ABSTRACT

DESIGN FOR MANUFACTURABILITY

by

Kocherlakota Sreedhar

Design for Manufacturability represents a new awareness of the importance of design as the first manufacturing step. It recognizes that a company cannot meet all its objectives with isolated design and manufacturing operations. The Design for Manufacturability approach embodies certain underlying imperatives that help maintain communication between all components of the Manufacturing and Design system and permit flexibility to adopt and to modify design during each stage of the product realization. Design for Manufacturability cannot be bought or sold and it should be implemented by management. Complete support of management to the implementation is very important to the success of the Design for Manufacturability.

In this thesis Design for Manufacturability and its inputs a proposed product concept, a proposed process concept and a set of design goals are explained, associated methodologies are discussed, and their effect on the design of a product and a plan implementation of design for manufacturability is developed.

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BY

KOCHERLAKOTA SREEDHAR

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APPROVAL PAGE

DESIGN FOR MANUFACTURABILITY

by

KOCHERLAKOTA SREEDHAR

Dr. Raj Sodhi, Thesis Adviser

Director of Interdisciplinary Program in Manufacturing Engineering

Associate Professor of Mechanical Engineering, NJIT

Dr. Nouri Levy, Committee Member

Associate Professor of Mechanical Engineering, NJIT

Dr. Kevin J. McDermott, Committee Member

Associate Professor of Industrial Engineering

Director of the Consortium in CAD/CAM-Robotics, NJIT

BIOGRAPHICAL SKETCH

AUTHOR: Kocherlakota Sreedhar

DEGREE: Master of Science of Manufacturing Engineering

DATE: May 1991

EDUCATION:

Graduate Education:

Sep 1988 * Master of Science in Manufacturing Engineering,
to
May 1991 New Jersey Institute of Technology, Newark, NJ

Undergraduate Education:

June 1982 * Bachelor of Engineer in Mechanical Engineering,
to
June 1986 Osmania University, Hyderabad, India, 1986

EXPERIENCE:

April 1990 Manufacturing and Industrial Engineer
to
Present Teledyne Adams, Union, N.J.

This thesis is dedicated to

Dr. Raj Sodhi, PhD, P.E.

Paul A. Labossiere, P.E

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

Engineering is concerned with using available resources to satisfy the needs of society, and design is the definition of that need and the implementation of the plan required to produce a solution. Design is primary function of engineering, and is concerned with problems requiring definite solutions needing remedial action. It is the intellectual attempt to meet certain demands in the best possible way. It is an engineering activity that impinges on nearly every sphere of human life, relies on the discoveries and laws of science, and creates conditions for applying these laws to the manufacture of useful products. The design process involves application of technology for the transformation of resources, to create a product that will satisfy a need in society. Significant advances in manufacturing technology, available materials, engineering tools, and computer availability have given rise to both the need and opportunity for engineering organizations to work more closely, which are isolated due to organizational, business pressures and other engineering functions.

The first generation of advanced manufacturing technology is known as flexible manufacturing systems (FMS). The impact of FMSs has been great. Particularly important is the manner in which product design is carried out with computer aided design (CD) systems and it is connected directly to manufacturing systems, automatic inventory control, tool operations, inspection, and quality control which are closely coupled operations. But the impact of FMSs on the way companies operate is minimal. Designers give too little consideration to important product life cycle issues such as product assembly, test, repair, and modification *(James L.Nevins & Daniel E. Whitney,1990)*. This is true even though designers are increasingly aware of the need to design product parts so that they can be fabricated economically and still meet performance requirements. When companies consider the second generation of advanced manufacturing systems like automated assembly, they find that, matters cannot be treated on a part by part basis. Assembly is coupled not only to manufacturing but also to design, vendor control, quality control, and the customer. As automation increases, it is important that designs be compatible with and take advantage of the new technology. Design for manufacturability(DFM) is a method of addressing this need by seeking new ways of representing and combining design data. New methods are desired for coordinating design and manufacturing departments. Improvements in engineering education should take place that will relate design to manufacturing resulting in a better understanding of the relationship among process flexibility, production volume, types and levels of automation, and the influence of product design on these factors. DFM also makes the designer aware of opportunities to use nontraditional materials in new products and the importance of considering material handling and assembly at the beginning of the design process. Design for manufacturing should also increase productivity.

1.1 Design Objectives:

The objectives of any design is to make profit for the manufacturer and the customer, within any constraints imposed by society. However, it is often convenient to establish objectives which are easier to asses than cost or profit but which are clearly convertible into money. Such objectives will usually be of local application in that they will apply more to one design than another or more to one part of a design than another. There are many factors which are often seen to be major objectives for a designer.

1.2 The Design Process:

All design is to some extent creative, requiring intuition as well as technical knowledge, but some designs need much less invention than others and many designs tend to evolve gradually as a series of modifications of the same basic plan. Engineering design covers a wide field, varies from product to product, and the process depends on the degree of innovation involved. The differences of procedures are mainly differences of emphasis, however all designs follow a common sequence of activities.

Design is almost always an iterative, problem-solving process which has similarity with the scientific method as shown in fig 1.1 (1). Observation of phenomenon leads us to the perception to formulate a problem and in design observation leads us to the perception of a need. In science we attempt to generate possible ways of solutions to the problem that we meet the need we have perceived. We test our proposed ways of meeting the solutions by experimenting the need, and our tests must be devised so that, if possible, they prove that our proposal may not work. It is probable that the tests will show a suggested solution to the proposal to be inadequate or that the problem is inadequate and modification or redesign is necessary.

There are many methods that are normally used to describe the nature of the design process. One of the approach is to examine all the factors effecting design of a product as shown in fig 1.2 (1) and to define each stage through which it passes from market evaluation to production as shown in Fig 1.3 (2).

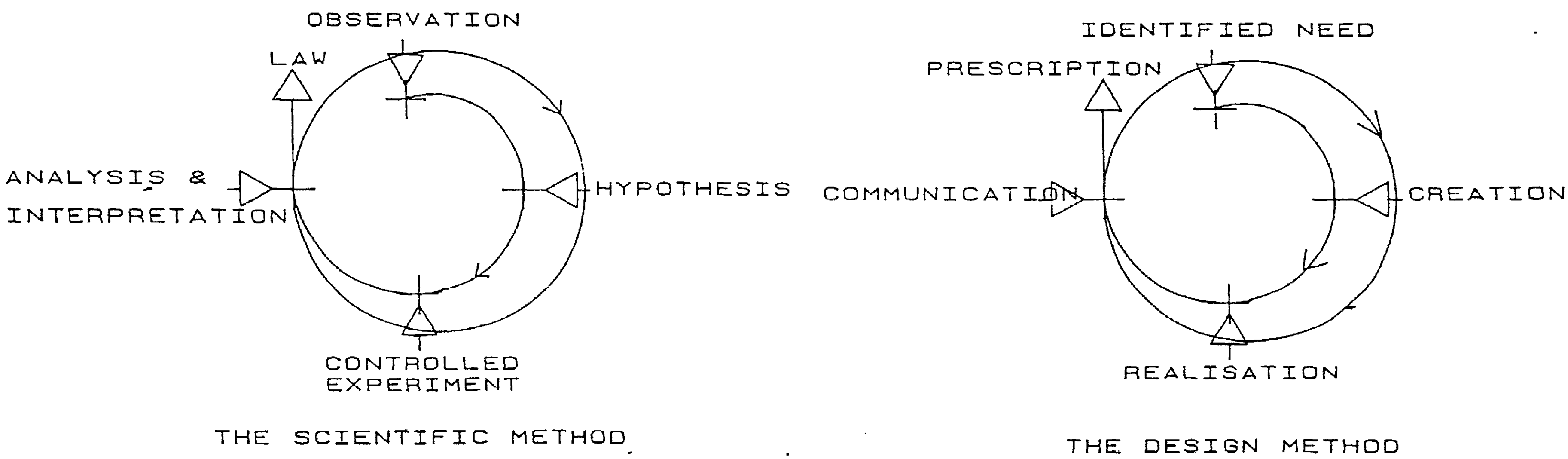


FIG 1.1 SCIENCE AND DESIGN

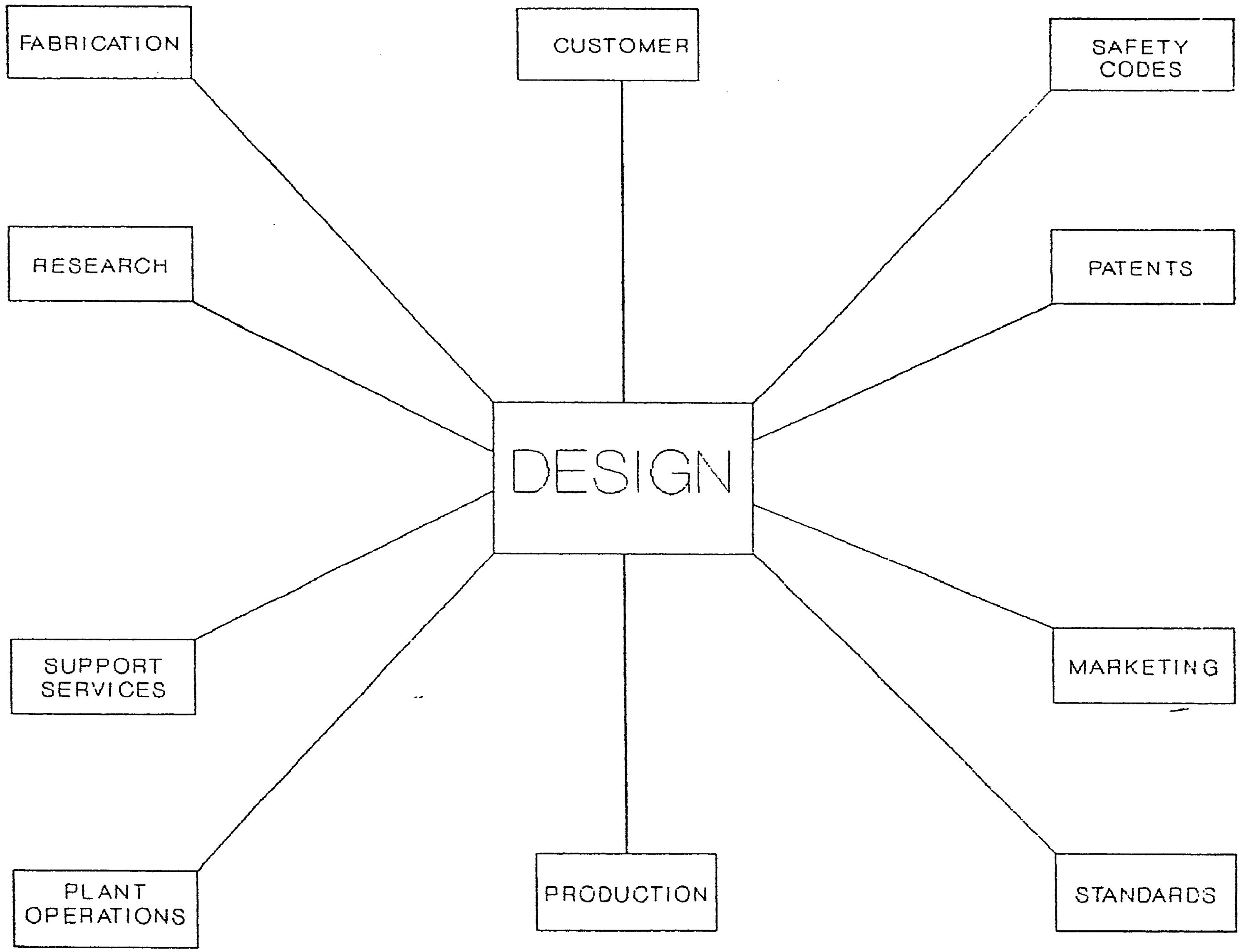


Fig 1.2 External Factors effecting Design

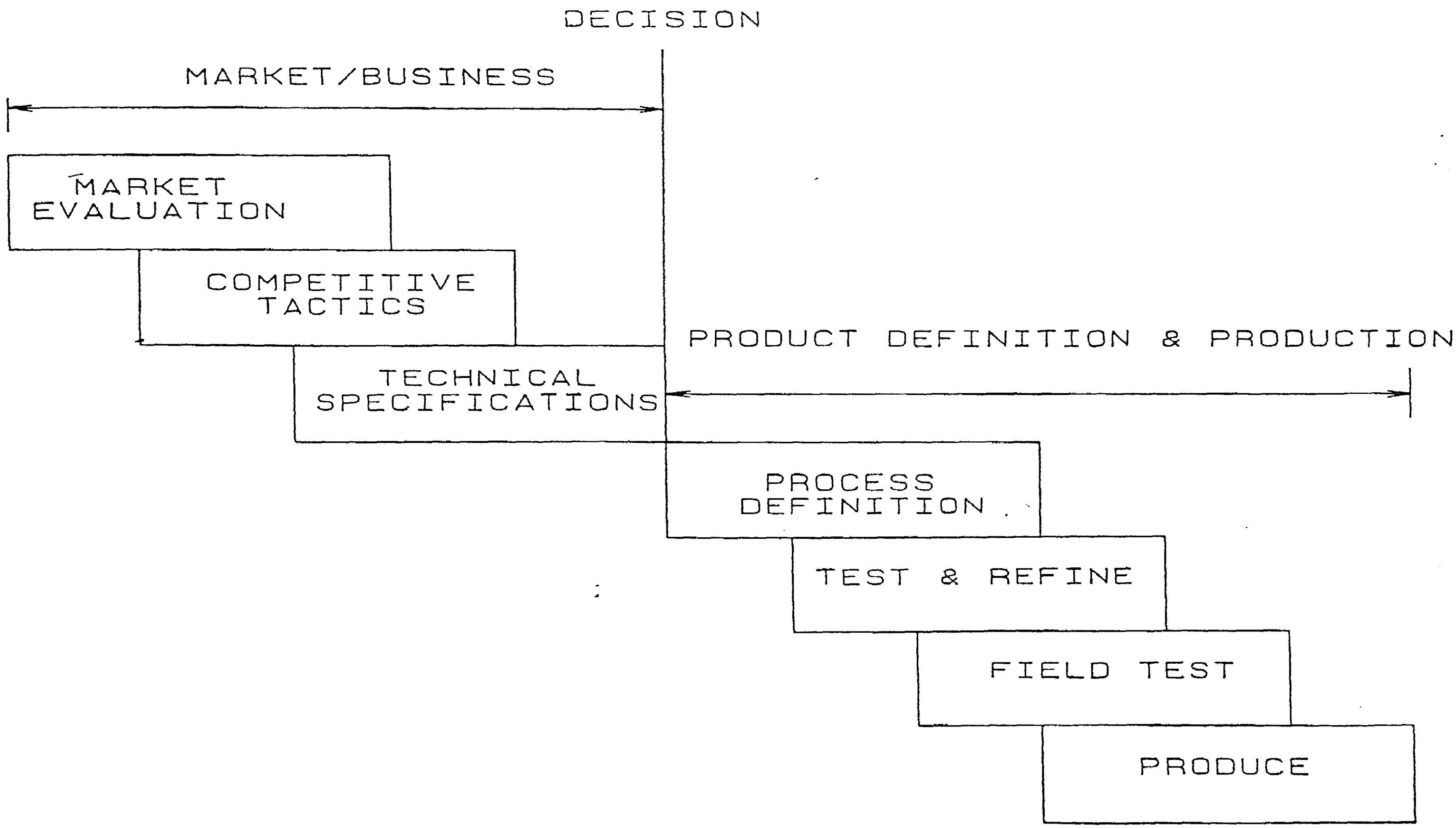


FIG 1.3 NEW PRODUCT INTRODUCTION CYCLE

In this morphology or structure of the design process, and the appropriate stages are shown in fig 1.4 (1) the following:

1.2.1 Identifying the problem:

The first step in the process of design involves identifying a problem, or a need. A full specification of this need must be obtained in order to avoid extra work at a later stage. Limitations and requirements of the design must be identified, and stated in terms of constraints and criteria. Other relevant information must be needed for effective design.

1.2.2 Feasibility Study:

Conducting a feasibility study is whether it is physically possible to produce the product, whether it is economically viable and acceptable. If the physical requirements appear possible then the economics of the various alternatives can be investigated and establish that any alternatives under consideration will be acceptable, not only to those who need but also to the society in general.

1.2.3 Preliminary Design:

Having defined the need and ascertained that a solution may be feasible, the selection of the best process must be done when alternatives exist. It should be remembered that the design choice is not irreversible and an alternative method may be preferred but the cost of the product is increased.

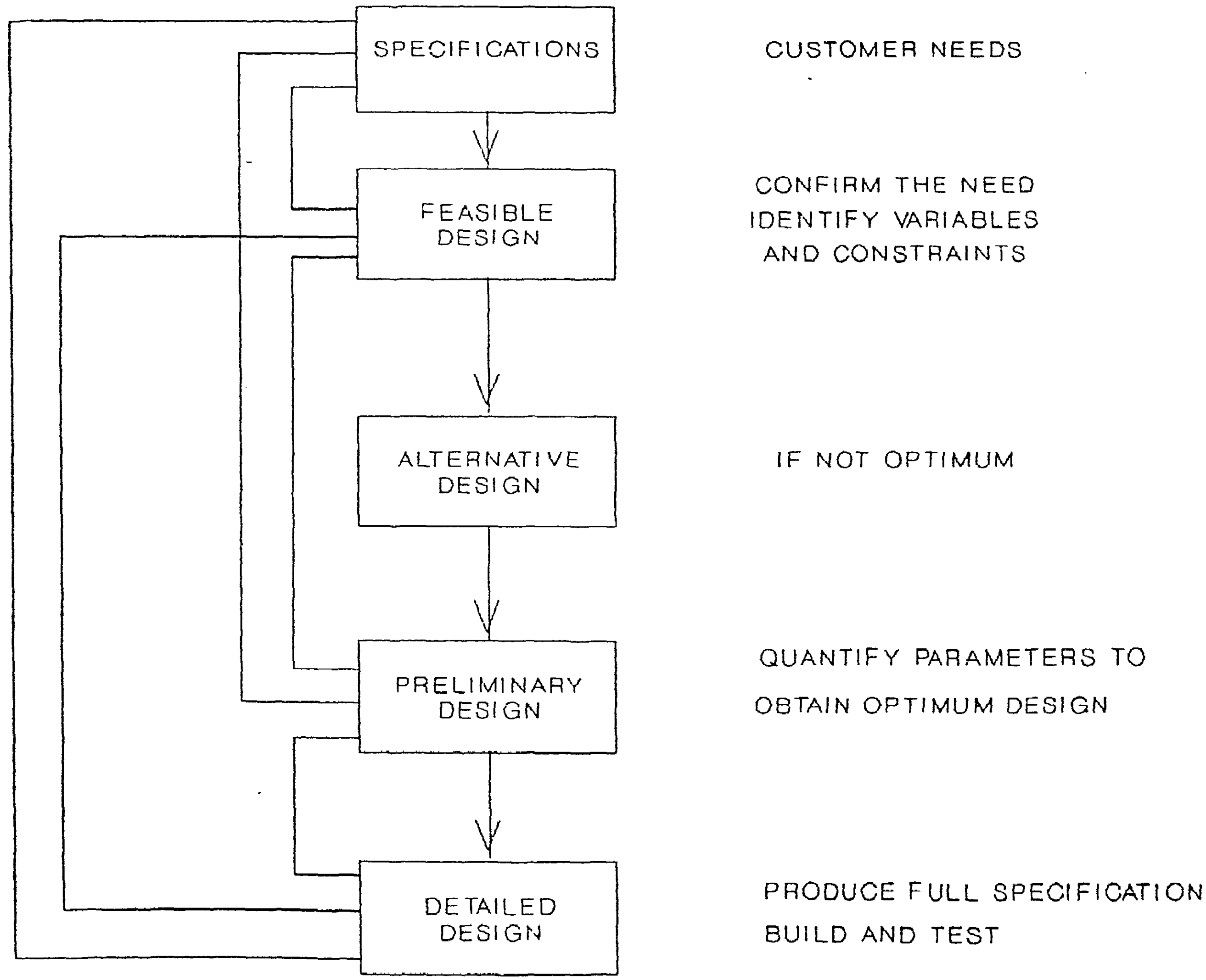


Fig 1.4 Design Process

1.2.4 Detailed Design:

A chosen approach and final design is prepared. All components and systems are fully specified and all in service requirements should be defined. A model is prepared from the complete set of production drawings and this prototype is tested in order to evaluate the performance and effectiveness, and to decide upon any modifications.

1.2.5 Production:

Having finalized and approved the detailed design, the prototype is constructed involving design and production engineer. The capital investment for the project must be available to pay for the material, labor, fabrication etc.. The detailed design should have time schedules, delivery dates, assembly times are to be calculated to avoid costly waiting time.

1.2.6 Distribution, sales, usage:

This stage is concerned with the supply of raw material and services, or the distribution of products to suitable sales outlets including storage, packaging, transportation etc. The final product must be used, and it must satisfy the need it was intended to fulfil. If this is not achieved, the capital investment in the project would have been wasted.

1.2.7 Obsolescence:

The design of the product should ensure that it will not wear or prematurely obsolete, and also that at the end of its useful life it is still capable of prolonged operation. The occurrence of either of these situations indicates that the design economics could have been improved.

At each stage in the design process there should be a constant recycling of new information and decisions can be continually re-evaluated. In this way, unforeseen and unavoidable changes that effect the design will be detected at the earliest opportunity.

Designers as well as representatives of the marketing, research, and production departments should form a forward-thinking unit or product policy committee, and it should look into account of past product performances and the economic, social, and other external influences which will affect the products future. Such a committee would be responsible for providing the design team with such factors as an estimate of development work necessary to establish the technical feasibility of a new product, a survey of the market to determine probable sales and profits, and an estimate of the capital investment required. For this work, such data must be collected from inside and outside the company.

1.3 The successful design:

To achieve successful design, it is necessary to apply the total or integrated design process. This process is very complex and number of stages are passed through, some of which are suggested in Fig 1.4 (1). If the design is to be a purposeful activity the goals must be identified. Any business is polarized round the customer. The right product is the one that meets the customer needs, that sells in a competitive market and makes a profit. There will be many other functions within the company, such as accounts, personnel, and management services, but all these are to support the main business of designing, building, and selling hardware for profit.

Today, 85% of the engineering business volume comes from products which were unknown about ten years ago. Furthermore, there is an ever increasing tempo of technological change. The lag between discovery and use is beginning to reduce. Products and systems are becoming more complex, and this leads to high research and development costs and the need for expensive test equipment. The result of quickening pace of technology is that new techniques of surveillance, screening, and forecasting are essential if any degree of confidence is to be achieved in launching a new design.

A new product will start with a statement of the need to exploit a new development, which will lead to a design requirement specification. After examination of this, possible ways of meeting it would be considered. One of them would be finally selected; and the chosen design detailed and produced. Feed back from customers and factory floor would improve designs.

1.4 Design Communication:

Performing the activities of investigation, formulation, examination and selection costs money required to pay for the man hours. Performing them badly leads to the production of goods which are not profitable to manufacture. It is necessary therefore, to formalize the design process into a system in which the outcome and cost of each stage may be monitored and controlled. Looking briefly at this process, one can see how easy communication of the design to muddled up with its production. It is important to recognize that these are different phases of the process. Creative design requires accurate input information, from both inside and outside the design department, and all communication is best studied in terms of the recipient. Ideally, engineering design information should be conveyed numerically, suitable for direct input to a N.C. manufacturing machine. But in most cases the design intent has to be conveyed to human beings. During the last half century there have been tremendous developments in methods of communication, and these have produced changes which depend more on the medium than the use to which it is put. Two main trends are apparent, one, the increase in speed of communication and the other is increase in efficiency of communication.

The important stage of the design is communication, that is giving the instructions for making the product. The cycle will start with verbal statements, specifications and contract documents which will form design brief. These will be the raw materials from which designers produce diagrams, layouts drawings and sketches etc. Finally, the manufacturing instructions will be conveyed, mostly by means of detailed drawings in two dimensions, but also by written manufacturing specifications, three dimensional diagrams models and programmes for numerically controlled machine tools.

The foundation of any design program is the design specification. It is imperative that a formal specification be prepared. The specifications must be prepared prior to the initiation of the design process and a checklist is followed to make sure that all criteria are considered. It is important that the specification is available prior to team selection so that the team structure reflects the expertise implied by the specification.

1.5 Improving the Design Processs:

HDesign procedures and strategies utilizing disciplined and systematic methods and procedures are needed to effectively implement design integration. Improvements in the way a company does design can take many forms, but most will usually involve some or all of the following elements:

<u>Structural Change:</u> Organizational and procedural changes are made to enhance communication between functions, to facilitate integration of function, form, and fabrication, and to simplify and optimize work flow.

<u>Compatible CAD/CAM/CAE Systems:</u> Product and process designers work on compatible systems to allow CAD/CAM/CAE information integration.

<u>Focus on change:</u> Iteration is managed in a fashion allowing for continuous exchange of ideas and timely feedback of implications from the beginning.

<u>Life-Cycle Design:</u> Not only the product and process is optimized, the whole manufacturing system is optimized.

CHAPTER 2

MODERN DESIGN METHODS

In earlier times a manufacturing company would assemble its product design team, and in a reasonably short time be able to deliver design of a product to manufacturing who would then produce it. Process took place without the need for extensive engineeing lead time and manufacturing a plan. All this may indeed an ill-placed nostalgia. The sequential engineering process might have really did generate major headaches for manufacturing, maybe it didn't do products which were defect free. Governmental requirements and intense foreign and domestic competition place a great premium on a company's ability to rapidly bring new products or major modifications to the existing products and to the market place in the minimum amount of time. Speed is an essential ingredient, not only to remain competitive, but is absolutely necessary if a company is to beat its competitors to the market. Speed itself is not the only answer. The products must come to the market as defect free as consideration in the design of the products. The current buzz word is Design for Manufacturability or some times called 'Simultaneous Engineering', which is either something very new or it adds some innovations to the bromide of going "back to basics". Where ever it was used, it did achieved quantum improvements in the product design, manufacture and delivery of quality products to the market place.

Increasing competition in the world markets for technology oriented products has created powerful incentives to improve product quality, reduce flowtime, be more cost effective, and provide a better product to our customers. A recent trend in industries leading to these objectives is done using different design approaches, most of them recently developed. These new approaches to product development and manufacturing have changed the designing process, the way a product is manufactured and the way the companies operate. Some of the new design concepts are given below..

2.1 Axiomatic Design:

In axiomatic design, good design is achieved by using fundamental principles of axioms of good design to guide and evaluate design decisions. Extensive examination of successful designs has shown that good design embodies two basic rules (Yashuara and Suh, 1980). The first rule states that in good design, the independence of functional requirements is maintained. The second rule is among the designs that satisfy the previous rule, the best design is the one that has the minimum information content. The rules will tell us that information content of the design will be reduced by integrating functional requirements into a single physical part or design solution, but only if the functional requirements of the designs are satisfied independently. Maintaining independence of the functional requirements allows the use of "tried and true" solutions in new applications, and is often essential for acceptable product operation and performance. One way to visualize manufacturing information content of a particular design is to mentally create routing sheets for the product's manufacturing. That is, imagine the number of separate activities and the number of instructions per activity required to manufacture the particular product or subassembly. The best design would be the alternative requiring the least number of activities with the fewest instructions per activity.

Use of the rules in design is a two-step process. The first step is to identify the functional requirements and constraints. Each functional requirement should be specified so that the functional requirement is neither redundant or inconsistent. It is also useful in this step to order the functional requirements in a hierarchical structure, starting with primary and proceeding to the least important one. The second step is once the functional requirements and constraints are specified for a given design, proceed with the design, applying the rules to each design decision. An axiomatic approach design is based on the belief that fundamental principles of good design exist and that use of axioms guide and to evaluate design decisions leads to good design. Design axioms cannot be proven, but rather must be accepted as general truths because no violation has ever been observed, and application of the design axioms to the analysis and design of products and manufacturing systems is not always easy because the axioms are quite abstract, their use some time requires considerable practice and judgment.

2.2 Value Engineering:

Value is defined as a numerical ratio, the ratio of function or performance to cost. Because cost is a measure of effort, value of a product using this definition is seen to be simply the ratio of output to input. In a complicated product design or system, every component contribute to both the cost and the performance of the entire system. Obtaining maximum performance per unit cost is the basic objective of value engineering. Value Engineering provides a systematic approach to evaluating design alternatives that is often very useful and may even point the way to innovative design approaches or ideas. Also called value analysis, value control, or value management, value engineering utilizes a multidisciplinary team to analyze the function provided by the product and the cost of each function. Based on results of the analysis, creative ways are sought to eliminate unnecessary features and functions and to achieve required functions at the lowest possible cost while optimizing manufacturability, quality and delivery. The application of value engineering principles by design engineers will result in the development of goods and services which perform the required functions at the lowest possible cost. Because value engineering is function oriented, it often increases the value of the product while lowering the cost of producing it. Maximum value is obtained when essential function is achieved for minimum cost. A typical value engineering project involves the following five steps.

. Information

. Creation

. Evaluation

. Investigation

. Reporting

Value engineering is an excellent tool for integrating a company's design engineering, and manufacturing resources. Value engineering techniques are tools to be applied by a multi-discipline team to each phase of a new product develop project. Some of the tools are:

. Get all facts

. Define the function

. Work on specifications

. Analyze Costs

. Use own judgment

. Create, then refine

. Use standards

. Use specialty products

. Use Experts

. Think creatively

. Use effective employee relations

The value engineering is an attitude or a desire on the part of the individual to want to design, to want to manufacture, and to want to purchase with value in mind.

2.3 Group Technology (GT):

Group Technology(GT) is an approach to design and manufacturing that seeks to reduce manufacturing system information content by identifying and exploiting the similarity of parts based on their geometrical shape and/or similarities in their production process. GT is implemented by utilizing classification and coding systems to identify and understand part similarities and to establish parameters for action. GT can be used in a variety of ways to produce significant design efficiency and product performance and quality improvements. One of the most rapidly effective of the use of GT is to help facilitate significant reduction in design time and effort. In using a GT system, the design engineer needs only to identify the code that describes the desired part. A search of the GT reveals whether a similar part already exist. If a similar part is found to exist, and this is most often the case, then the designer can simplify or modify the existing design to design a new part. In essence, GT enables the designer to literally start the design process with a nearly complete design. GT can also be used effectively to control part prolification and eliminate redundant part designs by facilitating standardization approaches. If not controlled, part prolification can easily reach epidemic proportions, especially in large companies that manufacture many different products. By noting similarities between parts, it is often possible to create standardized parts that can be used interchangeably in a variety of applications and products.

2.4 Failure Mode and Effects Analysis:

Failure Mode and Effects Analysis (FMEA) is defined as the task that a component, subsystem, or product must perform. This is stated in a way that is concise, exact, and easy to understand for all users. Functions are typically actions such as position, support, seal, retain, and lubricate. Failure is defined as the inability of a component/subsystem/system to perform the intended functions.

FMEA is an important design and manufacturing engineering tool intended to help prevent failures and defects from occurring and reaching the customer. It provides the design engineer with a methodical way of studying the causes and effects of failures before the·8Hdesigns are finalized. Similarly, it helps manufacturing engineers identify and correct potential manufacturing and/or process failures. In performing FMEA, the product and/or production system is examined for all the ways in which failure can occur. For each failure, an estimate is made of its effect on the total system, its seriousness, and its occurrence frequency. Corrective actions are then identified to prevent failures. Failure modes are the ways in which a component/subsystem/system could fail to perform its intended functions. Typical failure modes would be fatigue, fracture, excessive deformation etc. Asking what could happen to cause loss of function is often an effective way to identify failure modes.

2.5 Process-driven Design:

In process driven design as shown in fig 2.1 (3) the manufacturing process plan is developed prior to performing the product design. Although having manufacturing-led product development approach, it can be very effective strategy because it is based on the recognition that product design decisions often inadvertently limit the manufacturing options available for production of the product. This is especially true if advanced manufacturing technologies are used. Process-driven design keeps the product design from unnecessarily constraining manufacturing by providing up-front guidance to the design engineer before the design concept is frozen and allows both to converge in a uniform and controlled fashion. Process-driven design is implemented by specifying process requirements and the preferred methods of manufacturing as design requirements before design of the product begins. The product is then designed so that it can be manufactured in the most desirable way as shown in fig 2.2 (2). In one of the approaches the required end results are defined first in the form of quality, reliability, productivity, and cost. Manufacturing then defines the best process for building the product that will achieve these goals. Next, guidelines based on the best process developed to help ensure that the design features required by the process are incorporated into the design. The product is then designed using guidelines to take advantage of the best process.

Process driven design seeks to ensure that parts and products are correctly designed to be produced using a particular production process. Design requirements for a given process are often stated in the form of design guidelines and rules of thumb. Typically, these guidelines are highly specialized for a particular industry, process implementation, plant or equipment.

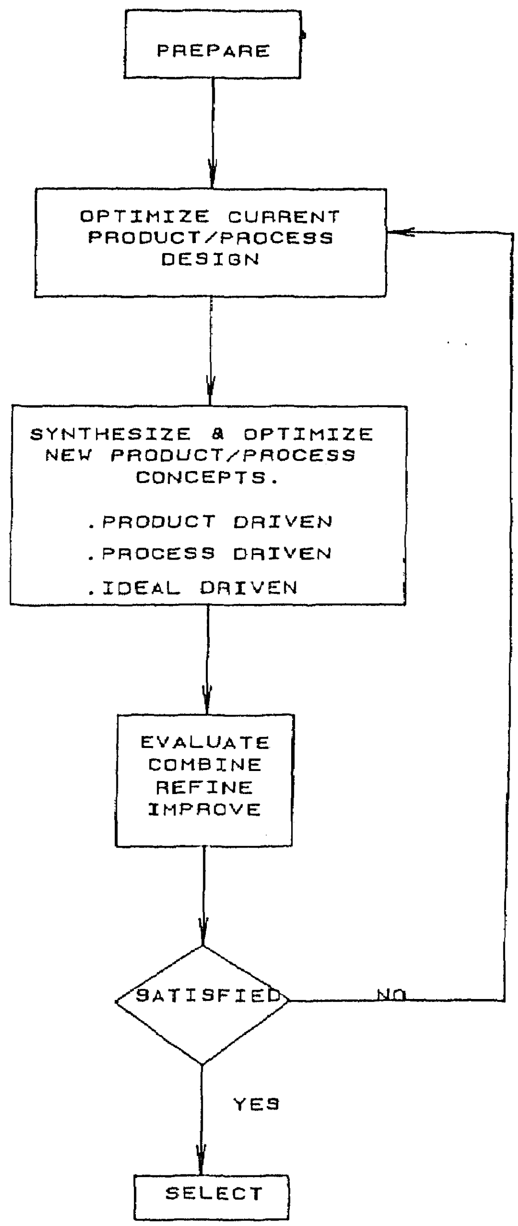


Fig 2.1 Product/Process Driven Design

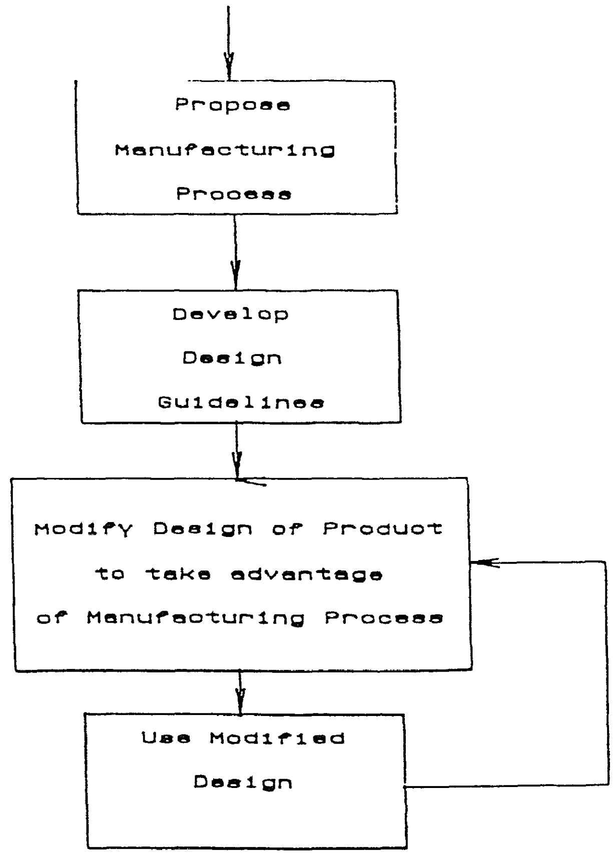


Fig 2.2 Process Driven Design

Making the designer aware of these process requirements and constraints early in the design process, before concepts are finalized and lines are put irreversibly on paper, is a key goal of process driven design. Design tools that help ensure product/process conformance and enable process-driven design can generally be classified as either process specific or facility specific.

2.6 Design for Quality:

The Taguchi method addresses the problems associated with determining robust design by statistical design of experiments theory. Robust design implies a product designed to perform its intended function under all circumstances. In particular, the Taguchi method seeks to identify a robust combination of design parameter values by conducting a series of factorial experiments and/or using other statistical methods. Termed as parameter design by Taguchi, this step establishes the mid-values for robust regions of the design factors that influence the system output. The next step, called tolerance design, determines the tolerances or allowable range of variation for each factor. The mid-values and varying ranges of these factors and conditions are considered as noise factors and are arranged in orthogonal tables to determine the magnitude of their influences on the final output characteristics of the system. A narrower allowance will be given to noise factors imparting a large influence on the output.

Few would disagree that quality is crucial to the survival of manufacturing. And most would agree that quality is the discrimination between superior and mediocre organizations. But agreement on what quality is and how it can be attained is more elusive. Quality is an attitude that compels every person in a company to demand two things: Every job will be done right the first time, and every product the company makes will work.

It is said that quality is free, but to realize improved quality requires investment in training, in trusting people, and in allowing them to make mistakes and learn from their mistakes. Similarly, new technology demands training. Many companies have failed to realize the benefits of technology, especially in the area of manufacturing automation *(A.Thomas Young, 1991)*. These failures have occurred because management did not adequately train and prepare the people who used the technology. There must be a match between the people and the technology, and that requires an investment in training. In fact, the tougher the times, the more training budgets should be increased, which of course counter to typical practice.

Variability is the enemy of manufacturing. It is a major cause of poor quality resulting in unnecessary manufacturing cost, product unreliability, and ultimately, customer dissatisfaction and loss of market share. Variability reduction and robustness against variation of hard-to-control factors are therefore recognized as being paramount importance in the quest of high quality products. In design-for-quality approach, the design team seeks to design the product and process in such a way that variation in the product's functional characteristics due to variations in hard to control manufacturing and the operational parameters are minimal. The ideas behind these are of Dr. Genichi Taguchi.

The key to minimizing variability in a product's functional characteristics is to symmetrically select values for controllable factors such that sensitivity to uncontrollable factors is minimized.

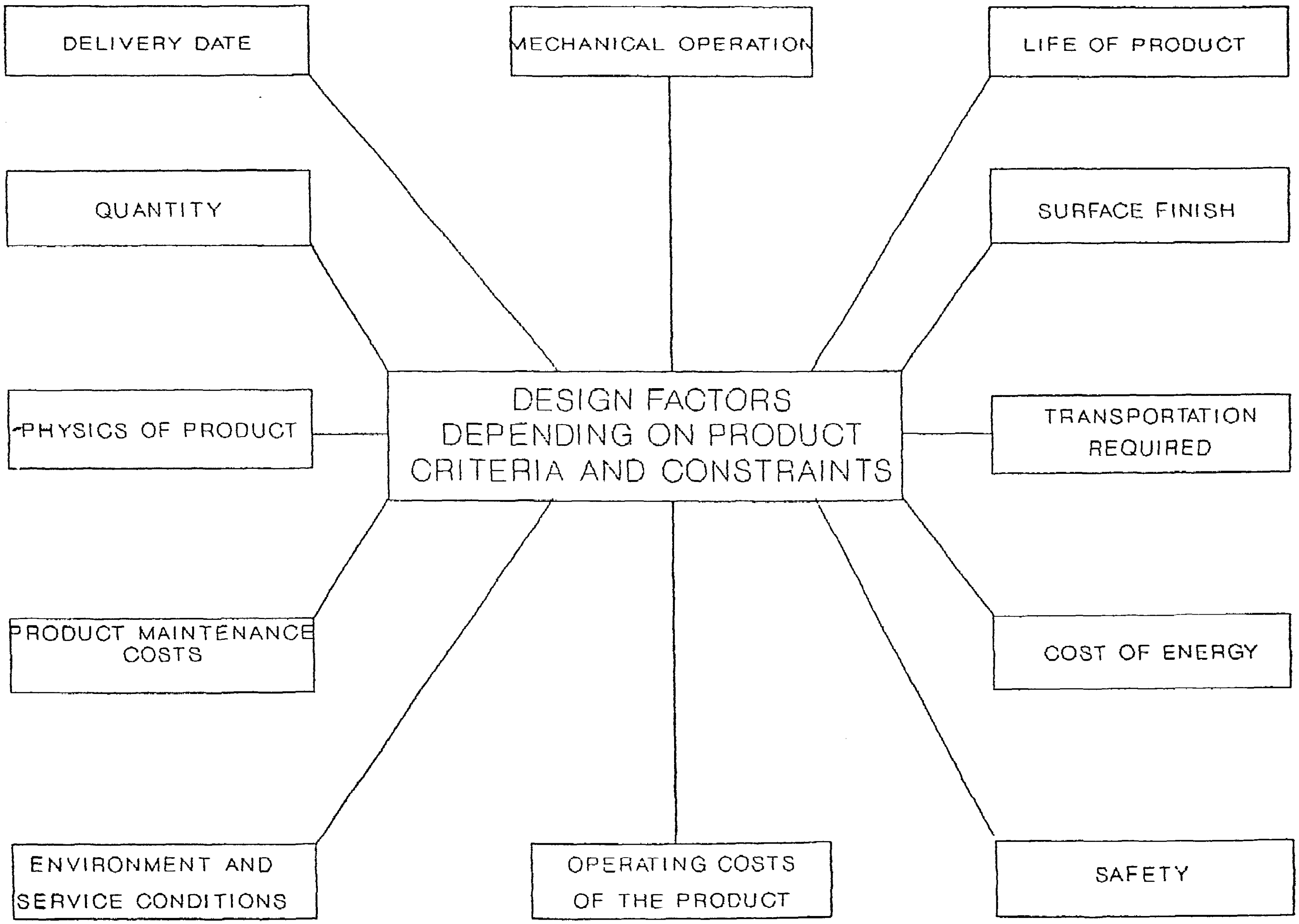


Fig 2.3 Factors Effected by Design

Factors as shown in fig 2.3 (1) include all product design parameters such as Material, Dimensions, Part Geometry, Design Configuration etc. and uncontrollable factors include environmental factors such as humidity, temperature, time and use factors, material wear. As practiced by Taguchi design for quality involves a three step optimization of product and process; system design, parameter Design, and tolerance design. System Design involves wise selection of material, part configuration and geometries, tentative product parameter values, production equipment, and tentative values for process parameters.

In parameter design, tentative nominal values are tested over specified ranges to determine the best combination of parameter values. If the reduced variations obtained by parameter design is not sufficient, tolerances on influential product and process parameters are tighten in the tolerance step. Tolerance design usually means spending money on higher precision, better grade materials, and more-complex machinery. Many design and manufacturing organization are conditioned to spend money to achieve required product functionality and performance. The tendency is therefore to jump from system design to tolerance design. In doing so, they omit the parameter design step where there is most to gain in terms of cost and quality. The key focus of Taguchi method is the focus on this step.

System design offers an equal opportunity for designed-in quality improvement. This is because, it is in the system design that the potential beneficial impact of design integration and the team approach is greatest. Design for quality can also be implemented in the system design step by intentionally designing the product and process to be tolerant of variation. Manufacturing complexity and cost reduced, product maintenance is simplified, and customer perceives the product to be of higher quality because no perplexing adjustments need to be worried about. Management's challenge in doing design for quality in the system and parameter design steps is to create and nurture the necessary team approach environment needed to make it work. Most importantly, management must expect design for quality, encourage it by providing opportunity and appropriate resources in the early stages of the design, and act decisively on findings and recommendations.

To improve manufacturing competitiveness manufacturers must move beyond quality concerns to plans for growth, price competition, and faster product development. Key performance measures for managers are quality, reducing unit cost and reducing new product development time. There is more to competitiveness than quality. Manufacturers must push themselves beyond the quality revolution at a faster pace to address the changing face of competition *(Jeffrey G. Miller and J.Kim).* A balanced approach is required. Such an approach would integrate manufacturing strategy, employee involvement and development, technical superiority, and continuous improvement in quality, cost, and time.

2.7 Design for Material Handling:

Parts must be handled many times during production and after. Handling involves several factors, including the following:

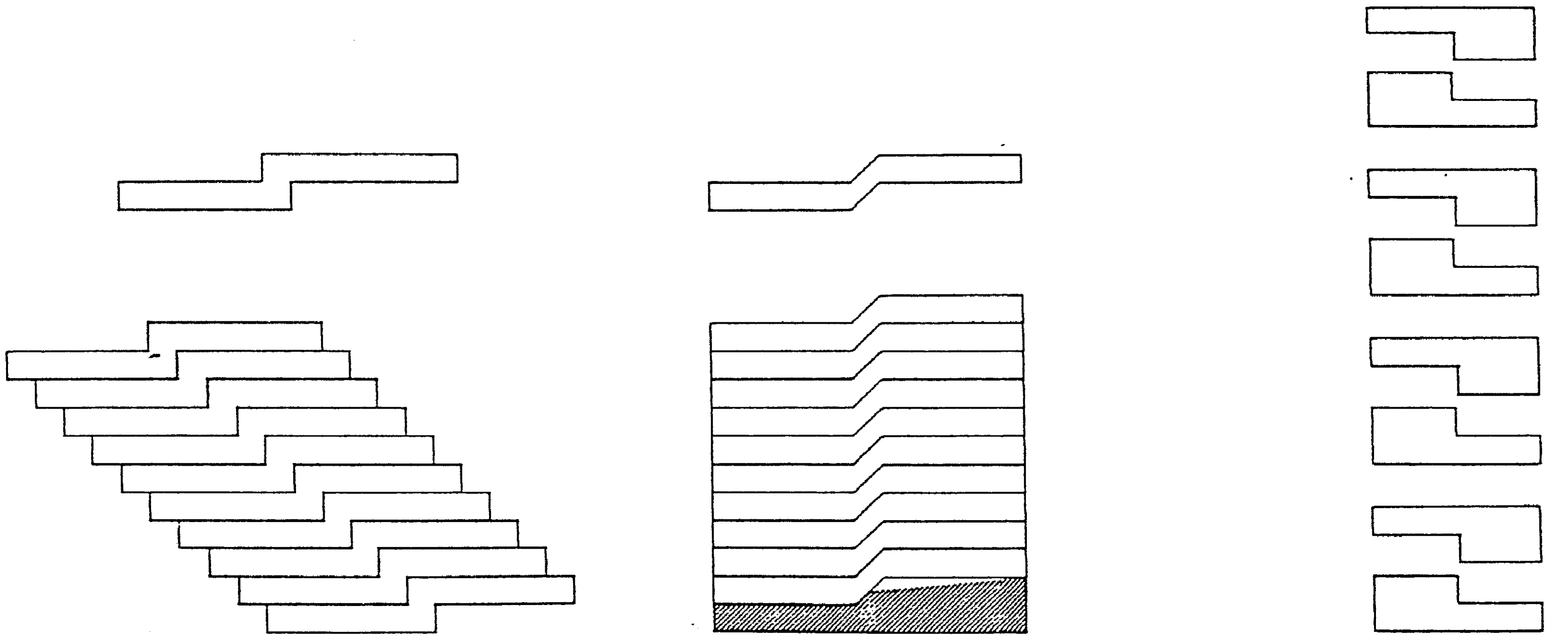
1. Efficiency in terms of parts carried per carrier
2. Protection of the parts from Material Handling damage.
3. Separation between parts to allow grasping
4. Check identify and otherwise accounting for the parts and documenting their arrival and use.
5. Recovery and reuse of the carrier

6. Easy to pack

The anticipated handling method influences how the part is designed. To maintain structure in the production operation, it is preferable to arrange parts uniformly rather than heaping in bins. At the moment of assembly, the most important factor is obtaining good grasp. Grasp must not only be firm but should also be easy. The best way to ensure accurate grasping is to arrange parts in the carrier in consistent locations and orientations, with some separation between them to permit fingers to reach around them. Sometimes, the nature of the parts permits quite dense packing with excellent uniformity. This can be achieved when parts can be made to stack fig 2.4 (3) on top of one another. Location may be provided by pins which pass through holes in the parts which may serve a functional purpose. It should be clear that material handling choices are fundamentally dependent on flow rate requirements and physical characteristics of the items being transported. Economic issues in material handling systems focus on two factors, the physical ability of the equipment to carry and deliver the payloads and the degree of flexibility needed.

2.8 Design for Change:

Change has become an increasingly important consideration in a product's life cycle. Customers needs and perceptions change, new product innovations and technology breakthroughs occur regularly, competition is constantly challenging and pushing the current products and new materials and processes are continually emerging. Change often initiates design cycle and it occurs during the design cycle because of iteration and continuing uncertainty, and may well occur as the direct result of a new product introduction.



Part cannot be stacked without skewing

Parts can be stacked with help of one fixture

Parts can be stacked without fixture but tolerence at the edges is needed

Fig 2.4 Designing for Material Handling

Like variation, change also create choas and uncompetitiveness when improperly managed or inadvertently overlooked. In a design-for-change approach, the design team seeks to make the inevitability of change compatible with the need for a stable and disruption free manufacturing environment. In most designs, the scope of design possibilities that must be considered typically diminishes as uncertainty reduced. However, at some point in the design, new needs and opportunities begin to emerge. This broadens the scope of design to include many new possibilities and generally triggers a variety of redesign activities as shown in fig 2.5 (2). Recognizing the narrowing and broadening of design scope as a natural tendency of product development. New product introduction time may be defined as the time from when a conscious managerial decision is made to provide a new competitive product to the time when the new product is accepted by customers as being satisfactory in service as shown in fig 2.6 (3). The purpose of stating new product introduction time, this way to mobilize and organize for action. A benefit of short development cycle is the business flexibility and ability to quickly respond to unexpected changes in the market and competition that it provides. In Design-for-change, the objective is minimal capital investment and timing consequences incurred due to inevitable and necessary design change. Hard-to-control factors include:

1) Changing day-to-day production, customer, and market needs.
2) Competitive pressure.
3) Availability of new technologies and materials
4) Design iteration due to continuous improvement in product and process
5) Design iteration due to uncertainty.

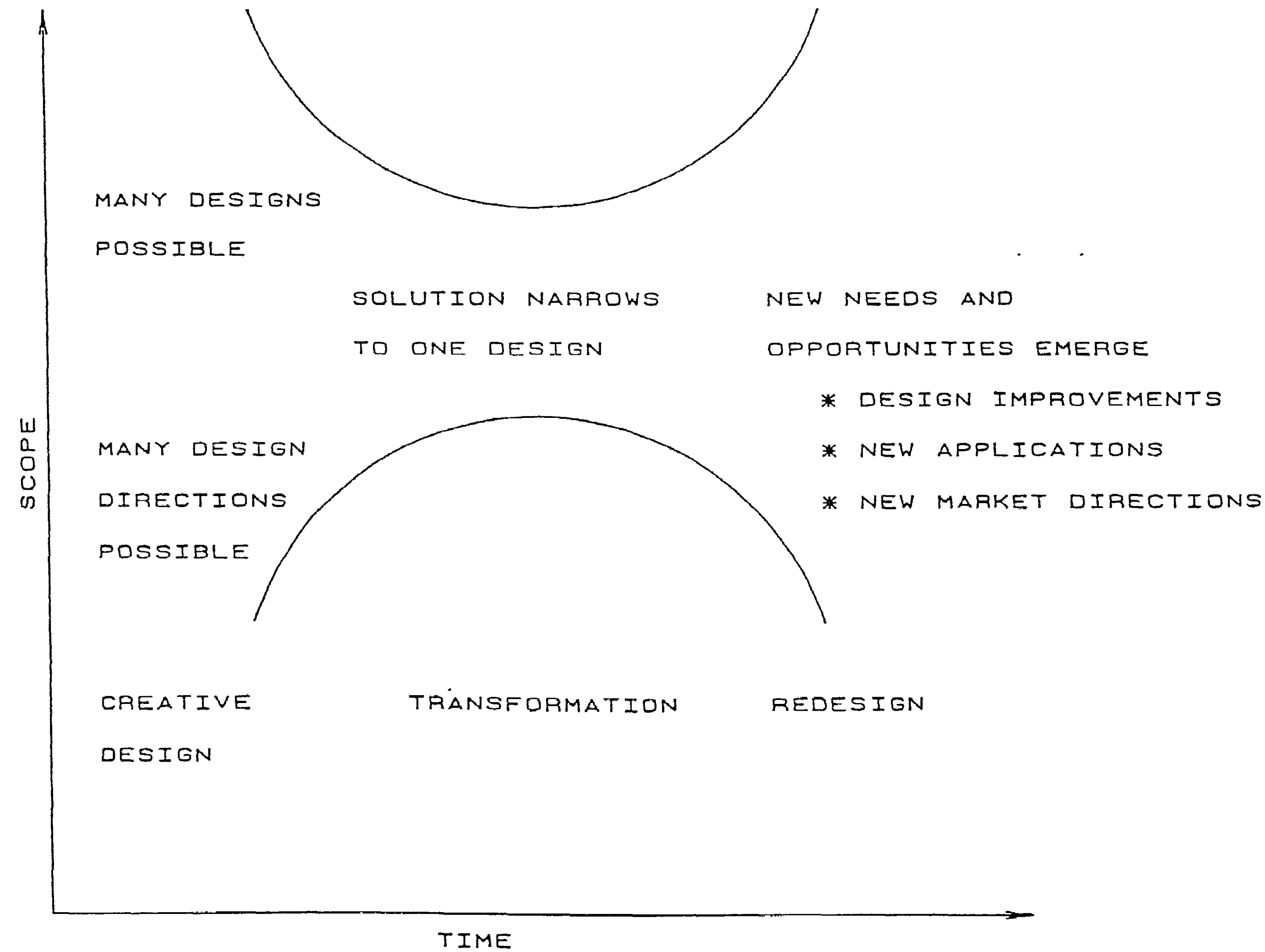


FIG 2.5 SCOPE OF DESIGN AS A FUNCTION OF TIME

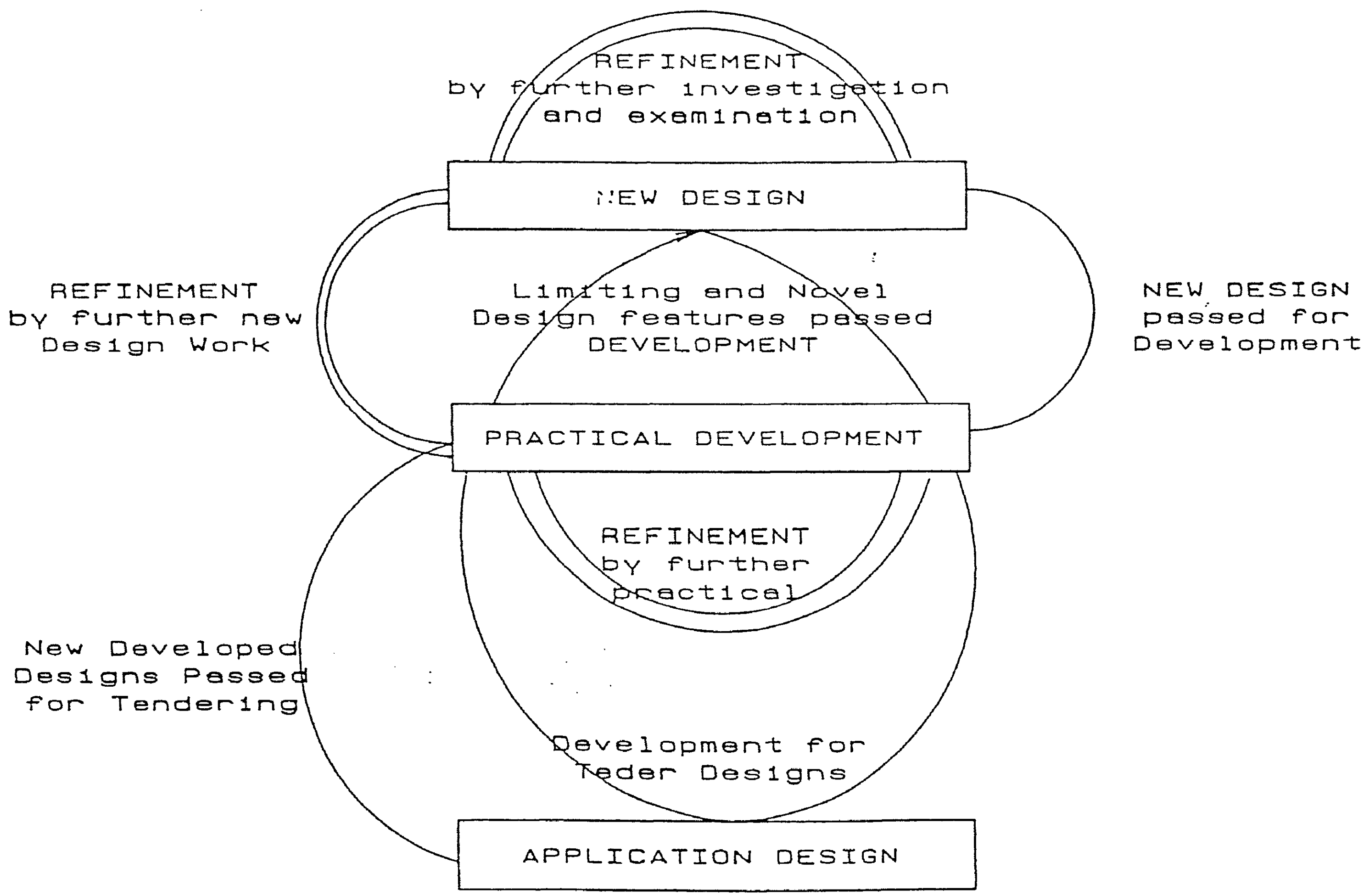


FIG 2.6 NEW PRODUCT INTRODUCTION AND DEVELOPMENT

Several strategies for designing a product and process to be robust against change appear to be possible. One of the most effective of these is standardization. Other is reverse-engineering of many successful integrated product and process designs will reveal similar underlying standardization principles which, when adhered to by the product design team, enable the flexible manufacturing philosophy to be implemented. The following simple three-step procedure can be suggested as a general approach for implementing the design for change:

1) How the following changes are going to effect the product design

a) The product may change over time

b) The change in customer needs

c) The new technologies applicable that are likely to become available

d) The changes in plan of production technology over time

e) The product or model variations planned

f) The product-process concept variations

2) Analyze the results of the evaluation and develop ideas and approaches in the design for accommodating the expected changes. Divide the design into stable "chunks" that can be combined in different ways to produce a variety of different products within a defined product family using essentially the same production facilities and tools.

3) Improve the product design and process plan according to the ideas adopted and re-analyze. Iterate until satisfied.

If the product design and process plan are fairly complete, then the procedure will help identify vulnerabilities to change. If the product and process concept is less well developed, then the procedure will help define change related design objectives and delineate concerns.

2.9 Design for Logistics:

Design for logistics is not intended to replace other design methods. Instead it is intended to sensitize designers to the influence of purchasing, stocking, delays, and lead times on the ability to produce a design as shown in fig 2.7 (3).

The height of the mushroom denotes the lead time or delay in obtaining a part after it is ordered. The width of the mushroom denotes variability between product models. If particular models are distinguished from each other by long lead time parts are used in every model so that they can be ordered well in advance. Small errors in delivery time or amount needed will not stop production of any one model. The models are distinguished by parts that have short time or so cheap that they can be stocked in large quantities with little economic penalty *(Mather, 1987)*.

2.10 Design for Assembly:

The design for assembly(DFA) method was developed by G.Boothroyd and P.Dewhurst. Based largely on industrial engineering time study methods. DFA method developed by Boothroyd and assembly seeks to minimize cost of assembly within constraints imposed by other design requirements. This is done by first reducing the number of parts and then ensuring that the remaining parts are easy to assemble. Essentially, the method is a systematic, step by step guidelines. These guidelines are the given in following page.

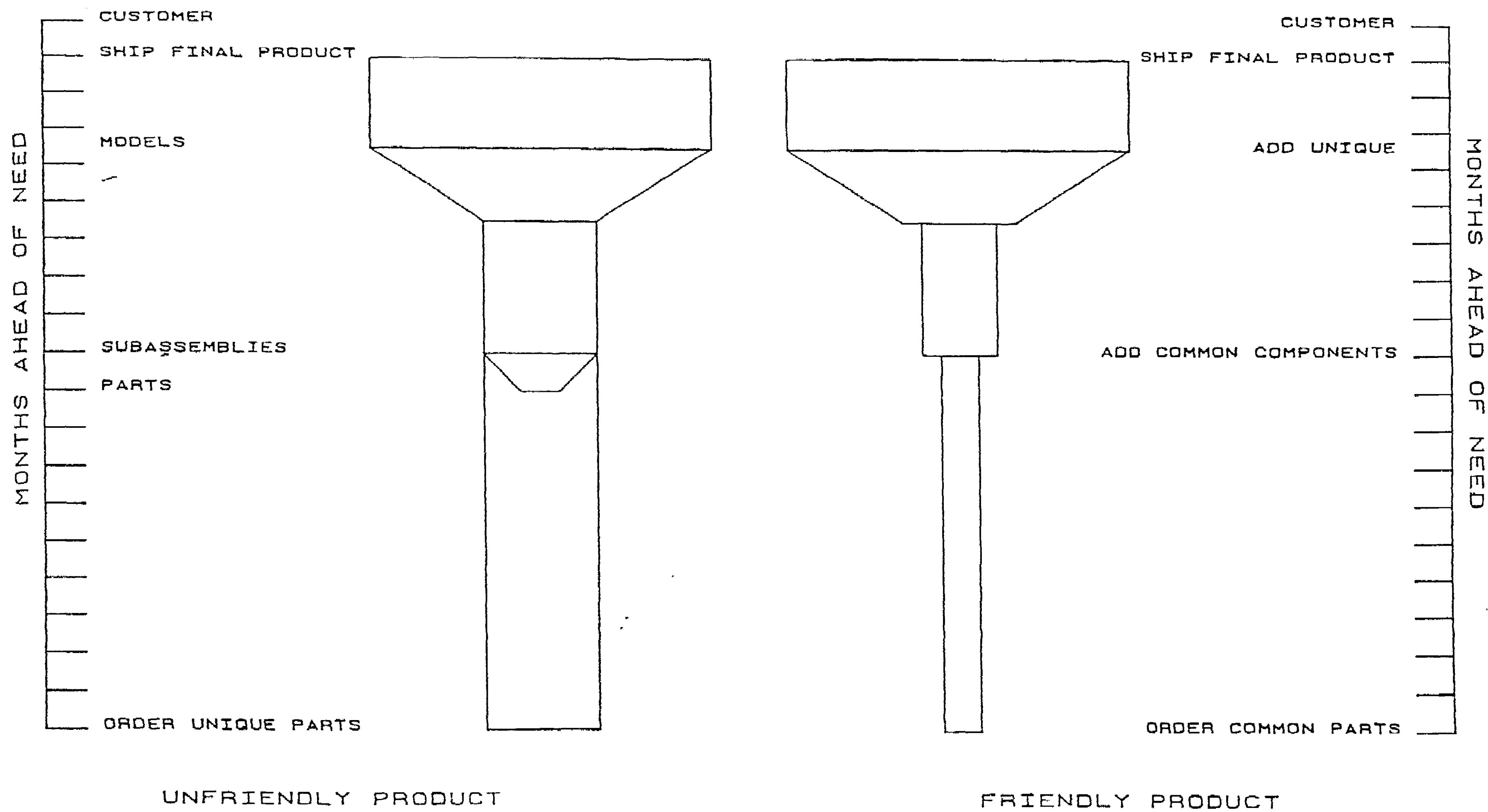


FIG 2.7 DESIGN FOR LOGISTICS

1) Design for Minimum number of parts

2) Avoid separate fasteners

3) Minimize assembly directions:; design for top-down assembly.

4) Maximize compliance; design for ease of assembly

5) Minimize handling; Design for handling and presentation.

DFA addresses the problems Until recently it was thought that manual assembly was always an option, and for many products it still is. Manual metal removal was never an option, so metal removal machinery developed early in the industrial revolution. Thus metal removal processes were among the first to be well understood. Manual assembly is rapidly disappearing as an option in high technology products because people have too much difficulty providing the required quality, uniformity, care documentation and cleanliness. This is not to say that remarkable human performance is impossible. Assembly can be used as the focussing issue for integration. Assembly is the first point in the process at which parts are put together is shown in fig 2.8 (3). Before assembly they are designed, made, handled, and inspected separately. During and after assembly, they are joined, handled, tested, and must work together. Assembly is inherently integrative *(James L. Nivens, and Daniel E.whitney 1990)*. It focuses attention on pairs, then groups, of parts. It is therefore a natural platform from which to launch an integrated attack on all the phases of a product from conception and fabrication to quality and life cycle. Decisions that affect assembly affect nearly every other aspect of production and use of a product. It is crucial to achieve this integration during the product design process because major part of the life cycle cost is determined when it is designed as shown in fig 2.9 (3). Design choices determine materials, fabrication methods, and to a lesser degree material handling options, inspection techniques, and other aspects of the production system.

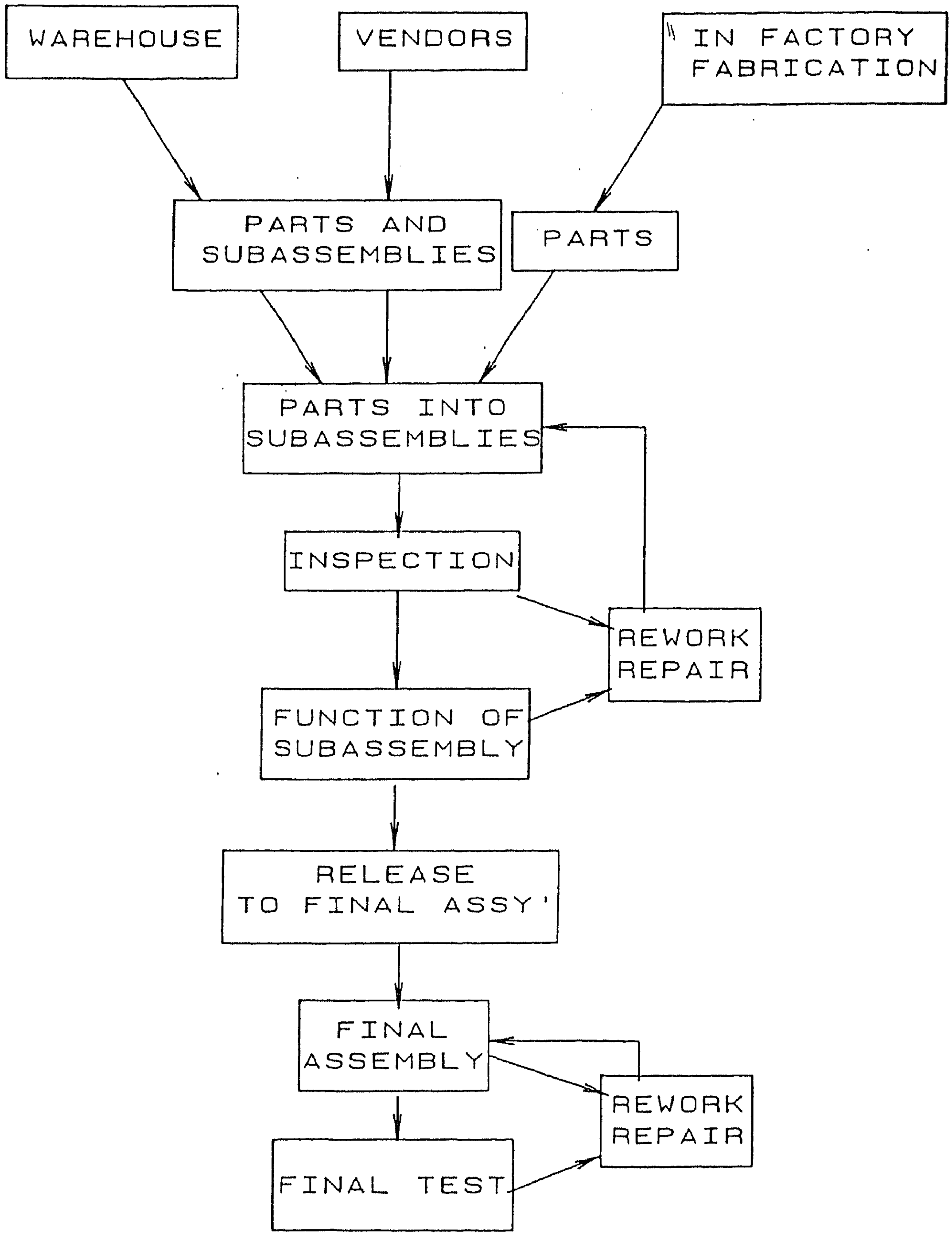


FIG 2.8 MAIN STEPS IN ASSEMBLY

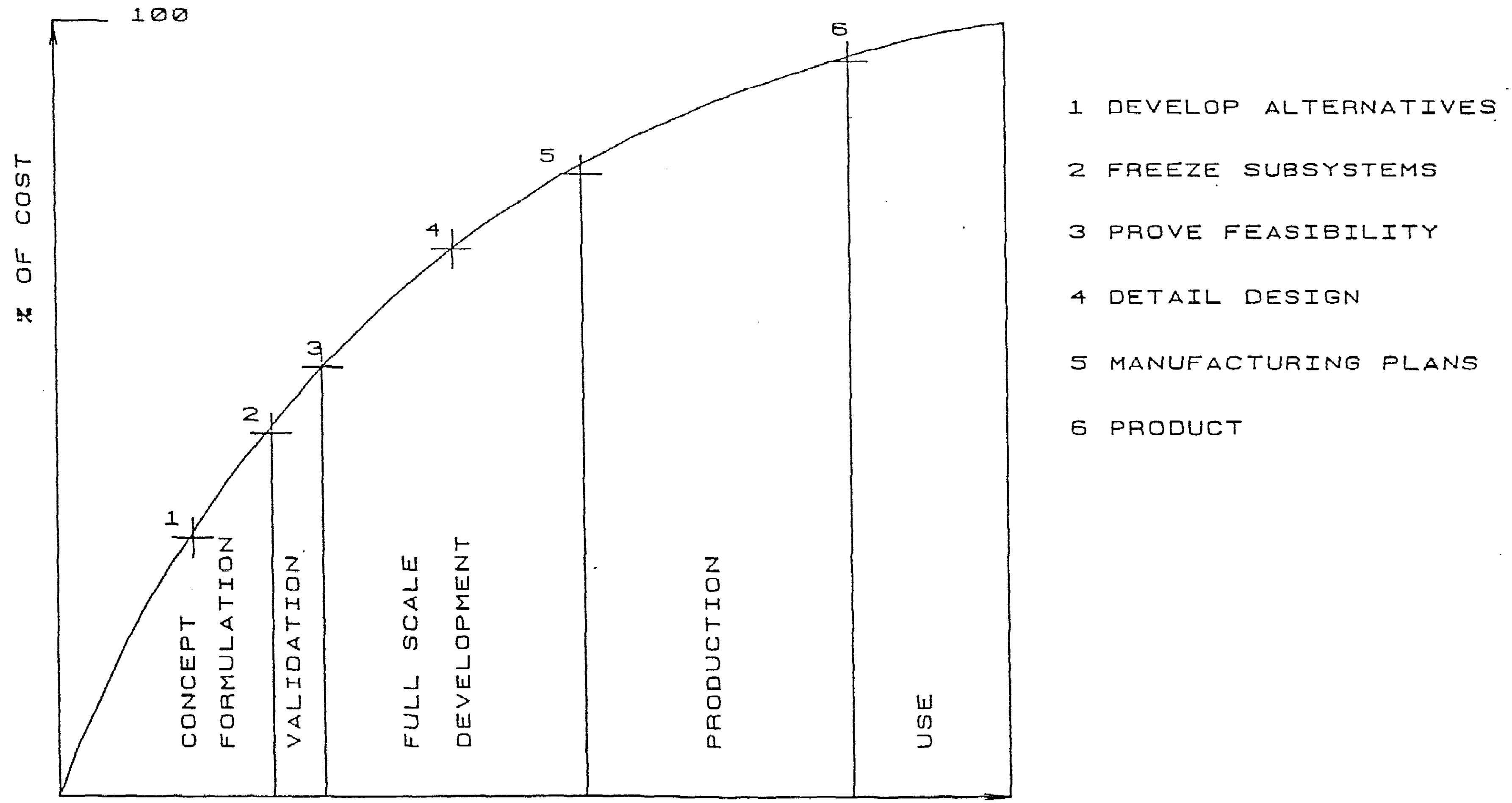


FIG 2.9 LIFE CYCLE COST OF PRODUCT

Manufacturing engineers and factory workers have very few choices and can affect only a small part of the overall cost if they are presented with a finished design that does not reflect their concerns. To make a product easier to assemble might make its parts cost too much. The design for Assembly method was developed by Boothroyd and Dewhurst which seeks to minimize cost of assembly within constraints imposed by other design requirements. This is done first by reducing the number of parts and then ensuring that the remaining parts are easy to assemble. Essentially the method is systematic, step-by-step implementation of aspects of the eliminate, simplify, and standardize approach.

CHAPTER 3

DESIGN FOR MANUFACTURABILITY

Once upon a time there was a world of engineering that changed only slowly. Product models remained unchanged for ten to fifteen years. Engineering was simpler, everyone understood the manufacturing process, standard parts were purchased from the supplier across town, and the materials choices were the standard steels. The engineering force was small and everyone knew and trusted everyone else. Communications freely flowed between design and manufacturing. But days were hectic; keeping the parts list on three by five cards, being sure there was a ninety day supply of raw materials and purchased parts on hand, process sheets lettered by hand, trying to find a batch of small parts in the warehouse, and blueprints to be make from inked drawings.

We now have a host of new manufacturing technologies, an abundance of new materials, parts lists sorted and printed by computers, drawings stored as 0's and 1's, and reports sent to the other side of the world in seconds. Along with these advances have come new ways of doing business, monthly profit reviews, a choice of assembly locations from around the globe, customer markets that appear around new products and grow to a peak in months, only to be replaced the next year with a higher function and lower cost model. New technologies that have wiped entire old product lines from the markets and in many instances, wiped out the companies also.

During this period the tools of the engineer have changed from the sliderule to 3-D color graphics. At the engineers fingertips is a calculating power more than that available to even the best computing centers of a few years ago. Costs are assigned to each step of the automated product production, using accounting procedures that track costs daily. In a few years manufacturing engineering has made many plants change more than they changed in the last generation. Research words of just a few years ago now appear on the manufacturing floor. Design engineering may have moved to a new building across town. Design engineers no longer stop by the assembly line to talk to manufacturing engineers. Parts lists are printed in seconds, without anyone thinking about each entry. Everyone becomes a specialist; at computer software for material planning, using the CAD system for finite element analysis, or programming the new robot to assemble the next product. Current engineering organization and management is well behind the magnitude of the change in manufacturing process and new power of the computer and information tools we use daily. Design process improvements focus on developing and implementing effective procedures and methodologies for design. Achieving a disciplined design procedures can be largely a matter of taking the time to clearly understand the activities involved in performing design and rationalization of these activities into a step-by-step procedure which makes sense in light of the Design For Manufacturing(DFM) philosophy. Activities that are needed or have marginal value are eliminated; those that are deemed important are simplified and streamlined.

3.1 Concepts of DFM:

Design solutions are arrived at by making choices between a variety of possible alternatives. Problems of design, therefore, seldom have one unique answer. Often, the design solution that is eventually evolved depends on the way the problem is defined. The evolutionary nature of design is very influential. Once a manufacturing approach is found that works, no one wants to tamper with it. The strongest determinant affecting the choices that are made is the culture, experience, availability of material and product knowledge and process of manufacturing. Given the same problem to different designers, they are likely arrive relatively different solutions depending upon how each chooses to interpret the problem and on methodologies, procedures and process of design that are followed. These considerations lead to the following:

1. In general, many different solutions to a design problem are possible.
2. The solution that is chosen may be selected for one or a combination of many right and wrong reasons.
3. Unlike the scientific method, the design process provides no intrinsic guarantee that the selected solution is, in fact, the best solution or event the right solution.

These observations raise a fundamental question of design. If many different design solutions are possible, which one is the best?. Design for manufacturability attacks this question. By superimposing manufacturing and other life-cycle process requirements on the functional requirements, the feasible design region is reduced to include only a small portion of the initial choices as shown in fig 3.1 (4). Because the narrowed region of design choices is relatively small, the best design can generally found quickly. And, because all needs are included, the best functional design will usually also turn out to be the design that is easiest to manufacture. Design iteration can be modeled as an iterative activity of generating and evaluating candidate designs as shown in fig 3.2 (2).

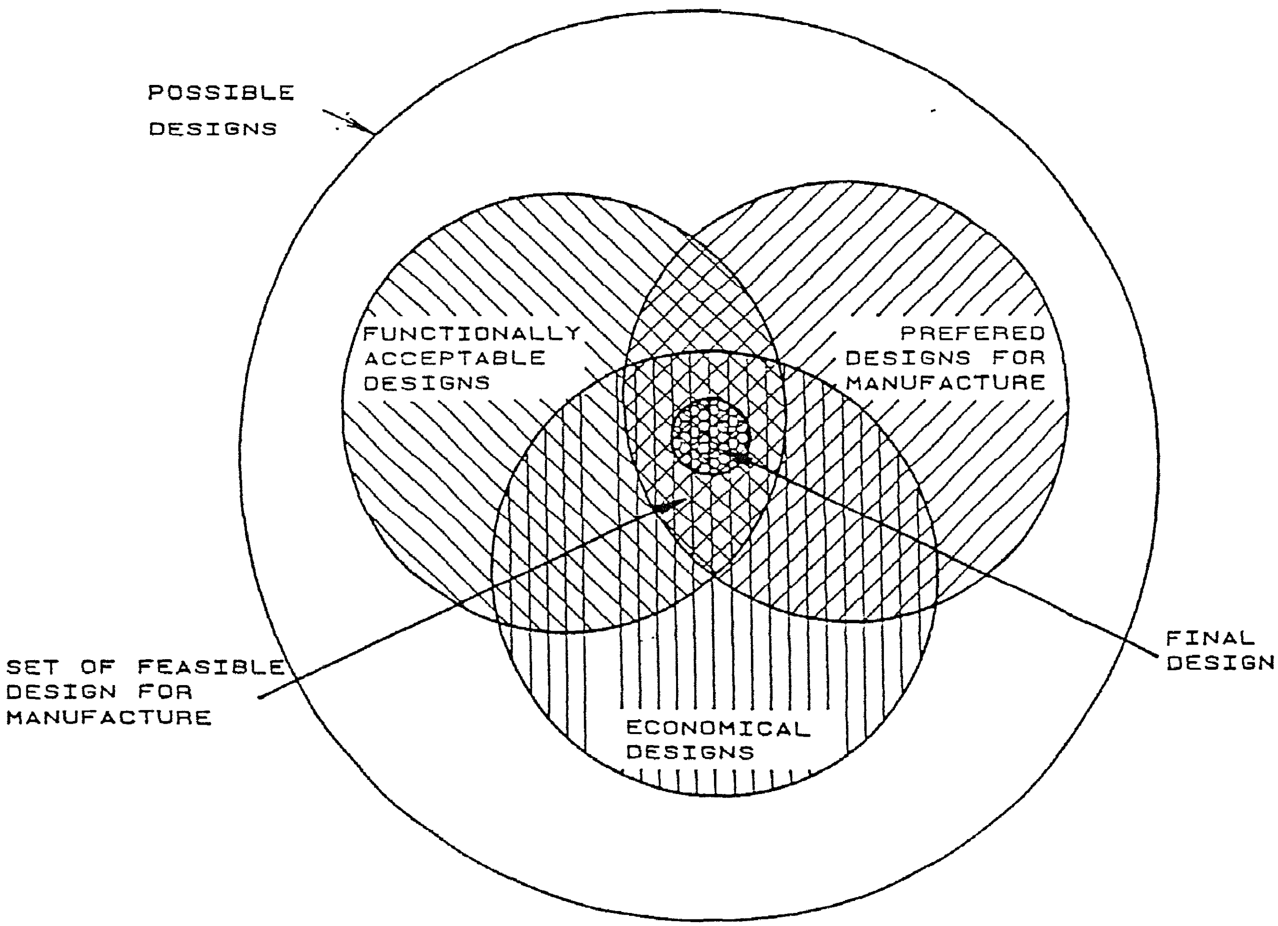


FIG 3.1 DFM RAPIDLY NARROWS THE FIELD TO BEST

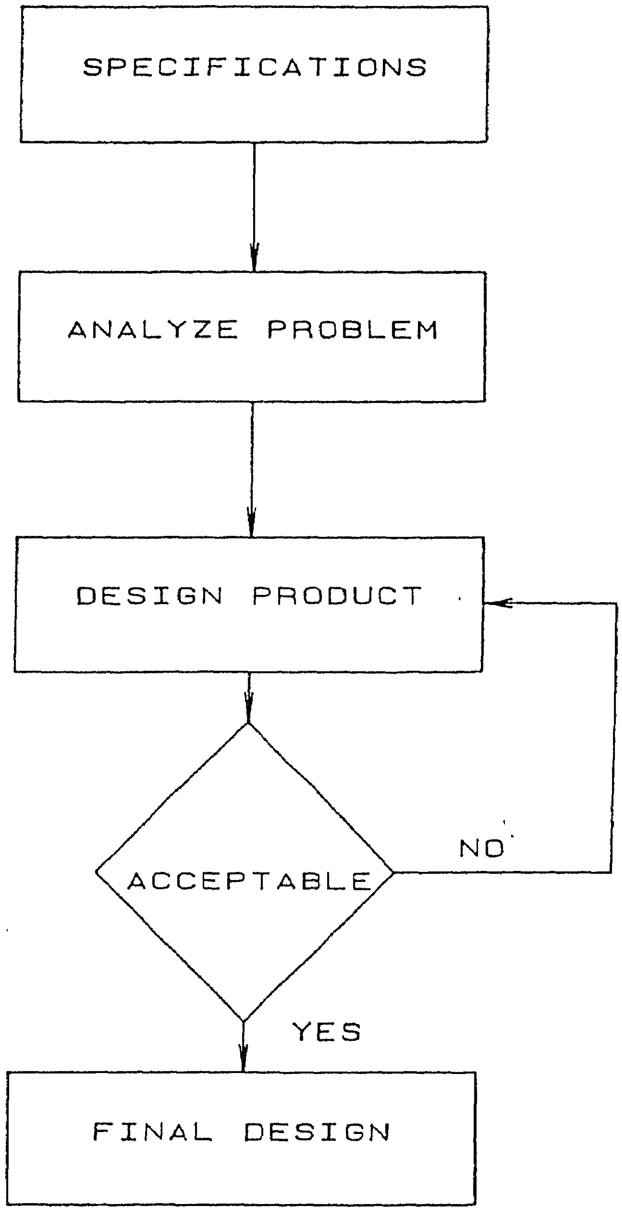


FIG 3.2 INTERACTIVE PROCESS OF DESIGN

The process begins with a design specification being given to the designer. Using both general and specific information about the design problem, together with past experience, the designer first analyzes the problem to find the best way to approach the design and then generates an initial design. The designer then evaluates this candidate design using the available engineering method. Based on this designer makes a judgement regarding the acceptability of the design. If the candidate design is unacceptable in one or more ways, the designer alters the design in an attempt to correct the identified failings, this is called redesign. The new design is then evaluated and process is repeated until acceptable design is found.

Basic Concepts:

Design represents a progression over time from the abstract to the concrete. The activities involved in this progression can often be divided into a time sequence phases. As part of the each phase many questions must be resolved and technical and economical decisions made. These decisions generally require a great deal of information and the quality of such decisions often depends directly upon the completeness, correctness, and availability of the information. If the required information is not available, the designer makes a decision and at a later date as more information becomes available. As time to design increases, the uncertainty is reduced through a series of iterative redesign cycles. Eventually, a particular design is selected and the detail design of individual parts is made. The detailed design of each part follows the same pattern of uncertainty reduction but on smaller scale. Many material and manufacturing process possibilties must be narrowed down to one particular material, geometry and method of manufacture jointly optimized to meet the functionality, cost and production rates specified.

3.2 DFM Approaches:

Many new and innovative design strategies and approaches become possible as the DFM philosophy becomes an integral part of a company's design practice and culture. In this section, we present a variety of ideas that build on the DFM philosophy. For the creative manager, these ideas can provide a basis for design optimization. For the design team, they offer a variety of possibilities for identifying innovative new product and manufacturing solutions and for identifying the best design possible in the least time possible.

Design for manufacture represents a new awareness of the importance of design as the first manufacturing step. It recognizes that a company cannot meet quality and cost objectives with isolated design and manufacturing engineering operations. To be competitive in today's market place requires a single engineering effort from concept to production. The essence of DFM approach is, therefore, the integration of product design and process planning into one common activity. The DFM approaches embodies certain underlying imperatives that help maintain communication between all components of the manufacturing system and permit flexibility to adapt and to modify the design during each stage of the product's realization. Chief among these is the team approach, in which all relevant components of the manufacturing system including outside suppliers are made active participants in the design effort from the start. The team approach helps ensure that total product knowledge is as complete as possible at the time each design decision is made. Other imperatives include a general attitude that resists making irreversible design decisions before they absolutely must be made and a commitment to continuous optimization of product and process.

The objective of design to manufacture approach are to identify product concept that are inherently easy to manufacture, to focus on component design for ease of manufacture and assembly, and to integrate manufacturing process design and product design to ensure the best matching of needs and requirements. Meeting these objectives requires the integration of an immense amount of diverse and complex information. This information includes not only considerations of product form, function and fabrication, but also the organizational and administrative procedures that underlie the design process and the human psychology and cognitive processes that make it possible.

Traditionally, many products have been designed by starting with functional optimization of the product design itself, followed by detail design of each part to be made by a particular product. As shown in Fig 3.3 (4) in design for Manufacturability process the progression of steps is reverse as that of traditional design approach.

3.3 Inputs for DFM:

The DFM needs three inputs beginning with a proposed product concept, a proposed process concept, and a set of design goals which include both manufacturing and product goals. Each of the activities within the DFM process as shown in fig 3.3 (4) addresses a particular aspect of the design. Optmization of product/process concept is concerned with integrating the proposed product and process plan to ensure inherent ease of manufacturer The simplification of activity focuses on component design for ease of assembly and handling. This activity can often be rapidly effective because the integrated product and process requirements and constraints help identify problem areas.

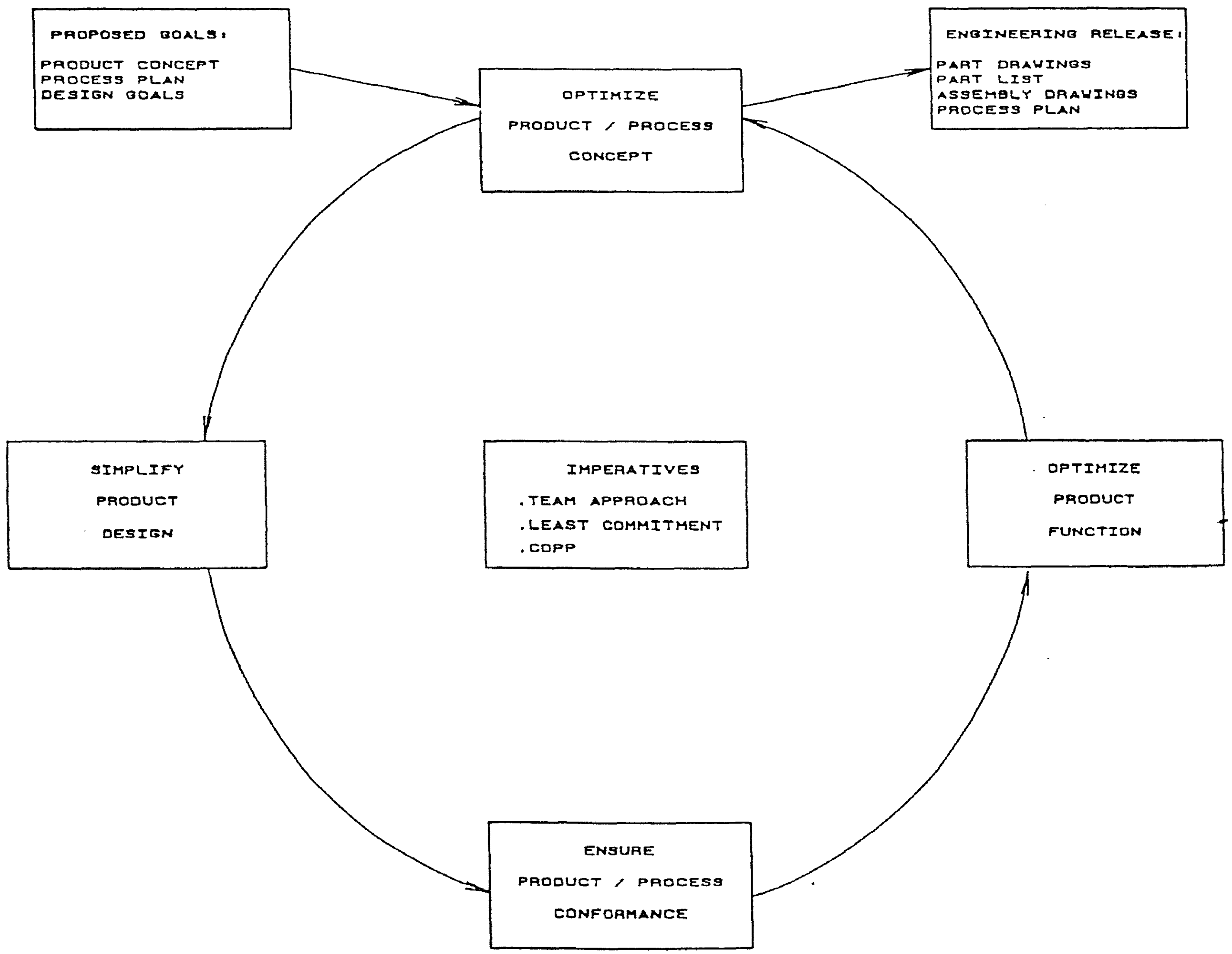


FIG 3.3 TYPICAL DFM PROCESS

The third activity ensures conformance of the design to processing needs. Functional optimization considers appropriateness of material selection and parameter specification that maximize the design objectives.

DFM approach helps ensure that all of the design constraints, including assembly, material transformation processes, and material handling requirements are included as part of the functional optimization of the design. This way the designer considers all aspects of the product's design and manufacture in the early stages of the design, so that the any design changes can be easily and cost effectively. By concurrent design, it is possible to include manufacturing recommendations and a process plan as part of the engineering release package. This leads to great advantages because it leads to less manufacturing changes. The development and use of design methods that help the design team achieve and optimized design solution is an important part of the DFM approach. Fig 3.4 (4) gives a selected list and indicates where they may fit into proposed DFM method. Use of these methods helps promote objectives of DFM by guiding the design team in creating better designs and manufacture instructions.

3.4 DFM guidelines:

DFM guidelines are systematic and codified statements of good design practice that have been empirically derived from years of design and manufacturing experience. Typically these guidelines are stated as directives that act to both stimulate creativity and show the way to good design for manufacture. If correctly followed, they should result in a product that is inherently easier to manufacture.

D F M TOOLS	D F M ACTIVITY: OPTIMIZE CONCEPT	SIMPLIFY	ENSURE PROCESS CONFORM-ANCE	OPTIMOZE PRODUCT FUNCTION
DESIGN AXIOMS	●	●	●	●
DFM GUIDELINES	●	●		
DESIGN FOR ASSEMBLY		●		
DESIGN FOR QUALITY	●			●
PROCESS DRIVEN DESIGN		●	●	
DESIGNER TOOLKIT			●	
GROUP TECHNOLOGY	●	●	●	●
F. M. E. A.	●			●
VALUE ANALYSIS				●
COMPUTER AIDED DFM	●	●	●	●

Fig 3.4 DFM Tools and Activity

Various forms of the design guidelines have been stated by different people and some of them are given below. DFM guidelines show the way, but do not replace the talent, innovation and experience of the designing team.

1) Follow axioms of design
2) Design for a minimum no. of parts
3) Standardize parts
4) Design parts for multiuse
5) Design parts for ease if fabrication
6) Design for ease of assembly
7) Minimize assembly directions
8) Evaluate assembly methods

3.5 DFM Review:

The primary purpose of the DFM review are:

1. To compare the design concepts with the initial requirements in the product design specification at a point where changes can be made most effectively
2. To compare the process design with requirement imposed by the design concepts.
3. To obtain consensus on the design approach.

Through periodic internal reviews, the team decides how many concepts to present at the DFM review to support the design direction selection. In some cases, they may want this selection to be conducted after the basic product design is done.

3.6 Elimination, standardization and simplification:

The DFM approach seeks to minimize manufacturing information content of a product design to the fullest extent possible within constraints imposed by function and performance. Although an eliminate, standardize and simplify strategy is applicable everywhere in manufacturing.

Rule 1) Minimize the total number of parts to the least parts possible without effecting the functionality of the part.

Rule 2) Simplify the design to ensure that the remaining parts are easy to fabricate, assemble, handle, and service.

Rule 3) Standardize where possible to facilitate desirable producability characteristics such as interchangeability, simplified interfaces, consolidation of parts and function, availability of components etc.

3.6.1 Elimination:

"The ideal product has a part count of one" *(Huthwaite)*. A part is a good candidate for elimination if there is no need for relative motion, no need to be separate to facilitate assembly or subsequent adjustment between parts, no need to be separate for service of repair and no fundamental reason for service or repair, and no fundamental reason for materials to be different. Perhaps the most effective way to eliminate parts is to identify a design concept or solution principle that requires few parts. Integral Design, or the consolidation of two or more parts into one, is also highly effective. Integral design reduces the amount of interfacing information required, and decrease weight and complexity. One-piece structures have no fasteners, no joints and fewer points of stress concentration, and often can be sculpted to better utilize material.

Another viable approach to part count reduction is to design multi-use or "building-block" parts that can be used interchangeably in variety of different products, product models, or applications. Multi-use parts reduce manufacturing information content by reducing the number of different part or part variations that need to be manufactured. They also produce economies of scale because of increased production volume of fewer parts and economics of scope because the same part is being used in variety of applications and products.

3.6.2 Simplification:

Simplicity of component and assembly design ensures easy fabrication, assembly, testing, and servicing. The first step in achieving a simple design is to develop a systemized product structure which standardizes relationship between product function, form, and fabrication. Once a carefully thought out and planned product structure has been formulated, a simple design configuration can often be achieved by implementing the following guidelines:

1) Minimize assembly directions and reorientations. If possible, develop a top-down manufacturing approach. i.e Z-axis assembly is very important, extra directions mean wasted time and motion, increased complexity, and added quality risk.

2) Minimize part variations such as the number of different types of sizes of screws used. Avoid any specials.

3) Avoid separate fasteners. Separate fasteners increase assembly complexity, add extra parts, and create quality risks.

4) Make parts easy to handle and orient by providing symmetry and easily identified features, by avoiding large and small sizes, and by avoiding the features that cause parts to nest, tangle, or become interlocked.

5) Eliminate or simplify adjustments when possible. Identify critical dimensions which, if not confined to a single part, require slots and other features which permit adjustment between parts. If possible, incorporate such dimensions into a single part.

6) Avoid uncertainty in the design. Use designs, components and devices which are well documented information on failure rate and derating is available.

7) Design to avoid or minimize the number of wear surfaces and rubbing parts and designs that are sensitive to hard-to-control factors.

8) Develop easy to service and maintain design. Provide sufficient hand and tool manipulation clearance for easy maintenance, adjustment, and measurement without removal of interfering components.

3.6.3 Standardization:

Standardization and rationalization is an approach which seeks to eliminate complexity and control prolification of information throughout the manufacturing system. Standardization is the reduction in the number of options used in the existing designs. Rationalization is the identification of the fewest number of options to be used in future designs.

The rationalization options are used only in new designs, no attempt is made to retrofit existing products with the rationalized components. However, where possible, low cost changes are made to existing product to eliminate unpopular options and increase the concentration of popular options.

In implementing the eliminate, Simplify, and standardize the approach it often prove useful to set "stretch" design objectives early in the design. One way of developing a realistic set of stretch goals is to carefully list the advantages and disadvantages of product design and manufacturing methods used in an existing or similar current product.

3.7 DFM toolkit:

As a company adopts and institutionalizes the DFM philosophy, design analysis tools that were originally used independently by various functions become tools for use in the concurrent engineering environment. The synergism that exists under these new conditions can change the way traditional designs and analysis methods and used, provide new application dimensions, and leverage them in ways and before considered. As shown in fig.3.4 and 3.5 in previous pages provides a list of traditional and not so traditional design and analysis tools and concepts that should be part of every design team toolkit.

A number of different DFM methodologies and tools have been discussed. All of these techniques are effective if properly implied and can produce significant improvements in product quality, cost, life-cycle. The question that arises is how to begin to do this in most effectively possible. Fig 3.5 (4) is a listing of specific advantages and appropriate applications for each methodology.

DFM is also recognizing the importance of integrated product and process design and then consciously going about design in a way that leads to a product inherently easy to manufacture and support. By superimposing life-cycle process requirements on the functional requirements of the design, many choices are narrowed down to few good choices. Using a functional requirements of a design, many choices are narrowed to a few good choices. Using a cross functional team approach accelerates the product knowledge growth and greatly expands the product knowledge base available for guiding and validating product and process design decisions. The result is shortened time to market with a higher quality, lower cost of product. both the plateau the typically develops because of the integration of various subsections and adjustments to satisfy manufacturing requirements, as well as the oscillations that occur at the end of the design cycle caused by manufacturing and assembly difficulties discovered late in the project, are avoided.

Providing disciplined anticipation that the product will be correctly designed for manufacture is the key action required by management in developing a good DFM program. Training the design team for DFM techniques such as Design for

Assembly, as well as providing a well integrated kit of DFM tools, creates awareness and sets the stage. A well thought out design process enables DFM approaches to be implemented. Setting stretch goals stimulates innovation and sends a clear message that DFM is expected. Providing an adequate budget of time and money for up-front activities, together with a design environment that facilitates easy communication, encourages and makes a well planned total design possible. Personal commitment and interest in the DFM aspects of the design on the part of the management make DFM an important part of the design project and sustains and expectations.

DFM TOOLS	IMPLEMENTATION COST AND EFFORT	TRAINING AND/OR PRACTICE	DESIGNER EFFORT	MANAGEMENT EFFORT	PRODUCT PLANNING TEAM APPROACH	RAPIDLY EFFECTIVE	STIMULATES CREATIVITY	SYSTEMATIC	QUANTITATIVE	TEACHES GOOD PRACTICE	OTHER ADVANTAGES	DISADVANTAGES	APPLICATIONS
DESIGN AXIOMS	1	2	1	1	1	1	1	2	3	1	A,B,E,F	A,B	A,B,C,D,E
DFM GUIDELINES	1	1	1	1	3	1	1	3	3	1	A,C,E,F	C	A
DESIGN FOR ASSEMBLY	2	2	3	2	2	1	1	1	1	1	A,E,H		A
DESIGN FOR QUALITY	2	3	3	3	1	2	2	1	1	2	D	B	A,B,C,D,E,F
DESIGNER'S TOOLKIT	2	3	3	1	2	3	2	1	2	2	F,G,H	E,F,G	F
COMPUTER AIDED DFM	2	2	2	1	2	2	2	2	1	2	G,H		A,B,C,E,F
GROUP TECHNOLOGY	3	2	1	3	1	3	2	2	2	3	A,D,G,H	B	A
FMEA	2	2	3	3	1	2	2	2	2	2	E,F		A,B,D
VALUE ANALYSIS	1	2	3	3	1	3	1	2	2	1	A,E		A,B,C,D,E,F
PROCESS DRIVEN DESIGN	2	2	2	1	2	2	2	1	1	1	F,G,H	E,F	C,E

KEY TO RATINGS

1 GOOD
2 AVERAGE
3 BAD

KEY TO ADVANTAGES

A Narrows range of possibilities
B Results in inherent "Robustness"
C Ready reference to "best practice"
D Emphasizes effects of variation
E Helps identify and prioritize corrective action
F Provides both guidence and evaluation
G Can shorten design cycle
H Can reduce tooling and fixturing

KEY TO APPLICATIONS

A Mechanical and eletromechanical
B Eletronic Devices
C Manufacturi and other process
D Software, instrumentation and control
E Material transformation
F Unique Manufacturing facilities ex FMS

KEY TO DISADVANTAGES

A interpretation not always simple
B Requires "buy-in" on part of user
C Exceptions are not indicated
D Rates only ease assembly not others
E Development requires experts input
F Implementation must be "designer friendly"
G Must be customized for specific application
H Requires difficult to obtain information

FIG 3.5 DFM METHODOLOGY COMPARISION

CHAPTER 4

DESIGN FOR MANUFACTURABILITY FOR ECONOMICAL PRODUCTION

4.1 Design:

The following principles, applicable virtually to all design and manufacturing processes, will aid designers in specifying components and products that can be manufactured with minimum cost.

4.1.1 Simplicity:

Other factors being equal, the product with the fewest parts, the least intricate shape, the fewest precision adjustments, and shortest manufacturing sequence will be the least costly to produce. Additionally, it will usually be the most reliable and the easiest to service.

4.1.2 Standard materials and components:

Use of widely available materials and off shelf parts enables the benefits of ·Qmass production to be realized by even low-unit-quantity products. Use of such standard components also simplifies inventory management, eases purchasing, avoids tooling and equipment investments, and speeds the manufacturing cycle.

4.1.3 Standardized design of the product itself:

When several similar product are to be produced, specify the same materials, parts, and subassemblies foe each as much as possible. This procedure will provide economies of scale for component production, simplify process control and operator training, and reduce the investment required for tooling and equipment.

4.1.4 Liberal tolerances:

Although the extra cost of producing too tight tolerances has been well documented, this fact is often not well enough appreciated by product designers. The higher costs of tight tolerances stem from factors such as a) extra operations like grinding after primary machining operations. b) higher tooling costs from greater precision needed initially when the tools are made and the more frequent and more careful maintenance needed as they wear, c) longer operating cycles. d) higher scrap and rework costs e) The need for more skilled and highly trained workers. f) Higher material costs and g) more sizable investments for precision equipment.

4.1.5 Use of most processable materials:

Use the most processable materials available as long as their functional characteristics and cost are suitable. There are often significant differences in processability between conventional material grades and those developed for easy processability. However, in the long run the most economical material is the one with the lowest combined cost of materials, processing, and warranty and service charges over the deigned life of the product.

4.1.6 Collaboration with manufacturing personnel:

The most producible designs are provided wen the designer and manufacturing personnel, particularly manufacturing engineers, work closely together from the outset.

4.1.7 Avoidance of secondary operations:

Consider the cost of operations and design in order to eliminate or simplify them whenever possible. Operation like deburring may prove expensive as the primary manufacturing operation and should be considered as the design is developed.

4.1.8 Design appropriate to the expected level of production:

The design should be suitable for a production method that is economical for the quantity forecast. This will reduce the cost of the product and manufacturing schedule can be done easily.

4.1.9 Utilizing special process characteristics:

Wise designers will learn the special capabilities of the manufacturing processes that are applicable to their products and take advantage of them. Utilizing special capabilities can eliminate many operations and the need for separate costly components.

4.1.10) Avoiding process restrictiveness:

On parts drawings, specify only final characteristics needed, not the process to be used. Allow manufacturing engineers as much latitude as possible·Hin choosing a process which produces the needed dimensions, surface finish, or other characteristics required.

4.2 Effects of Design:

4.2.1 Effects on Material Selection:

The choice of material seldom affected by the degree to which the manufacturing process is made automatic. Those materials which are most machinable, most capable, most moldable, etc., are equally favorable whether the process is manual or automatic. There are two possible exceptions to this statement 1) When production quantity are large, as is normally the case when automatic equipment is used, it may be economical to obtain special formulations and sizes of material which closely fit thew requirements of the part to be produced and which would not be justifiable if only low qualities were involved. 2) When elaborate interconnected equipment is employed it may be advisable to specify free-machining or other highly processable materials, beyond what might be normally justifiable, to ensure that the equipment runs continuously. It might be advisable to spend slightly more than normal for material if this can avoid down time for tool sharpening or replacement in an expensive multiple-machine tool.

4.2.2 Effects on Economic Production Quantities:

The types of special-purpose equipment listed above generally require significant investment. This in turn makes it necessary for production levels to be high enough so that the investment can be amortized. The equipment listed, then, is suited by and large only for mass-production applications. In return, however, it can yield considerable savings in unit costs. Saving the labor costs are the major advantage of special-purpose and automatic equipment, but there are other advantages as well: reduced work-in-process inventory, reduced tendency of damage to parts during handling, reduced throughput time for production, reduced floor space, and fewer rejects.

4.2.3 Effects on Design Recommendations:

There are few or no differences in design recommendations for products made automatically as compared to with those made with the same process under manual control. There are few limitations to automatic processes, with automatic processes an added operation, not normally justifiable, may be feasible, With this added cost consisting mainly of that required to add some element to the equipment or tooling.

4.2.4 Effects on dimensional accuracy:

Generally, special machines and tools produce with higher accuracy than general purpose equipment. This is simply a result of the higher level of precision and consistency inherent in purely machine-controlled operations compared with those that are manually controlled. Automatic feeding devices generally have little effect on the precision of components produced. They are normally more consistent than manual feeding except when parts have burrs or other minor defects.

Computer and Numerical Control:

Computer and numerically controlled equipment has other advantages for production design in addition to those noted below:

1) Lead time for producing new parts is greatly reduced. Designers can see the results of their work sooner, evaluate their designs, and incorporate necessary changes at an early stage.

2) Parts that are not economically produced by conventional methods sometimes are quite straightforward with NC or CNC. Contoured parts like cams and turbine blades are examples.

3) Computer control can optimize process conditions such as cutting feeds and speeds as the operation progresses.

4) Computer Aided Design of the product can provide data directly for control of manufacturing processes, bypassing the cost and lead time required for engineering drawings and drawings and process programming. Similarly, the process-controlling computer can provide data for the production and managerial control system.

5) Setup time greatly reduced.

To achieve these advantages, an investment in the necessary equipment is required and this can be substantial.

4.3 Material Design Recommendations:

Some general rules for minimizing materials-related costs are as follows:

1. Use commercially available mill forms so as to minimize in-factory operations.

2. Use standard shock shapes, gauges, and grades or formulations rather than specials whenever possible. Sometimes, larger or heavier sections of a standard material are less costly than smaller or thinner sections of special material.

3. Use of prefinished material as a means of saving costs for surface-finishing operations on the completed component.

4. Select material which are processable. It pays to take the time to determine which variety of the basic material is most suitable for the processing sequen8e to be used.

5. Design parts for maximum utilization of material. Make ends square or nestable with other pieces from the same shock. Avoid designs with inherently high scrap rates.

4.3.1 Simplicity:

In general, the simplest design that meets the specification would be used. The policy should always be to reduce the number of parts and make the product as small as is compatible with other requirements. The techniques of value engineering can be applied to this aspect with great effect. Sometimes, models are a useful aid to achieving to simplicity.

4.3.2 Lightness:

Unnecessary weight must be avoided if only less weight means less material and less money. Probably less material means less processing time. Company's past designs should be analyses so that realistic tagets can be set.

4.3.3 Standardization:

The use of standard parts, where possible, should be part of every company's design policy. Whenever possible, a tried and proven part should be used in a new system or as a subassembly in a new product. Non-standard parts require proving and tend to have higher production, inventory, and work-in-progress costs, as well as to create difficulties in planning and inspection. drawings should be coded, not by arbitrary piece numbers but by shape and size, so that it is easy to retrieve past designs of parts for use in new products. Similarly, preferred sizes of raw materials should be used in new designs since this encourages cost reduction by bulk buying.

There are two ways in which a design team can approach a design problem. The first and most common approach is to design the new part from scratch. The other approach is to begin with a set of existing parts and try to create the new product from these existing parts, modify them if necessary. Design standardization enables engineers throughout the company share design information more effectively. With design standardization, engineers can frequently find and reuse existing designs rather than redesigning the same part. Even when the existing designs are not exactly right, design standardization allows the engineer to locate similar designs that can be used as a starting point.

4.3.4 Flexibility:

With an entirely new design of a product such as a prime mover, design policy should lay down possible updating requirements for growth of performance. If the initial designs aims at too high an efficiency, it can lead to an inflexible product. In some cases compromises have to be made.

4.3.5 Tolerances:

Designer tend to choose their materials carefully from the points of view of availability, strength, and durability, although they may need to review the alternatives by considering the cost for the quality. But equally, tolerances must be set carefully and appropriate finishes selected. What every designer must do as a matter of policy is to select the widest possible tolerances on the trivial items and the needed tolerances on the vital. Too often costs escalate because due to tighter tolerances. and another consequence of tighter tolerance is the effect on competitive bidding. The inclusion of close tolerances on a drawing automatically reduces the number of sub-contractor, resulting the cost to be higher than need. The best policy is to ensure that drawings are prepared to good commercial practice with the minimum use of close tolerances.

4.4 Proper use of manpower:

Design policy must take account of the manpower available and whether the men have been trained for the work. More often than not, little provision is made for training or retaining. All designers concerned with project must be instructed in the complete history and requirements of the project, and there should be an acknowledged policy of ensuring that designers are taught about new techniques and tools as they become available.

CHAPTER 5

IMPLEMENTATION OF DESIGN FOR MANUFACTURABILITY PRINCIPLES

Even though the Design For Manufacturability is one of the most effective ways to improve designing, it cannot be bought or sold. Designing for Manufacturability means designing the product the best way to make it. Companies must, therefore, develop DFM plan from within to exploit their business and organizational strengths. Although initial costs for training, coordinating efforts, and computer hardware and software are high, long run costs are lower because product designs are simpler and faster to make. Justification for DFM comes from reducing cycle time, inventory, scrap and rework, and improves overall competitiveness. Management must apply support technologies to use time and resources effectively, and it must monitor them regularly to ensure their usefulness to the organization. Without adequate leadership from management and a general understanding throughout the company, however, DFM will fail. To ensure its successes, clear cut plan as the written plan as the primary preface for launching the plan and ongoing support. Its elements should apply to the appropriate levels within the organization and name key players and positions and, if possible, by name. The plan should also identify the key resources for support, including personnel, computer systems, production machines, economics. All face competition, customer demands for greater precision, and shorter delivery times. Only solution is modernizing facilities, refurbishing machine tools, and purchasing equipment such as a flexible manufacturing system.

Successful companies continuously face the challenge of designing new products that are more powerful, yet less expensive, than their predecessors. Check outside sources that take part in DFM before implementing an DFM program, which should include the following:

5.1.1 Operating Environment:

This means the company culture, quality programs, continuous improvement programs, customer and supplier involvement, and training and recruiting practices.

5.1.2 Current Practices:

Engineering and Design standards and other company policies and procedures make up current practices.

5.1.3 Computer Systems:

Key computer systems applicable to DFM include Computer Aided Design and Computer Aided Manufacturing and Computer Aided Process Planning. As shown in fig 5.1 (5) the computer aided design and manufacturing is a firm step towards the goals of design for manufacturability including time savings. While traditional design and manufacturing often proceeds in linear fashion, the DFM dictates that many tasks are performed in parallel. Facilitated by the use of CAD/CAM, DFM ensures that all tasks are coordinated and changes propagate quickly. The end result is a shorter time to market with higher quality products and all at a lower cost.

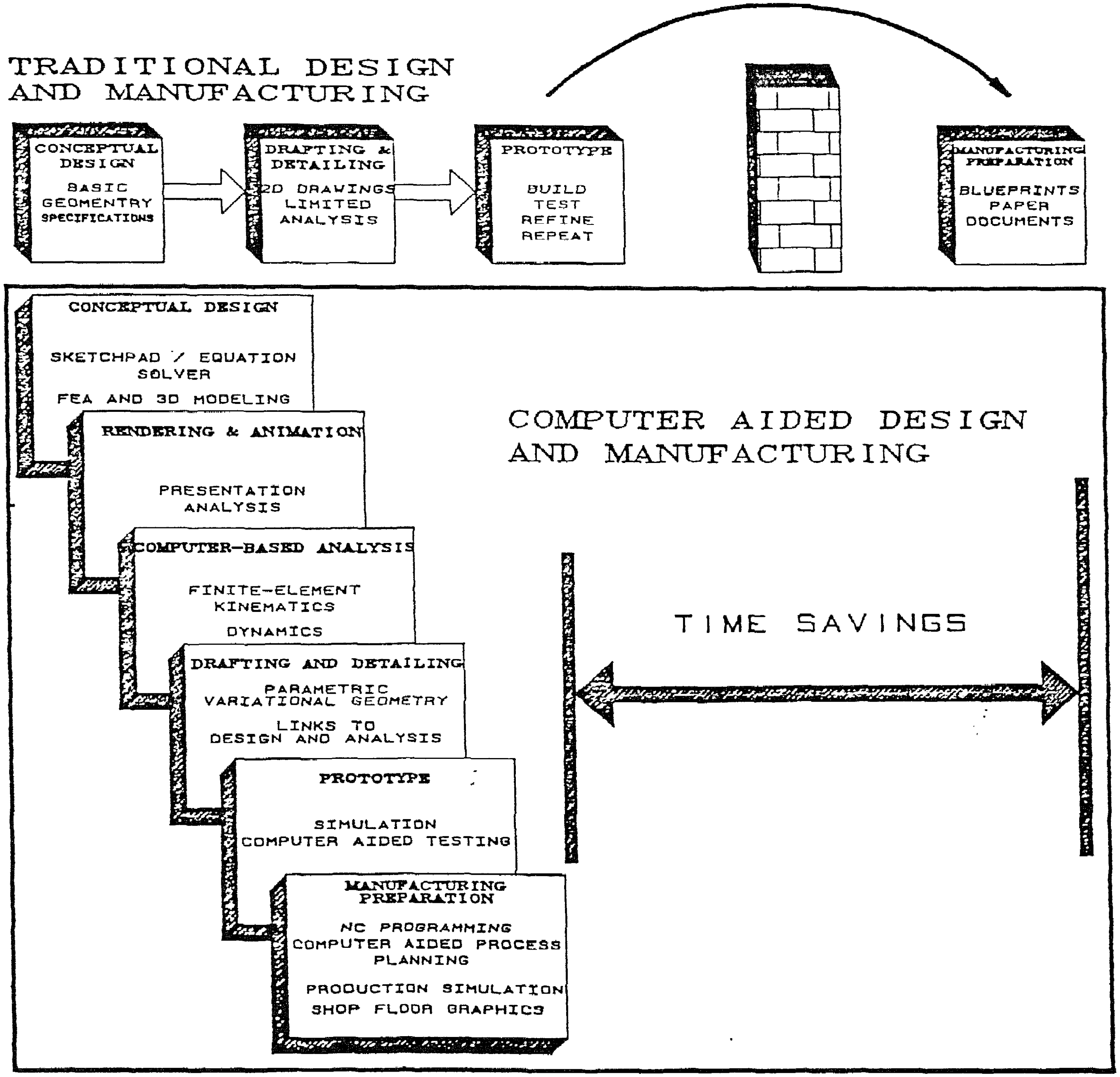


FIG 5.1 TIME SAVINGS DUE TO CAD & CAM

5.1.4 Manufacturability Technologies:

Such technologies support assessing manufacturability, standardizing product, reducing part count, simplifying designs, identifying functionally interchangeable parts, establishing robust manufacturing processes and products designs, increasing reliability, and shortening design time.

5.1.5 Design Reviews:

Appraise them according to their purpose, frequency, and perceived effectiveness. Many companies know DFM by another name, Simultaneous Engineering and tend to think of it as reviewing a Product and Process design for a particular company.

5.2 Steps to Achieve Goals

Since every business has its own unique combination of market, product mix, and manufacturing environment, customize the plan - one size does not fit all. The following are the ten steps ways in which manufacturing-oriented businesses can achieve their DFM goals.

1) Elimination
2) Simplify
3) Standardize
4) Standard Material
5) Liberal Tolerances
6) Processable Material

7) Secondary Operation

8) Preparation

9) Creating A DFM team

10) Manufacturing Involvement

11) Employee Involvement

12) Increase cost Awareness

13) Workers Arrangement

14) Key Player Recruitment

15) Offer Training

16) CAD Exploitation

17) Apply Analytical tools

5.2.1 Step 1) Elimination:

A part is a good candidate for elimination if there is no need for relative motion, no need to be separate to facilitate assembly or subsequent adjustment between parts, and no fundamental reason for materials to be different. Perhaps the most effective way to eliminate parts is to identify a design concept or solution principle that requires few parts. Integral Design, or the consolidation of two or more parts into one, is also highly effective. Integral design reduces the amount of interfacing information required, and decrease weight and complexity. One-piece structures have no fasteners, no joints and fewer points of stress concentration, and often can be sculpted to better utilize material.

Another viable approach to part count reduction is to design multi-use or "building-block" parts that can be used interchangeably in variety of different products, product models, or applications. Multi-use parts reduce manufacturing information content by reducing the number of different part or part variations that need to be manufactured. They also produce economies of scale because of increased production volume of fewer parts and economics of scope because the same part is being used in variety of applications and products.

5.2.2 Step 2) Simplification:

Simplicity of component and assembly design ensures easy fabrication, assembly, testing, and servicing. The first step in achieving a simple design is to develop a systemized product structure which standardizes relationship between product function, form, and fabrication. Once a carefully thought out and planned product structure has been formulated, a simple design configuration can often be achieved by implementing the following guidelines:

1) Minimize assembly directions and reorientations. If possible, develop a top-down manufacturing approach. i.e Z-axis assembly is very important, extra directions mean wasted time and motion, increased complexity, and added quality risk.

2) Minimize part variations such as the number of different types of sizes of screws used. Avoid any specials.

3) Avoid separate fasteners. Separate fasteners increase assembly complexity, add extra parts, and create quality risks.

4) Make parts easy to handle and orient by providing symmetry and easily identified features, by avoiding large and small sizes, and by avoiding the features that cause parts to nest, tangle, or become interlocked.

5) Eliminate or simplify adjustments when possible. Identify critical dimensions which, if not confined to a single part, require slots and other features which permit adjustment between parts. If possible, incorporate such dimensions into a single part.

6) Avoid uncertainty in the design. Use designs, components and devices which are well documented information on failure rate and derating is available.

7) Design to avoid or minimize the number of wear surfaces and rubbing parts and designs that are sensitive to hard-to-control factors.

8) Develop easy to service and maintain design. Provide sufficient hand and tool manipulation clearance for easy maintenance, adjustment, and measurement without removal of interfering components.

5.2.3 Step 3) Standardization:

Standardization and rationalization is an approach which seeks to eliminate complexity and control prolification of information throughout the manufacturing system. Standardization is the reduction in the number of options used in the existing designs. Rationalization is the identification of the fewest number of options to be used in future designs.

The rationalization options are used only in new designs, no attempt is made to retrofit existing products with the rationalized components. However, where possible, low cost changes are made to existing product to eliminate unpopular options and increase the concentration of popular options.

In implementing the eliminate, Simplify, and standardize the approach it often prove useful to set "stretch" design objectives early in the design. One way of developing a realistic set of stretch goals is to carefully list the advantages and disadvantages of product design and manufacturing methods used in an existing or similar current product.

5.2.4 step 4) Standard materials:

Use of widely available materials and off shelf parts enables the benefits of mass production to be realized by even low-unit-quantity products. Use of such standard components also simplifies inventory management, eases purchasing, avoids tooling and equipment in·estments, and speeds the manufacturing cycle.

5.2.5 Step 5) Standard design of product:

When several similar product are to be produced, specify the same materials, parts, and subassemblies foe each as much as possible. This procedure will provide economies of scale for component production, simplify process control and operator training, and reduce the investment required for tooling and equipment.

5.2.6 Step 6) Liberal tolerances:

Although the extra cost of producing too tight tolerances has been well documented, this fact is often not well enough appreciated by product designers. The higher costs of tight tolerances stem from factors such as a) extra operations like grinding after primary machining operations. b) higher tooling costs from greater precision needed initially when the tools are made and the more frequent and more careful maintenance needed as they wear, c) longer operating cycles. d) higher scrap and rework costs e) The need for more skilled and highly trained workers. f) Higher material costs and g) more sizable investments for precision equipment.

5.2.7 Step 7) Select most processable materials:

Use the most processable materials available as long as their functional characteristics and cost are suitable. There are often significant differences in processability between conventional material grades and those developed for easy processability. However, in the long run the most economical material is the one with the lowest combined cost of materials, processing, and warranty and service charges over the deigned life of the product.

5.2.8 Step 8) Preparation:

Before revealing specific objectives of the DFM Program each and every person related to the organization must understand usefulness of the DFM program and its benefits, requirements. If the tone of the program is not correctly set people will resist the change and it may lead to unexpected results. The people must understand that the DFM program represents a permanent change in the organization. Clarify weighted goals. At the initial meeting stress how DFM can simplify their jobs and explain program with specific references to the career opportunities.

5.2.9 Step 9) Create a DFM team:

At least a few members from all the departments should be made as a team. The members should be conversant to details of their departments. They should know where to begin attacking. This will effect very well when they know they understand design and Production and how these will effect the cost of the product. They should not be afraid to put forth their views and able to put hard work. Removing barriers between design and manufacturing departments. Many companies have subtle,

5.2.10 Step 10) Manufacturing Involvement:

Early involvement means providing a formal mechanism for manufacturing to work with marketing and design from the start. I· fosters a proactive rather than reactive attitude toward manufacturing opportunities. When manufacturing works with design, marketing and the customer from the beginning of the design cycle, the company can respond to customer needs better and make more orderly transactions in the prototype and design phases. If the company relies on design review to improve manufacturability. All too often, however, schedule conflicts delay them. And when marketing design, manufacturing quality, and management finally do get together, the emphasis is usually on whether the design meets customer expectations and whether the manufacturing can make it. Manufacturability design improvements are often identified too late.

5.2.11 Step 11) Employee involvement:

The more people aware of a problem, the more people available to solve it. Given the right information, design and manufacturing people will frequently devise unanticipated, novel solutions because they know their part of the business is better than anyone else, and by involvement of the employee can boost morale and interpersonal communication throughout the company, which creates the environment necessary for DFM to work.

One way to get feedback is to conduct an oral survey, in which an DFM team member identifies relevant people and them about problems in past and present products. They can be instrumental in pointing out problems often unknown to the rest of the company. By involvement of the employee often yield of critical information which will effect the product a great deal, but the employees inform only when they know somebody is listening to them.

any employees want to improve the company's competitiveness and the enthusiasm is very effective when given a chance. The program should credit not only those are feasible but all types of participation.

5.2.12 Step 12) Increase Cost Awareness:

Initial analysis can help identify the most significant problems so the organization can focus its collective effort on them first. Involve all company workers in the cost reduction program irrespective of whether involved with cost or not.

After enquiring necessary information, it needs repackaging. Presentation is critical, instead of long printout of the data present them in graphs, pie charts and par graphs make the data much easier to understand and use. Instituting a parts standardization program is one way to embark on DFM base cost reduction program. Management will appreciate the standardization program because it enhances profitability by enhances profitability by exploiting economics of scale and reducing engineering, inventory, and other costs related to special parts. But an agreement between the customer and the manufacturer is needed for standardizing.

5.2.13 Step 13) Workers Arrangement:

By placing the workers nearer increases the communication. Communication improves with daily face-to-face interaction. Direct contact stimulates all the senses, not just hearing. Some topics cannot be handled expediently or efficiently in scheduled formal meeting.

One approach is arranging departments by revenue generating program. When program ends, the people remain in their place and receive another project. Another approach brings people together from different departments to work on the new one. Once the project is finished they move to another one in another space as in aerospace industry.

5.2.14 Step 14) Key Player recruitment:

Engineering generalists - people who can handle variety - are essential to support DFM. An DFM team must balance design, manufacturing, accounting, purchasing, human resources, and management. Therefore, team members must have a strong background in the product's design, manufacture, or support. They also need strong interpersonal, general problem solving, and analytic skills, as well as an understanding of the business's goals and organizational dynamics. A good way to assemble the team is to look for qualified workers in the company. Welcome creative thinking and experience, and they should be able to influence others and tolerate significant changes in their responsibility.

5.2.15 Step 15) Offer Training:

Train key employees in recognizing and solving problems and in improving interpersonal skills. Training is best done at the company itself and should also consider the professional societies. Train them in not only do and don't checklist but beyond it. Good product designs come from tradeoffs between product performance and total cost. t8aining should include manufacturability measurement to justify manufacturability studies and analytic tools.

Along with manufacturability measurement topics must include quality philosophy, problem solving, group technology, value analysis and engineering, solid modeling, and continuous improvement. Because job rotation exposes people to the needs of other, it can supply considerable training to support DFM. Let DFM personnel work with Sales, Quality, Product Engineering, Purchasing, Inventory, and manufacturing.

5.2.16 Step 16) CAD Exploitation:

CAD can support many communication and information needs during the proposal development phases. It displays, Bill of Material and contains the master product files, and giving more people access to the product design and information regarding the product. They also can give routing, tooling, and reference information.

5.2.17 Step 17) Apply analytical tools:

The need for timely manufacturability feedback poses major problems for product designers. First, maintaining the database relevant to the manufacturing environment can be difficult. Second although the product designers need the information, they have usually have little manufacturing background. Finally, a manufacturability evaluation must provide feedback early enough to influence the design before its too late to change it. So a list of critical designs and manufacturing factors can be effective analytical tool.

The guidelines could be Color coding and identifying for purpose of fasteners to simplifying the product. design. Boothroyd and Dewhurst developed the most widely used manufacturability technique to improve product design when assembly contribute significantly to total cost. This technique determines the minimum number of parts for an assembled unit and how to design them to improve assembly. We need new guidelines, however, to handle cases where a product's assembly cost is low compared with total cost. Statistical methods lessen product variation and reduce scrap, rework, and warranty expense. Experimental design techniques with sensitivity analyses can evaluate both products and processes.

Many expert system shells address the manufacturability issue. With the right and complete knowledge base, a computer can evaluate manufacturability of conceptual product designs.

If the people involved with the DFM program not understood its tone correctly it may lead to unexpected consequences. Explain the program's goals at a formal launch meeting. Clarify weighted goals like shorter cycle time, lower manufacturing unit cost, and reduced manufacturing variability. And describe methods for quantifying and reporting improvements for current policies and practices. DFM programs must avoid pitfalls like these:

5.3 Pitfalls in Implementation of DFM:

5.3.1 Complex coordination of the activities of many departments:

The organization should move toward program driven responsibilities for the DFM team and away from traditional job descriptions. Coordination involving dividing responsibilities into prototype material procurement, manufacturability, conformance testing, program scheduling, proposals to customers, and product supportability. This promotes flexibility in job assignments and often results in increased productivity.

5.3.2 No one owning the program:

Program ownership comes from involvement in developing goals, resources, and a timetable. Goals that are unclear, unrealistic, or too numerous can make implementation and monitoring impossible. If key people wait to participate until others make major decisions, their sense of ownership will be minimal. Programs falter without a consensus about their outcomes. A program must set specific priorities to avoid false starts and prevent diluting its effectiveness.

5.3.3 Fear of reprimand:

Employees will not take risks when there is no potential for reward. The fear of reprimand is not addressable at the worker level because it is a function of the perceived company culture and management's boldness and leadership. The best way for management's boldness and leadership. The best way to stimulate a DFM team's creativeness and willingness to question the status quo is to set pace: set its boldness and support employees who unafraid of breaking away from the pack.

Results from an DFM Program are complex and far reaching. Fortunately, most people understand the basic idea and are not afraid of the concept. Once implemented it will give good results and change present design procedures very much.

The design situation is a complex array of diverse and often contradictory human activities and technological issues that differ with each problem and continually change and evolve during the realization of the design. Design is open minded, with many solutions possible and the final solution possible and the final result determined largely by the way and extent to which the design problem is understood and by the process with which it is solved. The increased complexity of the modern information age, the continual need for change, and the constant emergence of new material and technology are placing ever increasing demands on proper and complete understanding of the design problem and on the broad spectrum of needs to be met by the design process.

The DFM process as shown in fig 5.2 (4) and associated DFM methodologies explained in previous chapters and table 5.1 help the design team deal more effectively with these demands. DFM helps improve quality of early design decisions. Design decisions, especially those made early in a design project, have a tremendous impact on the life-cycle cost of the product. Early quality decisions can ensure business success by enabling the production of better performing, reliable and robust products with improved cost and, quality and productivity.

FIG 5.2 DESIGN PROCESS

DFM TOOL	METHOD	REMARKS
Design for assembly	Systematic method for simplifying a design by reducing the number of parts and ensuring that the remaining parts are easy to ass-emble.	Rapidly effective and easy to learn. DFA is easiest starting point for DFM.
Computer aided DFM	Computer based tools which help integrate product and process. Includes a variety of tools ranging from va-riation simulation an-alysis to solid model-ing and design with feature techniques.	Saves time and can simplify effort. Faci-litates "what if" opt-imization. Fosters team building.
Value engineering	Systematic application of recognized techniq-ues which identify fu-nction,establish value for the function, and provide the necessary function at the lowest overall cost	Offers an organized approach to assesment of cost impact of design decisions
Design for quality	Seeks to define a rob-ust combination of de-sign parameter values through use of fracti-onal factorial designs and orthogonal arrays.	Based on powerful qua-lity engineering conce pts. Moves quality in-to design stage.
Statistical process con-trol	Use of Satistical mon-itoring and control techniques to achieve desired outgoing qual-ity in products.	Helps to surface prod-uct design problems and to guide tolerenc-ing and other product design practices.
Group Techn-ology	A technique for exploi ting the sameness or similarity or parts based on their geomet-rical shape and simil-arities in their prod-uction process.	Facilitates standardi-zation and rationaliz-ation. Attacks part prolification and save design time.
Failure mode and effect analysis	A methodical way of studying the cause and effects of failure be-fore design is final	Helps prevent failures and defects from occur ing and reaching cust-omer

TABLE 5.1 DESIGN FOR MANUFACTURABILITY

DFM is recognized as key to minimizing life cycle cost and design team, assuring product quality, eliminating "over the wall to manufacturing" mentality, and realizing the productivity increase promised by advanced manufacturing technology. For many companies, the DFM approach can ultimately lead to the innovative product and process solutions needed for a measurable competitive edge and a healthy balance sheet.

CHAPTER 6

DFM FOR GEAR DESIGN

Gears are machine elements which transmit angular motion and power by the successive engagement of teeth on their periphery. They constitute an economical method for such transmission, particularly if power levels or accuracy requirements are high.

6.1 Applications:

Gears are useful when the following kinds of power or motion transmission are required

1) A change in speed of rotation
2) A multiplication or division of torque or magnitude of rotation
3) A change in the direction of rotation
4) Conversion from rotational to linear motion or vice versa
5) An offset or change in the angular orientation of the rotating motion.

Power-transmission gears are normally of coarse pitch and can be very large. Power-plant gears as large as 24 ft have been made. They can transmit tens of thousands of horsepower. Contrast with these are fine-pitch miniature instrument and watch gears as small as 0.08 in pitch diameter. Normally, these small gears transmit motion only the power they transmit is negligible.

Gears of 20 diametral pitch or coarser are classified as coarse-pitch gears. Fine-pitch gears are those with a diametral pitch greater than 20. The usual maximum fineness is 120 diametral pitch. However, involute-tooth gears can be fabricated with diametral pitches as fine as 200 and cycloidal-tooth gears with diametral pitch to 350.

Other typical gear applications are automotive transmission, differentials, and steering mechanisms, small appliances and instruments of various kinds.

6.2 Gear Types:

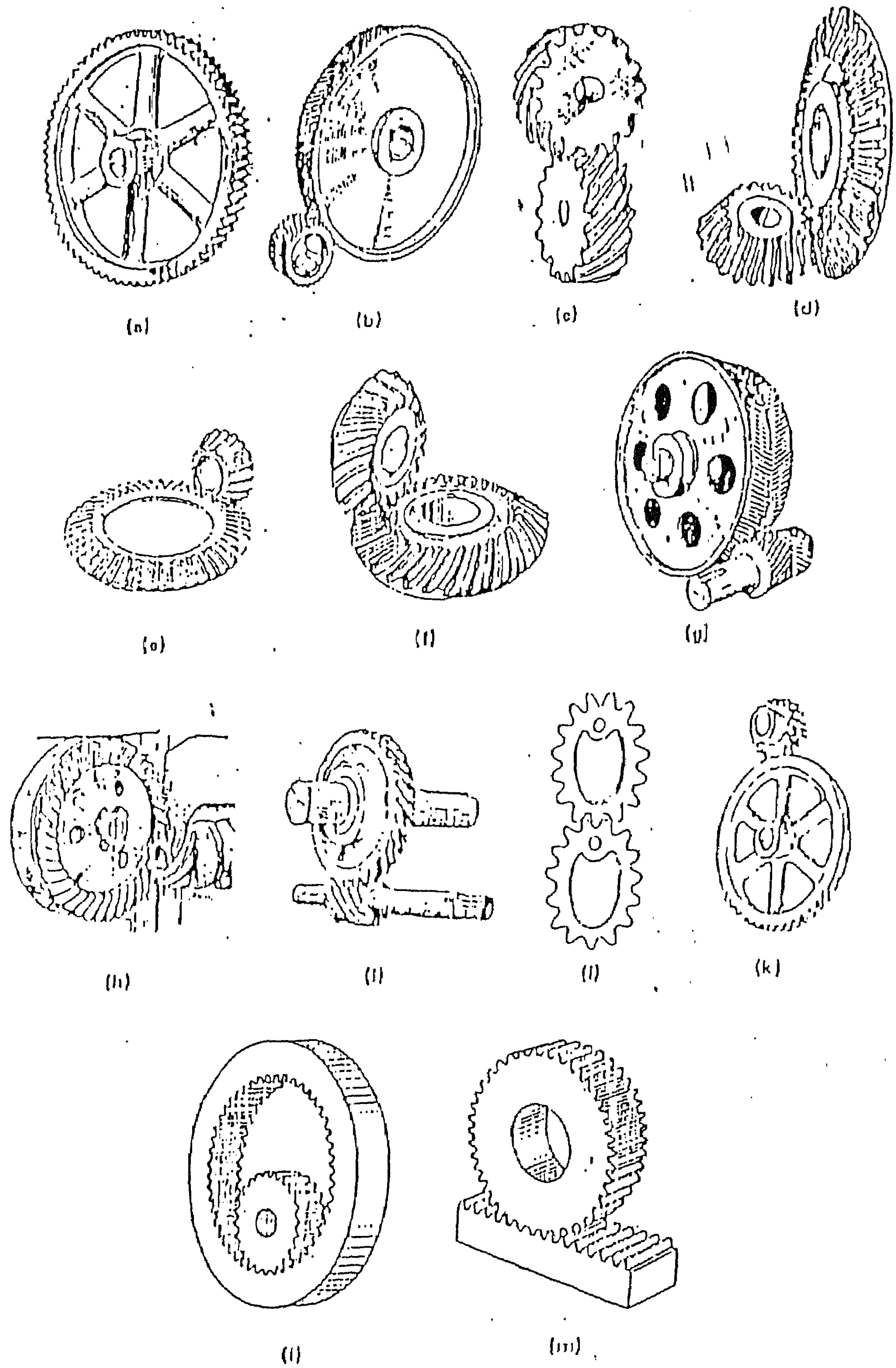
Various types of gears shown in fig 6.1 (6) and can be described as follows:

Spur Gear: These are the most economical to manufacture. Their overall shape is cylindrical, and teeth are parallel to the axis of rotation. Axes of mating gears also parallel.

Helical Gears: These also have a cylindrical shape but the teeth are set at an angle to the axis. This provides smoother and quieter action but somewhat reduces the straight-forwardness of manufacturing operations. Helical gears may be run on nonparallel axes. When the axes are at right angles, the gears may be run on nonparallel axes. When the axes are at right angles, the gears are known as Crossed helical Gears.

Herringbone Gears: These gears are double helical gears. Both right-hand and left-hand helix angles exist side by side across the face of the gear. Thus, axial thrust from helical teeth is neutralized.

Internal Gears: These have teeth on the inside surface of a hollow cylinder.



(a) Spur Gear
(b) Parallel Helical Gears
(c) Crossed Helical Gears
(d) Straight Bevel Gears
(e) Zero Bevel Gears
(f) Spiral Bevel Gears
(g) Herringbone Gears
(h) Hypoid Gears
(i) Worm Gears
(j) Elliptical Gears
(k) Intermittent Gears
(l) Internal Gears
(m) Rack and Pinion

Fig 6.1 Kinds of Gears

Rack Gears: These have gears on a flat surface instead of on a curved surface, They provide straight-line instead of rotary motion.

Bevel Gears: These have teeth on a conical surface and operate on axes which intersect, usually at right angles. Because the teeth are tapered, bevel gears are more difficult to produce than helical, spur or rack gears.

Spiral Bevel Gears: Theses bevel gears which have teeth that are curved and oblique to any plane passing through the axis. They have the advantages of quietness and smoothness as helical gears. Spiral bevel gears are more difficult to manufacture than straight bevel gears. The negative draft of the back side of gear teeth complicates molding and forming processes.

6.3 Elements of Gear:

Gear elements and key dimensions are shown in fig 6.2 (7) Diametral Pitch is a measure of the coarseness of the gear. It is equal to phi divided by the circular pitch in inches. For any gear it is the ratio of the number of teeth to its pitch diameter.

6.4 Machining :

The variety of machining process used in the manufacture of gears includes milling, hobbing, shaping, Broaching, shear cutting, and several specialized processes as primary machining methods. Shaving, Griding are used as refining operation to improve accuracy and surface finish

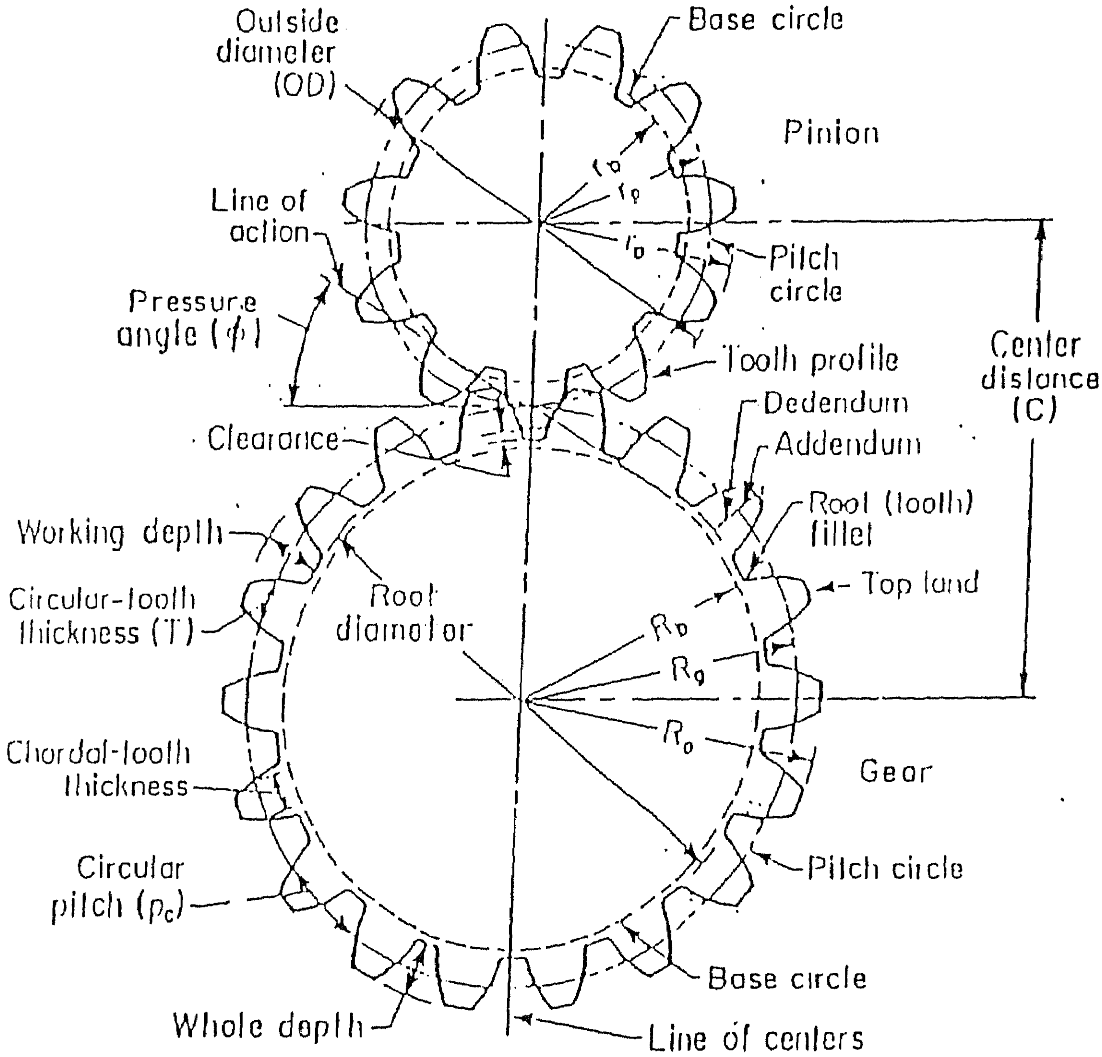


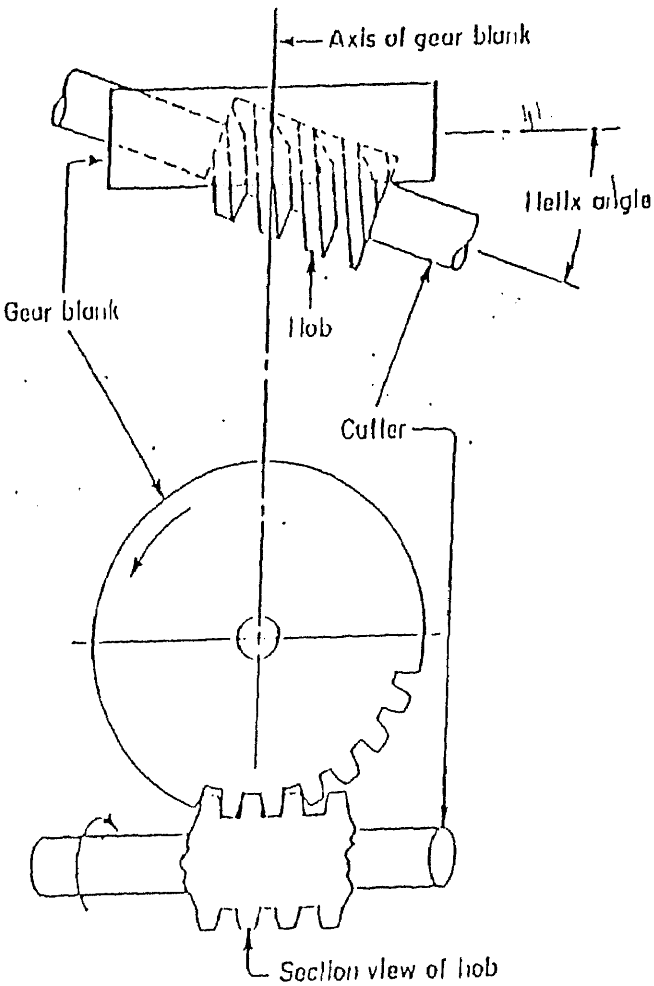
Fig 6.2 Gear Elements and Key Dimensions

6.4.1 Milling:

A milling cutter with teeth ground to the shape of the gear-tooth spacing is fed across the gear blank. After each tooth space is cut, the cutter is returned to its starting position, the blank is indexed, and the cycle is repeated. Tooth spaces are machined one at a time. the blank is stationed one at a time. The blank is stationary during the cutting cycle. Indexing of the blank between cutting cycles may be manual or automatic, depending on the degree of sophistication of the milling machine. Gear milling can apply to both roughing and finishing operation although the latter is less common because of accuracy limitations. For the same reasons and because other methods are more rapid, gear milling is normally confined to replacement-gear making or low-quantity production. Milling cutter are less costly than hobs and other types of cutters. Spur, helical, and straight bevel gears are machined by gear milling. Bevel gears require two passes because of tooth tear. Spiral bevel gears are preferable for gear milling. Internal gears can, in some cases, be cut by milling machines.

6.4.2 Hobbing:

Hobbing is a generated process. As shown in fig 6.3 (8) a spindle carrying a gear blank is geared to second spindle carrying a rotating hob(cutting tool) at approximately right angles to the blank. The hob is similar in appearance to worm gear but has gashes to form cutting edges. The hob is similar in appearance to a worm gear but has gashes to form cutting edges.



Gear Hobbing

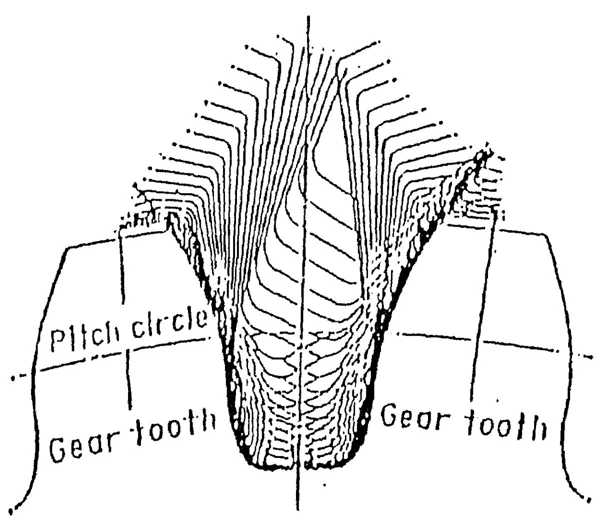


Fig 6.3 Generating action of Hob cutting Tooth

The hob, if it has a singe pitch, makes one revolution for each tooth of the workpiece, and as two rotate continuously, the hob is fed parallel to the face of the gear tooth. The hob tooth are helical, and when a spur gear is machined, the hod axis is inclined from the particular position by the helix angle of the hob.

Hobbing is used to produce spur, helical, and worm gears and worms but no bevel or internal gears. Production rates are high. Though hobbing is most economical at medium and high rates of production, its accuracy, versatility, and ease of setup makes it adaptable to low-quantity production also. Though more expensive than milling and shape cutters, gear hobs are cheaper than shear cutters and gear broaches.

6.4.3 Shaping:

Shaping is also a generating method. A cutting tool resembling a gear is mounted on a spindle parallel to the axis of the gear to be cut. The blank and cutter are geared together, and as they slowly rotate, the cutter reciprocates in an axial direction and generates the teeth of the gear in successive cuts. The gear like cutter is slightly tapered to allow a Clarence angle on the sides of the cutting teeth Cutting occurs on the downward stroke. On the upward stroke, the cutter and the work are moved apart to prevent the cutter from rubbing against the work. When helical gears are to be cut, a guide which procedures a helical motion in the cutter spindle is provided. A separate guide is required for each helix angle, and the amount of the helix is limited.

Shaping can be used to produce both internal and external spur and helical gears. Bevel gears are not produced by this method. However, herringbone and face gears are machinable by shaping. Shaping is also well to the machining of gears that are located close to obstructing surfaces or in a cluster since the clearance required for cutter overtravel is much less than with hobbing or milling. Since tooling is relatively inexpensive. Shaping can be used for low-quantity production. However, because it can be made automatic, it is used at moderate and high production levels as well even though it is not as rapid hobbing.

6.4.4 Broaching:

Broaching is a useful machining method for gears, especially when productions runs are large. Both internal and external spur and helical gears can be broached, although internal gears are the more, especially if large, require bulky and expensive broaching tools.

Fine finishes and high accuracy levels are possible with broaching. Gears are usually completely machined in one pass, although separate roughing and finishing operations are sometimes are employed. If the gear is helical, the tooth or work rotates as the broach advances. Either the work or the tool is pushed and pulled.

Broaches are expensive and therefore normally require high-volume production if tool costs are to be amortized. Broaching's short cycle time adds to its attractiveness for mass-production applications.

6.4.5 Shear Cutting:

This process could be considered a cross between broaching and gear shaping. Like the gear broach, the formed cutters simultaneously remove material from all tooth spaces of the gear. Like the gear shaper, the cutting head has a reciprocating motion. The cutters all advances slightly with each stroke of the cutting head until the full form of the gear is machined.

Shear cutting is applicable to spur gears of diameters upto 20 in and face widths upto 6 in. While helical gears are not machinable with the process, internal spur gears can be shear-cut.

6.5 Casting Methods:

Gears can be cast to these if finished state by all casting processes but process limitations, particularly dimensional limitations, restrict the widespread use of all except die casting.

6.5.1 Sand-Mold Casting:

The sand-mold casting of gears provides only the lowest levels of accuracy. Large mill gears produced in underdeveloped countries are one applications. In such cases gear-tooth profiles and surfaces are improved to some degree by hand filling. Other applications include slow-moving mechanisms when irregularities of gear action and backlash are not objectionable. Normally, however, gears cast in sand molds are used only when machining facilities are not available.

6.5.2 Plaster-Mold, Permanent-Mold, and investment-Cast Methods:

These casting methods are more accurate than sand-mold casting and are usable in many commercial applications, generally those for which loads and velocities are not high and tooth-profile and positional errors are tolerable. These methods, though far more accurate than sand and shell molding. Still do not provide the accuracy obtainable by machining. Of the methods, permanent and old casting is better suited to simpler configurations, while investment casting is applicable to the most complex shapes, although normally only in the smaller sizes. With investment casting, helical and spiral-bevel gears can be cast.

6.5.3 Die Casting:

This process is widely used for the production of gears employed in appliances, business machines, etc. When quantities are large, loads are light or moderate, and commercial tolerances are sufficient, die-cast gears may be called for. Spur, helical, worm, bevel, and shouldered are stepped gears can be produced. The approximate normal maximum pitch diameter is 6 in..

In face width exceeds 1/4 in., draft is required to permit the workpiece to be removed from the die. Trimming operations ar necessary after the part has been removed from the die, and in some cases trimming involves shaving or broaching teeth. Trimming die costs may be very high in such cases.

6.6 Gear-forming Methods:

A number of forming methods are available for gear making, either for forming the teeth in material that is processes further to provide the finished gear or for making the gear completely. These processes include extrusion, cold rolling, and drawing, stamping, powder metallurgy, and forging. In many cases, these methods are fully as accurate as machining. Often they also are applicable to high strength ferrous metals, which is not the case with the die casting and some other casting methods.

6.6.1 Extrusion:

Typical cross sections of extruded gears are shown in fig 6.4 (9). Best results are obtained with pinions of coarse pitch. The process involves forward extrusion. To get the accuracy required for gears, a secondary drawing operation is required after extrusion. The stock is then cut off, turned, and bored as necessary on lathes or screw machines equipped with special collets. Gears made from extruded stock are used in various commercial; applications such as clocks, instruments, and appliances. The process is limited to straight spur gears and is most economical when quantities are moderate or greater.

6.6.2 Cold Drawing:

The cold gear drawing of gears goes beyond extrusion to involve repeated passes of bar material through dies of progressively smaller openings, each closer to the final gear shape than the one preceding it. As the extruded-gear stock, the material is cut off and machined to produce all surfaces except the gear teeth themselves. The process produces gears with teeth to fine surface finish and high density. Accuracy is approximately equivalent to the achieved by gear-machining methods. for high-precision or high-load application, however, drawn gears may inferior to machined gears because of built-in stresses from the drawing operation.

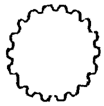
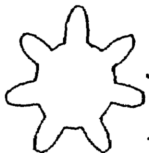
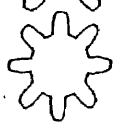
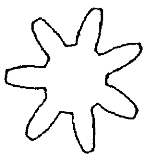
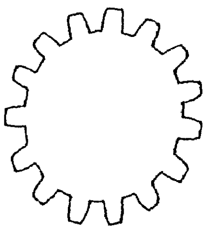
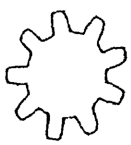
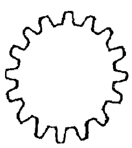
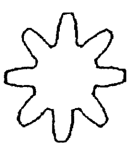
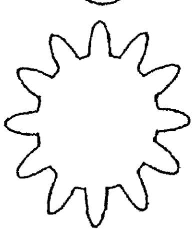
	Number of teeth	Outside diameter, in	Pitch diameter, in	Root diameter, in	Pitch	Tooth thickness, in
	18	1.241	....	0.972	16	0.098
	7	1.407	1.062	0.775	8	0.261
	8	0.985	0.800	0.644	10	0.157
	7	1.430	....	0.712	6	0.261
	15	2.020	....	1.688	8	0.1963
	9	1.325	....	0.920	14	0.196
	16	1.285	....	0.985	15	0.112
	11*	1.8	....	1.265 hole drawn to 1.215		
	7	Segment for Easy washer, body 0.720, radii 1/32 in				
	12	5.25	4.438	3.625	Tolerance = ±0.034	

Fig 6.4 Typical Cross sections of extruded gear stock

The cold-drawing method is applicable to spur pinion gears in various drawable materials including steel. Involute and cylindrical tooth forms can be produced, as can other special shapes such as noncircular gears and ratches. Maximum outside diameters currently available are on the order of 2 in. Quantity production is necessary to amortize tooling costs. Cold-drawn gears are used in business machines, motion-picture projectors and similar equipment.

6.6.3 Powder Metallurgy:

The methods of powder metallurgy are used increasingly for fabrication of the gears. Spur gears, helical gears to a 35 degree helix angle, bevel gears, and face gears can be made with this process. Coarse spur gears involve the most straightforward processing. Pitches as fine as 64 can be produced. The size of gears producible depends on the press size, but gears of diameters up to 3 1/2 in. are routinely made, and diameters to 6 in. possible.

To achieve the accuracy required for most applications, powder-metal gears are subjected to repressing or coining after sintering. Repressed gears have an excellent surface finish. The surface of non-repressed gears is sufficiently porous so that they can be vaccum-impregnated with oils for longlife lubrication.

An advantage of powder-metal processes for gear manufacturing is that projections, notches, collars, bosses, keyways, and other irregular shapes can be incorporated into the part without additional operations. Tooling costs tend to be high. Therefore, large quantities of powder-metal gears are required if the full manufacturing economy of this method is to realized.

6.6.4 Stamping:

The stamping processes can be used as economical means of producing means of producing spur gears of good accuracy. Best results require accurate tooling to blank all teeth and pierce the center hole in one press stroke. Short-run stamping methods which utilize less elaborate tooling and multiple press stroke. Short-run stamping methods which utilize less elaborate tooling and multiple press strokes are less apt-to sufficiently accurate for the usual applications. Hence this method is economic only for large-quantity production.

Metal stamping is a sheet-metal operation. The thickness of the stock which can be stamped for gears depends somewhat on the coarseness of the teeth. Normally, it ranges from 0.010 to 0.100 in.. When greater face widths are required, a number of individual blanked pieces are laminated together. these are fastened by riveting, press fitting, or welding.

Although the edges of stamped gears exhibit the same areas8Hof drawdown, shear, and breakaway evidence by the edges of other stampings, the sheared portion can exhibit quite high levels of accuracy. When fine blanking is used, virtually the entire edge is sheared and is of this quality. The fine blanking process, because of its accuracy and the smooth, square edges it produces, is well suited to gear blanking.

Diametral pitches range from 20 to 120. Slots, tabs, extra holes, and special shapes are producible without extra operations if the necessary elements can be incorporated in the blanking die. Application include electric and water meters. clocks and appliances. Stamping rates range from 35 to 200 pieces per minute. Secondary operations are tumble deburring and plating.

6.6.5 Forging:

Forging is normally used only to produce gear blanks, but there has been limited production of forged gears in recent years. The process involved has additional steps compared with the most common commercial forging processes. It includes accurate machining of the forging blank and both rough and finish forging. The process is most applicable to straight-bevel and face gears. Spur gears are possible, but die life is short. Spiral-bevel gears have been produced experimentally but not commercially.

Forged gears are not as accurate as machined gears but are superior in fatigue strength. Large-quantity production is required to amortize tooling and process-development costs.

6.7 Gear -finish-machining methods:

These methods include shaving, grinding, honing, lapping, and burnishing. They all have the same or similar objective: to provide more accurate an· smoother gear-tooth surfaces and thereby to provide smoother, quieter, and more uniform gear action. They remove variations that may be inherent from initial machining operation, distortion due to relieved stresses or heat treatment, and nicks and burrs, and other surface irregularities. These finish-machining operations are not by any means essential to gear machining; in most case they are not necessary. For precision-gearing applications and when noise reduction is important. however, they are quite common.

6.7.1 Shaving:

The most common gear-machining operation, shaving, involves the use of a highly accurate cutting tool which is gear-shaped and can mesh with gear to be shaved. The teeth of the cutter conform precisely to the shape of the final gear teeth, but each cutter edges. The cutter's tooth arrangement is helical even if the cutter is to be used on straight spur gears. In use, the cutter engages the workpiece gear with the axes of gear and cutter oriented about 15(degrees) differently from one another. As the gears rotate, there is an axial sliding motion of the teeth and the multiple cutting edges of the shaver cutter remove minute amounts of material from surfaces of the gear. A high degree of dimensional accuracy and a smooth surface finish result. Shaving is applicable to gears with diametral pitches of 2 to 180 and pitch diameters of 0.15 to 220 in.

Shaving tools are expensive, much more costly than hobs. The need for special shaving machines adds to costs. and setup must be careful. These factors necessitate long production runs if costs are to be kept to a minimum.

6.7.2 Grinding:

Although sometimes used to machine fine-pitch gears from solid stock, grinding is normally a finishing method for gears machined by other methods. The usual application is for post-heat-treatment machining to remove the distortion that occurs during heat treatment and otherwise improve tooth spacing, form, and surface finish.

There are numerous gear grinding methods. Some use form-dressed wheels to form the finished gear teeth fully, while others generate the tooth shape through relative motions between the gear and the grinding spindle. Some generating methods employ multiple or ribbed wheels. Some grinding methods are quite similar to gear machining methods except the a grinding wheel takes place of the cutter.

Almost any gear can be machined can also be finish-ground. Exceptions are internal gears smaller than 2 1/2 in. in diameter when sufficiently large grinding machines are not available. Grindability is best when gear material hardness range from 40 to 60. Gear grinding tends to be costly, but it is used at all levels of production when the application of the gear demands heat treatment and high dimensional accuracy.

6.7.3 Honing:

The process bears some similarity to gear shaving. The honing tool is a plastic gear impregnated with abrasive. As in a gear-shaving tool, the teeth are helical so that, when engaged with the workpiece gear, the axes of gear and tool are not parallel. The honing action takes place when the honing tool drives the workpiece gear for a time in each direction and there is transverse motion of the tool across the face of the gear.

Nicks, burrs, and surface irregularities are reduced or eliminated by the abrasive action of the particles embedded in the tool. Gear honing is normally performed after heat treatment, and if distortion from heat treatment is minimal, it can be substituted for grinding. It is far faster than grinding. Some errors in tooth-to-

tooth spacing and in tooth form can be corrected by honing, but the process is primarily one of the surface improvement. Honing is used in the manufacture of spur and helical gears with diametral pitches of 32 or coarser and is most commonly employed is high-production.

6.7.4 Lapping:

A similar method for finishing gears after heat treatment, lapping involves an external abrasive compound and either a gear-shaped lapping tool or two mating gears. The gear pair or the gear-lapping-tool pair are run together with the compound. This procedure corrects minute errors of profile, tooth spacing, concentricity, and helix angle and improves the gear-tooth surface.

Lapping is applicable to all classes of gears, including bevel, spiral-bevel, and hypoid gears. The last named gears are normally run in pairs rather than with a lapping tool. Lapping tools, when required, are reasonable in cost. Cycle time is usually from 1/2 to 2 min. The operation is applicable to all levels of production, being particularly suitable for small quantity situations if mating gears are lapped together.

6.8 Suitable Material for Gears:

Material	Machinalbility	Yield strength lbf/in^2	Remarks
Low-carbon steel	Good	30,000	For commercial gears of low or moderate power rating; can be case carburized
Medium carbo steel	Fairly Good	40,000	Can be flame or induct-ion hardened
High-carbon steel	Fair	54,000	For high power ratings
Resulfurized carbon steel	Excellent	34,000	For commercial gears of low or moderate power rating; can be case carburized
Chrome-molebdenum alloy steel	Fairly good	60,000	Suitable for nitriding and flame hardening
Chrome-molebdenum alloy steel-leaded	Excellent	60,000	Suitable for nitriding and flame hardening but not for heavy power
Nickel chrome molybdenum alloy steel	Fair	65,000	Suitable for nitriding and induction hardening
Stainless steel	Fair	40,000	Best corrosion resista-ce;nonhardenable, non-magnetic;for lower power application
Cast iron	Very Good	20,000	Can be heat treated for low or medium power applications; sound damping;low shock;
Ductile iron	Good	60,000	Better impact and fati-gue strength than cast iron
Aluminum Bronze	Excellent	60,000	Heat-treatable; high strength and corrosion resistance;low friction

TABLE 6.1 SUITABLE MATERIAL FOR GEARS I

Material	Machinalbility	Yield strengt lbf/in^2	Remarks
Manganese bronze	Excellent	65,000	For higher load applications;saltwater environment
Phosphor bronze	Excellent	45,000	Good resistance to wear in sliding applications
Silicon bronze	Excellent	35,000	Moderate strength and corrosion resistance
Free-cutting brass	Excellent	44,000	Low cost, noncorrosive for medium precision applications
Aluminum alloy	Excellent	47,000	Most widely used aluminium gear alloy;surface finish excellent for light duty applications
Zinc	Fair (use die-cast)	41,000	Fastest cycle,best die life;best surface finish and dimensional accuracy;good impact strength but not for prolonged service above 2000 ^oF
Aluminium alloy	Good (use die-cast)	36,000	Light weight; corrosion resistance
Magnesium alloy	Good (use die-cast)	33,000	Poor corrosion resistance;very light;for low-load applications
Brass	Good (use die-cast)	55,000	Good machinability; short die life;good impact strength

TABLE 6.2 SUITABLE MATERIAL FOR GEARS II

6.9 Design Recommendations For Gear Design:

The closely dimensioned and standardized configuration inherent in the function of gears severely limits the latitude of the designer in selecting a low-cost alternative design. Nevertheless, there are choices the designer can make which will have a significant effect on the cost and performance of gear components. Some points for consideration, applicable to machined, molded, cast, formed, or stamped gears, are the following:

1) Normally, the coarsest-pitch gear system which performs the required function will be the most economical to produce. The designer, if given a choice between fine-pitch gearing and coarse-pitch gearing and provided operating requirements permit, should choose the coarse-pitch system.
This is shown in fig 6.5 (1·)

2) Helical, spiral, and hypoid systems are more difficult and costly to manufacture than straight-tooth designs. Straight-tooth systems should be specified unless noise or other considerations necessitate a helical configuration.

3) Dimensional tolerances, as controlled by AGMA gear numbers and permissible tooth-to-tooth and total cumulative variations and surface finishes, should be as liberal as the function of the gears permits. Gears, like other manufactured components, are subject to geometrically increased costs as tolerances are reduced.

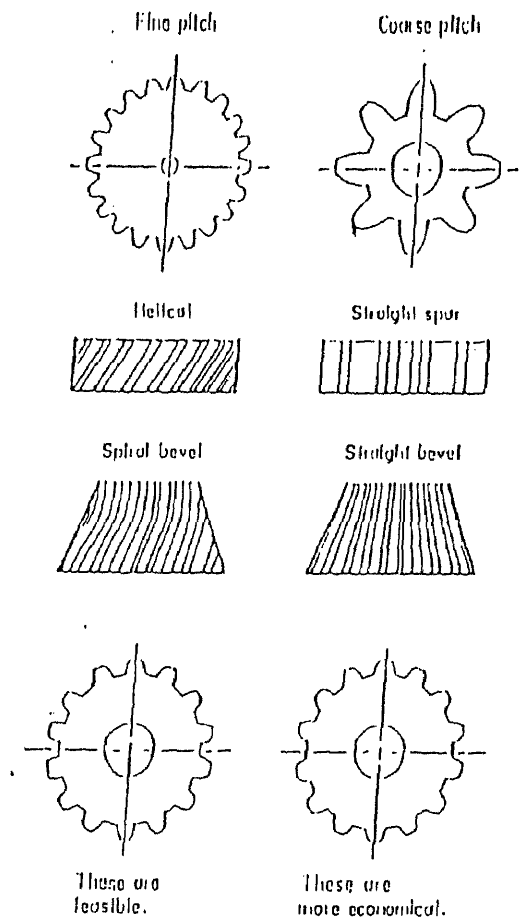


Fig 6.5 Economical Gear Designs

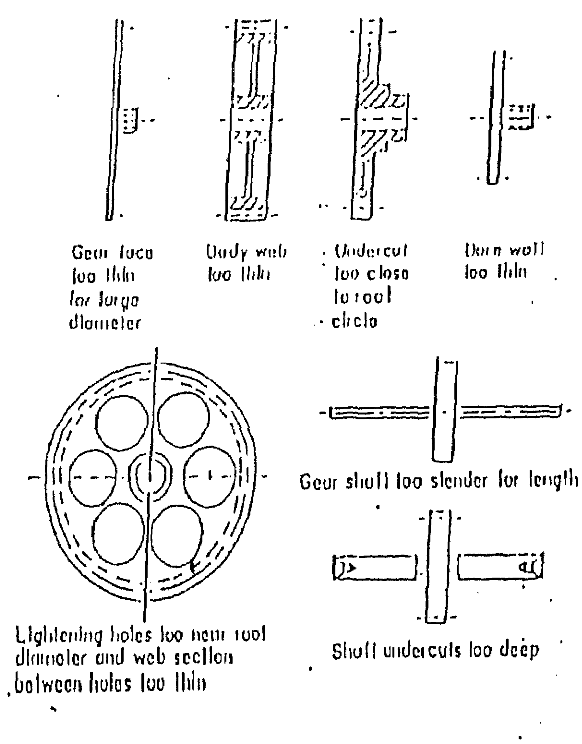


Fig 6 6 Gear Blanks for Better Clamping

6.9.1 Machined Gears:

1) Shoulders, flanges, or other portions of the workpiece larger than the root diameter of the gear should not be located close to the gear teeth; otherwise, there will not be sufficient clearance for the gear-cutting tool. When gears are hobbed, the space between the teeth and the shoulder should be greater than one-half of the hob diameter. Gear shapers require less clearance, but a good general rule is to avoid all such obstructions if possible and, if not possible, to keep the spacing liberal.

2) If steel gears are to be heat-treated for increased strength, consideration should be given to using non-heat-treated gears of larger size instead. The increased cost of the larger gears may be less than the cost of heat treating and of grinding or lapping after heat treating to correct the heat-treatment distortion.

3) All configurations also require clearance areas or undercuts to provide room for cutting tools. Herring bone gears should have a groove between halves, internal gears in blind holes require an undercut groove or other recessed space for cutter overtravel. This is shown in fig 6.7 (10).

4) Heat-treated gears should be uniform cross section to minimize heat-treatment distortion. Nitriding is preferred heat-treatment since it minimizes distortion and the consequent probability that grinding will be necessary after heat treatment.

5) As shown in fig 6.8 (10) the greater the helix angle of helical gears, the more difficult it is to machine to high levels of accuracy. Use as shallow a helix as possible.

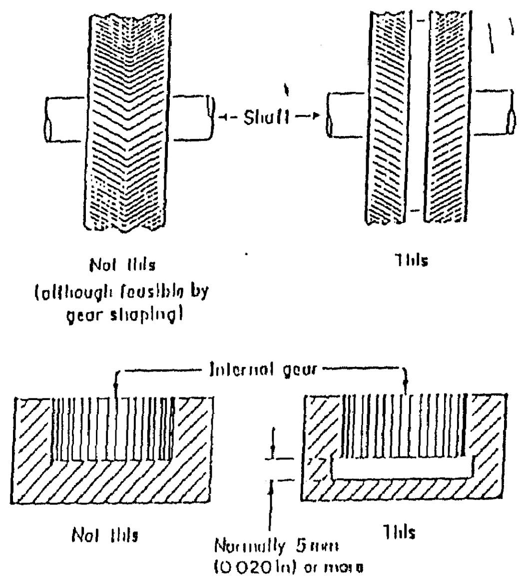


Fig 6.7 Clerance at end of Gear Teeth
are advisable to provide room for cutting tools

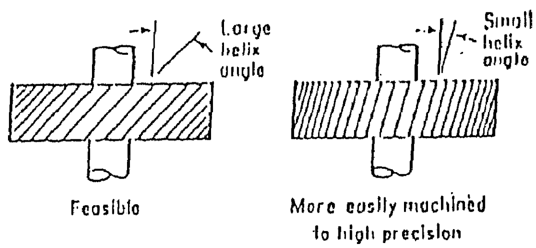


Fig 6.8 Helical Gears of low helix angle
easier to machine

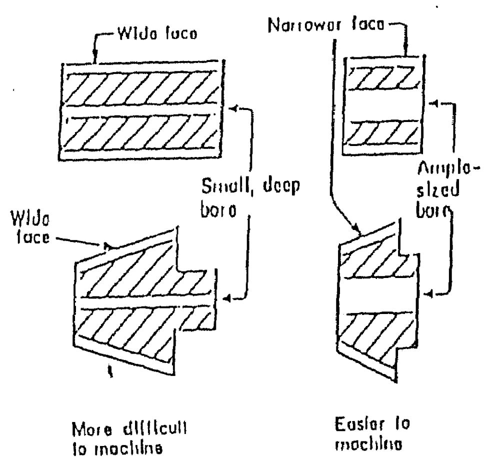


Fig 6.9 Narrower-face large-bore gears are
generally easier to machine

6) As shown in fig 6.9 (10) gear blanks designed so that they can be clamped securely and without distortion during machining from the cutting tool or clamping device.

7) As shown before in fig 6.6 (7) wide-faced gears are more difficult to machine to a given tolerance than marrow-faced gears. Small, long center holes are also more costly and are subject to loss of squareness. Extremes of both cases should be avoided.

8) When gear must be press-fitter to a shaft or other component, the fitting surface should not be too close to the teeth. The gear section must be heavy enough so that the pressure of the fit does not overstress the gear or change its dimension.

9) When gears are to be subject to a Secondary operation for improved tooth accuracy and finish. it is important to specify the proper stock allowance. Too great an allowance reduces production and increases costs. Since finish-machining operations have low material-removal rates, too little stock allowance many not permit the proper dimensions.

10) Standard pitches should be used as much as possible to minimize tooling costs and tooling inventories and to ensure better availability of cutting tools or stocked gears.

11) Correct design of the gear is important. Especially with bevel gears, the specified dimensions of the blank should be closely maintained, and the blank should be capable of being held securely in a rigid setup for machining the teeth.

12) The involute form of tooth is easy to machine. It works at any center distance and is used perhaps 99 percent of the time. It should be the standard specified tooth form for all normal gearing.

6.9.2 Formed, cast, and molded gears:

1) Rolled gears are an exception to the rule that coarse-pitch gears are more economical than the fine-pitch gears to manufacture. Because less metal needs to displaced, a finer pitch is preferable.

2) With plastics and die-cast gears, the use of a metal insert for the shaft or shaft hole should be considered. An insert normally provides a more accurate bore than the bore achievable by molding or casting, reduces shrinkage distortion, and provides a stronger means of fastening the gear.

3) If the load requirements are severe and the load-carrying ability of the gear material is limited, as is the case normally with molded plastic or die-cast gears.

6.9.3 Dimensional Factors:

Dimensional variations in gears result in noise, vibration, operational problems, reduced load carrying ability, and reduced life. These problems are compounded at higher gear operating speeds. Dimensions critical to precision gear operation are pitch, concentricity, tooth profile, tooth thickness, and tooth-surface finish. Tooth-to-tooth composite error is the combined effect of pitch, profile, and tooth-thickness variations. Tooth composite error is the combined effect of these tooth-to-tooth errors plus runout.

6.9.4 Gear Accuracy:

There is a definite and direct relationship between gear accuracy and manufacturing costs. Making a better quality will normally call for better than average processing. Allowing wider tolerances generally will permit methods less refined than one normally finds in present-day shops. There is a limit to the degree of accuracy attainable in machining the tooth profile. In general

1) At high levels of accuracy a very great increase in the amount of effort spent will produce only a slight improvement in accuracy.

2) When accuracy is waived in favor of saving money, the additional savings resulting from the large increase in allowable errors become slight.

Control of accuracy to high levels requires control of the environment and all manufacturing conditions and necessitates Secondary machining operations.

CHAPTER 7
CONCLUSION

It may be said that design is a cooperative creative activity requiring a holistic approach which demands a diverse number of skills in order to achieve sound communication of the design intent and to pay due attention to such matters as simplicity, standardization, flexibility, and requisite tolerancing. In addition there has to be adequate training of both designers and customer operator if total success is to be obtained.

The first generation of advanced manufacturing technology is known as flexible manufacturing systems(FMS). The impact of FMSs has been great. Particularly important is the manner in which product design is carried out with computer aided design(CAD) systems and connected directly to manufacturing systems, automatic inventory control, tool operations, inspection, and quality control can be closely coupled operations. But the impact of FMSs on the way companies operate is minimal. Designers give too little consideration to important product life cycle issues such as product assembly, test, repair, and modification. This is true even though designers are increasingly aware of the need to design product parts so that they can be fabricated economically and still meet performance requirements. When companies consider the second generation of advanced manufacturing systems like automated assembly, they find that, matters cannot be treated on a part by part basis. Assembly is coupled not only to manufacturing but also to design, vendor control, quality control, and the customer. As automation increases, it is important that designs be compatible with and take advantage of the new technology. Design for manufacturability(DFM), which is a method of addressing this need by seeking new ways of representing and combining design data. New methods of coordinating design and manufacturing departments, Improvements in engineering education that will relate design to manufacturing and a better understanding of the relationship among process flexibility, production volume, types and levels of automation, and the influence of product design on these factors. DFM also makes the designer aware of opportunities to use nontraditional material in new products and the importance of considering material handling and assembling at the beginning of design process. Design for manufacturing will increase productivity.

DFM is recognizing the importance of integrated product and process design and then consciously going about design in a way that leads to a product inherently easy to manufacture and support. By superimposing life-cycle process requirements on the functional requirements of the design, many choices are narrowed down to few good choices. Using a cross functional team approach accelerates the product knowledge growth and greatly expands the product knowledge base available for guiding and validating product and process design decisions. The result is shortened time to market with a higher quality, lower cost of product. both the plateau the typically develops because of the integration of various subsections and adjustments to satisfy manufacturing requirements, as well as the oscillations that occur at the end of the design cycle caused by manufacturing and assembly difficulties discovered late in the project are avoided.

Providing disciplined anticipation that the product will be correctly designed for manufacture is the key action required by management in developing a good DFM program. Training the design team for DFM techniques such as Design for Assembly, Design for quality as well as providing a well integrated kit of DFM tools, creates awareness and sets the stage. A well thought design process enables DFM approaches to be implemented. Setting stretch goals stimulates innovation and sends a clear message that DFM is expected. Providing an adequate budget of time and money for up-front activities, together with a design environment that facilitates easy communication, encourages and makes a well planned total design possible. Personal commitment and interest in the DFM aspects of the design on the part of the management make DFM an important part of the design project and sustains and expectations.

Results from an DFM Program are complex and far reaching. Fortunately, most people understand the basic idea and are not afraid of the concept. Once implemented it will give good results and change present design procedures very much.

The design process in DFM is a complex array of diverse and often contradictory humanactivities and technological issues that differ with each problem and continually change and evolve during the realization of the design. Design is open minded, with many solutions possible and the final solution possible and the final result determined largely by the way and extent to which the design problem is understood and by the process with which it is solved. The increased complexity of the modern information age, the continual need for change, and the constant emergence of new material and technology are placing ever increasing demands on proper and complete understanding of the design problem and on the broad spectrum of needs to be met by the design process.

The DFM process and associated DFM methodologies help the design team or designer deal more effectively with the demands. DFM helps improve quality by early design decisions. Design decisions, especially those made early in a design project, have a tremendous impact on the life-cycle cost of the product. Early quality decisions can ensure business success by enabling the production of better performing, reliable and robust products with improved cost and, quality and productivity.

DFM is key to minimizing life cycle cost and design team, assuring product quality, eliminating "over the wall to manufacturing" mentality, and realizing the productivity increase promised by advanced manufacturing technology. For many companies, the DFM approach can ultimately lead to the innovative product and process solutions needed for a measurable competitive edge and a healthy balance sheet.

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