; in some cases, as with ULA[2/], LSI and VLSI chips, nuclear power plants, civil aircraft and most computers, they could not be made without CAD; but in many other sectors, although CAD is not a necessary condition for design, it enables the product to be optimized and to shorten the time needed to reach the market place.

4.2 Price of CAD systems, pay-back period and break-even computations

Given the wide variation in the processing capabilities of the various systems and in the range of applications programmes provided by each vendor, it is hardly feasible to compare here the prices of alternative systems.

TABLE 10: ENGINEERS, KINDRED TECHNICIANS AND ARCHITECTS AS A PROPORTION OF THE LABOUR FORCE: USA IN 1960 * (%).(1)

High Intensity		Low Intensity	
Electrical machinery	17.8	Apparel	0.08
Transport equipment	12.22	Leather shoes*	0.09
Aircraft	10.67	Printing and publishing	0.12
Machinery	10.34	Fisheries	0.13
Professional and scientific equipment	8.13	Leather products	0.15
Office equipment	8.07	Wood and wood products	0.17
Non-durable manufactures	5.57	Tobacco products	0.17
Petroleum refining	4.72	Textile mill products	0.24
Synthetic fibres	4.57	Food products	0.33
Petroleum and gas extraction	4.40	Leather*	0.33
Durable manufactures	4.26	Canning, preserving, freezing	0.38
Fabricated metal products	4.21	Agriculture	0.61
Chemicals and allied prod.	4.	Coal mining*	0.73
Farm machinery and equip.	3.88	Cement products*	0.97
Shipbuilding	2.96	Paper containers*	1.28
Miscellaneous manufacturing	2.89	Stone, clay, glass products	1.31
Manufacturing - total	2.80	Rubber products	1.39
Railroad equipment	2.62	Plastic products	1.40
Metal mining	2.55	Non-metallic mining*	1.42
Primary metal products	2.28	Drugs and medicines*	1.43
Motor vehicles	2.24	Forestry	1.52
Blast furnace and steel	2.18	Paper and allied products	1.58
Construction	2.15	Furniture and Fixtures*	1.82

Median

Pulp and paper* 1.89

(1) Based on ISIC two digit classification, except for those subsectors marked with an * which are at the three digit level and are therefore subdivisions of two digit branches already represented in this table.

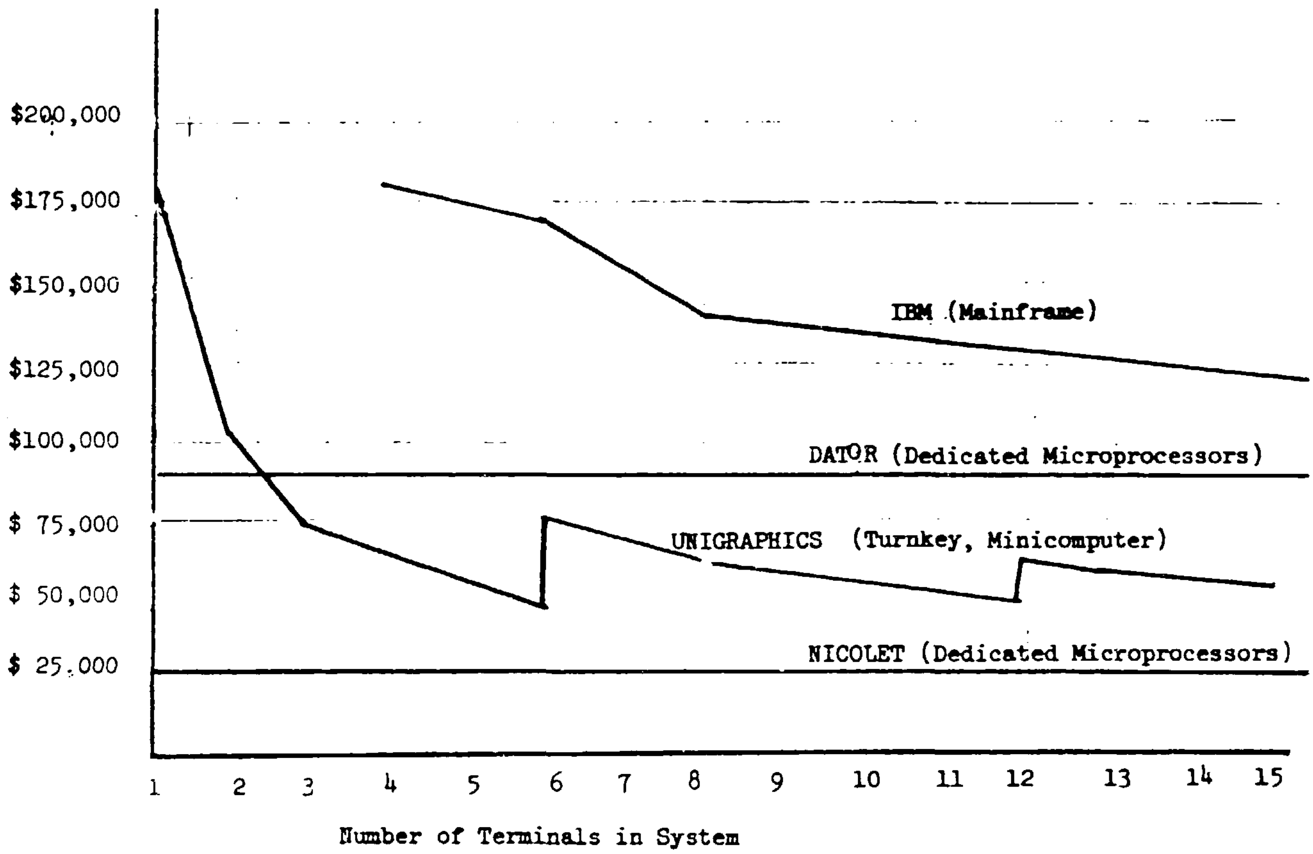
SOURCE: Calculated with data from the US Department of Labour (1969).

But basically it is possible to obtain (see figure 5) a single-terminal microprocessor-driven system which provides an elementary graphic capability with perhaps one or two simple applications programmes, for around $30,000 to 50,000. Minicomputer-driven systems have greater applications capabilities; they are consequently more expensive (around $70,000 per terminal, with software) and show limited scale economies. The mainframe systems naturally provide far greater capabilities (although the vendors have not generally developed as comprehensive a suite of applications programmes as in the minicomputer-driven systems) with more significant economies of scale but in general they tend to have the highest unit terminal costs.

However, wh ·er the variation in entry costs or unit terminal costs between these three different types of CAD systems, they all represent a considerably more significant outlay for the drawing office than the $2,000 per head worth of drawing equipment which backs draughtspersons in traditional drawing offices.

Although much of the cost of CAD systems comprises the software input and other overheads, the remarkable decline in electronic hardware prices has led to a sustained drop in the real price of CAD systems. Thus the first system with a graphics capability was developed by IBM in the 1960s and was used by the aerospace industry - it cost $3 m (Calma (1978)). Compared with the average system price of Computervision CAD equipment (which in real prices was around $394,000 in 1976, $403,000 in 1977, $345,000 in 1978, $412,000 in 1979, $347,000 in 1980) and assuming a broadly similar configuration of terminals per system over these five years, this represents a sharp decline in real terms of the price of CAD systems.

FIGURE 5: UNIT TERMINAL COSTS - SOME EXAMPLES

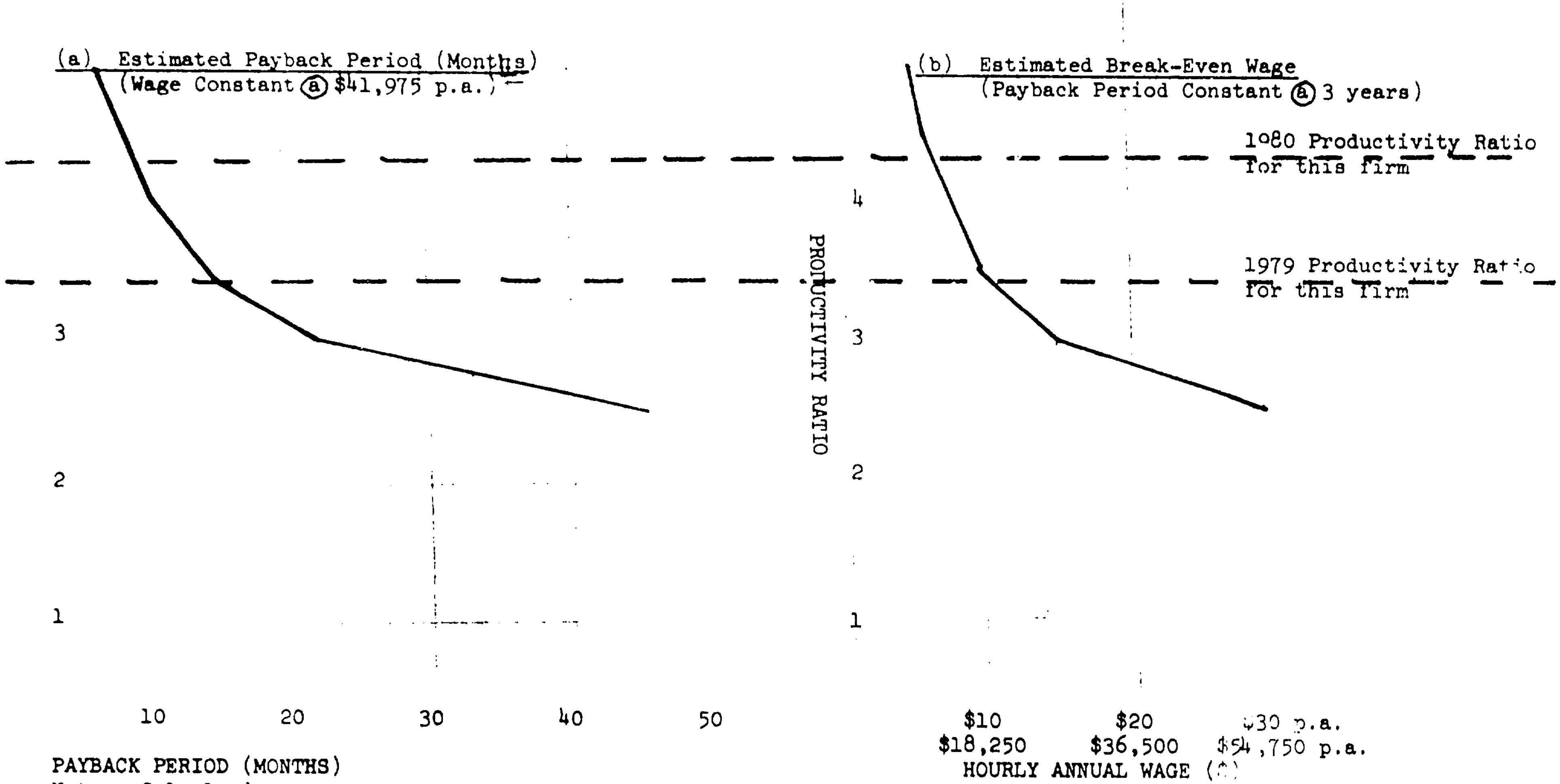


SOURCE: Field Interviews and the Anderson Report Vol. 2, No. 6.

One US user in the aerospace/defense sector has undertaken a detailed internal study of matching CAD and manual systems involving an equivalent work-load of 43 person years of manual draughting in 1980. Figure 6(a) shows how long it takes to pay back CAD equipment costs estimated at $126,727 p.a., with the 1980 productivity ratio of 3.32:1 (working on a double shift basis) when salaries total $41,95 p.a.; the outcome is less than 10 months. It can also be inferred (see Figure 6(b)) that given the 1980 productivity ratio, given the cost of CAD equipment and working on a double shift, it would pay to use CAD equipment when gross salary costs - including overheads - exceed $10,000 p.a. Costs, however, can be substantially reduced thanks to the emerging low-cost basic draughting tools. Further, Figure 7 shows that if the cost of such tools is $35,000[3/] - to which we add $5,000 to procure a system plotter and a further $10,000 for space and services - , and assuming a three-year pay-back period, a loan at 15% p.a., and a 3:1 productivity ratio, it would pay to use such low-cost draughting aids on a single shift basis when gross salary costs (including overheads) were more than $11,000 p.a., or when exceeded $5,500 if on a double-shift basis.

The pay-back period and the break-even figures for CAD equipment costs would however, be higher if the CAD equipment is mainly used for design for here the average productivity ratio is generally lower.

FIGURE 6: CAD AS A DRAUGHTING TOOL*

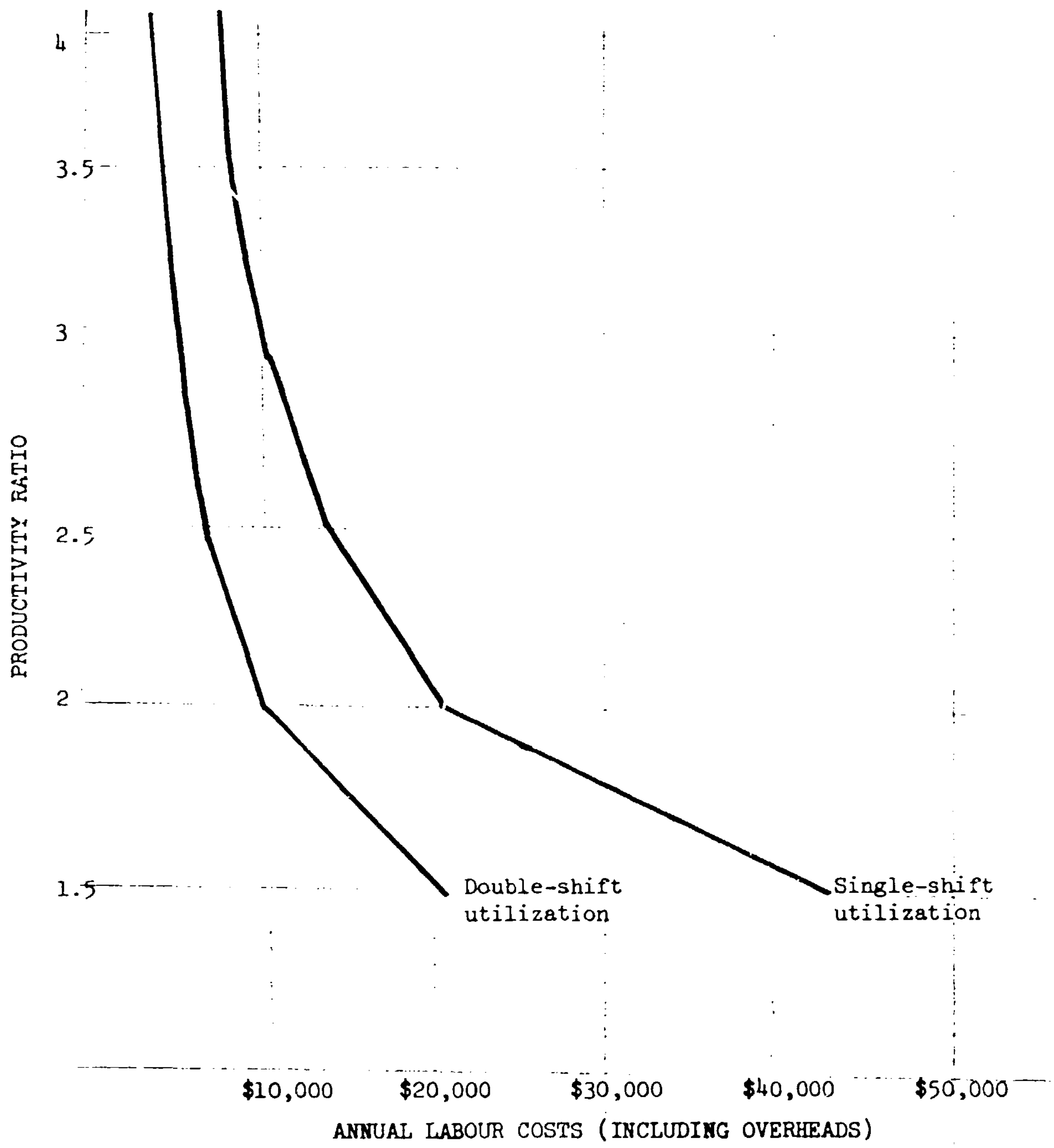


Note: Calculations based upon CAD Costs of major US Aerospace Firm

- Terminal Cost of $126,757 p.a.
- Operating Cost of $41,975 p.a.
- 4 Terminal Systems, working 2 shifts and giving 11,458 terminal hours p.a.

* (actual observation by a large US user).

FIGURE 7: SIMULATED BREAK-EVEN WAGE FOR LOW COST DRAUGHTING SYSTEMS



Assumptions

Costs of CAD equipment = $35,000   Share of plotter = $5,000
capitalized rent/services = $10,000

Life of equipment (i.e., payback period) = 3 years
Cost of finance = 15%

4.3 Major application areas of CAD Technology

In the early and mid-70s the electronics sector was clearly the main user of CAD technology. Penetration grew rapidly and almost all integrated circuit manufacturers now use CAD as part of their standardized design procedures. But the penetration of CAD into downstream firms manufacturing and assembling printed circuit boards has been much more limited; this has largely been due to the relatively high historic entry costs for CAD users.

The recent development of low cost dedicated micro-computer systems however, has begun to change this picture for although utilization of CAD in most of the printed circuit board industry is largely a choice of technique question, the technology has recently become available at a low enough cost to justify widescale use. Nevertheless, despite this growing market for low cost systems, few established CAD suppliers regard the electronics sector as a major future sector of diffusion for CAD technology.

From about 1978, especially in the USA and Japan, the mechanical engineering market began to "take-off" so that most large-scale CAD suppliers regard it as now being the chief market. The mechanical engineering sector is not only the largest area of current applications but also, due to its absolute size, the largest potential user. One source (Henwood (1980)) estimates penetration of the US mechanical engineering sector as being less than 5 %, suggesting plenty of scope for continued expansion.

Despite the rapid growth of the mechanical engineering market, the consensus in the industry appears to be that the major sector for expansion in the second part of this decade will be the architecture and civil engineering sectors. The latter currently use CAD technology only in the mapping fields and in pipework design, but the number of potential applications in other areas of process plant design, engineering works and building design is enormous.

4.4 Applications

CAD applications were hampered in the 1960s by the lack of corresponding hardware. Subsequently, in the 1970s it was the scarcity and immaturity of software that were the main constraints for the expansion of the sector. These limitations being now overcome, the CAD sector of the 1980s is likely to be handicapped by the limited ability to assimilate new features, that is, limited by the restrained capabilities of users to incorporate new applications.

CAD applications fall into three main categories: technical computation, project engineering and project control.

It was in the late 1950s that CAD was first used for technical computations such as stress analysis and mechanical engineering calculations, mathematical modelling and processes, and heat transfer. Technical computation programs are 5 to 50 times faster than normal calculations.

CAD applications in project engineering came about in the 1960s in batch mode and developed in the 1970s with the help of minicomputers an terminals. Being a more recent development, the level attained by different firms in project engineering computer tools varies significantly.

CAD applications in project control include planning, scheduling, estimating, cost control and performance monitoring systems. These are usually tailored to a company's needs and organizational structure.

Applications range from routines which are fairly standard by now (e.g. the calculation of optimum routes for linking the electronic components on a printed circuit board), to those which are actively under development (e.g., solid modelling[4/]). Some of these applications programmes are not heavy users of data (e.g., autorouting), whereas others (such as finite element stress analysis) require powerful mainframe computers for execution.

Because of the different origins of the various vendors, each has developed a speciality in a particular area (see Table 11), but because of the directions of market growth those suppliers with a poor base in the manufacturing and architecture and civil engineering (ACE) areas are making an effort to cover these sectors too. Moreover many users demand an all-round capability of their CAD systems; for example, they should not only be able to undertake mechanical stress analysis, but also be used for printed circuit board layout - and this, too, is forcing most vendors into developing a multi-sector applications-programme base.

From the operators point of view the primary method of using these applications programmes is via "menus" which are removable sensitized tablets which contain specific routines relevant to particular applications programmes and which enable rapid use[5/]. Characteristically, an efficiently run CAD system will have numerous menus, each designed to fit a particular set of applications.

TABLE 11: ESTIMATE OF SECTORAL DISTRIBUTION(a) OF SALES OF MAJOR VENDORS (%)

	Electronics	Mechanical	Architecture	Mapping	Other
Applicon (1980)	47.2	32.8	9.8	0	9.8
Auto-trol (1980)	10.	36.	50.	22.	18.
IBM(b) (1980 and stock)	0.	100.	0.	0.	0.
Calma (stock)	70.	17.1		12.9	
Computervision (1981)	20.	70.		10.	
Gerber (1980)	43.	57.	0.	0.	0.
Intergraph (stock)	0.	0.	51.	49.	0.
Unigraphics (1980)	0.	100.	0.	0.	0.
TOTAL	21.4	53.5		25.1	

(a) major end use
(b) excludes internal use of electronic software

SOURCE: Interview and Annual Reports

4.5 Requirements and acquisition of CAD operational skills

4.5.1 Requirements

Once the user has decided to acquire CAD equipment, the question arises about which are the skills required to use it.

When used for draughting, CAD takes up the skill associated with individually-tailored lay-outs and individually-developed lettering and reduces the draughting task to a mere machine operation. With analysis and design by contrast, CAD assumes the tasks for which no design skills are necessary, enabling the designer to concentrate on the application of his designing skills. In short, with CAD, draughting skills are no longer needed whereas design skills continue to be required.[6/]

In both cases, as CAD systems have an alphanumeric keyboard, typing skills are an advantage for feeding the data. Management felt, however, that attitude and flexibility were more important attributes.

Finally, IBM argues that manual dexterity is also a chief factor; the difference in performance due to this factor has been ascertained by observing that while the average IBM CAD operator works at around 30 interrupts per minute, the best operator may reach 100 interrupts per minute. Thus, the general view of management is that although a good draughting person makes a good CAD operator, the CAD system may make a good operator out of a bad draughtsperson.

4.5.2 Acquisition

The acquisition of CAD operational skills involves a series of steps. At around three months, most operators are up to the level of productivity of manual systems. There is then a short period of retrenchment stretching up to the sixth month during which the operators assimilate the newly-learnt basic operational skills which are thereafter continually improved via the assistance of menus. Then the operator begins to take advantage of the sub-designs stored in the CAD system and makes more effective use of analytical programmes. The majority of users reported that by the end of the first year, most operators were about as efficient with the system as they could ever get.

4.6 CAD Efficient Utilization

There are three factors which stand out in determining the success with which systems are utilized. The first concerns scale; the consequence of using three different types of computers is that there are economies of scale in purchasing any systems which run with minicomputers or mainframe computers. This is because unlike the microprocessor-driven systems which have a separate computer for every workstation, each of the more powerful computers are able to support a large number of terminals. Thus the minicomputers can cope with up to eight terminals (depending upon use and software), and some of the mainframe computers can support over fifty terminals with additional capability available for other batch-processing tasks (such as payrolls). Generally, CAD systems based upon minicomputers are unlikely to be profitable with fewer than 10 designers; those based upon mainframes have even greater economies of scale and require around 20 potential users.

Second, while the draughting gains obtained by the introduction of CAD are found to be similar across firms, this is not the case with CAD induced gains reaped from downstream activities, for gains in these activities depend upon appropriate organizational changes. Organizational changes in the system include complementary adjustments in the other spheres of the firm, that is in the information control and in the production/distribution sections; without these, the full benefits of the CAD system cannot be realized.

Gains in downstream activities are partly a function of improved applications software, but the attitude of management towards new forms of systems organization plays a determinant role[7/]. The time span within which management is able to comprehend the changes which are necessary, and then to implement them, is generally, but not always, longer than those involved in the individual learning curve. After one month the new system's productivity equals that of the manual system, but progress thereafter is slow until the fifth month, when complementary organizational changes are implemented, after which progress is rapid. By the tenth month the productivity increase sets at an average of 3:1.

Another important element ensuring the efficient use of CAD, is the provision of back-up services. CAD systems are new, different and software intensive. Users consequently require a great deal of back-up from suppliers until their systems function efficiently, particularly when the innovating firm is not experienced in using analogous types of equipment (e.g., automatic testing equipment). The services offered by the suppliers relate predominantly to software. Most suppliers reported that over fifty per cent of software "bugs" turned out, on inspection, to reflect the "ignorance" of users. But in addition to the ongoing services which suppliers offer, the growth of users' systems efficiency is enhanced by specialized courses which all suppliers provide and by regular meetings of users during which they can exchange experience, exchange (or market) software programmes they have written, and collectively place pressure on the suppliers to improve their software and support. The dominant conclusion which emerges from these considerations is that "closeness" to CAD suppliers is important, for efficient use often requires a lasting "handholding" relationship.

4.7 Assessment of Benefits

The following problems are encountered when trying to assess the benefits the use of CAD gives rise to. First, that CAD is a necessary and important element in the jigsaw leading to the emergence of the automated factory; but the systems changes invo[illegible] in this change in industrial organization are hardly susceptible to quantification. Second, many of the benefits of CAD are realized in the quality of the product and the speed with which new or modified products are launched - these improvements, often critical to the survival of particular firms, vary in importance between sectors and firms. Third, despite the strenuous efforts of management to standardize procedures, much of design is in an art-form (as is the case with software-writing in general), making it highly dependent upon the particular individuals involved and consequently open to variable levels of performance. Finally, and more generally, the productivity of most technologies can seldom be measured as a thing-in-itself since it will inevitably reflect the institutional and economic structure in which they are introduced.

In spite of the above constraints, an attempt will be made to identify the benefits deriving from the adoption of CAD technology. The two major considerations are cost-effectiveness and usefulness. Cost-effectiveness refers to actual savings in production cost resulting from the reduction in labour requirements or production time or from the optimum utilization of materials. The following points are here examined: Increase of productivity, staff reduction or displacement, CAD-paced work, reduction in lead-time and downstream benefits. Usefulness refers to the intangible benefits such as improvements in product quality and reliability; three points are discussed: Quality improvements, reduction of on-site contingency costs and enhanced control of proprietary information.

There are three factors at work in determining CAD induced productivity. First, there is the speed at which the technology actually operates; this is not just the speed (and precision) at which the lines are physically drawn on the screen, but includes the routine background calculations which lie behind the drawing. For example, changing the specifications of a biscuit-machine from one size to another, as occurred in the case of one user, requires the scaling of all components of the design; manually, this involves endless hours of routine calculation whereas on the CAD system used, the scaling is done automatically and almost instantaneously. Second, most users felt that on primary design drawings, the productivity of the CAD system was seldom higher than manual systems, but on modifications the productivity gains were higher, frequently over 20:1 and in one case computed at 100:1. Third, many of the gains from CAD depend upon the system with which the design office is organized. This is particularly important when the product is of a modular nature and particular parts can be stored in the memory of the CAD system - instead of manually redrawing a particular hopper or conveyor-belt in a plant design, the CAD operator can instantaneously recall it (or a variety of alternatives) from memory and append it to the lay-out under design. Fourth, the productivity gains depend on the use CAD is put to; the productivity of CAD systems varies depending on whether they are mainly used for design or for draughting, the new productivity ratio for the former being, as already mentioned, generally lower than the ratio obtained for the latter.

A number of users visited had computed the overall average productivity of their CAD systems, the results are shown in Table 12 below. On average most of these users set their overall productivity gains at a ratio of 3:1 in respect to manual systems[8/].

TABLE 12: PRODUCTIVITY OF CAD SYSTEMS

Sector of activity	Location	Primary use of CAD	Average productivity ratio	Range of PR between different types of drawings
Integrated circuits	US	Design	2:1 after 6 months	NI
Automobile components	UK	Design	3:1 after 12 months	NI
Plant design	UK	Draughting	3:1	1:1 - 20:1
Process plant	UK	Design	NI	1:1 - 50:1
Electric motors	UK	Draughting	6.6:1	NI
Printing machinery	UK	Design/ draughting	>2:1	NI
Architecture	UK	Design	3.5:1	NI
Automobiles	UK	Design	3:1	NI
Computers-pcb's	UK	Design/ draughting	>5:1	NI
Process plant	UK	Design/ draughting	4:1	NI
Petroleum exploration	UK	Design	2:1	NI
Automobiles	UK	Design/ draughting	2.78:1 after six months	NI
Aircraft	US	Design	2.5:1 in 1979 3.32:1 in 1980	NI
Instruments-pcb's	UK	Design/ draughting	3:1	NI
Public utility	US	Draughting	3:1	NI

NI: No Information
SOURCE: Interviews with users.

The introduction of CAD technology may lead to the reduction or displacement of existing staff, thus lowering personnel costs. By way of example, one user had displaced 25% of its draughtspersons and a further 15% reduction of design and draughting staff took place once designs were stored in memory; another large-scale user estimated that CAD equipment would displace around 2/3 of its draughtspersons before 1985. Some users reported, however, that they preferred to increase benefits by producing more drawings rather than by displacing staff. A number of other users found that CAD systems enabled them to make much less use of contract draughtspersons (who cost around twice more than permanent staff); the displacement of contract work appears to have been the major area in which the job displacing characteristics of the technology have been felt.

Furthermore, users reported that CAD significantly affected the pace of work drastically increasing the amount of time actually spent working; by contrast to the solitary work enviroments of CAD screens drawing offices are social environments - many managers lamented that, on average, draughtspersons only spent around 30% of their time actually drawing, with much of the rest spent in discussion. Besides environmental considerations, CAD systems offer reasonably rapid response and tend to prompt the operator. The outcome is that the design/drawing process becomes machine-paced rather than man-paced, and is consequently speeded up. Finally, when each draughtsperson had $2,000 of equipment to work with, fixed costs were small and there was little financial incentive to work multiple shifts, but when CAD operators are each backed by over $100,000 of equipment, it becomes imperative for design-office management to ensure full utilization. Therefore, most CAD systems - especially in the US - are used on a multiple shift basis[9/].

The benefits we have been mentioning so far only cover savings attributed to an increase in the overall per capita productivity of designers and draughtspeople. There are a range of other benefits, however, which arise from better quality drawings and drawings which have fewer errors. A user who designs process plants remarked that certain drawings are characteristically revised 8 to 12 times - in manual offices this gives rise to a messy and error-prone product; with CAD these problems are largely removed. Almost all of the users visited felt that the benefit of more accurate drawings was one of the major advantages of using CAD. Overall, on the quality side, CAD systems greatly facilitate the modification of products and their optimization.

The introduction of CAD can also reduce on-site contingency costs - one of the users reported a reduction from 15% down to 5% - and lead to a more efficient organization of information by reducing inaccuracies and misunderstandings, by increasing communication, and by systematizing the inventories. The latter systematization usually reveals an unnecessary proliferation of part-types and thus leads to a more structured organization of warehousing and numbering and often to a reduction in the number of the different parts held.

Besides cost and quality considerations, the time needed to launch a product is often of crucial importance. CAD enables a substantial reduction in lead-time[10/].

As for the CAD-induced downstream benefits in production and distribution, they depend upon the nature of the process and products involved, the following specific examples illustrate the variety of benefits that can be reaped:

Machine-setting The control mechanisms of numerically controlled machine tools utilize the same basic digital information with which the CAD systems operate.[11] Consequently, it is not a complicated task to link the two systems; in most cases, users had drawn links between CAD designs and NC milling and cutting machines but in the future, specifications for the automatic testing equipment are likely to be fed directly from the CAD systems. The benefit of these links are manifold, including the displacement of machine operators and a reduction in errors in machine-setting.

Material savings A particularly important benefit of CAD is the saving in material due to the optimization of design and nesting.[12] In one case, optimized designs had reduced the number of parts in a machine by 50%; in another, CAD had made it possible to reduce silver utilization by 50% in a process in which silver comprised 30% of direct production costs. Benefits from CAD nesting programmes are widely felt - one sheet-metal user had reduced wastage from 40% to 26% in its first-generation nesting programme; its annual savings in sheet metal equalled the total annual wage bill

Prototypes Four users reported that the primary benefit brought about by more accurate CAD drawings was the reduction in both the need and costs of having to manufacture prototypes.

Piping A major, and rapidly expanding field for CAD systems is "piping" software which is used for "interference checks", i.e., to find out whether pipes obstruct with each other or other sets of equipment in a process plant, thus avoiding subsequent on-site rectification of design errors. The elimination of such design-errors is already beginning to have an impact in reducing construction costs, despite the immaturity of much of the available software.

Finally, the centralization of the data base in a CAD system allows for an increased control of technological information and enables a more selective dissemination of information to subcontractors.

FOOTNOTES

1/ This is only comprehensive information available on the proportion of draughtspersons in the labour force.

2/ A new and very important potential trend in the electronics sectors concerns the emergence of uncommitted logic array (ULA) chips. Unlike existing chips, the final logic of the ULA chip is decided by the user, rather than by the manufacturer. The subsequent connexion of uncommitted logic gates cannot be done without the use of a very sophisticated CAD facility. According to one knowledgable source (Dr. I. Mackintosh of Mackintosh Consultants) there is at least an even chance of ULA chips becoming dominant within the next 5 to 10 years.

3/ Cheaper equipment is already available and prices are declining as microcomputer and data storage costs decline - the software component of these systems is minimal and stable.

4/ Currently the three-dimensional applications software of almost all CAD suppliers is built up of a series of wire-frames. These, although requiring substantially fewer data inputs and processing capability than real 3D solid modelling packages, have a number of disadvantages associated with the fact that they do not differentiate between "space" and "real matter". Consequently, they cause significant hurdles to some sorts of volumetric analysis and are inhibiting the development of automated assembly techniques. It is anticipated that the development of efficient solid-modelling software, which is currently underway in all CAD suppliers and numerous universities and research institutes, will take another two to four years.

5/ An analogy to changing menus would be the change from a statistical calculator (with buttons for regressions, square roots, etc.) to a scientific calculator (with buttons for trigonometric functions).

6/ This different impact upon draughtspersons and designers is reflected in the attitude of trade unions to the introduction of CAD. In the UK the draughtspersons' trade union (TASS) has been most active in resisting the diffusion of CAD, while the designers' union (ASTMS) has not raised major objections to its introduction.

7/ Thus, IBM draws as a matter of general policy the attention of users towards the systems changes required and insists that (i) before installation IBM staff meet with senior management to discuss the systems changes which are involved, that (ii) the best managerial manpower should be devoted to the system - indeed the less-efficient systems observed amongst users were generally associated with management having an inappropriate training, or trained primarily in data-processing rather than in management - and that (iii) the decisions on required work changes (e.g., the procedures for releasing final drawings) are worked out in detail before installation.

8/ Similar results were obtained by a survey of thirteen US users and 14 European users conducted in 1978 (see UK (1978)); the productivity ratio reported varied between 2/1 and 27/1.

9/ Computervision claims that on average, their CAD systems are used for 88 hours per week in the USA; the figure for Europe is substantially lower.

10/ As an example, a design engineer of a British firm close to bankruptcy, came up with a radical redesign of its major product which had to be launched within one year, otherwise the firm would go out of business. It would have required 12 person years of draughting but the design was sequential and there was a shortage of draughtspersons. A two-terminal CAD system was procured at short notice and three designers produced 8000 drawings in the first year compared to the average performance of 400 drawings per person per year in the manual office.

11/ Although for this information to be utilized it has to pass through a post-processor which, in the absence of direct numerical control (DNC), prepares the paper tape for the computer-numerical control (CNC) machine tools.

12/ This is the name given to the programmes developed to cut shapes out of a sheet of metal.

5. ASSESSMENT OF THE CURRENT INTERNATIONAL ECONOMIC SETTING AND POLICY IMPLICATIONS

5.1 The Current International Economic Setting

Developments in the global economy over the past thirty-five years since the end of the war can be viewed in a variety of contrasting ways. At one extreme, little appears to have changed; the mass of the world's population continues to subsist at, or near, the bread line, and most of these people live in less-developed countries. Further, developing countries continue to rely on developed countries technology; indeed the flow of trade consists predominantly in the developed countries exchanging manufactured goods and technology for primary products from developing countries. Yet within these overall trend, important changes have been taking place in the international division of labour. By 1975 over 40 developing countries each exported over $100 m of manufactures, while the developing countries manufactured exports aggregate increased from $4.6 b in 1965 to $55 b in 1977 (Hoffman and Rush (1980)). The share of developing countries in global manufacturing value-added has grown from around 7% in 1965 to nearly 10% in 1979 (UNIDO (1980)).

This growing participation of developing countries in global industrial output and trade reflects two interrelated tendencies in the world economy. The first concerns the specific attempts made over the years by newly independent developing countries to foster industrial production. This involved protecting and subsidizing production, at first mainly for local consumption and then subsequently destined for global markets. The growing presene of TNCs, actively seeking new markets in the face of fiercely competitive oligopolistic markets (Knickerbocker (1973)), is another factor contributing to the industrialization of developing countries.

Associated with these changes there has been a growing capability by developing countries in the realm of science and technology. In the early post-war period educational facilities in almost all developing countries were minimal; their expansion and upgrading became a priority for most of these countries. The resulting increase of skilled manpower in developing countries fostered and facilitated the transfer of technology. An indication of this has been that developing countries manufactured exports have progressed beyond the "mature" labour-intensive traditional industries (Vernon (1966)), and have increasingly come to encompass a variety of technology-intensive goods (Lall (1979), Katz (1978), O'Brien (1981)).

As a consequence of these developments there has been optimism that developing countries will be able to maintain the pace of their growing industrial role in the international division of labour - the 1975 UNIDO Lima Conference, for example, set a target for developing countries of 25% of global value-added in manufactures by the year 2000 (UNIDO (1979))[1/].

But this horizon has in recent years become clouded both by the persistent and worsening recession in the world economy and by the rapid diffusion of efficient electronics-related technologies in developed countries manufacturing enterprises. These technologies not only tend to save labour, the source of developing countries comparative advantage, but also provide other substantial benefits to innovating enterprises. So their differential diffusion in the world economy is likely to significantly affect the ability of non-innovating enterprises to compete in global markets. If this differential diffusion takes the line of a developed-developing countries split, then the existing technological gap between them may widen, in which case, the anticipated industrial share of developing countries is likely to be smaller than current perspectives suggest.

5.2 The role of electronics in the modern economic context

It has been argued (see Freeman (1981)), that over the course of the last two hundred years, there have been a series of major, "heartland technologies" which have fueled "big wave effects". The first of these, beginning in the late 18th century was based upon textiles and the diffusion of the steam-engine; the second, with its onset in the mid-19th centry, was fueled by the combined expansion of railroads and the diffusion of steel; the third, with its origins at the turn of the 20th century, was based upon the internal combustion engine, electricity and the chemical industry; and the fourth, has been fueled by electronics technology, beginning with the use of the valve in the 1930s, and proceeding with the invention of the transistor in the 1940s, the integrated circuit in 1959 and the microprocessor in 1971. The present "heartland technology" continues to be the field of electronics which is the frame encompassing this study on computer-aided-design.

During the first 25 years after World War Two economic growth reflected a combination of two sets of factors. The first of these was the reconstruction which followed the devastation of war. The second concerned the expansion associated with the introduction of new products based upon the heartland technology. Such products can be divided into four major categories[2/], namely consumer electronics (radio, TV, recordplayers, tape-recorders, etc.), electronic capital goods (radar, computers, communication equipment, process control etc.), electronic components (valves, transistors, integrated circuits, resistors, etc.), and military equipment (radar, missile control systems, etc.). In each sub-sector the introduction of new products was associated with rapid expansion of production, employment and trade.

By the end of the 1960s, reconstruction was largely complete, markets had begun to be saturated[3/] as more imitative firms had entered the sector, attracted by high profits and the rapid growth of markets. Besides increasing competition, the power of organized labour began to grow after a period of sustained near-full employment, and changes in technology were forcing investment in more capital intensive technologies.

The consequence was that the 1970s saw a significant decline in the rate of profit in almost all economies (Hill (1979)), growing overcapacity in most major markets such as steel, shipbuilding and cars (OECD, (1979) Mandel (1980)), growing unemployment , inflation, and low/negative rates of economic growth.

In the latter period further fuel was added to the flames of stagflation by the increase in energy costs. Next to the increase in energy prices, perhaps the most important development was the decline in the rate of growth of world trade, which had expanded rapidly when the advanced economies were experiencing rapid economic growth and near-full employment, but fell off as these conditions faded. In the late 1960s and early 1970s CAD was a "new" product, largely being used within the expanding electronics sector as an essential component in the design and manufacture of integrated circuits and printed circuit boards. More recently, CAD has begun to filter down to established manufacturing subsectors where in the face of growing competition, innovating enterprises are using it to increase productivity, optimize designs, reduce costs and shorten lead-times.

Thus the CAD sector rather than following the present recessionary trend, is one of the few experiencing a high growth rate. Actually, in spite of a general capital shortage and lack of new engineering graduates, there is more venture capital available and more new electronic companies being formed than ever before.

5.3 Impact of CAD on the Comparative Advantage of both Developed and Developing Countries

CAD is representative in many ways of other electronics-related technologies, but it must be stressed that it is only one out of the many advanced electronics-based technologies which are spreading to the manufacturing industry. It would therefore be mistaken to place too great an emphasis on the sole potential impact of CAD on the exports of manufactures of developing countries. The use of CAD, however, provides firms with substantial benefits; it is of importance therefore, to assess the impact of CAD on comparative advantage, so as to be able to foresee any changes in the competitiveness of individual firms or of specific sectors and take appropriate measures.

Given that socio-economic conditions within the developed world are rather similar, the introduction of CAD may be decisive in stemming off rival products unless, of course, the competition also adopts CAD technology in which case efficiency increases but relative mutual competitiveness remains unchanged.

A different picture emerges when the industries of developed and developing countries are compared. In many sectors the developing countries enjoy a comparative advantage which is chiefly based on cheap and abundant labour supply. CAD technology, however, may partially erode this labour-based comparative advantage, for its introduction in the developed countries will increase profits thus provoking to a deterioration in the comparative advantage of developing countries. It is of crucial importance for firms from developing countries to evaluate the extent to which their comparative advantage vis-á-vis rival firms in developed countries would be eroded. A substantial erosion might, in the short term, compromise the procurement of badly needed foreign currency and, in the long term, the very industrialization efforts pursued so far unless, of course, developing countries also adopt CAD technology.

Table 13 shows the extent of growth and the value of all developed countries imports of manufactures from developing countries between 1970 and 1978 and relates their ranking by size and growth to design an draughting intensity.

A number of relevant observations can be drawn from this table. First, the growth in overall manufactured exports (7.3%) over the eight years was remarkably high. Second, exports of higher-technology manufactures grew more rapidly than those of traditional manufactures, although the difference between these two groupings was not as large as some observers suggest (e.g., Lall (1979)). Third, textiles and garments remained the largest group, accounting for 48% of all developed countries imports of manufacturers from developing countries in 1978 (but down from 55% of the total in 1970). Finally, it is to be noted that traditional manufactured products are of low design and low draughting intensity - by ranking they fill the last four places in each case.

TABLE 13: DEVELOPED COUNTRIES IMPORTS OF MANUFACTURES FROM DEVELOPING COUNTRIES IN RELATION TO DESIGN AND DRAUCHTING INTENSITY.

	Value $ m		Growth	Rankings (N=15)			
	1970	1978	1978/1970	Value 1978	Growth	Draughting intensity	Design intensity
Traditional Manufactures							
Semi-finished textiles	1815	9610	5.3	1	13	11	11
Leather	183	950	5.2	9	14	13	12
Clothing	1181	9502	8.1	2	10	12	14
Shoes	151	2033	13.5	7	6	14	13
Higher Technology Manufactures							
Chemicals	588	2282	3.9	5	15	9	6
Metals and metal products	319	2223	7	6	12	10	9
Machinery except electrical and business	81	1136	14	8	5	4	3
(Farm machinery)	2	29	14.5	15	4	7	7
Electrical machinery	372	4463	12	3	7	1	1
Business machines	81	600	7.4	12	11	2	5
Scientific instruments	24	359	15	13	3	3	4
Motor vehicles	23	603	26.2	11	2	8	10
Aircraft	18	737	40.9	10	1	6	2
Shipbuilding	40	355	8.9	14	9	5	8
Consumer electronics	214	2391	11.2	4	8	*	*
Total Manufactures	5493	40195	7.3				
Total Traditional Manufactures	3330	22095	6.6				
Total Higher Technology Manufactures	2163	18100	8.4				

SOURCE: Calculated with data on ISIC sectors from US Department of Labour (1979) and with data on Standard International Trade Classification (SITC) sectors from the US Central Intelligence Agency (1980).

* Figures are not available; it can be indicated, however, that the design and draughting intensity of this sector is high.

The major export oriented industrial sectors of most developing countries have very low draughting and design intensities, which might lead to expect that it will take quite some time before they introduce CAD. Rival developed country firms, however, might quickly snatch CAD equipment in order to stop losing competitiveness and even regain comparative advantage. Thus, the redeployment of non-competitive industries to developing countries might be delayed or discontinued, especially since the high rates of unemployment in developed countries increase the pressure in favour of protectionist measures.

Furthermore, although some products may have low draughting and design intensities, they or some adjacent complementary products may be design-intensive, or they might greatly benefit from the downstream uses of CAD. Thus, electronic toys for example, are particularly sensitive to changes in design; food products in turn, although they are neither draughting nor design intensive, their packaging frequently is. Further, the use of CAD cutting and nesting techniques has had a crucial impact on the garments sector which is a design-sensitive sector.

Several of the most industrialized developing countries have recently developed draughting to a capacity for the production of more sophisticated products which are highly draughting and design intensive. In the electrical machinery sector, for example, one in six of the labour force, are in the design category, and in process plants design costs can be as high as 20% of total fixed capital costs. Hence, these industries are likely to be most affected by CAD equipment; the developing country firms concerned should therefore examine the possibility of adopting CAD without delay, lest they be forced back to the export of more traditional manufactures.

5.4 Redeployment to Developing Countries

Redeployment of industries from developed countries to developing countries so far took place as a response by large companies, mainly TNCs (initially American and subsequently, though to a lesser extent, Japanese and European) to growing competition in the world market and large wage differentials; production processes were decomposed and the labour-intensive elements were transferred to low wage economies.[4/]

In the case of electronics, requirements for labour are substantial and have prompted location in developing countries. Manufacturing the silicon chip, for example, is cheap when provided in sufficient numbers; marginal labour costs are almost insignificant. By contrast the labour costs of packaging these chips in plastic containers and the insertion of connecting wires are high, with little difference between marginal and average unit costs. Consequently there was intense pressure to reduce these assembling costs (which were predominantly labour costs) by using low wage labour in developing countries.

Another driving force of OECD based companies to redeploy was the securing of market access in some of the larger developing countries.

The confluence of these factors explain the great increase in the growth of developing countries' manufacturing capacities and exports over the past fifteen years. It also explains why so many developing countries began to institute policies designed to emulate the success of these economies.

The factors which have underlain previous redeployment to developing countries now seem to be affected by the increased automation of production processes in developed countries.

As unemployment rates in developed countries have begun to rise mainly due to the general recession but also resulting from electronics-related innovations both in the manufacturing and services sectors, so have protectionist barriers, beginning in the most labour-intensive sectors (e.g., garments) and now spreading to other consumer (e.g., cars and television) and intermediate goods (e.g., steel). Further, the downstream use of electronics in other sectors has begun to undermine the comparative advantage of developing country firms producing with traditional technology and low-wage labour, for developments within the electronics sector, such as the automated insertion of integration circuits onto printed circuit boards, the packaging of the circuits themselves and the reduction of the number of circuits in many products due to the development of more powerful very-large-scale integration (VLSI), have increased productivity and diminished the requirement for cheap labour.

It seems therefore, that the redeployment process which has been a major element in speeding up the industrialization of developing countries is undergoing drastic changes. The increasing application of CAD in industrialized countries will contribute to these changes.

5.5 Development of endogenous CAD production capacity in developing countries

To the best of our knowledge only one set of developing country CAD equipment exists and this was produced by the TATA Institute of Fundamental Research in India. The TATA Institute had in the 1950s already built its own digital computer[6/] and was then abreast of technological developments in the US. The total stock of software input for the TATA applications programmes is however, less than 30 person years, which is very small by comparison with the major turnkey vendors.

There are currently four imported turnkey systems in India, three of which are predominantly for electronic applications. Working with the basic graphics software of these turnkey systems, the Tata Institute has assembled four further systems, two of which have been sold to research institutes. Their basic operating systems and graphics software do not appear to be as sophisticated as the turnkey counterparts - the Tata CAD systems only run two terminals off a minicomputer whereas most of the turnkey minicomputers are able to drive between four and eight terminals each.

Nevertheless, despite these deficiencies, the Tata systems do work; the major obstacle to wider diffusion probably relates more to lack of demand from an unsophisticated industrial base than to the inadequacy of their own software. Indeed there is a relative stagnation of demand for industrial goods in India itself. In 1976 for example, the average (unweighted) coefficient of capacity utilization in 307 engineering sectors was only 53.7% and in industrial machinery industries only 55.4% (See P.O'Brien, 1981)

5.6 Socioeconomic and Technological constraints of developing countries

Developing country producers wishing to maintain or increase their competitiveness in the markets of developed economies will have to use electronics-related technologies such as CAD. There are, however, a number of factors which handicap the introduction of these technologies; they are discussed below.

Most developing countries enjoy an abundant supply of labour and therefore they wish to take advantage of this factor by fostering labour-intensive industries in their territories. But the introduction of CAD changes the nature of design, transforming this traditionally labour-intensive activity (with a cost per workplace of less than $2,000) into a capital-intensive one (frequently involving capital costs per workplace of over $80,000). Developing countries who are faced with capital constraints, foreign exchange constraints (CAD systems will most likely have to be imported) and high levels of unemployment will find themselves using a seemingly inappropriate technology; it is a technology, however, that by virtue of its performance, renders manual design techniques suboptimal. This is not the first time that developing countries have been faced with a trade-off between technological efficiency and economic appropriateness; nor, is the dilemma confined to developing countries, since many developed countries currently face balance of payments constraints and untypically high levels of unemployment. Despite the undesirable characteristics of such technologies it seems that if developing country producers (developed country producers for that matter) wish to maintain their competitiveness in world markets they will be forced to make more active use of CAD-type technologies, however inappropriate in the context of existing conditions they might seem.

Another particular feature of developing countries might seem to be the lack of skills required to operate a CAD system. Actually, the skills required are certainly lower than those needed in the traditional drawing and design offices; from this point of view, therefore, there are no grounds for arguing that developing country firms will be unable to utilize the new technology. However, the implications for management are more fundamental than those for operators; managers have to ensure that the design and draughting offices are organized in different ways and have to be aware of the systems gains which CAD technology permits.

In fact there are many reasons to suppose that it is easier to implement systems reorganization in developing countries than in developed countries. In part this is because of the difference in the relative powers of labour and capital in the two environments. Moreover, it can also be argued that such systems will be more easily introduced in greenfield sites in developing countries, for in developed countries existing enterprises will have to struggle with established procedures and interest groups and with the implementation of changes in the existing work practices. Probably, in the latter case, the power of labour to inhibit the efficient introduction of electronics technologies will be significant, especially when the survival of whole categories of activity such as the draughtspersons are at stake.

Further, CAD equipment might act as a synergetic agent favouring the automation of the factory. High wage costs have provided developed country enterprises with an incentive to introduce complementary downstream technologies in order to capture systems gains. This incentive however, is not present in developing country enterprises which might therefore have less motivation to introduce complementary electronics techniques and would thus fail to capture these external economies.

Another constraint for developing country users is the distance from suppliers. As it has been previously indicated the immaturity of particular CAD applications programmes usually leads to a hand-holding relationship between suppliers and users. As the major mode of competition moves in the 1980s from the strength in specific applications software to price and servicing, most CAD suppliers are now offering users the capability to respond to their problems within four to eight hours. From the users point of view this rapid response is essential not only because the high capital cost of CAD requires high utilization rates, but also because their reliance on a centralized data base makes them highly dependent on the unhindered functioning of their CAD system. From the suppliers point of view this rapid response can only be provided if service centres are near, but most developing countries do not have the service base required to service these CAD systems.

Therefore, and on the basis of the experience of developed country users visited, this isolation must be seen as a disadvantage despite the possibility that isolated users will be forced to learn more about the CAD software itself than their more pampered counterparts. The disadvantages of distance are probably acutely felt in relation to the extension of the CAD systems to wider uses outside of the particular applications programmes for which the systems were initially intended. Given that the most effective US and UK users had achieved their major design gains by widening applications in this way, this restriction in use is likely to be a major disability.

5.7 Policy Considerations

The stage is now set for an assessment of the wider issues involved, and for the prescription of policies to enable developing countries to adapt successfully to the rapidly changing economic and technological environment.

At a higher level of abstraction (e.g., within the framework of neo-classical economic theory) some would conclude that policy intervention is unnecessary - market forces will lead to the rapid diffusion of CAD-type technologies to developing countries. But the evidence so far suggests that CAD type technology has been very slow to diffuse to developing countries. Only 32 Systems, out of more than 6000 systems sold, have gone to developing countries (including Yugoslavia); moreover, many of these were for the use of non-manufacturing sectors. (See Table 14). As for the possibility of developing countries producing their own CAD equipment, only India , as has been pointed out above (see 5.5), seems at present to have an embrionic capability, but the systems produced have barely penetrated industry. Besides, developing countries are not only slow in introducing CAD technology, but moreoever, CAD suppliers report that developing countries are largely ignorant of the existence of this technology, let alone its potential.

Furthermore, the present oligopolistic CAD market structure is unlikely to speed-up the diffusion of this technology to developing countries. The competitive pressures which might lead to its active marketing in developing countries are currently focusing on the developed countries, the markets of which are just beginning to be exploited and offer therefore enormous scope for expansion; indeed CAD suppliers are experiencing difficulties in coping with the pace of market growth in the developed countries[7/]. Moreover, the extra costs of servicing developing country users add to the relative state of neglect in which the markets of developing countries are held.

Indeed, even developed country governments recognize the limitations of the market in producing the incentive required to diffuse CAD technology as rapidly as competitive conditions require. Thus, the UK government heavily subsidizes the CAD Centre in Cambridge which is designed to spread CAD to industry; it also provides aid to firms which pioneer the use of the technology. Similarly, the German government provides tax incentives to firms using CAD (The Anderson Report, Vol 1, No.4), and the Norwegian Government heavily aids CAD supplying firms. More recently the Canadian Government

(Government of Canada (1980)), has established a special programme of action for the introduction of CAD technology which, inter alia, notes that:

> "Productivity will be especially important to the Canadian manufacturing industries in the 1980s if traditional markets are to be retained and new ones gained . . .
>
> "In this context, the rapidly emerging use of Computer-Aided-Design and Computer-Aided-Manufacturing (CAD/CAM) technology is of special importance".

Consequently the governments of developing countries cannot remain passive if they are to stem a deterioration of their current pattern of trade and maintain or increase their share of the markets of developed countries.

It is pertinent therefore to evaluate other methods of increasing the rate of diffusion; two come to mind - TNCs using these technologies and government intervention.

TABLE 14: SALES OF CAD SYSTEMS TO DEVELOPING COUNTRIES BY US TURNKEY SUPPLIERS (up to July 1981)1/

Number of Systems	Country	Use	Type of User
2	India	Electronics (pcb's)	Post Office
3	Yugoslavia	?	State
1	Zaire	?	?
3	Brueni, Sarawak Oman	Oil field mapping	TNC
1	Argentina	Military	State
1	- " -	ACE	Indigenous firm
1	Honduras	Mapping	State
1	Chile	Mapping	State
1	Mexico	Mapping	State
3	Venzuela	Oilfield mapping	State
1	Argentina	Mechanical	TNC
1	Brazil	Mechanical (Automobiles)	TNC
2	S. Korea, Republic of	?	?
1	Hong Kong	Electronics	indigenous bureau
1	Island of Taiwan	Iron-works	indigenous firm
2	Iran	Out of operation	?
1	Mexico	?	?
1	India	?	?
3	Yugoslavia	?	?
1	India	Mechanical	indigenous firm
7*	Brazil	Mechanical (aircraft)	State

*Comprises 14% of 1980 sales of around 50 systems.
SOURCE: Interviews.

1/ It is important, here, to emphasize that this data on the numbers of CAD systems used by developing countries refers only to the sales of the major US and UK turnkey vendors which were visisted (and who account for the overwhelming share of global turnkey systems sales). It is possible, therefore, that a number of isolated sales of small dedicated microcomputer driven terminals or of pure software based systems have been made to developing countries.

5.8 TNCs and CAD technology

Since between 30 and 40 per cent of total world trade in manufacturing occurs within TNCs, and a substantial proportion of the rest also involves TNCs (either as buyers and/or sellers), their locational decisions in the context of changing technological, economic and political environments, are of critical importance.

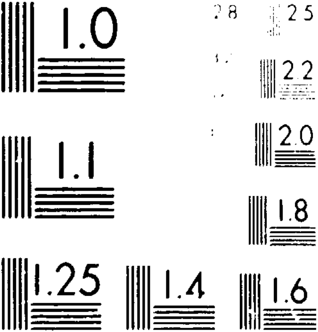
During most of the 1970s the market structure of the CAD supplying industry had been dominated by new, specialized firms. By the end of the decade three new forms of concentration were becoming apparent in the CAD supplying sector. First, in addition to IBM, a number of existing electronics firms producing computers (mainframe and mini) and terminal screens were beginning to penetrate the industry. Second, there has been an increasing tendency for established engineering firms supplying automated technologies to industry to include CAD technology. And third, despite the recent trend towards new small firms supplying dedicated microprocessor systems, there is at an aggregate level an increasing tendency towards the production of CAD technology within TNCs.

More importantly it appears as though there is also a trend towards TNCs becoming heavy users of CAD technology. Unlike the early 1970s when CAD supplying firms operated at a low scale and sold to any knowledgeable firm able to use this new technology, the growing scale of the market is forcing CAD suppliers to regard TNCs, who are the largest potential purchasers of multiple systems[8/], as their prime target[9/].

So TNCs in developing countries are becoming suppliers and users of the new CAD technology. How will they then react to the new technological environement in their future locational decision-making process? There are two alternative scenarios. The first is that the advantages of CAD and other electronics related technologies reduce the incentive to site production in developing countries, because CAD diminishes the comparative advantage of the low cost labour in the latter; besides, by locating in developing countries, TNCs will suffer the disadvantage of distance from the main markets and from technology supplying firms. The alternative view is equally tenable - forthcoming developments in communications technologies will make it feasible for TNCs to locate design in advanced countries and, by direct electronic transmission of design parameters, to maintain productive facilities in developing countries. Moreover, as already mentioned, the weaker power of labour in developing countries will make it easier to establish greenfield sites which, as the move to the automated factory quickens, will allow for systems gains. In this way by locating design in developed countries and production in developing countries TNCs might get the best of both worlds. It is premature to judge which of these two alternative paths TNCs will take.

5.9 Action-oriented Policies

Government intervention by developing countries is likely to prove necessary if they are to acquire CAD technology. In addition to specific measures for particular industries (e.g., shipbuilding), a series of more wide-ranging policies will have to be implemented , namely:


1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

(a) Increasing Awareness

Local firms, - state and privately-owned -, will need to be informed of the potential benefits associated with the use of CAD-type technologies and of the problems and skills they involve. The non-governmental induced international flow of information does not suffice to convey vital technological information to the developing countries and therefore an active government programme to raise awareness is essential.

(b) Training

It will be necessary to train manpower for these technologies, both at the operators and management levels. Of particular importance here, is the awareness by management of the potential systems gains which automation in

general and CAD in particular permit. A second arena in which specific training is desirable (currently done in most developed countries) is to incorporate CAD and other electronics technologies in the syllabi of engineering and related courses.

(c) Aid

Just as many developed governments are doing, developing countries will have to help indigenous firms to acquire CAD equipment and related technologies by providing financial subsidies and/or access to scarce foreign currency resources. In most developing countries electronics equipment sells for between two and three times the price prevailing in developed countries. This is due to a variety of reasons including the low level of sales (which does not allow suppliers to spread-out unit overhead costs), tariffs and local sourcing policies[10/]. This Aid will not only speed up the purchase of these technologies by particular firms, but can also assist in the dissemination of information. Thus, the experience of the UK government has been that the provision of aid to certain key users has provided fairly open access of these systems to other UK firms who have been exploring the introduction of CAD technology.

(d) Services centres, research centres and bureaux

In developing countries the establishment of service centres lies in the hands of the CAD supplying firms. However, as we have already mentioned, developing country users are usually a high-cost operation and this is one of the reasons why CAD suppliers have been slow in marketing in developing countries. There are two major options open to developing country governments here; either they duly subsidise supplying firms wishing to establish service centres, or, as an alternative, they can themselves establish "machine transparent service centres", that is, service engineers and software specialists[11/] who are sufficiently knowledgeable to service a variety of different systems. This latter path presents immediate difficulties in that some servicing problems (involving, for example, specific sets of "firmware" hardware) are highly firm-specific. But on the other hand, it will allow developing countries to take advantage of a variety of different supplying firms' software strengths and will at the same time inevitably increase the extent of learning with regard to electronic technologies, particularly if these "machine transparent" service centres are linked to universities and research centres. Associated with this strategy of establishing service centres there is the possibility of establishing bureaux to service a number of users thus spreading costs.[12/]

(f) Indigenous firms as producers of CAD systems

Given the nature of the origin of CAD technology, it is unlikely that developing countries will become viable producers of analogous CAD technologies in the near future. However, there is no reason why the government of a particular developing country (or perhaps a group of governments) should not buy up an existing CAD supplier in the USA or Europe. Purely as a speculative investment there may well be substantial gains in a judicious purchase of this sort, but even more impotantly, there may be a number of other spin-offs which might result from such a bold step, including the greater likelihood that CAD technology will be actively marketed in the relevant developing countries.

FOOTNOTES

1/ However, this optimistic scenario was deflated at the subsequent UNIDO conference held in New Delhi in January 1980 to a goal of around 15%.

2/ See Freeman (1981) pp. 7-8.

3/ For example, by the late 1970s, there was one car on the road in the USA for every 1.2 licensed drivers, with 84% of households owning at least one car. In Western Europe there was one car for every two adults. See Transatlantic Perspectives (1981)

4/ But, as Scriberras (1979) shows, this strategy placed firms in the TV sector at a disadvantage. Although the American firms were able to cut costs by taking advantage of cheap labour in export processing zones, manually assembled sets were less reliable than those assembled in automated plants. As a result Japanese firms were able to capitalize on automated assembly and dominate the American market.

5/ Thus, in the mid-1970s around 40% of all developing country manufactured exports were in the shoe and leather and garment and textiles industries (Chenery and Keesing (1978)).

6/ The Indian version, however, was non-electronic and worked with vacuum cubes.

7/ As one CAD supplier reported, market shares in the 1980s will depend upon the extent to which CAD supplying firms can actually manage (i.e., provide the organizational facilities to cope with) compound growth rates of over 70%.

8/ For example, by the end of 1978, General Motors alone possessed more than 300 CAD terminals in the USA; by 1983 it was estimated that they would be using over 3,000. (Anderson Report, Vol 1, No. 1, September 1978). General Electric had over 100 systems in use in 1980 (each of which comprises of a number of terminals) and expects to purchase another 25 systems in 1981 alone.

9/ Thus, one CAD supplier reported that he followed the DEC strategy of working its way down the Fortune 500 list of US firms.

10/ Brazil and India both virtually prohibit the import of mini and microcomputers in order to protect their indigenous electronics industries.

11/ Some American firms use a number of different CAD systems which are managed centrally. Clearly, therefore, there are some levels at which "machine transparent" software and organizational skills are interchangeable between different CAD systems.

12/ CAD is seldom viable with less than ten design staff, for design currently involves entry costs of at least $160,000 for a basic two terminal system.

6. CONCLUSION

The conclusion bears out that the diffusion of CAD and, by extension, related electronics equipment, provides major gains to user firms thus increasing their competitive edge.

Besides giving rise to substantial gains in productivity and to savings in labour costs, CAD technology will also allow for substantial benefits in the sphere of product development and marketing by optimizing products and increasing the speed with which these can be introduced into the market.

Given the enhanced control over technology and the marketing advantage arising from the use of CAD, developing countries should envisage introducing CAD technology if they are to compete in the markets of developed countries and maintain current sales performance in these markets, let alone improving it, particularly with regard to non-traditional manufactures - sectors which have experienced the highest exports growth over the past decade, have enjoyed the highest value-added rates and the promotion of which developing countries intend to further.

APPENDIX

Research Methodology

(a) Interview Technique

From inception to completion only six months were available for this case study to be undertaken. It was thought that this would be sufficient to undertake basic fieldwork and visits were made to a variety of supplying and using firms. Unfortunately the lack of time curtailed the number of users who could be visited (not only in Continental Europe and Japan but also in developing countries), as well as a more detailed investigation of CAD firms specializing in software (especially in solid modelling).

Two alternative interview techniques are possible in such field visits. The first is that of a detailed questionaire, and the second comprises of free-flowing but structured discussion, backed up by check-lists to ensure that all major areas of interest are covered. The former technique was rejected since experience has shown that it predetermines responses and antagonizes the interviewees. Consequently, structured discursive interviews were held, based upon the following two check-lists, one for CAD vendors and one for CAD users.

<u>Checklist for CAD vendors</u>

1. **BACKGROUND**

   (a) Firm

   (b) Size and Growth over Time - turnover
   employment

   (c) Product range - hardware
   software
   other products

   (d) Sectoral distribution of sales

   (e) Geographical distribution of sales

   (f) Marketing policy - Developed Countries/Developing Countries
   Small/Large firms
   Packaged/Unpackaged
   Mode of Competition

2. HISTORY OF CAD

   (a) Its origins

   (b) Major developments

   (c) Growth of industry

   (d) Branches - are there different types of CAD?
   e.g., electrical
   mechanical
   civil
   electronic

3. **THE MARKET**

   (a) Price trends of systems

   (b) Availability of systems - supply v demand

   (c) Market structures - globally) past, present and future
   within country)
   within sector)

   (d) Hardware v software

   (e) Packaging v unpackaging

   (f) Sales by sector, area over time

   (g) Barriers to entry

4. PROPRIETARY RIGHTS

(a) Specific or general skills

(b) Property rights

(c) Technical interchange

(d) Other methods of appropriation

5. ECONOMIC BENEFITS OF CAD

(a) When it is justified to use?

(b) Savings in labour - in drawings
absence of drawings

capital -working
fixed

(c) Materials

(d) Scale implications of production

(e) On product - leadtime
quality: differentiation of existing and new products

(f) Systems gains

(g) Avoiding bottlenecks

(h) Impact upon market share

(i) Other

6. SKILL IMPLICATIONS IN USE

(a) Is there a learning curve)
operator and management
(b) What skills are required)

7. DIFFUSION

(a) Projected rates

(b) Which sectors?

(c) Obstacles

8. THE FUTURE

(a) Changes in technology

(b) Changes in price

9. CONTACTS

Within CAD supplying industry

Successful users

Unsuccessful users

Users who compete with developing countries.

CHECK-LIST FOR CAD USERS

1. BACKGROUND

(a) Firm

(b) Size and growth turnover
employment

(c) Products, market structure and market share

(d) Breakdown of costs - labour
capital
materials
energy

(e) Design as a proportion of product costs.

2. CAD SYSTEMS USED

(a) Hardware) Fixed - historic and replacement

(b) Software) Variable -

(c) How do they define CAD

(d) Their use - draughting
design
downstream
other

(e) Capacity utilization

(f) Search procedure

3. MANPOWER

(a) Did it lean on existing skills?

(b) Training costs and programmes

(c) Learning curves - manager and operator

(d) Profile of skills - with CAD v without CAD

4. BENEFITS

(a) Why was CAD introduced?

(b) Were these achieved

(c) Additional benefits?

Note Product

Leadtime

Improvements in - appeareance
operating characteristics

New products

Process

Labour - in drawing
absence of drawings
Capital - fixed
working
Materials
Flexibility capacity utilization
Scale

General

Avoid bottlenecks

Systems gains - e.g., in clerical
organization of firm

Other

(d) Impact upon market share

5. PROPRIETARY RIGHTS OVER OWN SOFTWARE

(a) Specific or general

(b) Property rights

(c) Sales of CAD software

6. TECHNOLOGY

(a) What changes in hardware are desirable?

(b) What changes in software are desirable?

(b) Sample frame

All the major representatives of the US turnkey firms operating in the UK were interviewed, some in the UK and others in the US and the UK. In some cases multiple visits were made. A list of users was obtained from each of these vendors and visits were made to a significant proportion of each firm's customers, selected upon the basis of:

(i) their sectoral activity (e.g., mechanical, civil or electronic engineering). While attempts were made to cover most major sectors, the emphasis was placed upon mechanical engineering since it is the sector in which most developing countries hope to compete in developed markets in the 1980s, and because it is probably the major growth area of CAD use over the coming few years.

(ii) Particularly successful users.

(iii) Particularly unsuccessful users.

Visists were made to a number of industry observers, particularly in the USA, and analysis was also based upon a variety of published documents.

In total 24 users were visisted. Of these 5, were interviewed in the US and the remainder in the UK. Six were only producing in their country of incorporation and the remainder were TNCs. Turnover varied and ranged from $1.7m (a CAD bureau) to $10 m (the smallest manufacturer) to billions of dollars. The firm with the smallest design staff provided 2 terminals for 3 designers. Of the 24 users, 2 were CAD bureaux, 3 used it predominantly for electronics, 6 predominantly for civil/structural/process engineering and mapping, and the remainder predominantly for mechanical.

Thirteen CAD suppliers were interviewed with a turnover ranging from zero to $26 b. Of these only one was a wholly British firm, the rest were American. Additional information on these and other firms were obtained from the Anderson Report and The Harvard Newsletter on Computer Graphics.

GLOSSARY

Entries in quotation marks are drawn from a more specialized glossary published in Computervision (1980).

ACE	Architecture, construction and civil engineering, a term used to describe a particular set of markets for CAD equipment.
Add-on memory	The capability to store information outside of the central computer.
Applications Software	CAD software programmes which have been developed to meet the requirements of particular users.
Batch Processing	A "group of jobs to be run on a computer in succession, without human intervention". Turnaround of work is consequently not instantaneous and the process is consequently not interactive.
Bills of Materials	A listing of all the sub-assemblies parts, materials and quantities required to make one assembled product.
Binary Code	"System of representing numbers (or subsets of logic) using the characters 0 and 1 to represent any number".
Bit	A single binary code.
CAD (computer-aided-design)	The use of computers in design with interactive, graphic capabilities.
CAM (computer-aided-manufacture	The use of "computers technology to manage and control the operations of manufacturing facility".
Chips	See integrated circuit.
Component	"Symbol which has a physical meaning e.g., switch, resistor, capacitor".
Core memory	"Main memory resident in the computer".
Data Base	"Comprehensive collection of information having predetermined structure and an organization suitable for communication, interpretation, or processing".
Dedicated	A set of hardware or software confined to a single use.
Digital	A synonym for a system working with binary code logic.

Digitiser	A method of converting drawings into digital numerical co-ordinates which can be processed by a computer.
Disc	One method of storing information outside of the central computers. Discs can be either rigid or pliable ("floppy discs") and require a disc-drive (an equivalent to a record player) for use.
Downstream	Activities in information control or manufacture/distribution affected by decisions made in design.
Finite Element Analysis	A system of "wire-frame' meshes used to "determine the structural integrity of a mechanical path by mathematical simulation.
Firmware	Software instructions written into hardware.
Graphics Software	CAD software enabling the user to draw lines, arcs, circles etc. and to manipulate these on the terminal screen.
Hardware	The physical elements of electronics technology.
Interactive	The capability which allows the CAD user to manipulate and modify information and software in a computer system without delay.
Integrated Circuit	"Tiny complex of electronic components and their connexions produced on a slice of material such as silicon".
Large-Scale Integration (LSI)	Integrated circuits, each with the capacity to process more than 32,000 bits of information but less than about 262,000 bits of information.
Light-Pen	A pen-like object which allows the operator to write on the screen.
Machine Code	The basic binary code used by all computers.
Magnetic Tape	Similar to reel-type tape recorders, used for the storage of digital information outside of the central computer.
Mainframe	Large computers.
Menus	"Input device consisting of command squares on a digitizing surface. It eliminates the need for an input keyboard for common commands".
Memory	Storage of digital information. See, also, Add-On, Core, Disc, Magnetic Tape.

Microcomputer	The smallest-sized computer, usually based upon a single microprocessor.
Microprocessor	A single integrated circuit with logical capability.
Minicomputer	Intermediate-sized computers.
Nesting	The method of arranging the patterns of parts to make optimal use of materials from which they are to be cut.
Numerical Control	A control system based upon digital logic.
Numerical Co-ordinates	Information represented in binary code.
Operating System	Basic software which determines the functioning of hardware.
Paper Tape	Like a ticker-tape on telex, the major method of feeding digital information into numerically controlled machinery.
Parts List	See Bills of Materials.
Parts Programming	The process whereby the optimmum path is defined for cutting parts on a machine tool.
Plotter	A method for representing graphical information, drawn from computerized information, on to paper or film.
Printed Circuit Boards (pcb)	"Insulated substrate (usually plastic) upon which interconnected wiring (usually between components and integrated circuits) has been applied by photographic techniques." Almost all electronic products (whether in Ts, computers or digital watches) are built around circuit boards.
Small Scale Integration (SSI)	Integrated circuits, each with the capacity to process less than 32,000 bits of information.
Software	The instructions which enable electronic hardware to operate. See, also, Applications Software, Graphic Software, and Operating Systems Software.
Storage	See Memory
Terminal	A TV-like screen which allows CAD users to work graphically.
Turnkey	CAD systems sold with a combined package of hardware and software.

Uncommited logic Array (ULA)	Often called "gate-arrays". A method in which all the logic elements (called gates) can be built into the lower layers of an integrated circuit allowing the final user to make the connexion between the different gates, each of which represent a bit of information. This is a rapidly evolving technology.
Vacuum Tubes	"Valves" used in the days before the electronics industry produced "solid state" transistors, integrated circuits, microprocessors and components.
Very Large Scale Integration (VLSI)	Integrated circuits, each with the capacity to process more than about 262,000 bits of information.
Wire Frame	The mask used in Finite Element Analysis.
Workstation	See Terminal.

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