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Author(s): H. Oberhelman, J. Domogalla, R. Nayyar and R. Parmenter

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Abstract: Organizations always look for new tools and technologies to improve employee productivity, organizational competitiveness, performance and profitability. CAD/CAM promises a unique opportunity to realize these objectives. As a result, an increasing number of companies are acquiring CAD/CAM systems. This report highlights the implications of these acquisitions, explores the common inhibitors to optimal CAD/CAM usage, and suggests management actions to overcome them.

STRATEGIC IMPLICATIONS OF A CAE SYSTEM ACQUISITION

H. Oberhelman, J. Domogalla,
R. Nayyar, and R. Parmenter

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Portland State University
Engineering Management Program
Directed by Dr. Kocaoglu

EAS 541 Class Project
HENRY OBERHELMAN
JOHN DOMOGALLA
RAMAN NAYYAR
RON PARMENTER

ABSTRACT

Organizations are constantly on the lookout for new tools and technologies to improve employee productivity, organizational competitiveness, performance and profitability. CAD/CAM promises a truly unique opportunity to realize the above mentioned objectives.

CAD/CAM is hence becoming a strategic issue even though CAD/CAM technologies are not a strategy by themselves.They are among the most powerful tools available today for implementing various strategies like Time based competitive advantage, time based manufacturing, time based innovation, etc.

The potential benefits as promised by CAD/CAM are enormous, namely boost in productivity by about ten times, reduction in the labor costs,reduced time to introduce new products from concept stage to market introduction stage, etc. These benefits promised are across the board, for every organization and for every product.

This has led to a lot of organizations acquiring CAD/CAM systems. As a capital investment, however it requires sound management skills and methods to effectively utilize these tools. We would like to highlight the various implications that these acquisitions could have on the organization. We also explored the common inhibitors to optimal CAD/CAM usage and suggest management actions to overcome these inhibitions.

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1. INTRODUCTION

In theory CAD is often portrayed as the front end to the "factory of the future"in which a design is entered, automatically analyzed for stresses, strains and producibility, checked for fit with related parts and viewed as a model. It helps a product to be manufactured right the first time without going through the tedious and time consuming process of prototyping , revisions, etc. All these activities could be accomplished before the product is introduced to the manufacturing department.(Here, CAE is folded into the broad category of CAD).

With the push of a button the design can be transferred to the production site or a remote vendor site. On the CAM side, manufacturing automation automation means enhanced accuracy, repeatability and efficiency, and ancillary tasks like material handling an be automated as well.

Both CAD/CAM and stand alone CAD and CAM systems offer extraordinary possibilities for simplifying the elaborate administrative and control system for cost reduction and estimation, lot release, shop orders, materials and performance tracking.

To summarize: The potential benefits of CAD/CAM integration and stand-alone CAD and CAM systems are potentially enormous and multifarious, permitting both the elimination of many performance impediments and the enhancements of many performance contributors.

This gives us an impression that organizations must be going full steam ahead to tap this potential goldmine.

However, the reality is strikingly different than the rosy projections as portrayed earlier. The productivity benefits as promised by the vendors do not appear to be realistic in practice.

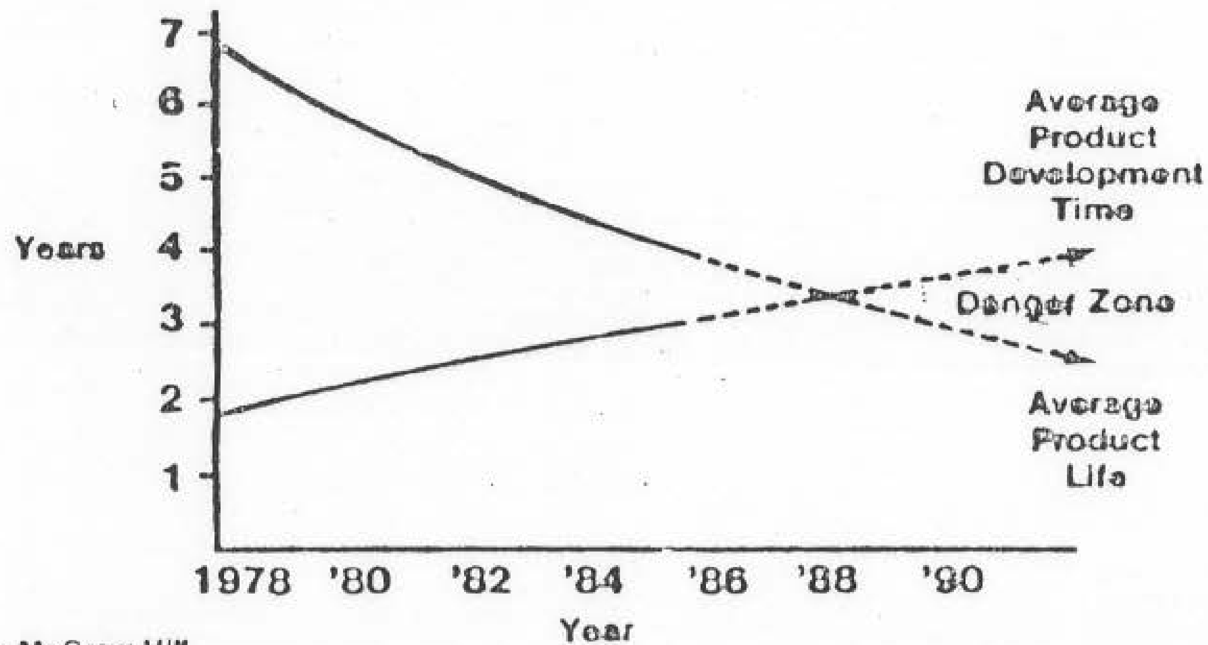
This report presents a study undertaken as a part of a graduate course in Engineering Management as part of a graduate course at Portland State University. The objective was to identify the leadership skills and methods necessary to utilize CAD/CAM systems in an engineering organization.

2. THE PRODUCT DEVELOPMENT ENVIRONMENT

The product development environment is the "playing field" where market focus, mission awareness and technological leadership meet to determine competitive success. This environment is rapidly changing in pace with the changing rate of technology. Increasing emphasis on reduced product development time will be the key to success. Adler notes that: "...NPD (new product development) is the key external measure of success."[23]

Merchant identifies the doubling of product development time from 1978 to 1988 along with the concurrent shortening of product life by one third.[16] The result is a fundamental shift in business economics that indicates Time to Market is much more important than product cost and development cost. Stalk cites that "Time is the equivalent of money, productivity, quality, even innovation" and relates that the Japanese ability to maintain and strengthen their competitive edge is due to their ability to anticipate fundamental technological changes and to innovate effective approaches to these changes."[14]

COMPLEX PRODUCTS ARE TAKING LONGER TO DESIGN, BUT NOT LASTING AS LONG IN THE MARKETPLACE



Source : McGraw Hill

Although CAE technologies are not a strategy in themselves, they are among the most powerful tools available for implementing various competitive strategies. In the hands of a competitor, CAD/CAM tools become a threat, managed competently within an enterprise, they present a competitive opportunity." [10]

Design is a strategic activity (Corbett, 1988). Historically product development has been a sequential series of discrete steps focused upon narrowly defined activities and culminating in designs "thrown over the fence to manufacturing." Feedback between steps has been difficult and the design development process has been taken for granted. The increasingly common usage of exotic materials, specialized knowledge bases and pressure for faster product development is focusing on the design process as a strategic tool In Daniel Whitneys words: "Strategic product design is a total approach to doing business" and "..sign evolution begins "taking on the character of an interwoven, historical chain in which later decisions are conditioned by those made previously" [15]

The environmental effects changing the business scene clearly are: rapidly moving technology, more complex designs, more competitive marketplace and market leadership tied to product timing, innovation and cost. CAE tools can shape the strategic design process through: reducing product complexity, shortening product development cycles and honing product focus.

2.1 Product Complexity

Products of all kinds have become more complex with more functions, features, interrelationships and materials. Todays automobile incorporate digital displays for speed and distance and on board computers for power plant control, devices that were not feasible ten years ago. Automobiles on the drawing boards will incorporate automatic location and guidance features. The changes include increased use of a variety of different engineered materials such as composite materials and high strength alloys, more electronics, much more standardization and more links to the external environment.

The influences driving this increased complexity come from more of the environment than ever before. Continuing concern for preservation of the physical environment, growing consumer awareness and expectations, higher levels of affluence, more rapid global communication and improved product distribution networks all foster product differentiation and specialization.

These forces are unlikely to abate: global environmental issues continue to be in the headlines, global communication effectiveness improves through more satellites, uncertainty of world energy resources persists and world population continues to increase.[16]

Consequently , increasing product complexity will continue to be the trend. Product designs will call for more energy efficient materials, will be produced with less waste and will serve many disparate users. The pressure will be for longer development cycles and reduced product life. The graph displayed by Berkely Merchant summarizes these impacts.

The net result of these effects is more opportunities for product differentiation and thus more product development niches. However, this is a two edged sword: if you are a market challenger the small incremental niches present rich ground to penetrate existing markets. If you are the defender your product integrity will require increasing attention to refinements and cost reduction. In either case, the previously mentioned total approach to the business will be required.

2.2 Product Development Cycles

CAE systems have long promised great advances in product engineering design speed and sophistication. Mixed results are available to document these claims. Reductions in PCB design time up to 30% are reported. By contrast there is little evidence that integration of Design and Manufacturing Engineering in being advanced with CAE [23]

There is, however, widespread recognition of the relationship between product cost and design activity. For example, Daniel Whitney reports that according to General Motors executives, 70% of the manufacturing cost of truck transmissions is determined in the design stage. Similarly, he relates that a study at Rolls Royce reveals that 80% of the final production costs of 2000 components are determined by design.[15]

In a similar recent report, Ford Motor Company found that 80% of product costs are incurred with 20% of the design costs incurred.

Peter Marks, as part of a seminar on "Understanding CAD/CAM's Strategic Importance" presented graphically the contrast between design and product costs and the allocation of resources thereto. (See following graph)

The graph illustrates that normal design decisions; material selection, feature geometry and functional requirements, made early in the design cycle dictate subsequent manufacturing processes and thus product costs.

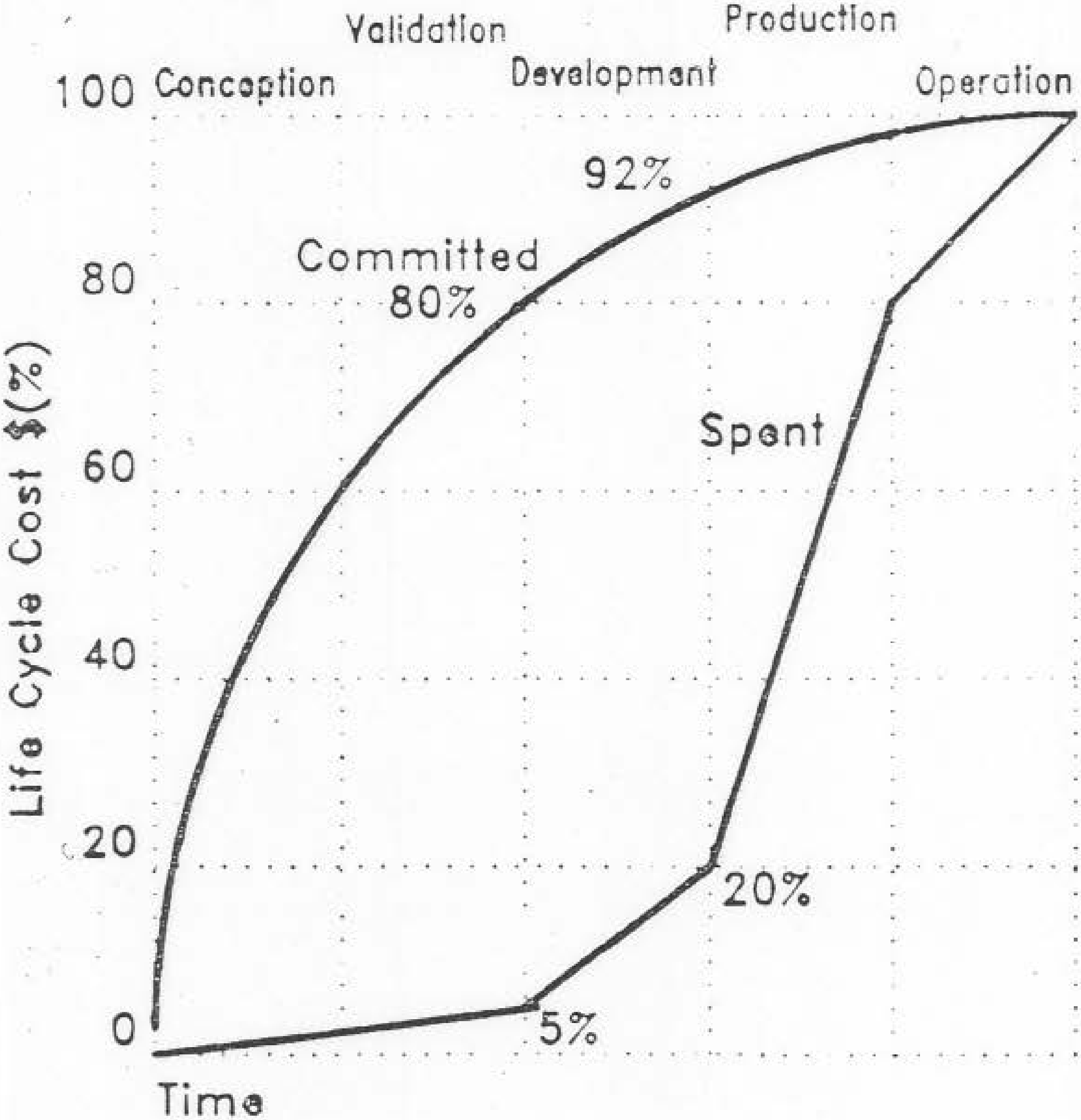
Another study of the acquisition of integrated CAD/CAM for a manufacturer of small optical/mechanical devices disclosed the extent of the information pyramid. The study found that the average product design drawing resulted in the creation of more than 5 manufacturing documents. [17] Since the typical product consists of more than 50 unique parts, the implications of the value of an integrated CAE system accessible for early design review are enormous.

2.3 Product focus and definition

There is widespread consensus about the need for a true strategic focus for the business among the long term CAD/CAM consultants. The National Research Council's, report on Computer Integration Of Engineering Design and Production stresses the Program Life Cycle as developed by the Air Forces ICAM program and guides through "Needs analysis and Requirements definition". [18] In another terminology, Peter Marks[19] advocates a "Product Performance Profile" management tool to tailor selected product appeals(values) to the product or service at hand.

The key issue is that a company that does not incorporate an appropriate set of values into its design is not likely to win many customers.

Product Life Cycle Costs



Source:
Automation Technology Products
Peter Marks

Peter Marks identifies several ways for using CAE tools to improve product value:[10]

* Faster response
* Greater design and manufacturing flexibility
* Improved product cost or performance
* More efficient use of scarce expert knowledge

Success in improving these product values through CAE tools has been reported though the use of the following currently available techniques:

2.3.1 DESIGN FOR MANUFACTURE

Design for manufacture as presented by Stoll is a broad array of techniques aimed at integrating the design/manufacturing process. In his words: "Design for manufacture recognizes..sign as the first manufacturing step."[20] Stoll lists ten separate tools as part of the design for manufacture methods. The technique of group technology is one example.

Hyer and Wemmerly report significant savings from GT in design activities, e.g. 24% reduction in design time, 22% fewer new parts designed and 30% fewer design errors.[21] Similarly they report 37% reduction in the time required to create a new process plant.

Another technique is the use of design axioms (design rules), e.g. prescribed orientation of electronic components for product assembly standardization.

2.3.2 MATHEMATICAL MODELING and SIMULATION

Mathematical modeling can also both reduce or eliminate the need for time consuming physical models. It has been reported that one company has been able to eliminate one prototype step through the use of modeling.

In addition, simulating the production processes assists in visualizing new product introductions thus providing the opportunity to provide timely process and facility changes. Corporations such as Intel and Rockwell have documented production flexibility gains through the use of process modeling[22]

2.3.3 MORE EFFICIENT USE OF SCARCE EXPERT KNOWLEDGE

Introduction of CAE shifts the knowledge base "...towards the science end of the art-science spectrum".[2] This effect coupled with the previously recognized need for integrating design and manufacturing suggests that the use of expert systems will become essential to retain and build the database for technology.

Automated tools have become perfected to develop integrated circuits because their complexity was high, the prototyping took a long time, and the debugging had to be done with black box methods. To effectively build an integrated circuit at todays state of the art requires these tools. CAE as applied to IC development has matured and now provides some real creative power in such thing as silicon compilers.

Lately the CAE tool makers have begun to turn their efforts toward electronic systems development. The ability to simulate a system of varied modules such as programmable devices, microprocessors, ASICs ... all acting together as a system will add to systems development that which it has for IC's.

3. ORGANIZATIONAL EFFECTS.

(Managerial Challenges of CAD/CAM)

The literature research showed that the U.S.A. industry as a whole had been successful only in designing more complex designs, but it had not been able to capitalize on the "Time" and "Cost" benefits as proposed by CAD/CAM. There is also enough indication that the "Middle managers and engineers strongly disagree with the common assumption among senior executives that advanced process technology was being applied widely in U.S.A.".

In a recent article Lester Thurow (Thurow, 1987) marshals evidence from a broad array of industries showing a serious gap between proven possibilities and current practice in process technologies. It is believed that U.S.A is lagging behind its international competitors (especially Japan) in the effective use of CAD/CAM technology.

The organization should undergo five levels of learning process to implement CAD/CAM effectively. We would like to identify the impediments and possible ways of surmounting these problems. The five levels of learning are:

A) upgrading of skill base of the organization.
B) change in the prevailing procedures.
C) changes in the organization structure.
D) changes in the organization strategy.
E) Cultural change(Culture shock).

The above five levels are also a major challenge for the Engineering manager and the management to overcome, in case they want to tap the potential benefits offered by CAD/CAM.

3.1 SKILLS

The general trend is towards an increase in skill requirements in specific occupational categories. The job contents are changing across the board. The shift is towards greater training needs, both initially and at later stages. There also is a shift towards higher wages and salary rates.

3.1.1 Job contents

CAD/CAM causes a net upgrading pressure in all the major occupational groups.

* Design engineering: The engineers should master the continuously evolving complex software, thereby requiring new skills.With increased automation(hopefully),the engineer is also expected to have an idea of manufacturing process.

* Drafting technicians: They need higher levels of abstract problem solving skills, computer expertise and an idea of manufacturing constraints.

* Manufacturing workers: The key factor in upgrading of skills is probably the speed increase as a result of automation. CAD/CAM also demands more out of maintenance workers. They should supplement other skills with electronic expertise.

* Manufacturing engineering: The engineers here should be able to understand and program new CAM systems and manage the software and communications link to the CAD database.

* CAD/CAM system development engineers: Firms that plan to go in for a make/buy strategy for the software and maintenance of CAD/CAM systems soon realize that it is better to have in house capability to develop new software, maintain and install new systems to support the design and manufacturing departments.

3.1.2 Implications

* The thrust of CAD/CAM is to shift the knowledge base in both design and manufacturing towards the science end of the art-science spectrum.

* Higher formal education and more intensive training is required. This affects training and recruiting policies.

* A gap is created between the people with generic skills (skills acquired by experience) and firm specific tacit skills. This has serious implications on motivation and personnel retention policies, as turnover proves very costly.
* Employees should be able to adapt to the continuous change. They should always have a pro-learning attitude.

3.2 Procedures

An adequate skill base is only a necessary condition for successful CAD/CAM implementation, but one of the sufficient conditions is the state of Design/Manufacturing procedures.

3.2.1 Just in time for Engineering activities.

Most of the firms use CAD stations as an electronic drawing board, i.e. only the drafting function is automated, but the other sub-procedures remain as they were before CAD was introduced. e.g. the drawing could be lying in the memory or a floppy disk for days even though the time required to create it or modify would have been comparatively insignificant.This seriously retards the efficiency of the system.

Managers should observe the existing procedures carefully, analyze it and then try to simplify it thereby removing many redundant or unwanted procedures.

3.2.2 Total quality control

The design department should incorporate the manufacturing constraints, i.e. producibility criterion as advised by the manufacturing department, at the time of designing a product. This would help in reducing the number of pre-manufacturing releases and save precious time.

3.2.3 Design/Manufacturing coordination procedures

It is imperative that the design/manufacturing coordinate before the inception of a design project, during the project and after the project has been completed.Activities before the start of a design project could be making the design team aware of manufacturing constraints, producibility rules, incorporating flexibility in the design, etc. This in turn would save valuable time when the design goes to the manufacturing phase. It might help to come out with the right design first time.

3.3 Structure: Differentiation and Integration.

Due to rapid technological change and increasing competition, both domestic and global ,the organizations have been encouraged to develop highly specialized, differentiated sub-units (divisions within an organization?). These sub-units in turn need new coordination mechanisms to ensure success in their efforts.

CAD/CAM's implementation and maintenance introduces uncertainty and complexity in to the system. This calls for new differentiation and integration needs.

3.3.1 Differentiation

As indicated earlier, CAD/CAM systems development calls for new forms of organizational differentiation(similar to the MIS department, caused by the introduction of computers in a big way).

New CAD/CAM system development skills are required to maintain the existing level of software and to enhance it to meet the future requirements of the organization. The accelerating changes in the process technology forces the user to develop in house expertise and not to depend on the CAD/CAM vendor. This would help the organization to weather any storm effectively because it would be self-reliant.

3.3.2 Coordination through integrating structures

As discussed earlier, the potential benefits of CAD/CAM integration are multifold. Moreover, the competitive pressures to utilize these benefits calls for some new mechanisms to help coordinate the efforts of CAD/CAM. Changing the organization strategy could possibly set the organization on the right track.

As the commitment of the organization towards CAD/CAM increases, the coordination aspect between different functional departments becomes all the more critical.This is because, the activities of one department could help improve the performance of the other. This may be from the cost, time or quality point of view. e.g.standardization of data base could help the manufacturing and purchase department to operate in a cost effective manner.

3.3.3 Ways of integrating the functions

The various possible ways of integrating the functions are:

i) By having CAD/CAM committees, where representatives from Design/Manufacturing departments exchange information about present and future projects.This is one of the most elementary form of coordination.

ii) By having task forces: members from design and manufacturing departments are assigned to a project. They are directly responsible for the coordination of the particular project, i.e. they are directly accountable. This proves more effective in real life situations.(The shift is towards a matrix form of functioning)This team would be supported by CAD/CAM system development group in times of need.This serves a dual fold purpose,the integration problem is taken care of and the system development team can improve its capabilities at the same time.

iii) By having a product definition data base: This should be jointly prepared by the design and manufacturing team. Then, manufacturing can use any system, so long as they stay within the realms of this data base. This is a very powerful form of integration.

iv) A central CAD/CAM organization: This would help minimize the duplication of efforts in different departments and also a central knowledge base would be created which can be used by the entire organization. e.g. In an aircraft company,that designs different types of aircraft, instead of each department having its own CAE tool for performing analysis, the different designs could be analyzed by the CAE department.This department would only support and not replace the distinct CAD and CAM efforts in the design and manufacturing.

3.3.4 Implications

i) If the organization is structured along a product/project, the Project manager may not be interested in contributing for the CAD/CAM budget through his project's budget,i.e. his goals are short term and he cannot afford to concentrate on the long term plans for CAD/CAM implementation.

ii) On the other hand even if the organization is based on the functional lines,the CAD/CAM development may still be impeded. Typical problems like, who would control CAD/CAM department, why should one department spend money from its budget on CAD/CAM development, when the true beneficiary is some other department. This might sub-optimize the organization's objectives in the long run.

Thus, an organization that is strategically committed to CAD/CAM in the long run may find itself benefited by having a separate CAD/CAM department and a structure based on the lines of matrix form of organization.

3.4 Strategy

CAD/CAM is a significant investment from any organization's point of view. A particular decision might block the company's resources for a long period of time, say five to six years. This could be called the direct effect, but an indirect effect could be loss of a product, a market segment or in the worst case the company may be eliminated from the market place(a small company indulging in a big investment,it is no exaggeration). In other words, we would like to reiterate the importance of a proper planning and a sound forethought to the CAD/CAM strategy.

We could identify three different implementation strategies as existing in the industry today from our literature search. They are:

i) Energetic anarchy: Every department is given a free hand to automate in any appropriate way they can.The idea is, instead of wasting time,it is important to build certain capability initially and the problems could be tackled later. The organization is cognizant of the fact, that the different departments may not be able to communicate with each other in the future(real fire fighting process,i.e. an organization that has no time left to catch up with its competitors and is really desperate?).

ii) Minimal government: Everything remains the same as above except that there is a condition that every system should be able to communicate with a central product definition database in the future. This sounds logical and practical. The advantages are that a competent base is assured and integration also is possible at a later date.

iii) Integrated planning: This is one of the most difficult to implement from the practical point of view.This planning process is very systematic and takes into account the products and the technologies that would be introduced over a long period of time ,e.g. five to seven years.

However, none of the strategies involve the manufacturing department during the planning process. This itself might create an incompatibility problem between the design/manufacturing at a later date. e.g. the change of PCB manufacturing process to surface mount technology requires a very close coordination between the design and manufacturing departments.

Hence, a CAD/CAM implementation strategy should very clearly specify all the relevant policies:

* skill formation
* organizational interfaces
* CAD/CAM make buy policies
* CAD/CAM system capacity expansion policies
* line vs staff roles in systems development and maintenance
* centralization vs decentralization of CAD/CAM system development activities,etc.

The main impediment could be lack of familiarity with the technology at the upper echelons of the hierarchy and insufficient capability at the middle level to manage the technology in a strategic manner.

It might also happen that the management doesn't lend full support to the CAD/CAM development process, which can cause the best laid plans by the middle manager to go awry.Without the steadfast support and faith of the top management the entire process is futile.

In case the long term planning for the design and manufacturing is done in a proper way, the hassles of day to day communication and coordination can be largely taken care of.

3.5 CULTURE

The word coordination and integration have been stressed again and again to achieve the best results from CAD/CAM system implementation.Introduction of CAD/CAM causes a relative upward shift of skills in all major occupational groups. Incidentally, the various departments e.g. design, manufacturing, purchase,etc have had a status/influence hierarchy since ages,but this upward shift of skills in the manufacturing department in particular called for an equal status/influence vis-a-vis the design department.

This represents a significant change in the culture and values in an organization. This change in the culture is what we call "Culture shock" for the management and other historical high status groups/departments in the organization.

This is one of the most difficult and important challenges that the management must overcome. Incidentally, it is also one of the least tangible aspects of CAD/CAM implementation and learning process, yet one of the most important ones.

There are three key relationships that pose cultural challenge in CAD/CAM:

a) between workers and manager: The worker's job classification calls for a greater abstract problem solving skills and team responsibility. Under these conditions, the authoritarian style of the manager can no longer work wonders and is rendered obsolete.

b) between Design and Manufacturing: As discussed earlier, it is the great status gap that comes in the path of the coordination procedures.

c) between lower and higher level of managers: The successful implementation strategy calls for a participatory style of management. The top down strategy of the management has to change and accommodate the lower level managers in the decision making process.

The CAD/CAM vendor may target the upper level management to close a deal for a particular configuration of the CAD/CAM system. The top management cannot be expected to be cognizant about the intricacies of these highly sophisticated and complex systems. They should draw upon the reserves of the actual users and the functional managers who are dealing with these issues on a daily basis.

The general observation is that the time taken to implement a change in the prevailing procedure or to upgrade the skill level is not as large as compared to the time required to bring about a cultural change.Moreover, the lower levels are relatively receptive to change as compared to the top management.

The learning curve also slows down for the top level management. The point is that the management has to be equally receptive to an ever changing world of technology and automation, where automation leads to further automation and one technology leads to another that is increasingly complex yet promising higher productivity and other strategic advantages.That is the only way to ensure existence in today's highly competitive field.

4. The Technology of CAE

A recent National Research Council committee [18] defines CAD as that "...which applies the computer to the creation, modification , and evaluation of product design..." and CAM as that "... applies the computer to the planning, control, and operation of a production facility.

However many organizations give the title of Designer to a person who supports an engineer.

A designer may use CAD tools to do the layout of a circuit board. In this context the acronym CAD means computer automated layout programs. We choose the acronym CAE, computer automated engineering because we needed a recognizable key word. We are speaking of automated systems that aid engineering in the process of product development.

As a person tries to become wiser regarding CAE tools they are likely to gain many facts from commercial and literary sources. So many facts without a framework can easily cause confusion. CAE,CAD,CAM,ATM ??? We believe that Peter Marks has a good structure for these facts. He asserts that the general technologies of CAE are:

Data Base Management
Computer Graphics
Analysis and Modeling
Data Acquisition and Control
Computer Communications

The following section will spotlight each of these areas.

4.1 DATA BASE MANAGEMENT

The single central issue in CAE is the existence of the data base as the representation of the abstraction that is the product. The National Research Council refers to data communication, data consistency, data representation as three key areas for need advances.[18]

The data base is the information storage mechanism of any CAE system. It naturally is in some computer readable media, though it is not often interchangeable between various computers. The Data base is the key component affecting compatibility among application programs. In the ideal CAE system there would be only one data base. It would store all the information needed by the various applications, from graphics to manufacturing part numbers, component costs and performance etc.

Information stored redundantly can not be reliably updated and is difficult, though not impossible to manage. The data base also contains the results of many man hours of work so its integrity must be maintained. It is desirable to have the entire data base accessible from a single platform so that periodic backups can be the responsibility of a single person or support organization.

The initial information for the data base will likely be an option at extra cost called a library. After installation it will need customization to specific organizational needs. The data base technology, whatever form it takes will become the major factor relating organizational functions. For instance the library of electrical components an engineering unit uses will affect inventory, flexible manufacturing, purchasing.

Though it may be technically desirable to have the unified data base accessible to any application on any computer at the touch of a key, the effectiveness of a database can be gained through personnel cooperation and management direction. John Domogalla worked in a small special product unit of his corporation. The engineering team used inexpensive design aids running on personal computers. The library sent with these tools was modified to specify the corporate part number. Each component in the library was screened for redundancy with other parts and manufacturability using a robotic assembler. The library (Data Base) was distributed on floppy disk. The actions made the interface to purchasing much simpler since the corporate part numbers were related directly by the tools. The reduced part count lowered inventory and increased purchase quantity. The engineers found it simpler to use parts acceptable to automated manufacturing.

4.2 COMPUTER GRAPHICS

The technology of computer graphics provide the primary interface for the worker that deals with geometry or abstraction. This maturing technology is also a significant portion of the cost of CAE tools. The need for graphics increases with the complexity of a creation. For examples, a good documentation tool to create manuals may be best served by good resolution black and white displays while complex layouts of circuit boards and ICs will require higher resolution color monitors present the greater complexity. Three dimensional views from a mechanical CAE system relieves need for good visualization. It also forces geometric detail to be completely created. Which eliminates fabrication questions in the model shop. Presentations which show solid surfaces rather than wire frames completely define what is solid, what is inside and what is outside. This eliminates surprising interferences.[9]

Graphics also reduces the complexity of the worker/computer interface. This will be reflected in reduced skills required to operate the systems, thus less training time and more focus on the subject of creation. Context sensitive lists of commands aid the memory. Symbols (icons) make data manipulations more tangible. Graphic input allows users to point at, rather than describe in text, what they want.

4.3 Mathematical Modeling, Analytical, Verification tools

Modeling programs reduce days of painstaking data collection and error prone calculation, to searching for satisfaction in the results a system would produce if actually fabricated. Simulation allows abstractions to be rapidly prototyped in detail. The devil hides in the details. Verification uses the digital computer trait of perfection to assure that all requirements are met in all places. (That it has been told to look!)

Of all the technologies, modeling uses the raw compute performance of the platform. The expenditure on compute hardware will depend significantly on decisions regarding simulation and verification throughput. The technology of communication will allow one to use an expensive simulation computer as a shared resource will maintaining the convenient accessibility desired by individuals.

4.4 Data Acquisition and Controlling Physical Prototypes

Test systems can be $Million integrated solutions with a particular product focus or loosely coupled instruments sharing a common interface like General Purpose Interface Bus, with a computer controller.

Test systems can aid in evaluation a device by putting the control of stimulus and acquisition of results in an automated environment. In such an environment the stimulus flexibility needed for finding a bug can be controlled from a key board. The verification of complex results can be done rapidly and repeatably. They can present only the important information in a manner that makes sense to the worker.

4.5 Computer Communications

Beyond the technologies Peter Marks outlined is that of communications. This rapidly evolving technology seems to embody most of the complexity, installation problems and integration issues. It is often the cause of dissatisfaction. In certain areas it will also be the most effective technology.

Examples of pitfalls in computer communication are beyond the scope of any written work. Sometimes there is a ray of hope for standards but if more than one manufacturer adheres to a standard one ought to be wary. When the technology stands still enough some good things can result. For instance job shops accepting IGES(International Graphic Exchange Standard) technical specifications allows geometries to be fabricated without full drawings. Documentation does not have to be as complete and dimensioned to fabricate a prototype. In fact the time consuming documentation does not have to be completed until no further changes are predicted.[9]

Other emerging standards such as MAP/TOPS by GM, IDSN by AT&T, and NFS by SUN as well as those used by the military show promise due to the economic power of their promoters. Standards that arise by committee often cause problems due to slight differences in implementation by particular adherents.

5. The Business Mission

In small growing firms most capital expenditures are defensive in nature, designed to maintain the status of the firm, rather than expanding its capabilities.[7]

In almost every commercial technical publication the virtues of CAE are presented. But in order to view the forest you must have the proper perspective and know your viewing angle. Assuming that your mission is in part to produce products, some combination of three competitive strategies will define your viewing angle.[6]

* General Cost Leadership
  Manufacturing processes tuned for cost effectiveness at high quantities

* Differentiation
  Success found in flexibility, introduction time and product quality.

* Focused Concentration
  Success found in high flexibility, short introduction time and customer service.

The historical strategy of your company is important if it is changing. The leaders who were successful with one strategy will likely have a perspective developed from that strategy.

6. Implementation Strategy

I would propose that the initial motive in many CAE champions comes from a gut feel that the magic in these tools can bring glory by increasing success rate and eliminating embarrassing failures. Certainly the industry literature would lead one to believe only a fool would not enlist the products. However, detailed technical problems and organizational change are belittled by the zealot. So beware of feelings and support yourself with rational. An approach from greater perspective should result in less of a righteous crusade and more of a professional lead.

A grandiose attempt to install all technologies at once in a small firm or division will likely meet in failure. The change is to great. To use the technology would divert limited time and talent away from the salable product and actually extend the time to market. The time a infant business spends in the red is critical. In a larger corporation or a cash rich firm the organizational changes will be more of a throttle than the financing.

The relatively high cost of capital in the U.S. (10-15%) implies that payback on an investment must come in 2-3 years to be successful. An engineering manager interviewed by us, said his key objective was to reduce the time to market of new products. His engineering team had been using a CAE system, but the vendor went out of business. He was rapidly trying to replace the capability through another vendor. His corporate division could afford the large investment and the team would make relatively minor adjustments to their skills. Even so the investment would be justified in terms of dollars lost per day lacking product availability.[8]

It is difficult to write a CAE installation strategy for every instance, but a general theme seems to play well. That is; build a long term strategy from several short term plans aligned to the mission and current financial capabilities. In the long run should strive to provide an Integrated set of technologies. Good functionally specific tools interfaced to a data base that can provide relevant information to the diverse requests from users with different needs.

Integrated tools can be purchased turnkey at a high price. Turnkey systems lead to consideration of CAE vendor as a partner in your business. And the vendors stability, market power, and credibility are more important than the performance of the technology they provide. Implementation plans will be most successful if those planning, understand the technologies well enough to provide the most effective solutions first. The introduction and expansion plans should be laid in a progressive manner aligned with financial capability and the market strategy of the firm.

6.1 Technologies aligned to Mission

For a market strategy of Cost Effectiveness the most important technologies are data base, data acquisition, and communications. The value added by an engineering group will be to improve the manufacturing processes. Manufacturing test and inspection equipment should communicate(directly input) information to a database so that problems can be prioritized. The systems effectiveness will come by providing quantitative information for decisions on resource use to improve the process. Further usefulness will come by reducing the work involved in, and cycle time of process control.

The market strategies of Differentiation and Concentration will find their effectiveness closer to the design cycle. Here the technologies of modeling and graphics will be needed earlier than the data base. With a long view one might say that test equipment and communications would improve when the information in the data base grows large enough to become cumbersome to handle without automation.

A Structured design approach without CAE tools starts as general scheme is partitioned into modules. When the detailed design brings out incompatible functional specs between the modules patches are applied because of the time invested in the current concept. A deadline demands a release to prototype. The prototype highlights other problems and decisions are made along the line of reduced performance or further patches as time runs out and the product must be released to production. Experienced engineers will do it right the next time. The next time either the product is a differentiation which is improved or a new state of the art where experience in prior art is diminished in value.

A structured design with CAE tools can speed up this patch work or allow changes to the general scheme eliminating the patches. Since the effort invested in evaluation/design of the scheme is is smaller it is more effective to dispose of it and restart with a "simpler" concept than to patch. The overall result will be faster cycles of differentiated products or higher quality of state of the art products.

The time to market and quality of product will be most improved by mathematical modeling which should be the first implementation focus. The results of this modeling is more rapidly assessed when viewed graphically thus graphics interface should be the second focus. Communication technology will allow greater access to the modeling equipment which is most effective as a shared resource. The data base will improve shared knowledge. However, the later two technologies need not be purchased until the modeling shows its return value through successful product development and market acceptance.

The concept of modeling as most important has been reinforced through by the managers interviewed for this project. Steve Skidmore felt that 2d Mechanical CAE nearly useless. Unless time per item can be reduced by using replication. Items with small differentiation may be done faster on a table.[9] A study done by Liker and Fleisher of two large manufacturing companies aligned to this perception. In these firms engineers assigned to the support of current products were either not chosen or did not choose to use CAE systems. Unfortunately it seemed that designers of new product were not using the modeling capability and thus not reaping the effectiveness of CAE systems.[13] Here we had an instance where graphic and communication technologies were installed and used first.

Acquisition of particular technologies best suited for your market mission and phase of product development that fit within an implementation strategy directed toward integration will have the highest chances for success. The control aspect of the implementation strategy will be to provide training for and direct usage toward the advanced features of the CAE system. If the right systems are used effectively significant competitive advantage can be obtained.

7. EVALUATION METHODS

7.1 The Checklist Approach

The Checklist Approach[1]

An Engineering Manager may be involved in the evaluation of CAD equipment for use in his own group, functional area or across two or more functional areas such as design, manufacturing, and test. What questions should be asked of potential suppliers of CAD equipment (hardware, software, and peripherals)? What items are important to the group(s) objectives and goals?

Using a well thought out checklist can help evaluate suppliers and their equipment. The checklist developed is intentionally general and is intended to be used as a starting point to helpdevelop the appropriate selection criteria to be used in the formal evaluation.

7.1.1 Computer Hardware

Computer Hardware
- Mainframe
- Stand Alone Workstation
- Personal Computer

The CAD software will be run on a mainframe processor; stand alone work station; or a personal computer; or a combination of the above.

7.1.1.1 Mainframe

If a mainframe is available with the computing capability required, then we are considering the selection of software and additional hardware to acquire CAD capabilities.

Questions and concerns to be investigated include:
What hardware will be required to run the CAD system?
- graphics terminals
- terminals
- plotters
- printers
- additional memory

What effect on existing applications running on the mainframewill the acquisition of CAD have?

7.1.1.2 Standalone Workstations

Questions and concerns to be investigated include:

What is the processing capability of the workstation?
Is the operating system compatible with existing systems?
Can the workstation be networked with other systems as well as other workstations?
What functions can the workstation be used for other than CAD?
Can the workstation handle the largest anticipated design?

7.1.1.3 Personal Computers

Many CAD software packages are now available for personalcomputers that take advantage of the increasing performance of PC's in recent years. Questions and concerns to be investigated include:

How much memory is required for the various applications?
How much disk space is required?
Does the CAD software supplier recommend math or arrayco-processing boards?
What operating system is used?
Is networking supported?
Can the PC be easily used to support other processing functions when it is configured for CAD use?

7.1.2 Input/Output Devices

Various input and output options are required to support CAD. A combination of high resolution monitors, pen or electrostatic plotters, printers and digitizers will be required to operate effectively.

Questions and concerns to be investigated include:

What type of plotters are supported?
Can plotting be done in parallel with other activities?
Are several digitizing options available?
Are various families of printers supported (laser, dot matrix,high speed, etc.)?

7.1.3 Basic Communications

Basic communications include serial and parallel ports.
Questions to be asked include:
How many ports are supported and what types? RS-232? RS-422?
RS-488? Centronics?
What software is available to make use of the ports?

7.1.4 Networking

Networking is used for various tasks such as uploading files to be analyzed by a mainframe or resource sharing. Commonimplementations of local area networking (LAN) include Ethernet, token ring and bus.

Questions and concerns to be investigated include:

What type of network is supported?
What is the cost of adding a new node to the network?
What type of wiring is required?
What is the speed of the network?
How many nodes can the network handle?
Is special hardware or software required if a mainframe isincluded in the network?
Which vendor or vendors will support the network?
What peripherals can be attached to the network?

7.1.5 Peripherals

Questions to be asked include:

What is the maximum number and storage capability of the diskdrives?
What type of tape devices are supported?
What are the sizes and formats of the floppy drives that aresupported?

7.1.6 Software

Software categories are:

- Operating systems
- Language support
- Design software

7.1.6.1 Operating Systems and Languages

Questions to be asked include:

Which operating system is used and how is it updated?
If a proprietary operating system is used, can files be converted to standard operating system files?
What languages are supported?
What utilities are provided to assist with programming?

7.1.6.2 Design Software

The questions to be asked about the software will be very specific to the application(s) intended for the CAD system.

For example, questions to be asked in the area of printed circuit board design would be related to:

- Schematic capture
- Circuit simulation and analysis (including stress, thermal, analog, digital, reliability)
- Placing and routing of components
- Numerical control (NC) outputs
- Inspection data
- Artwork generation
- Automatic test equipment (ATE) post-processors

7.1.7 Databases Supported

Questions to be asked include:

How are graphics data represented?
Can the graphics data communicate with the outside world using,for example, IGES?
How much disk storage is required for design representation?
Can special application programs be created to manipulate thedesign data?

7.1.8 Documentation

Documentation will be provided with the CAD system and the user will need the ability to produce design documentation.

Questions and concerns to be investigated include:

Is the user documentation well organized and easy to read?
How are user documentation updates supplied?
Is there an easily accessible on line help feature?
What type of editor is available to produce design documentation?
Can design documentation be easily checked to verify compliancewith ANSI and MIL specifications?
Are symbols and equations easily accommodated?

7.1.9 Vendor Specific

Basic questions that would be asked of any vendor include:

What is the size of the company (financial and number ofemployees)?
How long has it been in business?
How many employees are involved in customer service?
Does the vendor have a support hot-line?
Does the vendor have a reference list of installations?
CAD specific questions include?
How many customer installations are there?
How many customer installations are in the local area or region?
Is training done at the customers' site or at the vendors' site? How much does it cost?

7.1.10 Maintenance

Where are the closest service centers?
What is there responsetime?
Is on-site service available?
What kinds of maintenance contracts are available? How much do they cost?

7.1.11 Operations Cost

Will new personnel be required to support the system?
What is the cost of supplies necessary to support the system?
What are the training costs, both internal and offsite?
What are the additional utility costs?
What is the impact on floor space?

7.1.12 Selection Matrix

The checklist information in the preceding sections can be formed into a selection matrix. Each vendor being evaluated should be rated numerically in each general category. The categories themselves should have a weighted rating based on the relative importance of the selection criteria. After the vendors have been rated in each category an overall vendor rating can be obtained. (see table 1)

TABLE 1

EVALUATION METHOD

The Criteria Checklist Approach

Selection Matrix

Category Importance	Vendor Capability	A	B	C	D
20%	Computer Hardware	10	8	6	9
5%	I/O Devices	5	7	9	10
5%	Basic Commun-ications	8	8	7	5
5%	Networking	10	3	6	2
5%	Peripherals	8	6	8	7
25%	Software	8	10	7	6
5%	Databases	4	7	5	9
5%	Documentation	10	8	5	6
5%	Vendor Information	3	7	3	9
5%	Maintenance	3	4	10	8
15%	Operating Costs	6	3	10	8
100%	Total Rating	7.45	7.05	7.10	7.30

7.2 EVALUATION by BENCHMARK

Another evaluation technique is to "benchmark". Pick a technical problem about which you have good information, a problem that you have recently solved or one that you are anticipating, and have each vendor solve it using the hardware, software and other equipment in their proposal. The vendors should have a limited amount of time to solve these problems that is similar to a realworld situation. This technique is valuable in that it:

- is a method to help verify the intended use and benefits of the CAE equipment.

- is an opportunity to observe and evaluate the vendors performance in terms of support and response time.

- is a method to help asses the validity of your selection criteria.

8. Justification

The champion of CAE systems is often of engineering background and may not know what it means to speak the language of management. The skilled manager will use various financial justification methods to evaluate alternatives. We do not pretend more than awareness that the justification process important to these large investments. The following sections attempts to point out issues relevant to justification and to suggest a simple method as example.

Conventional business methods rely heavily on financial measures such as Return On Investment(ROI), Net Present Value(NPV) and Internal Rate of Return(RoR) to measure the desirability of new product and capital acquisition. The National Research Council Committee [18] reports that these usual methods were inadequate and that responsiveness, productivity, quality, lead time, design excellence, flexibility, and work-in-process inventories are the best measures. They further go on [18] to point out that ROI methodology assumes stability in the economy, technology, labor and marketplace behavior.

Just because it seem appropriate to note how general competitors do it. The Japanese [24] use their management accounting systems as influences to motivate employees towards long term strategies rather than in an informing role which "precisely" informs of costs, variances and profits. The cost of capital in Japan is lower and the Management turnover is less.

The most enlightened yet pragmatic paper We've read was by James V. Poapst. Many of the following concepts are attributed to him.

A decision on capital expenditure for a small firm or new division can make or break the business since it is a large percentage of the value of the firm.[3] In larger organizations the limited capital budget must be allocated among multiple supporting projects. The value of the firm itself is hard to estimate. Much of the justification is done on estimated variables. In trying to be accurate we closely evaluate the impact. During the evaluation the estimated results are often of less importance than the ACT of estimating the results.[3]

Some time should be taken getting alternatives on the table and sorting them to a significant few. The manpower that can be allocated to an investment decision is small. And the effort of evaluation tends to develop a vested interest. James Poapst suggests a list alternatives be shortened by "executive judgment"![3] We would like to say in the light of CAE's recognized complexity that the list of alternatives be formed and sorted first by participating methods then decisions made as necessary.

For example an outstanding cost or performance difference may reduce the alternatives. In the CAE replacement senario outline earlier, the manager saw the new system as replacing VAX based systems.[8]

- A Vax system cost $162K a year to maintain.
- Daisy was estimated to be $130K
- Mentor $240K.
- The rule of thumb is about 10% of installed cost per year

He evaluated the Mentor system because of a corporate directive. However he may have saved himself some effort. We presented the names of vendors because this was a real evaluation and they are real vendors. We would like to point out that it represents the technologies deemed required by a single manager. Other criteria may produce other results.

Since long term gains effect, and are affected by, strategic decisions made regardless of CAE, and payback period will have to be earlier than 3 yrs in most cases, focus on estimating financial effects in this range and leave continued returns and improved product quality to support a CAE strategy. To be clear, CAE is a long range investment.

A basis for the long range plan is predicted future returns. If the plan is formed as we promote, it will be structured of smaller sequential investment steps each of which should show justification of the step, to be aligned with the companies needs and capabilities in the next 2-3 years. This is simply a pragmatic and rational approach for business in the USA of today.

8.1 Justification Example

8.1.1 Consider the Dollars

<u>Estimate the benefits.</u>

What is the payback? Estimate it. Things can be justified in terms of dollars lost per day of product sales.[8] The organizational effects dimensioned in manhours estimates expenses saved. The worth of the system improves over time as the user become more capable of using the data base, sharing information,[9] and using advanced features.[13] So the saved expense increases as a function of time.

Consider for examples:
? Reduced prototyping and technical support expenses?
? Serial development tasks such as software after hardware will run concurrently.
? Improved product quality through reduced design patches.

Using the same methods and tactical assumptions regarding the organizational changes, one should generate a baseline case. Consider the future without CAE. The predicted financial gain will be the difference the investment brings, from that which would happen regardless of the investment.

Estimate costs

Consider resources of firm needed to customize turnkey solutions.[2] That is install and customize libraries for the organization. Consider training cost in manhours expended learning instead of producing plus consulting fees.

Conceive of the purchase as if you had borrowed the money from a bank. A cost center manager may see the cost of capital as Depreciation assessed against his budget. But this is not the cost of the investment. You should use the cost of capital as determined by corporate staff based on company average return on investment. An estimate based on the interest rate at the local bank could be used if a clear answer for you businesses RoI is difficult to get. The cost of capital is 10-12% in the U.S. and can be higher for small firms with low equity.

Benefit$(time) - Cost$(time) = Net Cash Flow$(time)

Your company's Rate of Return is the slope of the Net Cash flow curve plotted against time. The average rate of return for American companies is 4.8%. Most high tech companies expect a RoR better than you could get by investing in a savings account at the local bank. Your own estimate should unquestionable by those involved in the decision.

Most firms use a single bottom line number called Net Present Value. The present value of a future net cash flow is that cash flow discounted by the RoR. For instance $1000 invested today at a RoR of 5% would be worth $1050 one year from now. So $1000 that isn't available until a year from now is worth only $952. Present Value = Value in 1yr / (1 + RoR). Compounding makes this presentation more complex but the concept is the point. The Net Present Value is the sum of Present values over the life of the investment.

8.1.2 Consider the Risk

Considering the risk evaluation. Only future impacts are evaluated, past expenses excluded.[3] Simply said, don't throw good money after bad. If a tactic is built on replacing an existing successful program the elimination of that program is considered a cost not a risk.

Implementation time and expense is very critical to a small firm. It will probably be the most significant risk. In most small firms the pay back period is used as a measure for evaluating capital expenditures[7]. J. Poapst see's it primarily as a measure of risk. He develops a term called Present Value Payback Period or PVPP. The time period required for the discounted cash flows to accumulate to zero is the PVPP. You must stay in business longer than the PVPP if the expenditure is to be called an investment. The faster projects payback the faster they free capital for other projects.[3]

Now if your proposal seems acceptable you may still need to make a hurdle rate in some companies. Hurdle Rates are decision boundaries based on acceptable Rate of Return.[5]

For each of the alternatives selected for evaluation the preceding financial analysis should be done. Which profitable proposal should be taken? J. Poapst outlines an interesting concept for decision making called searching for satisfaction.

Briefly, for each evaluation develop 3 senarios, Most likely NPV, Optimistic NPV, and Pessimistic NPV. Assign a chance of occurrence to each senario. Multiply the NPV's by the weights and perceive the resulting products as satisfying and dissatisfying. Dissatisfaction would occur if the pessimistic senario had a negative NPV and a significant chance of occurrence. Finally if the sum of the satisfying products out weights those that are dissatisfying, go for it. [3]

STRATEGIC IMPLICATIONS OF A CAE SYSTEM ACQUISITION.

CONCLUSIONS:

* The product design process has become a strategic factor in successfully competing in rapidly changing global markets.

* CAE tools significantly shape and influence the strategic design process.

* Successful utilization of CAE adds product value, reduces product development time and cost.

* Implementation of CAE needs a proponent with a broad perspective to install and direct the CAE investment to achieve the expected return.

* CAE introduction changes the organizations power structure, training requirements, recruitment practices and skill mix.

* Ill planned and/or misdirected CAE investments will effect the insignificant.

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10. Appendix -- Case Study

Method

Information regarding the environment and use of CAD in this study case was gathered through informal interviews with design and manufacturing personnel familiar with the company operations. Particular emphasis was given to interviewing the original members of the CAD evaluation team, the rationale being that of capitalizing on their interest, knowledge, involvement as well as training received through the CAD/CAM study.

The subject company of this case study is a small/medium sized company in Portland, OR. The company has been privately held throughout its more than 50 year existence.

The company's product lines have consisted of optical measuring instruments and electronic measurement systems. More than 80% of the current business comes from the optical products The optical product group includes six major product line divisions and product line variety within these groups ranges from three to thirty seven different models. Within the product line groups there is strong similarity between product features and design. Products within subgroups typically share more than 50% of detail components. A single product may have sixty different component parts.

Product design and manufacture process has been evolutionary and has been accomplished by one engineer and one or more designers using conventional design methods. Consultants are used for analysis and selection of optical systems. Product design is generally straightforward with little analysis of mechanical properties performed. Product performance is generally evaluated by comparison of desired functions against historically developed standards.

Approximately three years ago the company initiated and completed a study of CAD for product design and manufacture. This study was conducted by four The purpose of the study was to evaluate the suitability and justification of CAD and CAM for optical product design. It included an exhaustive study of current design operations, detailed analysis of product characteristics, extensive interview and evaluations of prospective CAD vendors and broad use of CAD research literature and seminars.

The study concluded that the defined $250,000 systems were unsuited at that time. This conclusion was based upon lack of clear market focus, lack of structured approach to the design process and the recognition that these factors would only be exaggerated by introduction of complex CAD technology.

Following that decision, Personal computer based CAD was introduced into the tool design area within manufacturing on an ad hoc basis. Introduction of this same level of CAD into the product design followed in six months. At the present time virtually all new product and tool design is done on these systems and approval has been received for introduction of limited CAM within manufacturing. Currently there are 10-12 users sharing 5 systems.

Summary

The informal interviews with corporate executives and system users reveal that:

* CAE, as introduced, has not significantly assisted with new product introduction. No documented improvements have been achieved.

* The company remains committed to the introduction of CAE tools and is willing to spend the time to learn on a trial and error basis.

* Lack of product focus has hindered the successful use of CAD as tool for new product introduction.

* A general perception is that introducing CAD on an ad hoc basis obscured the underlying organizational/structural barriers that are impeding effective design processes.

* Many problems of training, system usage and design consistency hampering effective CAD use remain to be resolved. The view among several users is that Higher level management is unaware of these issues. This is consistent with observations reported in the research material.

* The initial system was installed for the Manufacturing Engineering department. It was observed that the tool designers were the assigned users of the system, but that even though system time was available for other users there was very little self training or self motivated use.

* The value of applying the group technology principles to a product part data base is widely acknowledged yet this remains less than 5% completed. This was attributed to the lack of an integrated approach to CAD implementation.