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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – I – INTRODUCTION – SME1310

Definition of a product - Types of product- levels of product- New product development product-market mix- New product development (NPD) process- Idea generation methods-Creativity-Creative attitude, creative design Process - Morphological analysis- analysis of interconnected decision areas, brain storming, and synectics. Product life cycle- The challenges of product development- productanalysis- product characteristics

PRODUCT DEFINITION

In marketing, a product is anything that can be offered to a market that might satisfy want or need. In retailing, products are called merchandise. In manufacturing, products are bought as raw materials and sold as finished goods. A service is another common product type.

Commodities are usually raw materials such as metals and agricultural products, but a commodity can also be anything widely available in the open market. In project management, products are the formal definition of the project deliverables that make up or contribute to delivering the objectives of the project. In insurance, the policies are considered products offered for sale by the insurance company that created the contract. In economics and commerce, products belong to a broader category of goods. The economic meaning of product was first used by political economist Adam Smith

TYPES OF PRODUCTS

Firstly, what specifically is a consumer product? A consumer product is a product bought by final consumers for personal consumption. But not every consumer product is the same. There are four different types of consumer products. Marketers usually classify consumer products into these 4 types of consumer products:

- Convenience products
- Shopping products
- Speciality products
- Unsought products.

These 4 types of consumer products all have different characteristics and involve a different consumer purchasing behaviour. Thus, the types of consumer products differ in the way consumers buy them and, for that reason, in the way they should be marketed.

(i) Convenience products

Among the four types of consumer products, the convenience product is bought most frequently. A convenience product is a consumer product or service that customers normallybuy frequently, immediately and without great comparison or buying effort. Examples include articles such as laundry detergents, fast food, sugar and magazines. As you can see, convenience products are those types of consumer products that are usually low-priced and placed in many locations to make them readily available when consumers need or want them.

(ii) Shopping products

The second one of the 4 types of consumer products is the shopping product. Shopping products are a consumer product that the customer usually compares on attributes such as quality, price and style in the process of selecting and purchasing. Thus, a difference between the two types of consumer products presented so far is that the shopping product is usually less frequently purchased and more carefully compared. Therefore, consumers spend much more time and effort in gathering information and comparing alternatives. Types of consumer products that fall within the category of shopping products are: furniture, clothing, used cars, airline services etc. As a matter of fact marketers usually distribute these types of consumer products through fewer outlets, but provide deeper sales support in order to help customers in the comparison effort.

Number three of the types of consumer products is the speciality product. Speciality products are consumer products and services with unique characteristics or brand identification for which a significant group of consumers is willing to make a special purchase effort. As you can see, the types of consumer products involve different levels of effort in the purchasing process: the speciality product requires a special purchase effort, but applies only to certain consumers.

Examples include specific cars, professional and high-prices photographic equipment, designer clothes etc. A perfect example for these types of consumer products is a Lamborghini. In order to buy one, a certain group of buyers would make a special effort, for instance by travelling great distances to buy one. However, speciality products are usually less compared against each other. Rather, the effort must be understood in terms of other factors: Buyers invest for example the time needed to reach dealers that carry the wanted products. To illustrate this, look at the Lamborghini example: the one who wants one is immediately convinced of the choice for a Lamborghini and would not compare it that much against 10 other brands.

(iii) Unsought products

The 4 types of consumer products also include unsought products. Unsought products are those consumer products that a consumer either does not know about or knows about but does not consider buying under normal conditions. Thus, these types of consumer products consumers do not think about normally, at least not until they need them. Most new innovations are unsought until consumers become aware of them. Other examples of these types of consumer products are life insurance, pre-planned funeral services etc. As a consequence of their nature, unsought products require much more advertising, selling and marketing efforts than other types of consumer products.

Below you can find relevant marketing considerations for each of the 4 types of consumer products.

Types of Consumer Products				
Marketing consideration	***Convenience***	***Shopping***	***Speciality***	***Unsought***
Customer buying behaviour	Frequent purchase, little effort (planning, comparison), low customer involvement	Less frequent purchase, much effort (planning and comparison of brands on price, quality, style etc.)	Strong brand preference and loyalty, special purchase effort, little comparison of brands, low price sensitivity	Little product awareness and knowledge or little interest
Price	Low price	Higher price	High price	Varies
Distribution	Widespread distribution, convenient locations	Selective distribution, fewer outlets	Exclusive distribution in only one or a few outlets	Varies
Promotion	Mass promotion	Advertising and personal selling	More carefully targeted promotion	Aggressive advertising and personal selling
Examples	Toothpaste, magazines, laundry detergent	Television, furniture, clothing	Luxury goods (e.g. Rolex watch), designer clothing	Life insurance and pre-planned funeral service

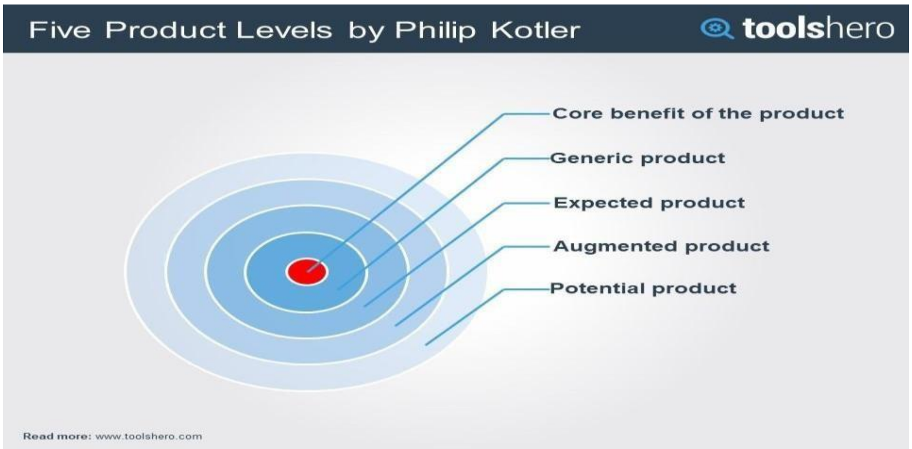
Table 1.1 Types of Consumer Products

LEVELS OF PRODUCT

1. Core Product

This is the basic product and the focus is on the purpose for which the product isintended. For example, a warm coat will protect you from the cold and the rain.

Figure 1.1 Levels of Product



2. **Generic Product**

This represents all the qualities of the product. For a warm coat this is about fit,material, rain repellent ability, high-quality fasteners, etc.

3. **Expected Product**

This is about all aspects the consumer expects to get when they purchase a product. That coat should be really warm and protect from the weather and the wind and be comfortable when riding a bicycle.

4. **Augmented Product**

This refers to all additional factors which sets the product apart from that of the competition. And this particularly involves brand identity and image. Is that warm coat in style, its colour trendy and made by a well-known fashion brand. But also factors like service, warranty and good value for money play a major role in this.

5. **Potential Product**

This is about augmentations and transformations that the product may undergo in the future. For example, a warm coat that is made of a fabric that is as thin as paper and therefore light as a feather that allows rain to automatically slide down.

NEW PRODUCT DEVELOPMENT

In business and engineering, new product development (NPD) covers the complete process of bringing a new product to market. A central aspect of NPD is product design, along with various business considerations. New product development is described broadly as the transformation of a market opportunity into a product available for sale. The product can be tangible (something physical which one can touch) or intangible (like a service, experience, or belief), though sometimes services and other processes are distinguished from "products." NPD requires an understanding of customer needs and wants, the competitive environment, and the nature of the market. Cost, time and quality are the main variables that drive customer needs. Aiming at these three variables, companies develop continuous practices and strategies to better satisfy customer requirements and to increase their own market share by a regular development of new products. There are many uncertainties and challenges which companies must face throughout the process. The use of best practices and the elimination of barriers to communication are the main concerns for the management of the NPD.

NEW PRODUCT DEVELOPMENT PROCESS

It is of crucial importance to understand consumers, markets, and competitors in order to develop products that deliver superior value to customers. In other words, there is no way around a systematic, customer-driven new product development process for finding and growing new products. We will go into the eight major steps in the new product development process.

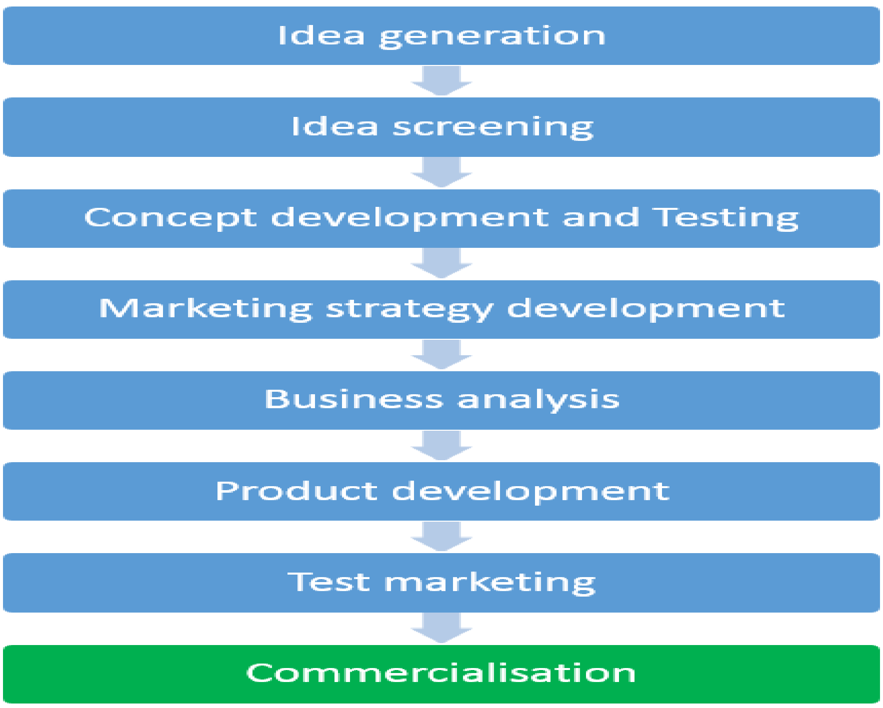


Figure 1.2 The 8 steps in the New Product Development Process

Idea generation

The new product development process starts with idea generation. Idea generation refers to the systematic search for new-product ideas. Typically, a company generates hundreds of ideas, maybe even thousands, to find a handful of good ones in the end. Two sources of new ideas can be identified:

- Internal idea sources: the company finds new ideas internally. That means R&D, but also contributions from employees.
- External idea sources: the company finds new ideas externally. This refers to all kinds of external sources, e.g. distributors and suppliers, but also competitors. The most important external source are customers, because the new product development process should focus on creating customer value.

Idea screening

The next step in the new product development process is idea screening. Idea screening means nothing else than filtering the ideas to pick out good ones. In other words, all ideas generated are screened to spot good ones and drop poor ones as soon as possible. While the purpose of idea generation was to create a large number of ideas, the purpose of the succeeding stages is to reduce that number. The reason is that product development costs rise greatly in later stages. Therefore, the company would like to go ahead only with those product ideas that will turn into profitable products. Dropping the poor ideas as soon aspossible is, consequently, of crucial importance.

CONCEPT DEVELOPMENT AND TESTING

To go on in the new product development process, attractive ideas must be developed into a product concept. A product concept is a detailed version of the new-product idea stated in meaningful consumer terms. You should distinguish

- A product idea à an idea for a possible product
- A product concept à a detailed version of the idea stated in meaningfulconsumer terms
- A product image à the way consumers perceive an actual or potentialproduct. Let’s investigate the two parts of this stage in more detail.

Concept development

Imagine a car manufacturer that has developed an all-electric car. The idea has passed the idea screening and must now be developed into a concept. The marketer’s task is to develop this new product into alternative product concepts. Then, the company can find out how attractive each concept is to customers and choose the best one. Possible productconcepts for this electric car could be:

Concept 1: An affordably priced mid-size car designed as a secondfamily car to be used around town for visiting friends and doing shopping.

Concept 2: A mid-priced sporty compact car appealing to young singlesand couples.

Concept 3: A high-end midsize utility vehicle appealing to those wholike the space SUVs provide but also want an economical car.

As you can see, these concepts need to be quite precise in order to be meaningful. Inthe next sub-stage, each concept is tested.

Concept testing

New product concepts, such as those given above, need to be tested with groups of target consumers. The concepts can be presented to consumers either symbolically or physically.

The question is always: does the particular concept have strong consumer appeal? For some concept tests, a word or picture description might be sufficient. However, to increase the reliability of the test, a more concrete and physical presentation of the product concept may be needed. After exposing the concept to the group of target consumers, they will be asked to answer questions in order to find out the consumer appeal and customer value of each concept.

Marketing strategy development

The next step in the new product development process is the marketing strategy development. When a promising concept has been developed and tested, it is time to design aninitial marketing strategy for the new product based on the product concept for introducing this new product to the market.

The marketing strategy statement consists of three parts and should be formulated carefully:

- A description of the target market, the planned value proposition, andthe sales, market share and profit goals for the first few years
- An outline of the product’s planned price, distribution and marketingbudget for the first year
- The planned long-term sales, profit goals and the marketing mix strategy.

Business analysis

Once decided upon a product concept and marketing strategy, management can evaluate the business attractiveness of the proposed new product. The fifth step in the new product development process involves a review of the sales, costs and profit projections for the new product to find out whether these factors satisfy the company's objectives. If they do, the product can be moved on to the product development stage.

In order to estimate sales, the company could look at the sales history of similar products and conduct market surveys. Then, it should be able to estimate minimum and maximum sales to assess the range of risk. When the sales forecast is prepared, the firm can estimate the expected costs and profits for a product, including marketing, R&D, operations etc. All the sales and costs figures together can eventually be used to analyse the new product's financial attractiveness.

Product development

The new product development process goes on with the actual product development. Up to this point, for many new product concepts, there may exist only a word description, a drawing or perhaps a rough prototype. But if the product concept passes the business test, it must be developed into a physical product to ensure that the product idea can be turned into a workable market offering. The problem is, though, that at this stage, R&D and engineering costs cause a huge jump in investment.

The R&D department will develop and test one or more physical versions of the product concept. Developing a successful prototype, however, can take days, weeks, months or even years, depending on the product and prototype methods. Also, products often undergo tests to make sure they perform safely and effectively. This can be done by the firm itself or outsourced.

In many cases, marketers involve actual customers in product testing. Consumers can evaluate prototypes and work with pre-release products. Their experiences may be very useful in the product development stage.

Test marketing

The last stage before commercialisation in the new product development process is test marketing. In this stage of the new product development process, the product and its proposed marketing programme are tested in realistic market settings. Therefore, test marketing gives the marketer experience with marketing the product before going to the great expense of full introduction. In fact, it allows the company to test the product and its entire marketing programme, including targeting and positioning strategy, advertising, distributions, packaging etc. before the full investment is made.

The amount of test marketing necessary varies with each new product. Especially when introducing a new product requiring a large investment, when the risks are high, or when the firm is not sure of the product or its marketing programme, a lot of test marketing may be carried out.

Commercialisation

Test marketing has given management the information needed to make the final decision: launch or do not launch the new product. The final stage in the new product development process is commercialisation. Commercialisation means nothing else than introducing a new product into the market. At this point, the highest costs are incurred: the company may need to build or rent a manufacturing facility. Large amounts may be spent on advertising, sales promotion and other marketing efforts in the first year.

Some factors should be considered before the product is commercialized:

- Introduction timing. For instance, if the economy is down, it might be wise to wait until the following year to launch the product. However, if competitors are ready to introduce their own products, the company should push to introduce the new product sooner.
- Introduction place. Where to launch the new product? Should it be launched in a single location, a region, the national market, or the international market? Normally, companies don’t have the confidence, capital and capacity to launch new products into full national or international distribution from the start. Instead, they usually develop a planned market rollout over time.

In all of these steps of the new product development process, the most important focus is on creating superior customer value. Only then, the product can become a success in the market.

CREATIVE AND DESIGN PROCESS

Essentially the design process is a problem-solving process, and the designer, just like the laboratory scientist, will be most successful if the problem is approached in a systematic manner. Successful fine artists generally follow the same pattern in developing their creative ideas, though they may be less conscious of the process they are following. Initially the designer will tend to experiment in a rather random manner, collecting ideas and skills through reading or experimentation. Gradually a particular issue or question will become the focus of the reading and experimentation. The next step is to formulate a tentative problem, and begin to explore that topic. Eventually the problem is refined into a design problem that the person will then pursue through repeated experimentation. In design, this takes the form of works created in a series. Each effort solves certain problems, and suggests issues to be dealt with in the next work (or experiment).

Working in a series is the most important stage of the design process. The ability to experiment, to value and learn from mistakes, and build on the experience achieved is the hallmark of the truly successful and creative individual, whatever the field.

MORPHOLOGICAL DESIGN

A design project goes through a number of time phases. Morphology of design refers to the collection of these time phases. The morphology of design as put forward by Morris Asimow can be elaborated as given below. It consists of seven phases.

Phase 1: Feasibility Study

This state is also called conceptual design. A design project always begins with a feasibility study. The purpose and activities during feasibility study are

- To ascertain there really exists a need [i.e., the existence of need must be supported by necessary evidence, rather than the outcome of one's fancy
- Search for a number of possible solutions.
- Evaluate the solutions.

Phase 2: Preliminary (Embodiment) design

This is the stage at which the concept generated in the feasibility study is carefully developed. The important activities done at this stage are:

- Model building and testing.
- Study the advantage and disadvantages of different solutions.
- Check for performance, quality strength, aesthetics etc.

Phase 3: Detail design

It is the purpose to finish the complete engineering description of the tested product. The arrangement, from, dimensions, tolerances and surface properties of all individual parts are determined. Also, the materials to be used and the manufacturing process to be adopted etc., are decided. Finally, complete prototype is tested.

Phase 4: Planning for manufacture

This phase include all the production planning and control activities necessary for the manufacture of the product. The main tasks at this phase are:

- Preparation of process sheet, i.e. the document containing a sequential list of manufacturing processes.
- Specify the condition of raw materials.
- Specify tools & machine requirements.
- Estimation of production cost.
- Specify the requirement in the plant.
- Planning QC systems.
- Planning for production control.
- Planning for information flow system

Phase 5: Planning for Distribution.

The economic success of a design depends on the skill exercised in marketing. Hence, this phase aims at planning an effective distribution system. Different activities of this phase are

- Designing the packing of the product.
- Planning effective and economic warehousing systems.
- Planning advertisement techniques
- Designing the product for effective distribution in the prevailingconditions.

Phase 6: Planning for Consumption/use.

The purpose of this phase is to incorporate in the design all necessary user- oriented features. The various steps are

- Design for maintenance
- Design for reliability
- Design for convenience in use
- Design for aesthetic features
- Design for prolonged life
- Design for product improvement on the basis ofservice data.

Phase 7: Planning for Retirement.

This is the phase that takes into account when the product has reached the end ofuseful life. A product may retire when

- It does not function properly
- Another competitive design emerges
- Changes of taste or fashion.

The various steps in this phase are:

- Design for several levels of use
- Design to reduce the rate of obsolescence.

ANALYSIS OF INTERCONNECTED DECISION AREAS (AIDA)

In every design process, the first step is to confront the problem, examining the situation to determine its true nature. The intensity of this analysis depends on the level of under- standing of the issues and the experience the designers have with the problem. Then, designers gather information on the problem at hand, including the requirements and constraints that the solution should meet. After which, a detailed problem definition can be made. This problem definition ensures that designers do not needlessly pursue a solution to something that is not, in fact, the true issue. Next, designers will use various techniques to create a solution and evaluatea solution. Finally, they will decide whether to implement the solution based on the specifications gathered during the information stage. Designers must repeat the process in eachsuccessive phase of the design process until the designers arrive at a solution that they deem appropriate.

Given this understanding of the design process, one can further examine a generalized flow of work, as described by Pahl and Beitz 1996. to understand how various design techniques relate to one another. The most design methods are applicable to one specific stage of the design process. One great advantage to using the AIDA approach is that it can be carried out in tandem or instead of several other techniques throughout the general process of design. Specifically, AIDA can be used to aid in defining the problem, creating a sample of applicable design solutions and evaluating these solutions against defined metrics.

In the early stages of design, designers will formulate the specifications and constraints through various methods, as discussed in the previous section. It is here, however, that many designers, especially ones with little prior experience in the field, face a daunting task of organizing their requirements Luckman, 1966!. Because of the intricacies that are inherent to most design tasks, designers are left to make assumptions so as to reduce complexity, and therefore their search space. Unfortunately, the issues are usually interrelated and dependent, meaning that the reduction process can lead to inconsistencies and losses of valuable information. It is in this arena of interdependence that the AIDA process flourishes, as it is a systematic approach to organizing and relating different decisions within the design space. Moreover, AIDA offers a heuristic for determining the compatibility of various design decisions and even methods for assessing the final design decision combinations against predefined performance metrics. One of the interesting characteristics of AIDA is that it does not matter whether the decision areas representing the choices are defined broadly or narrowly, generally or specifically Hickling, 1978. As such, it offers a means of opening up the process of problem structuring to participants who may see the elements of a decision situation from quite differentprofessional or representative perspectives, meaning that various kinds of professionals can evaluate different aspects of a design based on their separate expertise Friend & Hickling, 1987.

However, in practice, this generality is achieved at a cost, because users are often forced to accept drastic simplifications when striving to represent complex design decisions. Nonetheless, even this cost can be lessened by the aid of computer assistance, allowing decision makers to define and examine a complex search space.

Computer assistance pays off when the decision space is very large and when the chances or consequences of arriving at a poor decision are high ~Luckman, 1966!. However, it should be made clear that we do not intend for the designer to be superfluous and idle, while a computer solves the problem. Instead, we suggest that decision makers follow a systematic exploration of the decision environment with the aid of a computing agent that is used to perform organizational and computational tasks, thereby granting decision makers the luxury of time.

BRAINSTROMING

Brainstorming is the act of generating ideas to solve a design problem. It is an activity usually done with a group of people, whether they are designers or stakeholders, under the direction of a facilitator. The strength of brainstorming lies in its ability to facilitate associations between participants' ideas, thereby broadening the solution space.

Brainstorming uses the synergy of a group to generate new ideas by allowing people to build on each other's notions. However, all too often, brainstorming sessions become uncreative or misdirected when the wrong mind set facilitates them. Thus, a few rules exist to ensure that participants feel safe enough to share any idea that comes to mind. They are the following:

1. Set a time limit to create a focused and production-oriented atmosphere.
2. Start with a well-defined problem statement and keep the discussions focused.
3. Defer judgment or criticism, both verbal and non-verbal, so as to avoid blocking new associations and ideas.
4. Encourage weird, wacky and wild ideas to open up the solutions space, take a step outside the box, and create some fun in the team at the same time.
5. Aim for quantity instead of quality so as to create an atmosphere—one where *every* new idea is valuable; the results will only be selected afterward.
6. Build on each other's ideas so as to achieve new insights and perspectives, making ideas progressively more refined and targeted towards the central issue.
7. Be visual in order to really bring ideas to life and help other people view the ideas in a different way.
8. Keep to one conversation at a time so as to remain focused on the objective and show respect for the ideas put forward by others.

The freestyle, seemingly unsystematic nature of brainstorming belies an optimally structured design solution-creation/refining method.

SYNECTICS

It is a method of identifying and solving problems that depends on creative thinking, the use of analogy, and informal conversation among a small group of individuals with diverse experience and expertise.

PRODUCT LIFE CYCLE

In industry, product lifecycle management (PLM) is the process of managing the entire lifecycle of a product from inception, through engineering design and manufacture, to service and disposal of manufactured products. PLM integrates people, data, processes and business systems and provides a product information backbone for companies and their extended enterprise.

THE CHALLENGES OF PRODUCT DEVELOPMENT

Developing great product is hard. Few companies are highly successful more than half time. These odds present a significant challenge for a product development team. Some of the characteristics that make the product development challenging are:

Trade off: An airplane can be made lighter, but this action will probably increase manufacturing cost. One of the most difficult aspects of product development is recognizing, understanding, and managing such trades offs in such a way that maximizes the success of the product.

Dynamics: Technologies improve, customer preferences evolve, competitors introduce new products, and the macroeconomic environment shifts. Decision making in an environment of constant change is a formidable task.

Details: The choice between using screws or snap-fits on the enclosure of computer can have economic implications of millions of dollars. Developing a product of even modest complexity may require thousands of such decisions.

Time pressure: Any one of these difficulties would be easily manageable by itself given plenty of time, but the product development decisions must usually made be quickly and without complete information.

Economics: Developing producing and marketing a new product requires a large investment. To earn a reasonable return on this investment, the resulting product must be both appealing to customers and relatively inexpensive to produce.

For many people, product development is interesting precisely because it is challenging. For others, several intrinsic attributes also contribute to its appeal:

Creation: The product development process begins with an idea and ends with the production of a physical artefact. When viewed both in its entirety and at the level of individual activities, the product development is intensely creative.

Satisfaction of societal and individual needs: All products are aimed at satisfying needs of some kind**.** Individuals interested in developing new products can almost always find institutional settings in which they can develop products satisfying what they consider to be important needs.

Team diversity: Successful development requires many different skills and talents. As a result, development team involve people with a wide range of different training, experience, perspective, and personalities.

Team spirit: Product development teams are often highly motivated, cooperative groups. The team members may be collocated so they can focus their collective energy on creating the product. This situation can result in lasting camaraderie among team members.

PRODUCT ANALYSIS

Product analysis involves examining product features, costs, availability, quality and other aspects. Product analysis is conducted by potential buyers, by product managers attempting to understand competitors and by third party reviewers.

Product analysis can also be used as part of product design to convert a high-level product description into project deliverables and requirements. It involves all facets of the product, its purpose, its operation, and its characteristics.

Related techniques include product breakdown, systems analysis, systems engineering, value engineering, value analysis and functional analysis.

- Product breakdown: Recursively divide the product into components and subcomponents.
- Systems engineering: Ensure that the product satisfies customer needs, cost requirements, and quality demands.
- Value engineering: Consider alternative designs and construction techniques to reduce cost/increase profit.
- Value analysis: Assess the cost/quality ratio to ensure that the product is cost effective.
- Function analysis: Ensure that the product has features appropriate to customer requirements.

PRODUCT CHARECTERISTICS

These are the features that identify the product to the company, the market and the consumer. Each product is a complex of tangible and intangible characteristics which define the product, its use and value. Product characteristics can be viewed as technological, consumer and market:

- **Technological**: raw materials, composition, structure, size/shape, processing method, storage method, product type;
- **Consumer**: convenience, sensory properties, use, nutrition, safety, psychological, social;
- **Market**: type of market, marketplace, sales, price, promotion.

Variation of the characteristics and addition of new characteristics can make the product more appealing to the consumer and indeed give a unique product. Comparison with the characteristics of competitive products can define the positions of the different products in the market; this can reveal gaps in the market where there are no products, and also give better direction to 'me-too' products.

A product has a number of characteristics, and they can be ranked in importance not only to the consumer, but also technically and for the market. The important characteristics are combined to give a product profile. Each product has a unique product profile with a number of characteristics, some being more important than others. Some product characteristics can be needed or wanted by the consumer and are often called consumer product benefits. Other characteristics can be disliked by the consumer.

Product types have characteristics with different 'strengths', for example fruit juices could vary from slightly sour to very sour, slightly sweet to very sweet, cheap to expensive, subdued to gaudy packaging, ordinary to prestigious.

Studying product characteristics is widely used in developing product concepts both within the company and more often with consumers. Two important uses of product characteristics for product idea generation are in product morphology and in product positioning.

UNIT 1

INTRODUTION TO PRODUCT DESIGN

S.No.	PART - A
1	Define the term “Product”.
2	Classify the types of the Product.
3	Classify the levels of product.
4	What is a NPD process?
5	What is market mix?
6	What do you mean by creative attitude and creative design process?
7	What are the interconnected decision areas?
8	What is Brain Storming?
9	What is Product Life Cycle?
10	List the challenges of product development?

S.No.	PART - B
1	Explain the product types and levels of product with diagram.
2	Explain the phases of New Product Development with diagram.
3	Explain Idea generation methods with an example
4	Describe the following (a) The Challenges of New Product Development (b) Product characteristics
5	Explain the phases of product life cycle with diagram

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UNIT – 2 – BASIC CONCEPTS – SME1310

Product design- definition-Design by evolution- design by innovation-design by imitation -factors affecting product design. Standards of performance and environmental factors. Decision making and iteration - Morphology of design (different phases). -role of aesthetics in design. Introduction to optimization in design- economic factors in design-design for safety and reliability.

UNIT 2

BASIC CONCEPTS

PRODUCT DESIGN

The product design specification (PDS) is a document created during the problem definition activity very early in the design process. It details the requirements that must be met in order for the product or process to be successful. The document lays the groundwork for all engineering design activities and ensures that all relevant factors are accounted for and all stakeholders are heard from. A typical PDS includes the following information:

A. Product design & performance issues...

Expected product size and weight - customer requirement

Expected product performance requirements -- the voice of the customer!

Operational requirements.

- Speed (How fast? How slow? How often?)
  Continuous or discontinuous
- Loadings likely encountered Product power requirements.
- Product shelf life.
- Product service life.

Expected product service environment.

- What is the operating temperature range for this product?
- What is the operating humidity range for this product?
- Subject to shock loading?
- Will the product be exposed to dirt or other contaminants (corrosive fluids, etc.)?
- Will there be any anomalies in power/fuel available for this product?
- How will the product be treated in service?
- What impact will the product have on its environment?

Expected product safety requirements.

- Potential sources of product liability litigation.
  Potential operator hazards.
- Potential manufacturing and assembly hazards.
  Potential for misuse/abuse.

Expected product reliability standards and requirements.

What level of reliability can we expect for this product?

Expected product ergonomic requirements -- customer requirement

Which user/operator features are desirable in this product?

Are there problem areas for users/operators? Can we design around them?

Expected product aesthetics -- customer requirement

Expected product maintenance requirements.

Can product be maintenance-free?

If routine maintenance is required, can it be done by the owner/operator?

Will professional maintenance be required?

Possible off-the-shelf component parts.

Which parts of this product be purchased instead of being made by us?

Is the quality and reliability of purchases parts adequate for this design?

Material requirements..

What are the strength requirements?

What are the rigidity/compliance requirements?

Is product weight of importance?

Expected product recycling potential and expected disposal

Does the disposal of this product constitute an environmental hazard?

Can parts of this product be effectively recycled by existing processes?

Manufacturing process requirements and limitations.

Is protection from the environment necessary?

Is there a customer preference for a particular finish?

How do we minimize environmental impact?

Product packaging requirements.

Can we use environmentally friendly packaging and packing materials?

How much packaging and packing materials are really necessary?

Applicable codes and standards to be checked

A. Market issues...

Potential customer base

Who will buy this product? Why?

Have you listed all potential classes of customers?

Can we tap into a new segment of the market? How?

Market constraints on product.

Who is buying this type product? (Customer base) What is currently selling?

What is currently not selling

Expected product competition (These will be benchmarked)

What are the strengths of each competing product? Can we incorporate them? What are the weaknesses of each competing product? Can we improve?

What are the market shares of competing products?

Target product price -- OEM and MSRP Target production volume and market share.

Is there a market for this product? How do you know?

Is the potential market sufficiently large to justify investment in a new product? Is the new product sufficiently better than the competition?

Expected product distribution environment.

How will the packaged product be treated in shipping, storage, and on the shelf? Are adequate shipping facilities available?

Will installation require a professional?

B. Capability issues....

Company constraints on product design, manufacture, and distribution.

What are our manufacturing capabilities? Should we manufacture ourselves or outsource?

Schedule requirements -- time to market.

When should we have this product to market to capture maximum market share? How much time should we allocate to design?

How much time do we need to implement a manufacturing process?

DESIGN BY EVOLUTION

Evolution is Nature's design process. The natural world is full of wonderful examples of its successes, from engineering design feats such as powered flight, to the design of complex optical systems such as the mammalian eye, to the merely stunningly beautiful designs of orchids or birds of paradise. With increasing computational power, we are now able to simulate this process with greater fidelity, combining complex simulations with high-performance evolutionary algorithms to tackle problems that used to be impractical.

DESIGN BY INNOVATION

Design Innovation is not just about coming up with new ideas and products— it's also about changes that lead to growth and differentiation. Before you address new products, services, technologies, and processes, you need a foundation that leads to innovation. Here are 6 factors that will help foster an organisation of innovation

DESIGN BY IMITATION

For future humanoid robots, the cognitive capability of imitating the behavior of others is essential. Concerning human development, understanding imitation can help in understanding the origins of human intelligence. Imitation can be regarded as a key to higher-order intelligence.

Behavioural imitation is also a central issue in the cognitive and social development of human infants. Questions arise as to what and how to imitate. Exact copying of body motions is not useful because the model and the imitator often do not share either the same body characteristics or the same environmental or task situation. So at the beginning of the whole imitation process, it is necessary to extract meaningful features from the model's behavior, and to reconstruct them by using the imitator's own behavior. This in turn requires shared attention and understanding the concept of similarity among real-world events. In the real world, human behavior and task requirements alter depending on the given situation. For this reason, fixed response patterns are not suitable. Instead, actions adapted to the given situation are needed.

A synthetic study of imitation uses robots to create imitation capabilities. The use of robots for this purpose helps to understand the basics of human intelligence on the one hand, and contributes to realize multifunctional humanoid robots. Imitation and cognitive development are closely interlinked.

FACTORS AFFECTING PRODUCT DESIGN

There is a large member of factors which influence product design. These factors belong to different fields in production and industrial engineering. Also these factors vary in degree of complexity and character.

These factors can be broadly classified in four groups :

(a) Technical factors

(b) Industrial design factors

(c) Designing for production - economic factors

(d) Other factors

MORPHOLOGY OF DESIGN

Morphology means ‘a study of form or structure’. Morphology of design refers to the time based sequencing of design operations. It is a methodology of design by which ideas about things are converted into physical objects. The logical order of different activities or phases in a design project is called the morphology of design.

DESCRIPTION OF DESIGN PROCESS

A simplified approach to designing as outlined by Morris Asimow is given below. According to him the entire design process in its basic forms consists of five basic elements as given below.

- General Information
- Specific Information
- Design Operations
- Outcome
- Evaluation
- No
- Yes
- GO TO NEXT STEP

Morris Asimow was among the first to give a detailed description of the complete design process in what he called the morphology of design. His seven phases of design are described below,

I. Feasibility study / Conceptual Design

II. Preliminary Design / Embodiment Design

III. Detail design

IV. Planning for manufacture

V. Planning for distribution

VI. Planning for use

VII. Planning for retirement

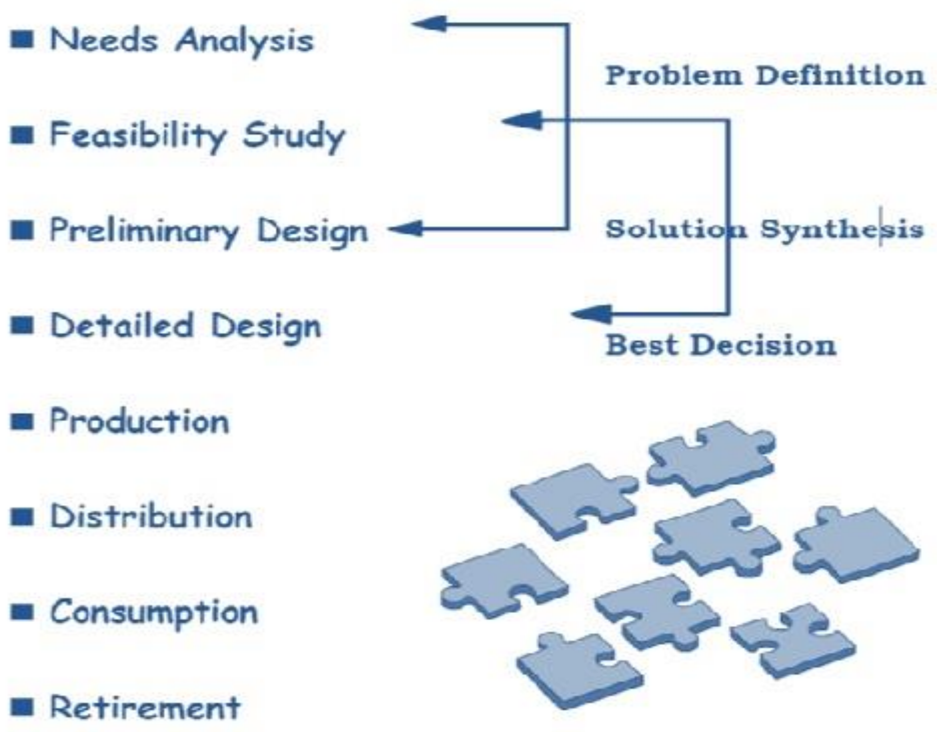

Figure 2.1 Phases of Morpology of Design

ROLE OF ASTHEICS IN DESIGN

Good design is essential in new product development, as functional, visually and ergonomically attractive products can be clearly differentiated from the competition. Designers usually have clear expectations of what they think needs to be incorporated into new products. However, it is not always easy to integrate design requirements into NPD, as there may be other, conflicting needs and so the aims of designers may be somewhat compromised in the race to market. This research project aims:

- To determine how designers perceive good and bad product design.
- To understand how design issues can be more effectively integrated into NPD.

This research started in May 2006 and is based on interviews with leading companies in Italy and the UK. It is being conducted by researchers from Cranfield School of Management and the Polytecnico di Milano and is already showing that the way designers approach their work is fundamentally different from the way managers view it.

INTRODUCTION TO OPTIMIZATION IN DESIGN

In the previous chapters, we discussed how to model uncertainty by probability theory. We also introduced commonly used uncertainty analysis techniques for quantifying the impact of the uncertainty of model input on the model output (performance). Our ultimate goal is to use the knowledge we have gained from uncertainty analysis to manage and mitigate the effects of uncertainty at the design level. Therefore, we can ensure that a design be robust and safe against various uncertainties. The commonly used probabilistic design methodologies include reliability-based design, robust design, and Design for Six Sigma. Since all of these methods need to use optimization during the design process, a brief introduction to optimization design will be given in this chapter. We will then discuss reliability-based design and robust design in Chapters 11 and 12 respectively.

Instead of providing a comprehensive presentation of optimization design techniques, this chapter is intended to present introductory materials about optimization design. It will ensure a reader acquire basic working knowledge that is necessary for optimization modeling, the use of optimization software, and the analysis of optimization results. To help one easily understand the optimization techniques, a graphical means is employed in some cases instead of providing mathematical details. After finishing this chapter and associated homework, one is expected to be able to formulate an engineering optimization problem and solve it with optimization software.

Optimization Design

Optimization is a design tool that assists designers automatically to identify the optimal design from a number of possible options, or even from an infinite set of options. Optimization design is increasingly applied in industry since it provides engineers a cheap and flexible means to identify optimal designs before physical deployment. Optimization capabilities have also been increasingly integrated with CAD/CAM/CAE software such as Adams, Nastran, and OptiStruct.

Even in our daily life, we are constantly optimizing our goals (objectives) within the limit of our resources. For example, we may minimize our expenditure or maximize our saving while maintaining a certain living level. When shopping for a car, we may try to meet our preference (performance of the car, safety, fuel economy, etc.) maximally on the condition that the price does not exceed what we can afford. It is the same case in engineering design where we optimize performances of the product while meet all the design requirements.

The first step of optimization design is to create an optimization model in mathematical formulations. This step is called optimization modeling. In this step, several decisions are to be made, such as what will be optimized, what design variables will be changed to produce an optimal design, and what requirements should be met. Modeling is the most important step in optimization design, and designers may spend a significant portion of time on modeling during the optimization process.

The second step is solving the optimization model. Three methods are usually used, including analytical method, graphical method, and numerical method. Methods of solving optimization problems will be discussed in Section 10.5.

The last step is the posterior analysis. In this step, designers perform some analyses on the optimal solution. The following questions will be answered.

Is the design optimal?

Is the design feasible?

Is the design reasonable?

What design variables are most important to the design performances?

How would the further improvement be made by modifying the optimization model?

As shown in Fig. 10.1, the optimization process is iterative. If the design solution is not satisfactory, designers will modify the optimization model and repeat the procedure until a satisfactory design is found.

Economic factors in design

Organization Size:

The smaller the organization the lesser chance of a formal structure of that organization will be. Instead of following in small organization the individuals may simply perform tasks the way they want and whatever is required to them. There may be rules set by the firm just to provide guideline with the help of which members of organization can make decisions.

As an organization develops, however, it becomes more difficult to manage the tasks without more formal structure of assigning tasks, or with delegating some of authorities to the lower hierarchy, and hence large firms produce specialized tasks and every work is done through proper guidelines and procedures.

Organization Life Cycle

Organizations tend to proceed and get progress through different stages which are called as a life cycle. Most firms go through the following stages:

Birth: In this stage, a firm is just beginning their business operations. At this stage the firms hardly have a formal structure. We can not find much delegation of authority in the beginning stage of the firm.

Youth: This is the phase in which firms try to grow the business. The focus of the firm in this stage is on becoming larger firm. The owner of the firm diverts its attention from satisfying his own wishes to satisfying wishes of the customers. During this phase there is a need for the firm to design more formal structure for operating their operations and some delegation of authority come into effect.

Midlife: This is where the organization has achieved a fair level of success. A larger organization in this stage, have a more formal structure. The levels start increasing in their chain of command and the organization may find it to difficult to manage everything with control.

Maturity: In this phase the organization reaches to maturity stage where their lack innovations and they are not usually interested in expanding their business. Their emphasis in this stage is more on increasing their profit and sustainability.

Organizations in this phase are slowly moving toward decline and may feel the need to make necessary changes to revitalize. As firms tend to get bigger, the organizations experience more structural changes

Strategy

Strategy refers to a situation in which the way firm settle itself in the market place keeping in view their services or products. An organization may decide to be always the first to introduce the newest and best products in the market (differentiation of products strategy), or it will produce already established products in the market more cost effectively (cost-leadership strategy). Any of these strategies requires a structure that must fit the strategy.

Environment

The environment is the place in which the firm is operating, and the factors such economic conditions, social and cultural situation, law and order situation, technological position and natural environment condition influences the design of organizations

Organization understand the demands of their customers very well in a more stable environment, and then firms try to satisfy those demands accordingly. That is the reason organization remains in the market for a long period of time. The customers' demands keep changing in the opposite of stable environment and hence firms experience difficulty in satisfying them.

In conclusion mechanistic organizational structure can be more beneficial for those operating in a more stable environment and hence this system increases the efficiency level of the organization which ultimately will improve their performance in the longer run.

Technology

Advancement in technology is the cause of change in the design of organizations because it helps organization in achieving higher efficiency level and help them in reducing their long term cost of production. The following are the form of latest technological production techniques:

Batch Production

Batch production is the process in which instead of manufacturing items individually, things are produced in batches. The manufacturing process takes place for each item at the same and batch of products or items are not shifted to another stage individually instead all batches are moved to the other stage of production when the each batch of items is completed.

Mass Production

Mass production is the process of manufacturing large amount of products in less time by utilizing time saving assembly. It helps a manufacturer to increase their worker per hour production and it also reduces the manufacturer labour costs of the final product. And then firms will be able to sell their products at lesser cost to attract more customers.

Continuous Process Production

In this system the manufacturers produce products by feeding the required raw materials continuously in a latest technological system. Such systems are operated by less labour; examples can be automated oil refineries and chemical factories.

Advantages of a Good Service or Product Designs:

- Firms can attract more customers by making more attracting products with good design and good services.
- Firms can better communicate with their customers through their good product or services designs.
- A good design makes a firm’s services or products more user friendly.
- It reduces the production costs of an organization and it enables them to gain better profit margin.
- As it reduces the costs of production therefore it helps an organization to gain

competitive advantage over their rivals because they will be able to sell their services and products at lower price.

- Its objects is that Tasks should achieve all required outputs and be carried out at minimum cost in order to gain competitive advantage.

DESIGN FOR SAFETY AND RELIABILITY

What is Product Reliability?

Reliability is the probability that a product will continue to work normally over a specified interval of time, under specified conditions. For example, the mouse on your computer might have a reliability of 0.990 (or 99%) over the

Next 1000 hours. It has a 99% chance of working normally during this time, which is obviously the same as saying it has a 1% chance of being faulty.

A more reliable product spends less of its time being maintained, so there is often a design trade-off between reliability and maintainability. Reliability is extremely design-sensitive. Very slight changes to the design of a component can cause profound changes in reliability, which is why it is important to specify product reliability and maintainability targets before any design work is undertaken. This in turn requires early knowledge of the anticipated service life of the product, and the degree to which parts of the product are to be made replaceable.

For example, a ballpoint pen could be:

Disposable

It will be reliable until the ink is exhausted, at which point it is discarded. Neither the ink nor parts of the pen body are replaceable, so the pen body needs to last no longer than the ink. The product has a short service life.

Refillable

It will be designed for routine replacement of ink (usually as an ink cartridge), but pen body parts will not be replaceable. The body must be reliable enough to outlast the specified number of ink replacement cycles. The product has a moderate service life.

Repairable (fully maintainable)

The pen is refillable and all body parts are replaceable. The product has an extendable service life (until the spare parts are no longer available).

Note that product service life is not the same as market life. The market life (also known as the design life) of a product is the length of time the product will continue to be sold in the shops and supported before being withdrawn. For example, a particular brand of disposable razor may have a service life of ‘3 shaves’, but a market life of 10 years.

Reliability & The Bathtub Curve:

For a sufficiently large population of a particular item (component or product), failures will be distributed in time as shown in the graph below. Different times and failure rates will obviously apply to different kinds of item, although the general shape of the curve will be similar in all cases. The graph goes by the name of ‘the bathtub curve’ because of its characteristic shape. Note that the highest failure rates correspond to premature failure (sometimes called ‘infant mortality’), and to end-of life wear out.

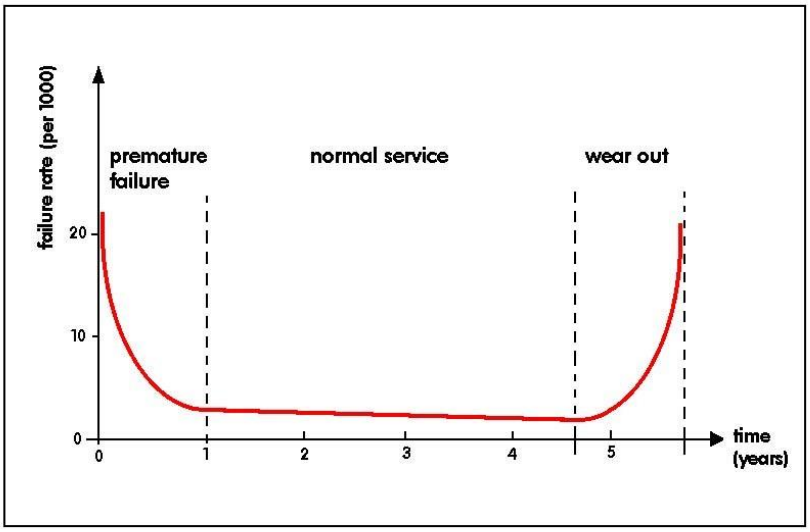

Figure 2.2 The Bath Tub Curve

While we expect our products to fail after some years of useful service, premature failures are particularly undesirable and are almost always the result of bad design or sloppy manufacturing. Premature failures can be largely eliminated by identifying and designing out the component failure modes, illustrated in the table below:

Life phase	Cause of failure	Prevention / remedy
Premature Failures	Component is good but inappropriately installed.	Installation method is part of design responsibility.
Premature failures	Component is damaged during product assembly.	Liaison with production management – change component design or

		assembly method.
Premature failures	Component is damaged during product maintenance.	Adjust design according to field data. Adopt 'design for maintainability'.
Premature Failures	Overall product design is poor and introduces unnecessarily high stress levels throughout.	Back to the drawing board.
Normal service phase (random) failures	Careless handling. Accidents.	Ruggedize, examine product with respect to shock and vibration.
	Severe natural phenomena (lightning, freak weather, sun-storms, meteorites). Acts of War.	Ruggedization, otherwise no economic remedy.
Wear-out failures	Mechanical wear. Component wears out at the end of its declared life (through abrasion or material depletion). E.g. tires	Consider product maintenance or disposal. E.g. replace tires
	Component wears out before reaching its intended life.	Increase specification, ruggedize, reduce stress environment, revise target life

Table 2.1 Components Failure Modes

Safety Critical Design:

Product reliability and safety are related. If a product is performing a safety-critical role, then failure of a key component can have dire consequences. There are several approaches to minimizing the risk of catastrophic failure:

1. **Over-specification**: For product applications in the building and construction industry, it is standard practice to include a 'x5' safety factor in all material strength calculations. For example: a suspension bracket for a 10kg light fitting will be designed to carry at least 50kg.
2. **Redundancy (parallel):** Multiple identical components are used simultaneously, any one of which would be capable of supporting normal product function. For example, a passenger lift has 4 cables carrying the lift cabin, all sharing the load. Any one cable would be capable of carrying the full passenger lift load. A failure of up to 3 cables will not endanger the lift occupants. Flight control and instrument systems in some aircraft adopt a similar strategy. Dual wiring in military systems improves survivability.

3. **Redundancy (standby):** A back-up system is held in reserve and comes into operation only when the main system fails, for example stand-by generators in hospitals, and reserve parachutes. The light fitting mentioned above might have a safety chain loosely fitted, to catch the light fitting if the support bracket fails. The chain would be an example of standby redundancy. Standby redundancy is often described as a 'belt & braces' approach.

4. **Fail-safe design**: Assumes an inherent risk of failure for which the cost of any of the above three strategies would be prohibitively high. The product or system is designed to drop into a safe condition in the event of partial or total failure. For example:

a. The gas supply to a domestic central heating boiler is shut off in the absence of a 'healthy' signal from the
b. Water pump, flame sensor, water pressure sensor, or exhaust fan.
c. Toys can be designed to fracture at pre-determined weak points so as to leave no sharp projections that would injure a child.
d. Railway train brakes are released by vacuum, and applied by admitting air. If a brake pipe bursts, the admitted air automatically applies the train brakes.

The 10 Rule:

Design errors create rework costs. Errors detected during the component design phase can be corrected locally without serious impact on development times and costs. However, with each successive stage in development, the rework cost increases by a factor of ten, so that:

Stage of production	Rework costs (correcting errors)
Component design and manufacture	X 1
Prototyping and Sub-assembly manufacture	X 10
Final product assembly	X 100
Volume product shipped to dealers	X 1000
Volume product sold to customers and in use	X 10000

Table 2.2 Stage of Production

Thorough testing at each stage of manufacture saves costs in the long run, especially during prototype and pre-production stages.

Pareto analysis (the 80/20 rule):

The 80/20 rule is an observation that populations (of people, objects or events) can often be roughly divided into the 'vital 20%' and the 'trivial 80%'. In the context of product reliability, it is said that 20% of product faults are responsible for 80% of the failure costs. Clearly the priority is to identify this 20% and provide an early remedy. A useful tool for identifying the vital 20% is the Pareto chart, which is a simple graphical technique for displaying recorded faults. Fault rates under specific headings are tabulated, costed, converted to graphical form (usually a bar chart) and examined for individual cost contribution. The individual faults responsible for the highest costs are obviously the ones to remedy first. For example, the chart below shows the 8 most common faults appearing on a particular automobile:

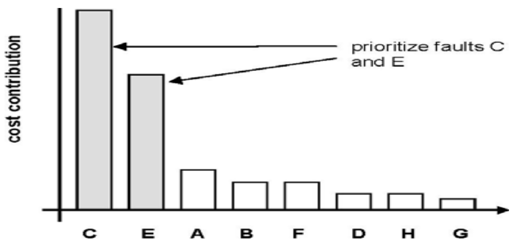

Figure 2.3 Pareto Chart

Faults C and E, being the most costly, should be prioritized for remedial design work.

More Reliability Design Examples:

Reliability problem	Remedy
Leaking drain plug in central heating boiler.	Sensitivity to insertion torque and temperature tested. All plugs inserted to the newly established optimum torque. Thread locking paste used.
Fretting of rolled brass foil receptors on aircraft electric wiring connectors, giving bad connections and errors in instrument readings.	Rolled foil design replaced by expanding wire cage design, giving 'wiping' action, larger contact area and higher retention force. Gold plated to eliminate corrosion.

Frequent breaking of piston rings in aircraft engine.	Optimum piston and bore dimensions established and tolerances tightened. Engine lubrication system revised.
Vibration leading to failure in domestic fan heater.	Vibration traced to misalignment of 2 stub axles on a cylindrical fan. Replaced with a single long axle.
Car side light bulbs showing weakness at base of bulb, where bulb stem and glass envelope are melted together in a gas/air flame during manufacture.	Process tightened to give greater control over gas pressure, jet size, melt time, rotation speed. Taguchi methodology used to find optimum settings and minimize sensitivity to factory air temperature variations.
Faults in aluminum casting for electric motor (1). Voids and sand inclusions.	Sensitivity to melt temperature, mould temperature, sand moisture content, additive content, and pouring speed established. Conditions reset to optimum.
Faults in aluminum casting for electric motor (2). Warping of casting, some areas not filled.	Design of casting revised – uniform wall and rib thickness throughout. Corners rounded to improve metal flow in some areas.
Handsets on public telephones. Rising breakage rate in the field – suspected vandalism.	Handsets found to be brittle when cold. Analysis of plastic showed departure from specified grade of polycarbonate. Material supply error corrected.
Mechanical contacts (ignition points) on car prone to corrosion and in need of constant adjustment. Common cause of vehicle breakdown.	Mechanical switch points replaced with a sealed inductive device and control unit – electronic ignition.
Premature failure of pivot points in hand-operated staple tacker gun.	Soft steel case rivets were being used as pivot axles to save cost. Design revised to provide hardened sleeves over rivets at points of high wear. Rivets upgraded.
Early wear-out failure of conveyor belt end bearings (ball bearings).	Caused by shocks from heavy materials passing over end roller and by ingress of dust. The ball bearings were replaced with sealed taper roller bearings to provide a bigger load-bearing area and keep out dust.
Frequent breakage of keys in a particular type of lock, due to need for excessive force in turning key.	Lock mechanism and guide plates found to be misaligned due to inconsistent choice of datum lines on engineering drawings. Error corrected on drawings.
Faulty electric food whisks being returned to shop within 6 months of purchase. All show signs of twist in the mains cord.	Some users impart a twist to the mains cord when coiling it up. Cable entry point revised to incorporate an anti-twist cord grip and strain relief sleeve.

Expensive integrated circuit failing prematurely in data logger prototype.	Found to be a 12-volt device running on a 20-volt supply. Power supply and prototype circuit had to be redesigned to operate at 12 volts, since the IC was not available in a 20-volt version.
Vending machine faults – outdoor location at seaside. Corrosion of tracks on electronic circuits.	Circuits given conformal coating (a waterproof coating to keep out the corrosive salt-laden damp air). Connector contacts gold plated.
Filament lamps on road vehicles have short lives because of vibration and thermal shock.	Filament lamp bulbs (indicators, brake, side and rear fog lamps) all replaced with high intensity LED arrays, which have longer natural life and are less affected by thermal and mechanical shock.

Table 2.3 Reliablity Design Examples

UNIT II

BASIC CONCEPTS

S.No.	PART - A
1	Define product design.
2	Summarize the factors affecting the product design.
3	Differentiate between design by innovation and design by imitation?
4	What is meant by standards of performance?
5	Define morphology of design
6	Define optimization in design.
7	How does the aesthetic factor influence in design?
8	Why the Economic factors should be considered in product design?
9	What is design by evolution and design by innovation?
10	What is design for reliability?

S.No.	PART - B
1	Explain the factors affecting product design
2	Explain about the design by Evolution, Design by Innovation and Imitation
3	Explain the standards of performance and environmental factors in product design.

4	Explain the phases of morphology of design with Flowchart
5	Explain the optimization in design with an example.
6	Explain the design for safety and reliability with example.

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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 3 – ROLE OF COMPUTERS IN PRODUCT DESIGN – SME1310

Geometric Modeling - types - Wire frame surface and solid modeling - Boundary Representation, constructive solid geometry - Graphics standards - assembly modeling - use of software packages Modeling and simulation-the role of models in engineering design- Design for manufacturing, Rapid proto typing (RP) - application of RP in product design.

INTRODUCTION TO GEOMETRIC MODELLING

Geometric modeling is as important to CAD as governing equilibrium equations to classical engineering fields as mechanics and thermal fluids."

- Intelligent decision on the types of entities
- Necessary to use in a particular model to meet certain geometric requirements such as slopes and/or curvatures.
- Interpretation of unexpected results
- Evaluations of CAD/CAM systems
- Innovative use of the tools in particular applications.
- Creation of new attributes, or modify the obtained models to benefit new engineering applications.
- Understanding of terminology

- Complete part representation including topological and geometrical data
  - Topology: the connectivity and associatively of the object entities; it determines the relational information between object entities
- Able to transfer data directly from CAD to CAE and CAM.
- Support various engineering applications, such as mass properties, mechanism analysis, FEM and tool path creation for CNC, and so on.

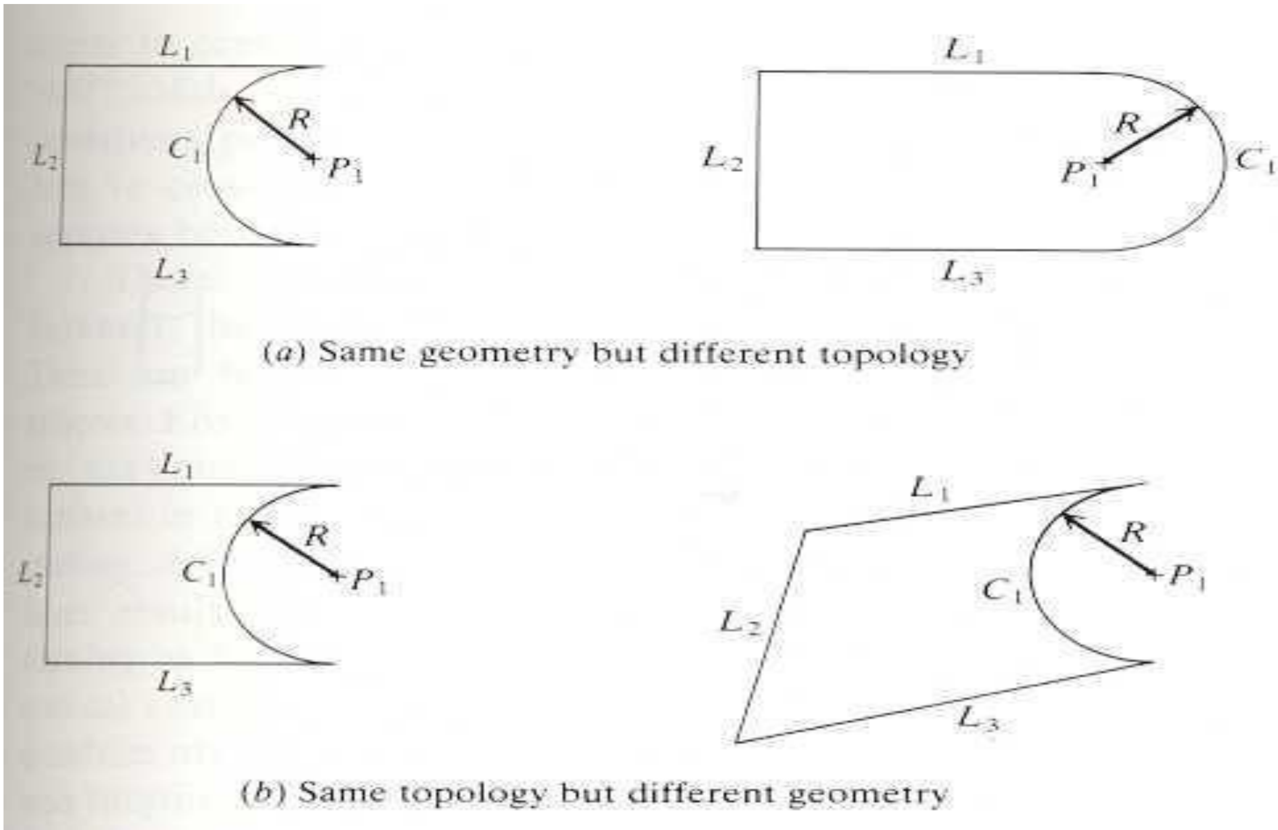


Figure 3.1 Geometry and Topology

Comments on Geometric Modeling

- Geometric modeling is only a means not the goal in engineering.
- Engineering analysis needs product geometry; the degree of detail depends on the analysis procedure that utilizes the geometry.
- There is no model that is sufficient to study all behavioural aspects of an engineering component or a system.
- Attributes facilitate analysis and grow with application

Basic Geometric Modelling Techniques:

- Wire frame Modelling
- Surface Modelling
- Solid Modelling

- 2D Projection (Drawings)

Problems:

- Training is necessary to understand the drawing
- Mistakes often occur
- Does not support subsequent applications such as finite element analysis (FEA) or NC part programming

Wireframe Modeling:

- Developed in 1960s and referred as "a stick figure" or "an edge representation"
- The word "wireframe" is related to the fact that one may imagine a wire that is bent to follow the object edges to generate a model.
- Model consists entirely of points, lines, arcs and circles, conics, and curves.
- In 3D wireframe model, an object is not recorded as a solid. Instead the vertices that define the boundary of the object, or the intersections of the edges of the object boundary are recorded as a collection of points and their connectivity.

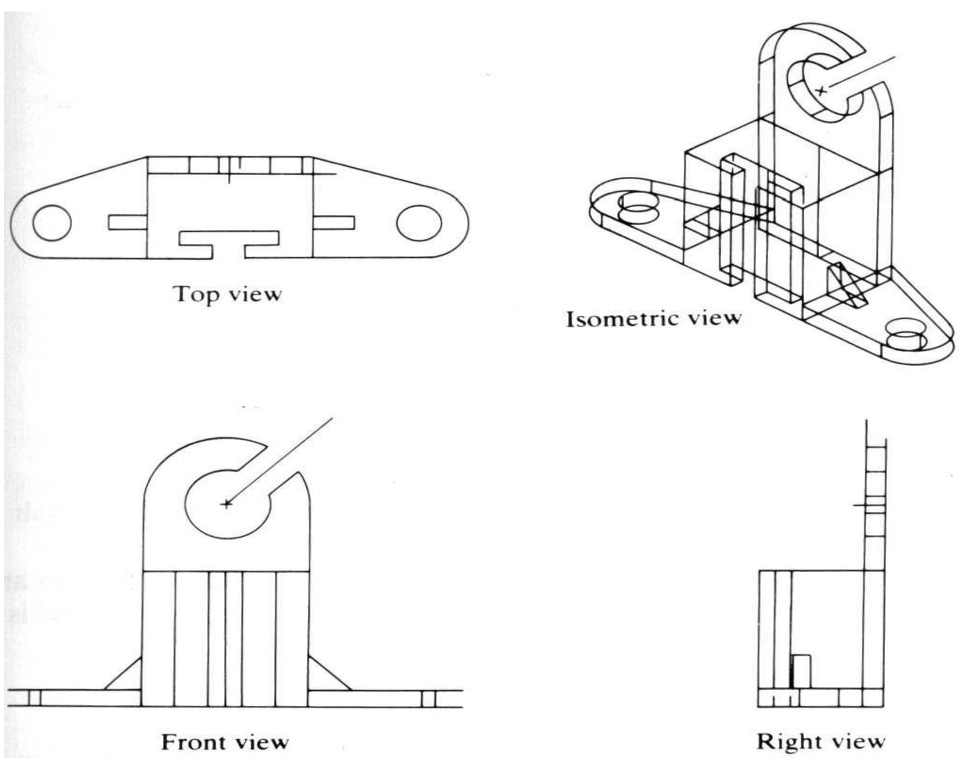


Figure3.2 Wire frame model and its views

Advantages of Wireframe Modeling

- Simple to construct
- Does not require as much as computer time and memory as does surface or solid modeling
- As a natural extension of drafting, it does not require extensive training of users.
- Form the basis for surface modeling as most surface algorithms require wireframe entities (such as points, lines and curves)

Disadvantages

- The input time is substantial and increases rapidly with the complexity of the object
- Both detailed topological and geometric data need to be user-input;
- Unless the object is two-and-a-half dimensional, volume and mass properties, NC tool path generation, cross-sectioning, and interference cannot be calculated.
- Models are usually ambiguous (figures) and "nonsense" object may result.
- Ambiguous

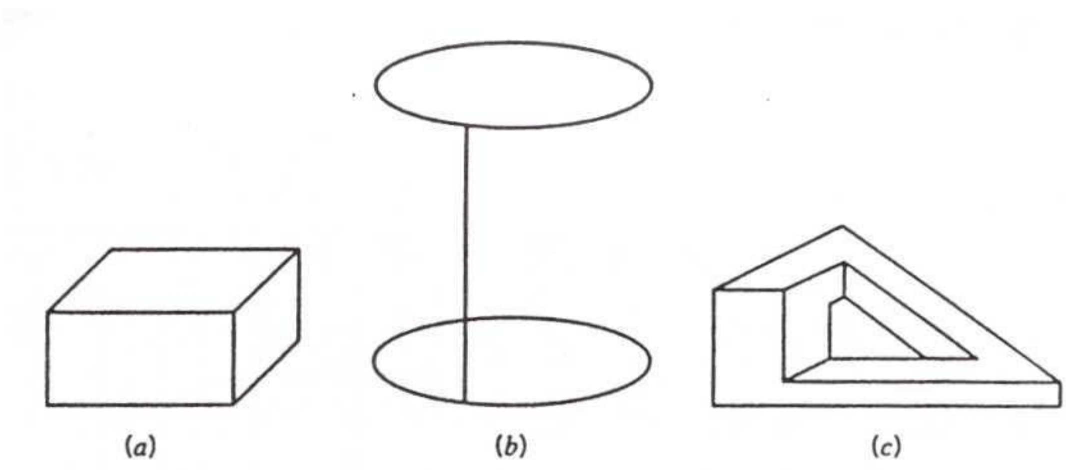


Figure 3.3 Wireframe Model

- Lack of visual coherence and information to determine the object profile

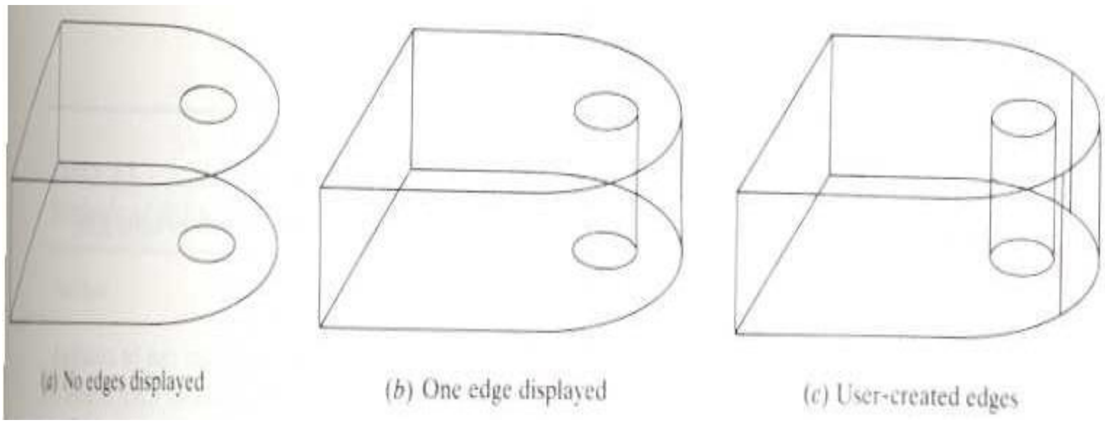


Figure 3.4 Wire frame Model with Edges

Surface Modeling

- A surface model is a set of faces.
- A surface model consists of wireframe entities that form the basis to create surface entities.
- In general, a wireframe model can be extracted from a surface model by deleting or blanking all surface entities
- Shape design and representation of complex objects such as car, ship, and airplane bodies as well as Castings

Examples of Surface Models

- Surface models define only the geometry, no topology.
- Shading is possible

Advantages of Surface Modeling

- Less ambiguous
- Provide hidden line and surface algorithms to add realism to the displayed geometry

- Support shading
- Support volume and mass calculation, finite element modeling, NC path generation, cross sectioning, and interference detection.

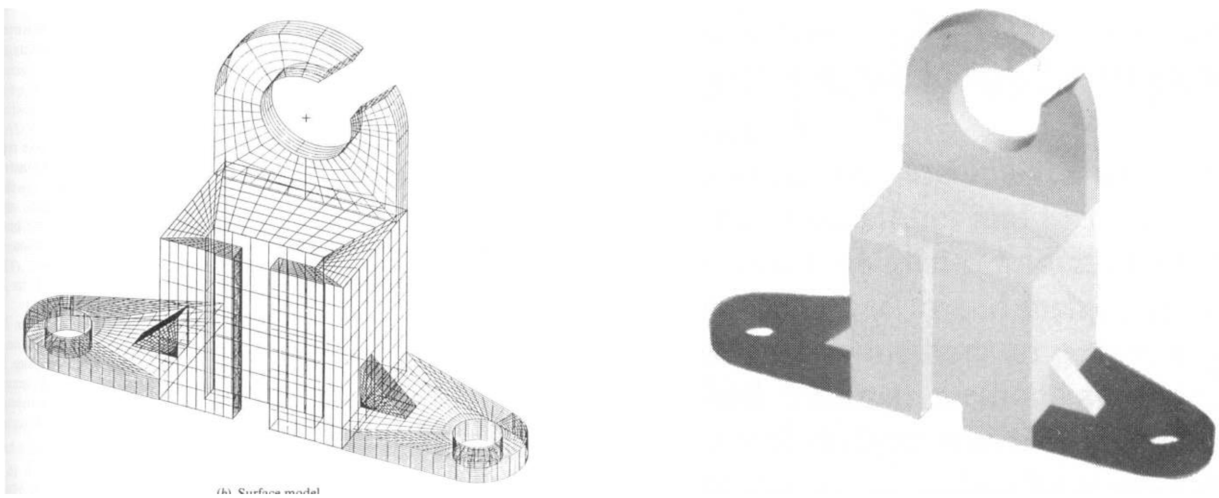


Figure 3.5 Surface Modelling

Disadvantages

- Require more training and mathematical background of the users
- Require more CPU time and memory
- Still ambiguous; no topological information
- Awkward to construct

Solid Modeling

- Informationally complete, valid, and unambiguous representation (Spatial addressability)
- points in space to be classified relative to the object, if it is inside, outside, or on the object
- Store both geometric and topological information; can verify whether two objects occupy the same space.
- Improves the quality of design, improves visualization, and has potential for functional automation and integration.

- Support
- Weight or volume calculation, centroids, moments of inertia calculation,
    - Stress analysis (finite elements analysis), heat conduction calculations, dynamic analysis,
    - Generation of CNC codes, and robotic and assembly simulation

Boundary Representation (B-rep)

Boundary representation is one of the two most popular and widely used schemes to create solid models of physical objects. A B-rep model or boundary model is based on the topological notion that a physical object is bounded by a set of faces. These faces are regions or subsets of closed and orientable surfaces. A closed surface is one that is continuous without breaks. An orientable surface is one in which it is possible to distinguish two sides by using the direction of the surface normal to point to the inside or outside of the solid model under construction. Each face is bounded by edges and each edge is bounded by vertices. Thus, topologically, a boundary model of an object is comprised of faces, edges, and vertices of the object linked together in such a way as to ensure the topological consistency of the model.

Topological and geometrical information of B-rep

The database of a boundary model contains both its topology and geometry. Topology is created by performing Euler operations and geometry is created by performing Euclidean calculations. Euler operations are used to create, manipulate, and edit the faces, edges, and vertices of a boundary model as the set (Boolean) operations create, manipulate, and edit primitives of CSG models. Euler operators, as Boolean

Primitives of B-rep

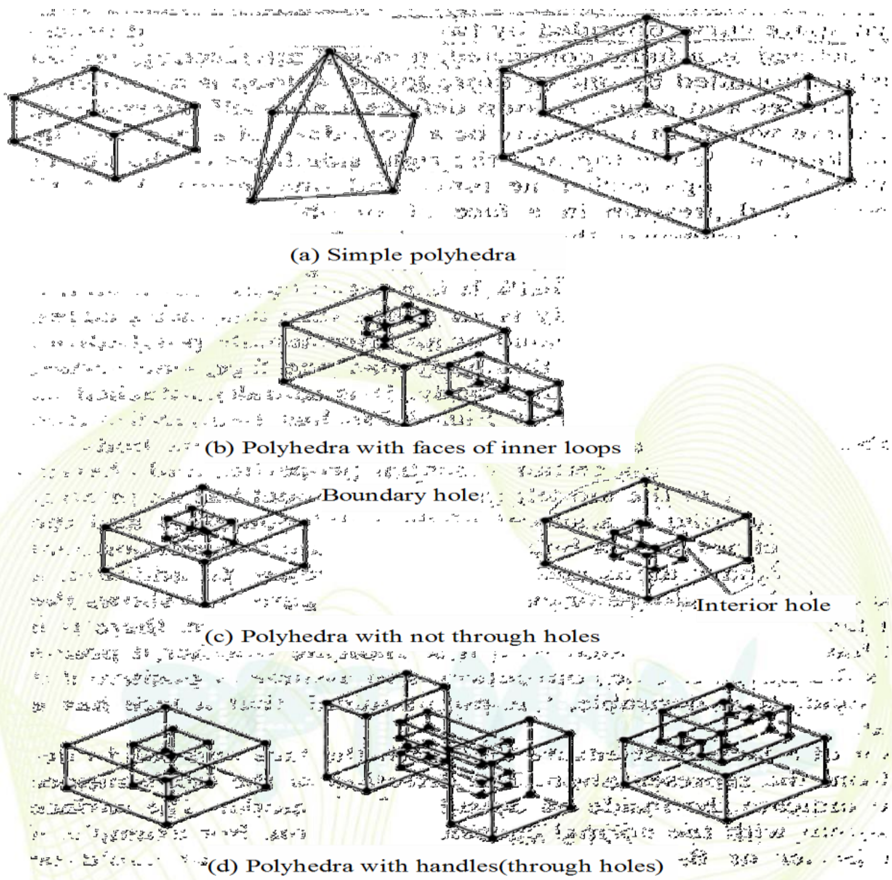
If a solid modeling system is to be designed, the domain of its representation scheme (objects that can be modeled) must be defined, the basic elements (primitives) needed to cover such modeling domain must be identified, the proper operators that enable the system users to build complex objects by combining the primitives must be developed, and finally a suitable data structure must be designed to store all relevant data and information of the solid model.

Objects that are often encountered in engineering applications can be classified as either polyhedral or curved objects. A polyhedral object (plane-faced polyhedron) consists of planar faces (or sides) connected at straight (linear) edges which, in turn, are connected at vertices. A cube or a tetrahedron is an obvious example. A curved object (curved polyhedron) is similar to a polyhedral object but with curved faces and edges instead.

The reader might have jumped intuitively to the conclusion that the primitives of a B-rep scheme are faces, edges, and vertices. This is true if we can answer the following two questions. First, what is a face, edge, or a vertex? Second, knowing the answer to the first question, how can we know that when we combine these primitives we would create valid objects?

Polyhedral objects can be classified into four classes. The first class is the simple polyhedra. The second class (Figure4 (b)) is similar to the first with the exception that a face may be bounded by more than one loop of edges. The third class (Figure4(c)) includes objects with holes that do not go through the entire object. The fourth and the last class includes objects that have holes that go through the entire objects. Topologically, these through holes are called handles.

With the above physical insight, let us define the primitives of a B-rep scheme. A vertex is a unique point (an ordered triplet) in space. An edge is a finite, non-self-intersecting, directed space curve bounded by two vertices that are not necessarily distinct. A face is defined as a finite connected, non-self-intersecting, region of a closed oriented surface bounded by one or more loops. A loop is an ordered alternating sequence of vertices and edges. A loop defines a non-self-intersecting, piecewise, closed space curve which, in turn, may be a boundary of a face. In Figure4(a), each face has one loop while the top and the right side faces of the object shown in Figure4(b) have two loops each (one inner and one outer). A handle (or through hole) is defined as a passageway that pierces the object completely. The topological name for the number of handles in an object is genus. The last item to be defined is a body (sometimes called a shell). It is a set of faces that bound a single connected closed volume. Thus a body is an entity that has faces, edges, and vertices. A minimum body point. Topologically this body has one face, one vertex, and no edges. The object on the right of Figure4(c) has two bodies (the exterior and interior cubes) and any other object in Figure 3.6 has only one body.



(a) Simple polyhedra

(b) Polyhedra with faces of inner loops

(c) Polyhedra with not through holes

(d) Polyhedra with handles(through holes)

Faces of boundary models possess certain essential properties and characteristics that ensure the regularity of the model; that is, the model has an interior and a boundary. Faces are two-dimensional homogeneous regions so they have areas and no dangling edges. In addition, a face is a subset of some underlying closed oriented surface. At each point on the face, there is a surface normal N that has a sign associated with it to indicate whether it points into or away from the solid interior.

In traversing loops, the edges of the face outer loop is traversed, say, in a counterclockwise direction and the edges of the inner loops are traversed in the opposite direction, say the clockwise direction.

Euler's Law

Euler (in 1752) proved that polyhedra are topologically valid if they satisfy the following equation:

$F - E + V - L = 2(B - G)$ --(1)

Where F, E, V, L, B, and G are the number of faces, edges, vertices, faces' inner loop,

bodies, and genus respectively. Eq.(1) is known as the Euler or Euler-Poincare law.

Open objects satisfy the following Euler's law:

$F - E + V - L = B - G$---(2)

Exact B-rep and faceted B-rep

The boundary model of a sphere has one face and one vertex. We now turn from polyhedral objects to curved objects such as cylinders and spheres. As shown in Figure 3.7, the boundary model of a cylinder has three faces (top, bottom, and cylindrical face itself), two vertices, and three edges connecting the two vertices. The other "edges" are for visualization purposes. They are called silhouette edges.

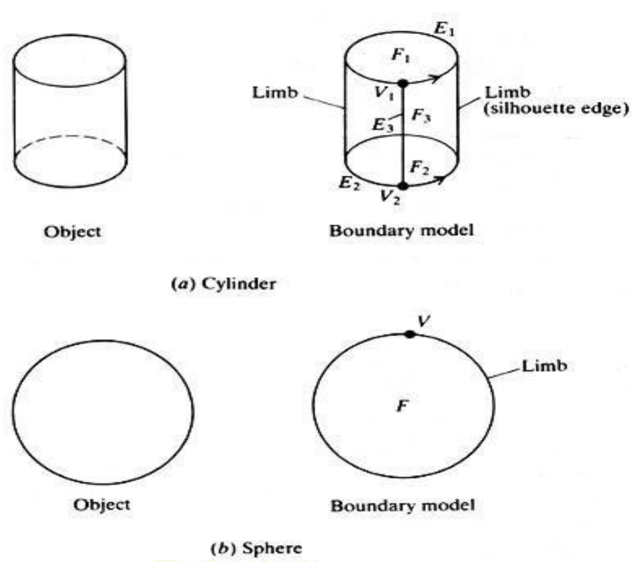


Figure 3.7 Boundary Model of a Cylinder

If the curved objects are represented by storing the equations of the underlying curves and surfaces of the object edges and faces respectively, the resulting boundary scheme is known as an exact B-rep scheme. Another alternative is the approximate or faceted B-rep. In this scheme, any curved face is divided into planar facets – hence the name faceted B-rep.

Advantages and disadvantages of B-rep

The B-rep scheme is very popular and has a strong history in computer graphics because it is closely related to traditional drafting. Its main advantage is that it is very appropriate to construct solid models of unusual shapes that are difficult to build using primitives.

Another major advantage is that it is relatively simple to convert a B-rep model into a wireframe model because the model's boundary definition is similar to the wireframe definition.

One of the major disadvantages of the boundary model is that it requires large amounts of storage because it stores the explicit definition of the model boundaries. It is also a verbose scheme – more verbose than CSG. The model is defined by its faces, edges, and vertices which tend to grow fairly fast for complex models. If B-rep systems do not have a CSG-compatible user interface, then it becomes slow and inconvenient to use Euler operators in a design and production environment.

Constructive Solid Geometry?

Contents

1.0 Introduction: Intelligent Geometry

Constructive solid geometry (CSG) is a type of intelligent geometry that gives the programmer extra information. CSG uses simple objects called "solids", constructed according to geometric rules. The special properties of CSG solids allow mathematical operations that are not possible with an arbitrary polygon mesh. It's no wonder that games like Half-Life 2, Doom 3, and Unreal Tournament 2004 rely on CSG as the basis of their world geometry.

2.0 **Constructive Solid Geometry Defined**

CSG solids are simple convex objects, made out of intersecting coplanar faces as shown in Figure 3.8:

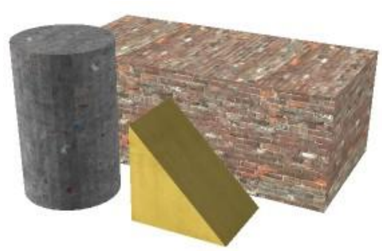


Figure 3.8a CSG Solids

Convex means that all faces point out away from each other:

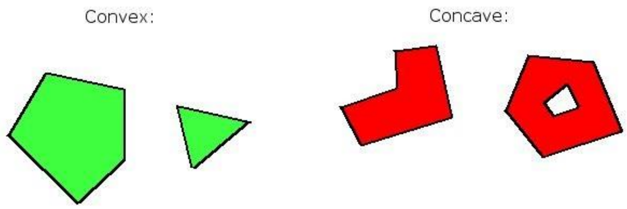


Figure 3.8 b Convex and Concave Faces

Coplanar means that all the vertices of a face lie along the same plane:

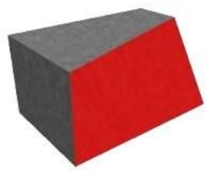
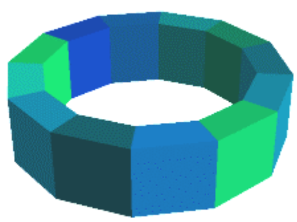


Figure 3.8 Coplanar Faces

The top right vertex has been moved inwards to make the selected face non-coplanar.

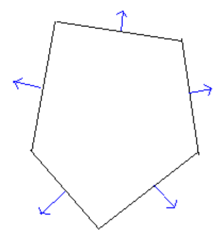
Concave objects can be created using multiple convex solids:



This concave solid still follows the rules of CSG; each individual solid is convex.

3.0 Constructive Solid Geometry in Action

The special properties of CSG solids allow mathematical operations that are not possible with an arbitrary polygon mesh. CSG solids are made out of intersecting coplanar faces. Each face has an ascertainable plane equation, defined as a 3D vector, plus a distance from the origin:



Each face has a normal indicating the direction it points, and a distance from the origin.

The intersection of the planes defines the solid.

Basic CSG Operations

Two equations form the basis of more complex operations.

Equation for distance between a point and a plane

The sign of the result indicates whether the point is in front of or behind the plane.

Distance between point A and plane B = (Bd–Bnx*Ax–Bny*Ay–Bnz*Az)

Equation for ray-plane intersection

Determines the intersection point of a line in 3D space with a plane.

Intersection of ray AB with plane C:

u = (-Cnx*Ax–Cny*Ay–Cnz*Az+d)/(-Cnx*(Ax–Bx)–Cny*(Ay–By)–Cnz*(Az–Bz))

x= Ax+(Bx-Ax)*u

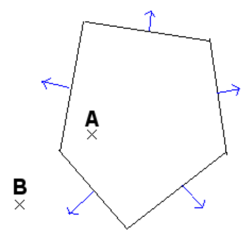
y = Ay+(By-Ay)*u z = Az+(Bz-Az)*u

3.1 Intermediate CSG Operations

Intermediate operations based on basic CSG operations can be useful during runtime, and form the basis of advanced CSG operations.

Point-solid intersection

If the point is behind every face of the solid, it lies within the solid. A radius value can be added to the "d" component of each plane to test a sphere instead of a point.



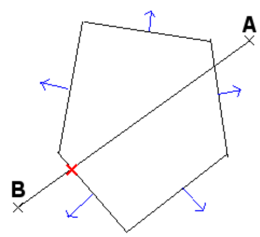
Point A lies behind each face, and is within the brush. Point B lies behind 3 faces, but in front of 2, so it is not within the brush.

Point-solid intersection can be used for:

Make a player step into water or an invisible trigger zone.

Ray-solid intersection

If the intersection point of the ray and any of the planes in the solid lies behind all the other planes, the ray must intersect the solid.



The intersection point, shown in red, passes the point-brush intersection test when the intersecting face is dismissed. Therefore, the line AB intersects the solid.

Ray-solid intersection can be used for:

- Check visibility between two players.
- Check visibility between a light and an object.
- Player collision (add a radius value to the d component of each plane).

Solid-solid intersection

If any vertex of either solid lies within the other solid, the solids intersect. If any edge of one solid intersects the other solid, the solids intersect.

Solid-solid intersection can be used for:

- Camera frustum occlusion.
- Make a projector that casts an image onto objects.

Find the silhouette of a solid from a point or vector

Each edge lies between two faces. If one face points towards the point, and the other points away, that edge is part of the outline. The silhouette of a convex object is always convex. This is the basis of solid extrusion.

GRAPHICS STANDARDS

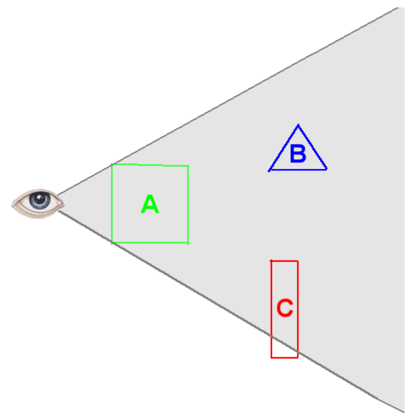
A brand is a perception people hold in their minds. It’s more than logos, colors, websites, cheers and chants, traditions or billboards. It’s the reputation, quality, personality and unique attributes of an organization. Our brand is everything people think when they hear the words University of Houston. It is our main vehicle for telling our story. By having a strong, unified brand we shape people’s perception of UH for the better.

Extrude solid from point or vector

Find the silhouette of the solid, then extrude away from the point or along the vector. This creates another solid that defines the shadow volume of the original. If a point or solid lies entirely within this volume, that object is completely occluded by the original solid. These kinds of extrusions are used frequently for lighting and portal occlusion systems.

Solid extrusion can be used for:

- Make a solid occlude another object.
- Calculate the shadow volume of an object.



Solid A occludes solid B completely, and partially occludes solid C. The silhouette of solid A has been extruded from the eye position. The resulting solid, shown in gray, encloses object B.

Solid slicing

A solid can be sliced in half with an arbitrary plane. This is used frequently in portal and BSP occlusion systems.

Solid slicing can be used for:

- Cut a solid in half along the bounds of a rendering zone.

3.2 Advanced CSG Operations

The previous operations described form the basis of even higher-level operations. These are advanced techniques that cannot be described with a simple equation, and will vary with implementation.

Texture mapping

Texture coordinates tell the GPU how a texture lies across the surface of an object. Solids' texture coordinates can be calculated on-the-fly, with user control over parameters like scale, position, rotation, and shearing. This is done by generating texture mapping axes per face, based on face normals. The texture coordinates for any vertex of a face can be calculated from the vertex position and face texture mapping axes:

u = unx*x+uny*y+unz*z+ud v = vnx*x+vny*y+vnz*z+vd

Portal occlusion systems

Portal occlusion systems separate the scene into large chunks (portal zones) connected to each other through “doorways” called portals. This allows the renderer to skip geometry that is not only off-screen, but occluded by other objects in the foreground. This is difficult, if not impossible, without CSG.

Static light calculation

Ray-tracer lightmappers create a colored texture to simulate the lighting environment. Light maps can quickly be allocated to CSG brushes, and volume intersections can quickly dismiss objects which do not cast shadows onto a surface.

Dynamic light calculation

Some rendering systems calculate lighting in real-time, usually using the stencil buffer to render shadows, and rendering the scene in multiple additive passes. These calculations are very demanding, and a good occlusion system (portal, BSP, or a combination of both) is crucial.

Binary Space Partitioning

Binary space partitioning (BSP) is a method of optimizing a static scene by splitting the geometry into a recursive hierarchy of BSP leaves and nodes, forming a BSP tree. A BSP tree can be used to optimize collision, occlusion, and other calculations, by excluding huge regions of the scene that are irrelevant. Performance gains are typically exponential when a BSP tree is utilized.

ASSEMBLY MODELLING

Assembly modeling is a technology and method used by computer-aided design and product visualization computer software systems to handle multiple files that represent components within a product. The components within an assembly are represented as solid or surface models.

The designer generally has access to models that others are working on concurrently. For example, several people may be designing one machine that has many parts. New parts are added to an assembly model as they are created. Each designer has access to the assembly model, while a work in progress, and while working in their own parts. The design evolution is visible to everyone involved. Depending on the system, it might be necessary for the users to acquire the latest versions saved of each individual components to update the assembly.

The individual data files describing the 3D geometry of individual components are assembled together through a number of sub-assembly levels to create an assembly describing the whole product. All CAD and CPD systems support this form of bottom-upconstruction. Some systems, via associative copying of geometry between components also allow top-down method of design.

Components can be positioned within the product assembly using absolute coordinate placement methods or by means of mating conditions. Mating conditions are definitions of the relative position of components between each other; for example alignment of axis of two holes or distance of two faces from one another. The final position of all components based on these relationships is calculated using a geometry constraint engine built into the CAD or visualization package.

The importance of assembly modeling in achieving the full benefits of PLM has led to ongoing advances in this technology. These include the use of lightweight data structures such as JT that allow visualization of and interaction with large amounts of product data, direct interface to between Digital Mock ups and PDM systems and active digital mock uptechnology that unites the ability to visualize the assembly mock up with the ability to measure, analyze, simulate, design and redesign.

ROLE OF MODELS IN ENGINEERING DESIGN AND SIMULATION

Modeling and simulation (M&S) is the use of models – physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process – as a basis for simulations – methods for implementing a model (either statically or) over time – to develop data as a basis for managerial or technical decision making through the exercise of simulation governance which covers analysis, experimentation, and training. As such, M&S can facilitate understanding a system's behavior without actually testing the system in the real world. For instance, to determine which type of spoiler would improve traction the most while designing a race car, a computer simulation of the car could be used to estimate the effect of different spoiler shapes on the coefficient of friction in a turn. Useful insights about different decisions in the design could be gleaned without actually building the car. In addition, simulation can support experimentation that occurs totally in software, or in human-in-the-loop environments where simulation represents systems or generates data needed to meet experiment objectives. Furthermore, simulation can be used to train persons using a virtual environment that would otherwise be difficult or expensive to produce.

The use of M&S within engineering is well recognized. Simulation technology belongs to the tool set of engineers of all application domains and has been included in the body of knowledge of engineering management. M&S helps to reduce costs, increase the quality of products and systems, and document and archive lessons learned.

M&S is a discipline on its own. Its many application domains often lead to the assumption that M&S is pure application. This is not the case and needs to be recognized by engineering management experts who want to use M&S. To ensure that the results of simulation are applicable to the real world, the engineering manager must understand the assumptions, conceptualizations, and implementation constraints of this emerging field.

Technically, simulation is well accepted. The 2006 National Science Foundation (NSF) Report on "Simulation-based Engineering Science" showed the potential of using simulation technology and methods to revolutionize the engineering science. Among the reasons for the steadily increasing interest in simulation applications are the following:

1. Using simulations is generally cheaper, safer and sometimes more ethical than conducting real-world experiments. For example, supercomputers are sometimes used to simulate the detonation of nuclear devices and their effects in order to

support better preparedness in the event of a nuclear explosion. Similar efforts are conducted to simulate hurricanes and other natural catastrophes.

2. Simulations can often be even more realistic than traditional experiments, as they allow the free configuration of environment parameters found in the operational application field of the final product. Examples are supporting deep water operation of the US Navy or the simulating the surface of neighbored planets in preparation of NASA missions.
3. Simulations can often be conducted faster than real time. This allows using them for efficient if-then-else analyses of different alternatives, in particular when the necessary data to initialize the simulation can easily be obtained from operational data. This use of simulation adds decision support simulation systems to the tool box of traditional decision support systems.
4. Simulations allow setting up a coherent synthetic environment that allows for integration of simulated systems in the early analysis phase via mixed virtual systems with first prototypical components to a virtual test environment for the final system. If managed correctly, the environment can be migrated from the development and test domain to the training and education domain in follow-on life cycle phases for the systems (including the option to train and optimize a virtual twin of the real system under realistic constraints even before first components are being built).
5. The military and defense domain, in particular within the United States, has been the main M&S champion, in form of funding as well as application of M&S. E.g., M&S in modern military organizations is part of the acquisition/procurement strategy. Specifically, M&S is used to conduct Events and Experiments that influence requirements and training for military systems. As such, M&S is considered an integral part of systems engineering of military systems. Other application domains, however, are currently catching up. M&S in the fields of medicine, transportation, and other industries is poised to rapidly outstrip DoD's use of M&S in the years ahead, if it hasn't already happened.

RAPID PROTOTYPING

1. Introduction

Rapid prototyping (RP) is a new manufacturing technique that allows for fast fabrication of computer models designed with three-dimension (3D) computer aided design (CAD) software. RP is used in a wide variety of industries, from shoe to car manufacturers. This technique allows for fast realizations of ideas into functioning prototypes, shortening the design time, leading towards successful final products.

RP technique comprise of two general types: additive and subtractive, each of which has its own pros and cons. Subtractive type RP or traditional tooling manufacturing process is a technique in which material is removed from a solid piece of material until the desired design remains. Examples of this type of RP includes traditional milling, turning/lathing or drilling to more advanced versions - computer numerical control (CNC), electric discharge machining (EDM). Additive type RP is the opposite of subtractive type RP. Instead of removing material, material is added layer upon layer to build up the desired design such as stereo lithography, fused deposition modeling (FDM), and 3D printing.

This tutorial will introduce additive type RP techniques: Selective Laser Sintering (SLS), Stereo Lithography Apparatus (SLA), FDM, Inkjet based printing. It will also cover how to properly prepare 3D CAD models for fabrication with RP techniques.

2.Advantages and disadvantages of rapid prototyping

Subtractive type RP is typically limited to simple geometries due to the tooling process where material is removed. This type of RP also usually takes a longer time but the main advantage is that the end product is fabricated in the desired material. Additive type RP, on the other hand, can fabricate most complex geometries in a shorter time and lower cost. However, additive type RP typically includes extra post fabrication process of cleaning, post curing or finishing.

Here is some of the general advantages and disadvantages of rapid prototyping [1]:
Advantages:

- Fast and inexpensive method of prototyping design ideas
- Multiple design iterations
- Physical validation of design
- Reduced product development time

Disadvantages:

- Resolution not as fine as traditional machining (millimeter to sub-millimeter resolution)
- Surface flatness is rough (dependant of material and type of RP)

3.Rapid Prototyping Process

The basic process is similar across the different additive type RP technologies. We will use a ball as an example here. It begins with using a CAD software such as Solidworks to design a 3D computer model. Figure 3.9 is a golf ball designed in Solidworks.

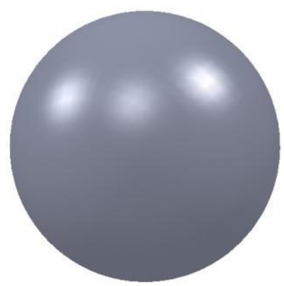


Figure 3.9 CAD Model of a Golf Ball.

This 3D CAD model is next converted into a Stereolithography or Standard Tessellation Language (STL) file format. The STL file format only describes the surface geometry of a 3D CAD model. It does not contain any information on the color, texture or material. STL file format can be saved in either ASCII or binary versions, with the latter as the more compact version. The surface geometry is described with triangular facets. Each triangle facets uses a set of Cartesian coordinates to describe its three vertices and the surface normal vector using a right-hand rule for ordering. An example of how an ASCII STL file format is show in Fig. 3.10.

```
solid print
  facet normal 0.00000e+00 1.00000e+00 0.00000e+00
    outer loop
      vertex 0.00000e+00 0.00000e+00 2.00000e+01
      vertex 0.00000e+00 0.00000e+00 0.00000e+00
      vertex 1.00000e+00 0.00000e+00 2.00000e+01
    endloop
  endfacet
      ⋮
endsolid print.stl
```

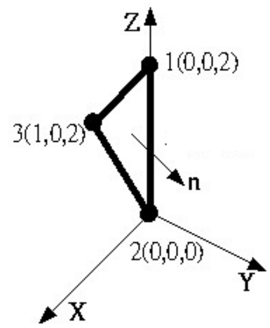


Figure 3.10 ASCII STL file format.

To convert a CAD model to STL in Solidworks,

File - Save as - Change ‘Save as type’ to .STL

Select ‘Options’ for more advance export options. Figure 3.10 shows a print screen of the STL export option.

As shown in Fig. 3.10, one can select to export the STL as Binary or ASCII file format in millimeter, centimeter, meter, inches or feet depending on the unit used in the CAD model.

Figure 3.10 – Solidworks STL export option.

The resolution options allow a user to control the tessellation of non-planar surfaces. There are two preset resolutions of ‘Coarse’ and ‘Fine’. The ‘Custom’ setting allows one to adjust the deviation and angle tolerances. Lower deviation tolerance sets tighter accuracy to the tessellation where as smaller angle deviation sets smaller detail tessellation. The caveat is that tighter tolerances create more triangle facets to describe the 3D CAD model’s surface more finely which causes the file size to be large. Figure 3.11 shows a CAD model exported to a coarse resolution STL (114KB), fine resolution STL (300 KB), and a very fine resolution STL file (1.51 MB). A more complicated design with complicated features would also result in a large

STL file size. Figure 3.11 shows an exaggerated view of how the export STL tolerance option affects how the 3D CAD model's surface is described. Furthermore, depending on how fine the tolerances are set, computation power to export the CAD model and process the file for fabrication could be an issue. Once the appropriate STL file has been generated, this is then loaded into the individual RP company's proprietary software to be processed into 2D slices for fabrication.

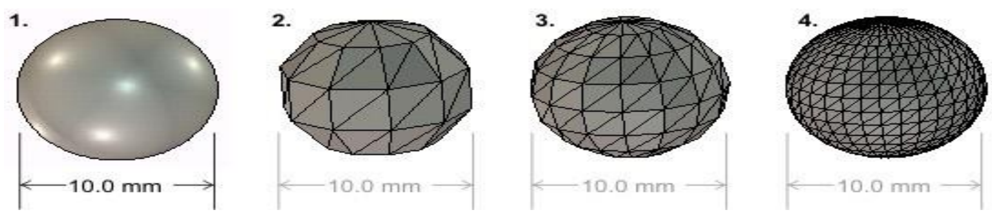


Figure 3.11 CAD model to a coarse ST

Additive Rapid Prototyping

The different types of additive RP technologies can be categorized into three types: liquid based (SLA and Inkjet based Printing), solid based (FDM), and powder based (SLS). These are just a few examples of the different RP technologies in existence. Regardless of the different types of RP technologies, all of them require the 3D CAD model's STL file for fabrication. These STL files are then used to generate to 2D slice layers for fabrication.

Liquid base - Stereo Lithography Apparatus (SLA) and Inkjet based printing

1.1 Stereo Lithography Apparatus (SLA)

SLA RP technology has three main parts: a vat filled with ultraviolet (UV) curable photopolymer, a perforated build tray, and an UV laser, Fig. 3.12. Figure 3.13 shows a production level SLA system by 3DSYSTEMS. The fabrication process starts with positioning the build tray a slice layer depth below the surface of the photopolymer. A slice layer is cured on to the build tray with the UV laser. The pattern of the slice layer is "painted" with the UV laser with the control of the scanner system. Once the layer is cured, the tray lowers by a slice layer thickness allowing for uncured photopolymer to cover the previously cured slice. The next slice layer is then formed on top of the previous layer with the UV laser, bonding it to the previous layer. This process is repeated until the entire 3D object is fully formed. The finished 3D object is removed and washed with solvent to remove excess resin off the object. Finally, the object is placed in a UV oven for further curing. During the fabrication process, support scaffolding can be fabricated to support overhangs or undercuts of the 3D object. These can be cut off after fabrication.

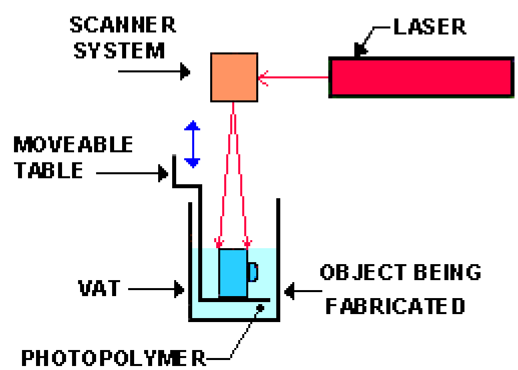


Figure 3.12 Stereolithography Apparatus (SLA)

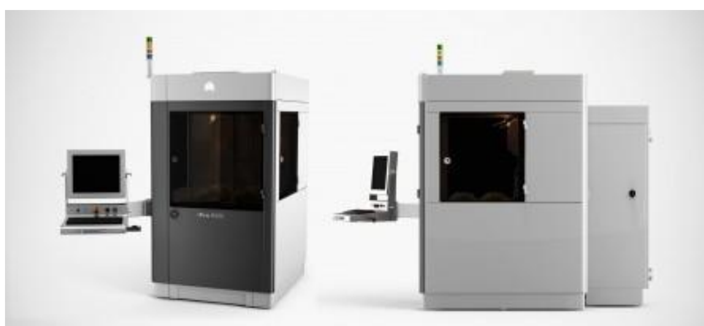


Figure 3.13 3DSYSTEMS SLA production RP Printers .

Inkjet based Printing

This RP technology is similar to the SLA technology, both of which utilize UV curable photopolymer as the build material. Two types of UV curable photopolymer materials are used: model that act as the structure and support material acting as scaffolding to the object. The technology is based on inkjet systems as shown in Fig. 3.14 where it has ‘ink’ cartridges and a print head.

During fabrication, a thin layer of photopolymer is jetted on to the build tray. The jetted photopolymer is cured by UV lamps mounted to the side of the print heads. Next, the tray lowers by precisely one layer’s thickness, allowing for the next slice to be jetted on to the previous slice. This process repeats until the 3D object is formed. Once completed, the support material is removed with a high pressure washer. A commercially available inkjet based RP printer by Stratasys is shown in Fig3.15.

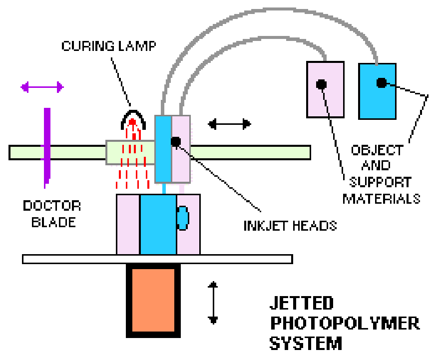


Figure 3.14 Inkjet Based Printing

Figure 3.15 Stratasys inkjet based RP printer.

Solid based: Fused Deposition Modeling (FDM)

FDM RP technologies use a thermoplastic filament, which is heated to its melting point and then extruded, layer by layer, to create a three dimensional object, shown in Fig. 3.16. Two kinds of materials are used: a model material which acts as the structure and a support material which acts as a scaffolding to support the object during the fabrication process.

During the fabrication process, the filaments are fed to an extrusion nozzle unwounded from a coil. This nozzle is heated to melt the filament which is then extruded on to a build tray forming a slice of the 3D object as cools and hardens.

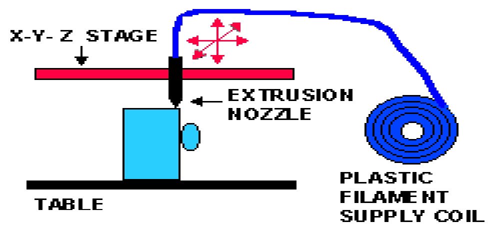


Figure 3.16 FDM RP Technique

The build tray is lowered or the extrusion nozzle is raised, by a thickness of an extruded layer, for the next slice layer to be extruded on top of the previous layer. As the extruded thermoplastic cools, it also binds to the previous layer. This continues until all the slices are printed to finally form the full 3D object. After the fabrication process, the support build material is typically dissolved by water if water-soluble wax was used or broken off if Polyphenylsulfone was used. An affordable desktop version by 3DSYSTEM is shown in Fig 3.17.

Figure 3.17 3DSYSTEMS FDM desktop RP printer

Powder Base: Selective Laser Sintering (SLS)

SLS is similar to SLA in which it also uses a laser and build tray except instead of using a vat of liquid photopolymer as the build material it uses a powder build material. The powder used can be plastic nylon, ceramic, glass or metal. A schematic of this system is shown in Fig. 3.18. This RP technique can be used to create both prototypes as well as final products. Figure3.19 shows a production level SLS system by 3DSYSTEM.

A high power laser is used to heat the powder build material to just below its boiling point (sintering) or above boiling point (melting) to fuse it together to form the 3D object's slice layers. Once a slice layer is formed, the build tray lowers by a slice layer's thickness. Next, the roller spreads more powder build material over the previously fused slice layer for the next slice layer to be sintered. This repeats until the 3D object is formed. Another difference to the SLA RP technique is that it does not require any support scaffolding as it is supported by the powder build material surrounding the object.

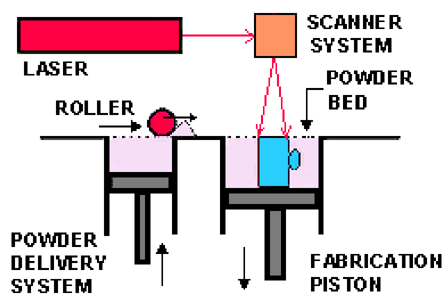


Figure 3.18 Selective Laser Sintering

Figure 3.19 3DSYSTEMS production SLS RP printer

4. COMPARISON OF DIFFERENT RP TECHNOLOGY

Comparison:

	Stereolithography Aparatus (SLA)	**Inkjet Based**	**Fused Deposition Modeling (FDM)**	**Selective Laser Sintering (SLS)**
Build tray size (inches)	20 x 20 x 24	12 x 6 x 9	24 x 20 x 24	27.5 x 15 x 23
System price range	$75K-800K	$46K-80K	$10K-300K	$200K-1M+
Speed	Average	Poor	Poor	Average to good
Accuracy	Very good	Excellent	Fair	Good
Surface Finish	Very good	Excellent	Fair	Good to very good
Strengths	Large part size Accuracy	Accuracy Finish	Price Materials	Accuracy Materials
Weaknesses	Post processing Messy liquids	Speed Limited materials Part size	Speed Part size	Size and weight System price Surface finish
Typical applications	Very detailed parts and models for fit & form testing Trade show and marketing parts &	Most detailed parts and models available using additive technologies for fit	Detailed parts and models for fit & form testing using engineering plastics Detailed parts for	Slightly less detailed parts and models for fit & form testing compared to photopolymer- based

	models Rapid manufacturing of small detailed parts Fabrication of specialized manufacturing tools Patterns for investment casting Patterns for urethane & RTV molding	& form testing Patterns for investment casting, especially jewelry and fine items, such as medical devices Patterns for urethane & RTV molding	patient- and food-contacting applications Plastic parts for higher-temperature applications Trade show and marketing parts & models Rapid manufacturing of small detailed parts Patterns for investment casting Fabrication of specialized manufacturing tools Patterns for urethane & RTV molding	methods Rapid manufacturing of parts, including larger items such as air ducts Parts with snap- fits & living hinges Parts which are durable and use true engineering plastics Patterns for investment casting

	Stereolithography Aparatus (SLA)	Inkjet Based	Fused Deposition Modeling (FDM)	Selective Laser Sintering (SLS)

Available build material	Acrylics (fair selection) Clear and rigid ABS-like Polypropylene-like (PP) Flexible or elastomeric Water-resistant	Polyester-based plastic Investment casting wax	ABS Polycarbonate (PC) Polyphenylsulfone Elastomer	Nylon, including flame-retardant, glass-, aluminum-, carbon-filled and others providing increased strength and other properties Polystyrene (PS) Elastomeric Steel and stainless steel alloys Bronze alloy Cobalt-chrome alloy Titanium

Table 3.1 Comparison of Different RP Technology

Rapid Prototyping Optomechanics

Additive RP technologies can be useful with fabricating the optomechanics in an optical system. Figure 14 shows a CAD design of a spectral image classifier and the fabricated system with an inkjet based RP printer shown in Fig. 15. New RP technology has allowed for optical systems to have an integrated design and be fabricated directly. One can design an optical system with a ray tracing program then easily design a 3D CAD model to match the optimization performed previously by the ray tracing program. The choice of additive RP technology would depend on fabrication time, cost, and build material requirements.

Typical 3D CAD design considerations that would need to be taken into account includes:

RP fabrication tolerances – fitting and alignment

- Optical fine adjustment ability

- Stiffness of material to support heavy optical devices
- Fasteners
- Adhesion

UNIT III

ROLE OF COMPUTERS IN PRODUCT DESIGN

S.No.	PART - A
1	Define Geometric Modeling?
2	Differentiate between surface and solid modeling?
3	What is boundary representation?
4	What is Constructive Solid Geometry?
5	What is the graphics standards?
6	What is design for manufacturing?
7	What is rapid prototyping?
8	List the applications of Rapid Prototyping.
9	What is assembly modeling?
10	Define simulation

S.No.	PART - B
1	What is geometric modeling and explain the types of geometric modeling?
2	Explain the boundary representation and constructive solid geometry with diagram?

3	Explain the use of the software package modeling and simulation?
4	Explain the Fusion Deposition Modelling (FDM) RP Technique with diagram
5	Explain the Selective Laser Sintering (SLS) and Stereo Lithography (SLA) RP Technique with diagram.
6	Construct the steps in Design for Manufacturing with diagram.

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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 4 – DESIGN FOR MANUFACTURE AND ENVIRONMENT – SME1310

General design principles for manufacturability - strength and mechanical factors, mechanisms selection, evaluation method, Process capability - Feature tolerances - Geometric tolerances - Assembly limits – Datum features - Tolerance stacks. Design for the Environment - Introduction - Environmental objectives - Global issues - Regional and local issues -Basic DFE methods - Design guide lines.

DESIGN FOR MANUFACTURABILITY

Introduction

Design for manufacturability (also sometimes known as design for manufacturing or DFM) is the general engineering practice of designing products in such a way that they are easy to manufacture. DFM describes the process of designing or engineering a product in order to facilitate the manufacturing process to reduce its manufacturing costs. DFM will allow potential problems to be fixed in the design phase which is the least expensive place to address them. DFM Requires a Cross-Functional Team. DFM utilizes information of several types, including (1) sketches, drawings, product specifications, and design alternatives; (2) a detailed understanding of production and assembly processes; and (3) estimates of manufacturing costs, production volumes, and ramp-up timing. DFM therefore requires the contributions of most members of the development team as well as outside experts.

DFM Is Performed throughout the Development Process. DFM begins during the concept development phase, when the product's functions and specifications are being determined. When choosing a product concept, cost is almost always one of the criteria on which the decision is made even though cost estimates at this phase are highly subjective and approximate. When product specifications are finalized, the team makes trade-offs between desired performance characteristics. For example, weight reduction may increase manufacturing costs. At this point, the team may have an approximate bill of materials (a list of parts) with estimates of costs. During the system-level design phase of development, the team makes decisions about how to break up the product into individual components, based in large measure on the expected cost and manufacturing complexity implications. Accurate cost estimates finally become available during the detail- design phase of development, when many more decisions are driven by manufacturing concerns.

Overview of the DFM Process

DFM method is illustrated in Fig.4.1. It consists of five steps plus iteration:

1. Estimate the manufacturing costs.
2. Reduce the costs of components.
3. Reduce the costs of assembly.
4. Reduce the costs of supporting production.

5. Consider the impact of DFM decisions on other factors.

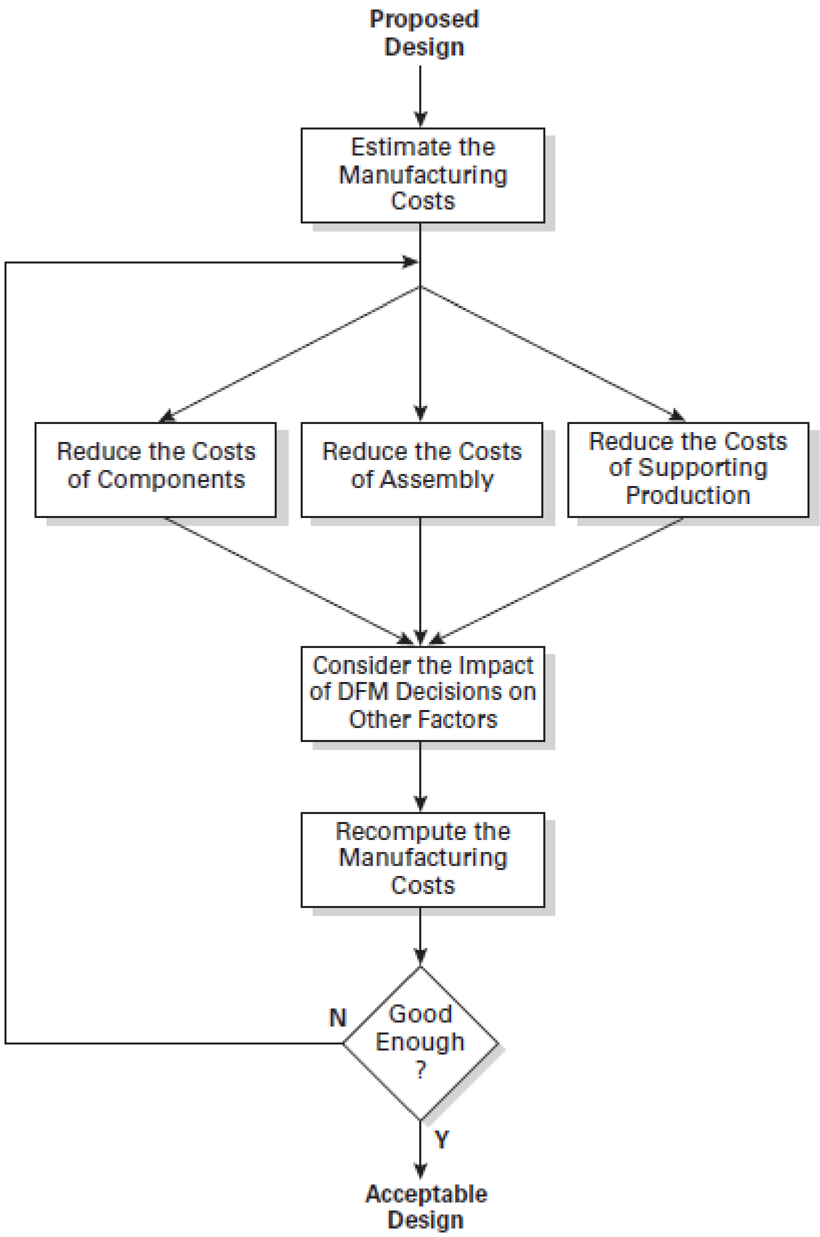


Fig. 4.1: The design for manufacturing (DFM) method.

GENERAL DESIGN PRINCIPLES FOR MANUFACTURABILITY

A.) Basic principles of designing for economical production

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

2. ***Standard materials and components*****:** Use of widely available materials and off-the-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 investments, and speeds the manufacturing cycle.

3. ***Standardized design of the product itself*****:** When several similar products are to be produced, specify the same materials, parts, and subassemblies for 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. ***Liberal tolerances***: Although the extra cost of producing too tight tolerances has been well documented, this fact is often not appreciated well enough by product designers. The higher costs of tight tolerances stem from factors such as (a) extra operations such as grinding, honing, or lapping after primary machining operations, (b) higher tooling costs from the 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 materials costs, and (g) more sizable investments for precision equipment.

Fig.4.2 graphically illustrates how manufacturing cost is multiplied when close tolerances are specified. Table 1 illustrates the extra cost of producing fine surface finishes. Fig. 4.3 illustrates the range of surface finishes obtainable with a number of machining processes. It shows how substantially the process time for each method can increase if a particularly smooth surface finish must be provided.

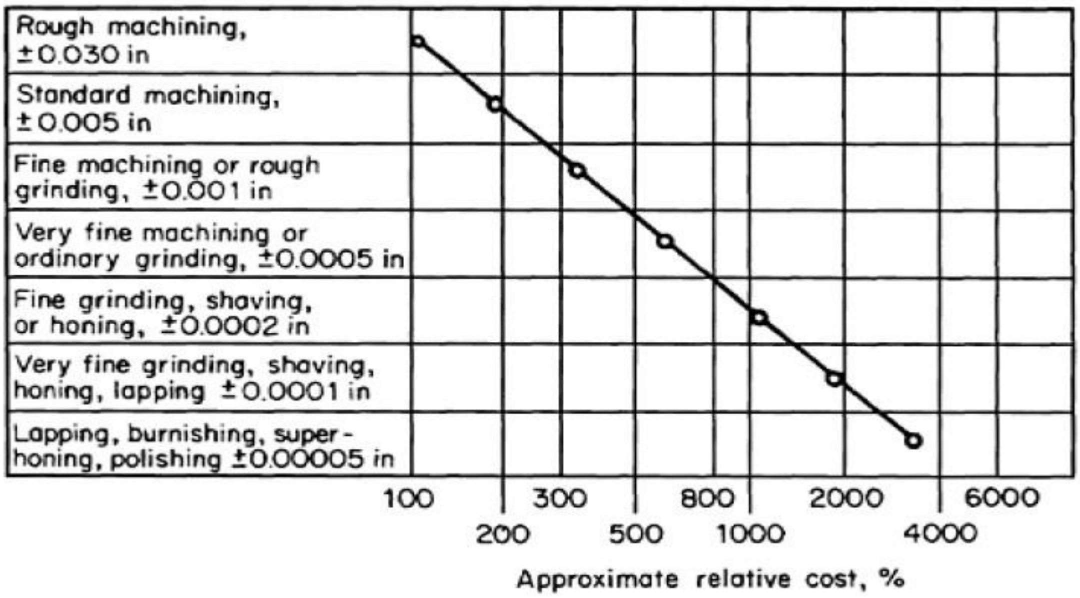


Fig. 4.2: Approximate relative cost of progressively tighter dimensional tolerances.

Surface symbol designation	Surface roughness, µin	Approximate relative cost, %
Case, rough-machined	250	100
Standard machining	125	200
Fine machining, rough-ground	63	440
Very fine machining, ordinary grinding	32	720
Fine grinding, shaving, and honing	16	1400
Very fine grinding, shaving, honing, and lapping	8	2400
Lapping, burnishing, superhoning, and polishing	2	4500

Table 4 1: Cost of Producing Surface Finishes

1. ***Use of the most processible materials***: Use the most processible materials available as long as their functional characteristics and cost are suitable. There are often significant differences in processibility (cycle time, optimal cutting speed, flowability, etc.) between conventional material grades and those developed for easy processibility. 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 designed life of the product.

2. ***Teamwork with manufacturing personnel***: The most producible designs are provided when the designer and manufacturing personnel, particularly manufacturing engineers, work closely together as a team or otherwise collaborate from the outset.

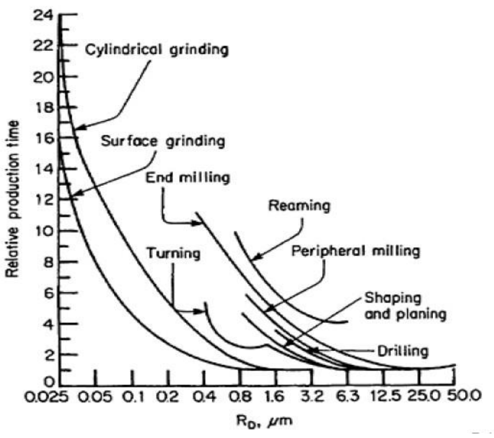


Fig.4 3: Typical relationships of productive time and surface roughness for various machining processes

5. ***Avoidance of secondary operations***: Consider the cost of operations, and design in order to eliminate or simplify them whenever possible. Such operations as deburring, inspection, plating and painting, heat treating, material handling, and others may prove to be as expensive as the primary manufacturing operation and should be considered as the design is developed. For example, firm, non-ambiguous gauging points should be provided; shapes that require special protective trays for handling should be avoided.

6. ***Design appropriate to the expected level of production***: The design should be suitable for a production method that is economical for the quantity forecast. For example, a product should not be designed to utilize a thin-walled die casting if anticipated production quantities are so low that the cost of the die cannot be amortized. Conversely, it also may be incorrect to specify a sand-mould aluminum casting for a mass-produced part because this may fail to take advantage of the labour and materials savings possible with die castings.

7. ***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. For example, they will know that injection-molded plastic parts can have color and surface texture incorporated in them as they come from the mould, that some plastics can provide "living hinges," that powder-metal parts normally have a porous nature that allows lubrication retention and obviates the need for separate bushing inserts, etc. Utilizing these special capabilities can eliminate many operations and the need for separate, costly components.

8. ***Avoiding process restrictiveness*:** On parts drawings, specify only the final characteristics needed; do not specify the process to be used. Allow manufacturing engineers as much latitude as possible in choosing a process that produces the needed dimensions, surface finish, or other characteristics required.

B.) GENERAL DESIGN RULES

1. First in importance, simplify the design. Reduce the number of parts required. This can be done most often by combining parts, designing one part so that it performs several functions.

2. Design for low-labour-cost operations whenever possible. For example, a punch press pierced hole can be made more quickly than a hole can be drilled. Drilling, in turn, is quicker than boring. Tumble deburring requires less labour than hand deburring.

3. Avoid generalized statements on drawings that may be difficult for manufacturing personnel to interpret. Examples are “Polish this surface….Corners must be square,” “Tool marks are not permitted,” and “Assemblies must exhibit good workmanship.” Notes must be more specific than these.

4. Dimensions should be made not from points in space but from specific surfaces or points on the part itself if at all possible. This facilitates fixture and gauge making and helps avoid tooling, gauge, and measurement errors.

5. Dimensions should all be from one datum line rather than from a variety of points to simplify tooling and gauging and avoid overlap of tolerances.

6. Once functional requirements have been fulfilled, the lighter the part, the lower its cost is apt to be. Designers should strive for minimum weight consistent with strength and stiffness requirements. Along with a reduction in materials costs, there usually will be a reduction in labor and tooling costs when less material is used.

7. Whenever possible, design to use general-purpose tooling rather than special tooling (dies, form cutters, etc.). The well-equipped shop often has a large collection of standard tooling that is usable for a variety of parts. Except for the highest levels of production, where the labour and materials savings of special tooling enable their costs to be amortized, designers should become familiar with the general-purpose and standard tooling that is available and make use of it.

8. Avoid sharp corners; use generous fillets and radii. This is a universal rule applicable to castings and molded, formed, and machined parts. Generously rounded corners provide a number of advantages. There is less stress concentration on the part and on the tool; both will last longer. Material will flow better during manufacture. There may be fewer operational steps. Scrap rates will be reduced.

There are some exceptions to this “no sharp corner” rule, however. Two intersecting machined surfaces will leave a sharp external corner, and there is no cost advantage in trying to prevent it. The external corners of a powder-metal part, where surfaces formed by the punch face intersect surfaces formed by the die walls, will be sharp. For other corners, however, generous radii and fillets are greatly preferable.

9. Design a part so that as many manufacturing operations as possible can be performed without repositioning it. This reduces handling and the number of operations but, equally important, promotes accuracy, since the needed precision can be built into the tooling and equipment. This principle is illustrated by Fig. 4.4.

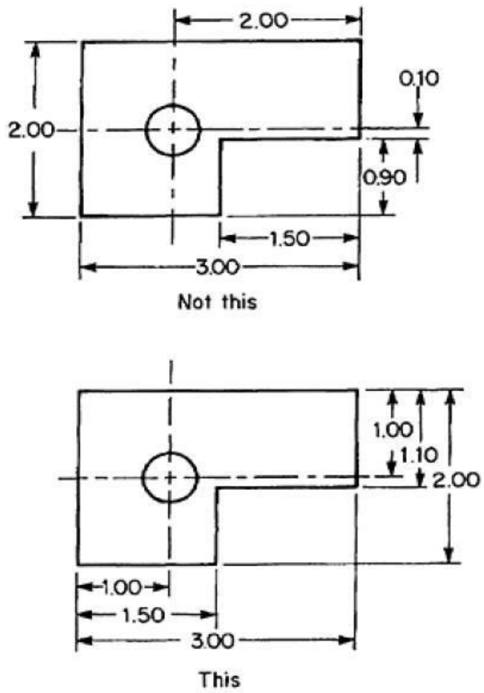


Fig.4 4: Dimensions should be made from points on the part itself rather than from points in space.

10. Whenever possible, cast, molded, or powder-metal parts should be designed so that stepped parting lines are avoided. These increase mould and pattern complexity and cost.

11. With all casting and molding processes, it is a good idea to design workpieces so that wall thicknesses are as uniform as possible. With high-shrinkage materials (e.g., plastics and aluminum), the need is greater.

12. Space holes in machined, cast, molded, or stamped parts so that they can be made in one operation without tooling weakness. Most processes have limitations on the closeness with which holes can be made simultaneously because of the lack of strength of thin die sections, material-flow problems in moulds, or the difficulty in putting multiple machining spindles close together.

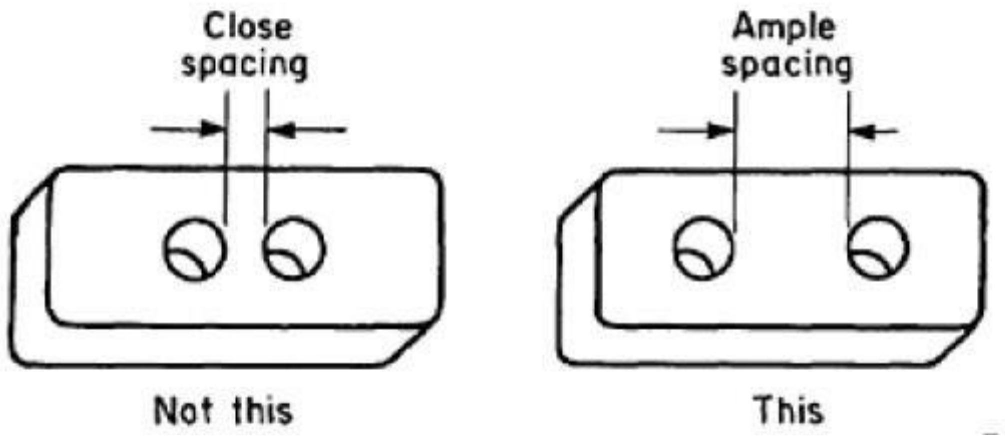


Fig. 4.5: Most manufacturing processes for producing multiple holes have limitations of minimum hole spacing.

C.) EFFECTS OF SPECIAL-PURPOSE, AUTOMATIC, NUMERICALLY CONTROLLED AND OMPUTER-CONTROLLED EQUIPMENT

For simplicity of approach, most design recommendations in this handbook refer to single operations performed on general-purpose equipment. However, conditions faced by design engineers may not always be this simple. Special-purpose, multiple-operation tooling and equipment are and should be the normal approach for many factories. Progressive designers must allow for and take advantage of the manufacturing economies such approaches provide whenever they are available or justifiable.

Types Available

Types of special-purpose and automatic equipment and tooling suitable for operations within the scope of this handbook include

1. Compound, progressive, and transfer dies for metal stamping and four-slide machines

2. Form-ground cutting tools

3. Automatic screw machines

4. Tracer-controlled turning, milling, and shaping machines

5. Multiple-spindle drilling, boring, reaming, and tapping machines

6. Various other multiple-headed machine tools

7. Index-table or transfer-line machine tools (which are also multiple-headed)

8. Automatic flame-, laser-, or other contour-cutting machines that are controlled by optical or template tracing or from a computer memory

9. Automatic casting equipment, automatic sand-mould-making machines, automatic ladling, part-ejection, and shakeout equipment, etc.

10. Automatic assembly and parts-feeding apparatus including both robotic equipment and that dedicated to a specific product

11. Program-controlled, numerically controlled (NC), and computer-controlled (CNC) machining and other equipment

12. Robotic painting and other automatic plating and/or other finishing equipment

Some high levels of automation are already inherent in methods covered by certain handbook chapters; for example, four-slide forming, roll forming, die casting, injection molding, impact extrusion, cold heading, powder metallurgy, screw machining, and broaching are all high- production processes.

Effects on Materials Selection

The choice of material is seldom affected by the degree to which the manufacturing process is made automatic. Those materials which are most machinable, most castable, most moldable, etc., are equally favorable whether the process is manual or automatic. There are two possible exceptions to this statement:

1. When production quantities are large, as is normally the case when automatic equipment is used, it may be economical to obtain special formulations and sizes of material that closely fit the requirements of the part to be produced and which would not be justifiable if only low quantities were involved.

2. When elaborate interconnected equipment is employed (e.g., transfer lines, index tables, multiple-spindle tapping machines), it may be advisable to specify free-machining or other highly processible materials, beyond what might be normally justifiable, to ensure that the equipment runs continuously. It may be economical to spend slightly more than normal for material if this can avoid downtime for tool sharpening or replacement in an expensive multiple-machine tool.

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.

Savings in labor cost 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.

Computer-controlled, numerically controlled, and program-controlled equipment noted in item 11 is an exception. The advantage of such equipment is that it permits automatic operation without being limited to any particular part or narrow family of parts and with little or no specialized tooling. Automation at low and medium levels of production is economically justifiable with numerical control and computer control. As long as the equipment is utilized, it is not necessary in achieving unit-cost savings to produce a substantial quantity of any particular part.

Effects on Design Recommendations

There are few or no differences in design recommendations for products made automatically as compared with those made with the same processes under manual control.
When there are limitations to automatic processes, these are generally pointed out in this handbook (e.g., design limitations of parts to be assembled automatically). In the preponderance of cases, however, the design recommendations included apply to both automatic and non-automatic methods. In some cases, however, the cost effect of disregarding a design recommendation can be minimized if an automatic process is used. With automatic equipment, an added operation, not normally justifiable, may be feasible, with the added cost consisting mainly of that required to add some element to the equipment or tooling.

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 which are manually controlled.

Compound and progressive dies and four-slide tooling for sheet-metal parts, for example, provide greater accuracy than individual punch-press operations because the work is contained by the tooling for all operations, and manual positioning variations are avoided.
Form-ground lathe or screw-machine cutting tools, if properly made, provide a higher level of accuracy for diameters, axial dimensions, and contours than can be expected when such dimensions are produced by separate manually controlled cuts. Form-ground milling cutters, shaper and planer tools, and grinding wheels all have the same advantage.

Multiple-spindle and multiple-head machines can be built with high accuracy for spindle location, parallelism, squareness, etc. They have a definite accuracy advantage over single- operation machines, in that the workpiece is positioned only once for all operations. The location of one hole or surface in relation to another depends solely on the machine and not on the care exercised in positioning the workpiece in a number of separate fixtures. Somewhat tighter tolerances therefore can be expected than would be the case with a process employing single-operation equipment.

Automatic parts-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, flashing, or some other minor defect that interferes with the automatic feeding action. No special dimensional allowances or changed tolerances should be applied if production equipment is fed automatically.

D) COMPUTER AND NUMERICAL CONTROL: OTHER FACTORS

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

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 computer or numerical control. Contoured parts such as 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 (CAD) of the product can provide data directly for control of manufacturing processes, bypassing the cost and lead time required for engineering drawings and process programming. Similarly, the process-controlling computer can provide data for the production and managerial control system.

5. Setup and changeover times are greatly reduced. Processing times are also being reducedas high-velocity computer control is being developed.

To achieve these advantages, an investment in the necessary equipment is require, and this can be substantial. More vital and even more costly in many cases is the training of personnel capable of developing, debugging, and operating the necessary control programs.

Mechanisms Selection

General Requirements for Early Materials and Process Selection

In order to be of real design value, the information on which the initial selection of material/ process combinations and their ranking is to be based should be available at the early concept design stage of a new product. Such information might include, for example:

- ✓ Product life volume
- ✓ Permissible tooling expenditure levels
- ✓ Possible part shape categories and complexity levels
- ✓ Service or environment requirements
- ✓ Appearance factors
- ✓ Accuracy factors

It is important to realize that for many processes the product and process are so intimately related that the product design must use an anticipated process as a starting point. In other words, many design details of a part cannot be defined without a consideration of processing. For this reason, it is crucial that an economic evaluation of competing processes be performed while the product is still at the conceptual stage. Such an early evaluation ensures that every economically feasible process is investigated further before the product design evolves to a level where it becomes process-specific.

As a design progresses from the conceptual stage to production, different methods can be used to perform the cost modeling of the product. At the conceptual stage, rough comparisons of the costs of products of similar size and complexity may be sufficient. While this procedure contains a certain degree of uncertainty, it only requires conceptual design information and is useful for the purpose of early economic comparison.

As the design progresses and specific materials and processes are selected, more advanced cost modelling methods may be employed. These may be particularly useful in establishing the relationship between design features and manufacturing costs for the chosen process. The basis of several cost-estimation procedures for different processes is outlined in later chapters.

Relationship to Process and Operations Planning

There is an obvious relationship between the initial selection of process/material combinations and process planning. During process planning, the detailed elements of the sequence of manufacturing operations and machines are determined. It is at this stage that the final detailed cost estimates for the manufacture of the part are determined. Considerable work has been done in the area of computer-aided process planning (CAPP) systems, although closer examination shows that the majority of this work has been devoted to machining processes only. These systems are utilized after a detailed design of the part has been carried out, and the manufacturing processes are evident. The initial decision on the material and process combination to be used for the part is most important, as this determines the majority of subsequent manufacturing costs. The goal of systematic early material and process selection is to influence this initial decision on which combination to use, before a detailed design of the part is carried out and before detailed process planning is attempted.

Selection of Manufacturing Processes

The selection of appropriate processes for the manufacture of a particular part is based on a matching of the required attributes of the part and the various process capabilities. Once the overall function of a part is determined, a list can be formulated giving the essential geometrical features, material properties, and other attributes that are required. This represents a "shopping list" that must be filled by the material properties and process capabilities. The attributes on the "shopping list" are related to the final function of the part and are determined by geometric and service conditions. Most component parts are not produced by a single process, but require a sequence of different processes to achieve all the required attributes of the final part. This is particularly the case when forming or shaping processes are used as the initial process, and material removal and finishing processes are required to produce some of the final part features.

Even when using moulding or casting processes, which can produce extremely complex geometries, there may be a number of features that are impossible to form and require subsequent machining operations. In other cases some of the features may be assigned to separate machining operations, because otherwise the die or mould may be uneconomically expensive. However, one of the goals of DFMA analysis is product structure simplification and parts consolidation. Experience shows that it is generally most economical to make best use of the capabilities of the initial manufacturing process in order to provide as many of the required attributes of a part as possible. As discussed in the introduction, the alternative approach of following guidelines to ensure that individual parts are as easy as possible to manufacture typically leads to an unnecessarily large number of separate parts, some of which add little value to the product. There are hundreds of processes and thousands of individual materials.

Moreover, new processes and materials are being developed continually. Fortunately, the following observations help to simplify the overall selection problem:

1. Many combinations of processes and materials are not possible. Figure 4.6 shows a compatibility matrix for a selected range of processes and material types.

2. Many combinations of processes are not possible and, therefore, do not appear in any processing sequences.

3. Some processes affect only one attribute of the part, particularly surface treatment and heat-treatment processes.

4. Sequences of processes have a natural order of shape generation, followed by feature addition or refinement by material removal and then material property or surface enhancement.

Processes can be categorized as:

- Primary processes
- Primary/secondary processes
- Tertiary processes

Some texts refer to primary processes as those used for producing the raw materials for manufacturing such as flat rolling, tube sinking, and wire drawing. In the context of producing component parts in this text, the term primary process refers to the main shape generating process, assuming that the material has been purchased in the appropriate stock form (wire, tube, sheet, etc.). Such processes should be selected to produce as many of the required attributes of the part as possible and usually appear first in a sequence of operations. Casting, forging, and injection moulding are examples of primary shape generating processes. Primary/secondary processes, on the other hand, can generate the main shape of the part, form features on the part, or refine features on the part. These processes appear at the start or later in a sequence of processes. This category includes material removal processes such as machining, grinding, and broaching.

Tertiary processes do not affect the geometry of the part and always appear after primary and primary/secondary processes. This category consists of finishing processes such as surface treatments and heat treatments. The selection of tertiary processes is simplified, because many tertiary processes only affect a single attribute of the part. For instance, lapping is employed to achieve a very good surface finish, and plating is often used to improve the appearance or corrosion resistance.

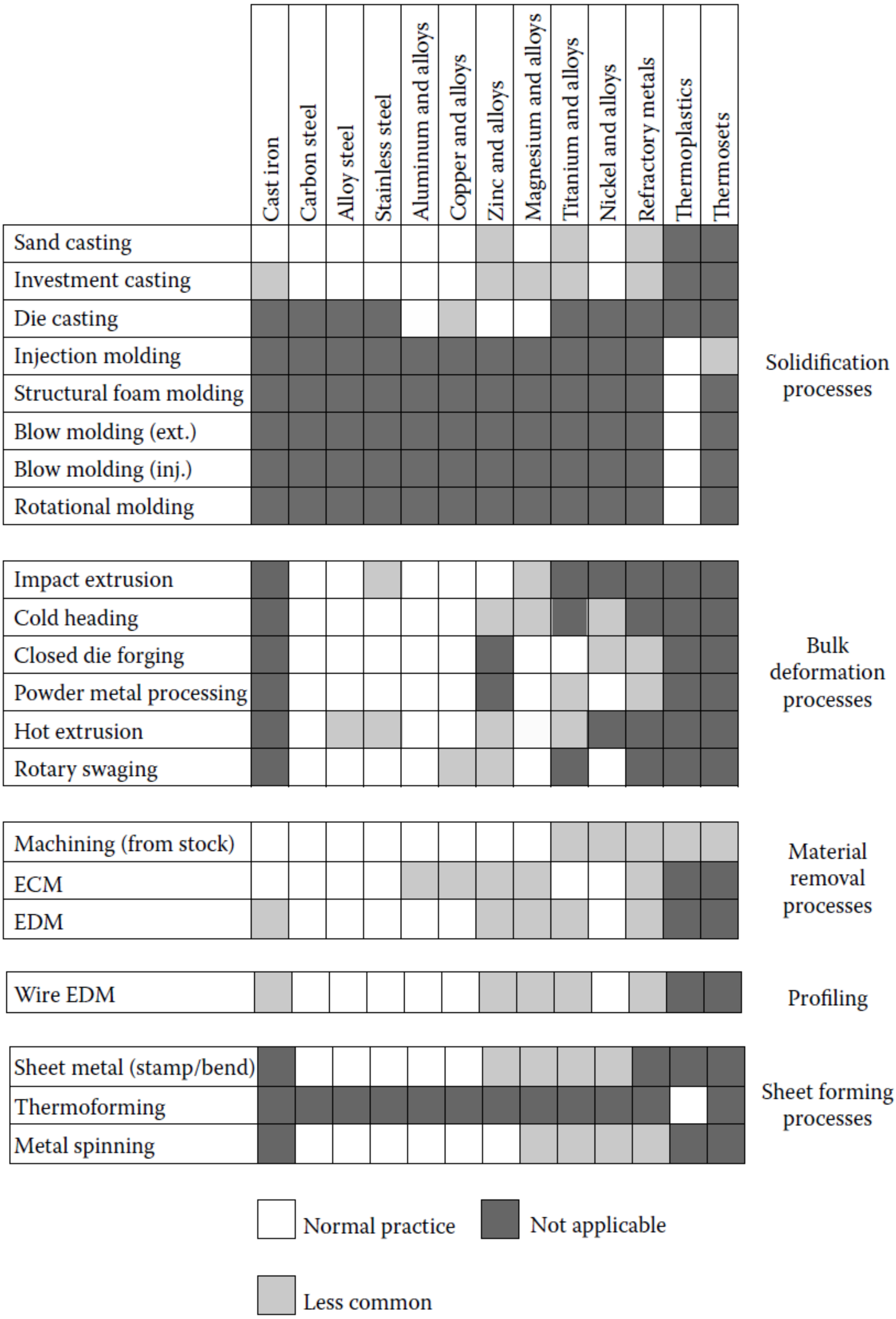


Figure 4.6 Compatibility Matrix for Processes and Materials

Process Capabilities

A great deal of general information is available on manufacturing processes in a wide range of textbooks, handbooks, and so on. Each process can be analyzed to determine the range of its capabilities in terms of attributes of the parts that can be produced. Included in these capabilities are shape features that can be produced, natural tolerance ranges, surface roughness capabilities, and so on. These capabilities determine whether a process can be used to produce the corresponding part attributes.

General Shape Attributes

Depressions (Depress): The ability to form recesses or grooves in the surfaces of the part. The first column entry refers to the possibility of forming depressions in a single direction, while the second entry refers to the possibility of forming depressions in more than one direction. These two entries refer to depressions in the direction of tooling motion and those in other directions. The following are some examples of tooling motion directions.

Processes with split moulds—the direction of mould opening.

Processes that generate continuous profiles—normal to the direction of extrusion or normal to the axis of the cutting medium.

Forging (impact) processes-the direction of impact of the tooling onto the part.

Uniform wall (UniWall): Uniform wall thickness. Any non-uniformity arising from the natural tendency of the process, such as material stretching or build up behind projections in centrifugal processes is ignored, and the wall is still considered uniform.

Uniform cross-section (UniSect): Parts where any cross-sections normal to a part axis are identical, excluding draft (slight taper) in the axial direction for die or mold release if required.

Axis of rotation (AxisRot): Parts whose shapes can be generated by rotation about a single axis: a solid of revolution.

Regular cross-section (RegXSec): Cross-sections normal to the part’s axis contain a regular pattern (e.g., a hexagonal or splined shaft). Changes in shape that maintain a regular pattern are permissible (e.g., a splined shaft with a hexagonal head).

Captured cavities (CaptCav): The ability to form cavities with reentrant surfaces (e.g., a bottle).

Enclosed (Enclosed): Parts that are hollow and completely enclosed.

Draft-free surfaces (NoDraft): The capability of producing constant cross-sections in the direction of tooling motion. Many processes can approach this capability when less than ideal draft allowances are specified, but this designation is reserved for processes where this capability is a basic characteristic and no draft can be obtained without cost penalty.

DFA Compatibility Attributes

Manufacturing processes have varying levels of compatibility with the basic goals of the DFA of simplified product structure and ease of assembly. This relative compatibility is measured in the following key areas.

Part consolidation (PConsol): The ability to incorporate several functional requirements into a single piece, eliminating the need for multipart assemblies.

Alignment features (Alignmt): The ease of incorporating in the part positive alignment or location features that aid in the assembly of mating parts.

Integral fasteners (IntFast): The cost-effectiveness and scope of fastening elements that can be designed into the part. The ability to incorporate features such as threads, which generally involve separate fasteners, is not given as much consideration as elements such as snap features.

Geometric Tolerance

***Conventional or Coordinate Tolerancing* System:**

Coordinate tolerance is a dimensioning system where a part feature is located (or defined) by means of a rectangular dimension with the given tolerance.

Geometric Tolerancing:

Geometric tolerance of a feature (point, line, axis, surface or medium plane) specifies the tolerance zone within which the feature is required to be contained. The geometric tolerance feature provides a precise and brief method of indicating brief geometric requirements on engineering drawings. The symbols being internationally been accepted are very useful when overseas manufacture is involved. Geometric tolerancing is very useful especially when conventional dimensioning and drawing methods are inadequate and doesn't ensure that parts will assemble satisfactorily after manufacture.

Basic Definitions

Maximum Material Condition (MMC)

It is that condition of a feature or a part, which contains the maximum amount of material, e.g. minimum hole size or maximum shaft size. In certain cases its use allows an increase in the specifies tolerance if it is indicated that the tolerance applies to the feature at its MMC.

Straightness

It is the shortest distance between two points. The tolerance value is the specified distance between two parallel straight lines.

Datum

A datum feature may be a plane or axis. For practical purposes the plane surface or axis is used for manufacture or inspection.

Flatness

Flatness tolerance controls the deviation of the surface from the true plane and is the space between the two parallel planes

Roundness

It is the condition where the feature is a continuous curved surface, any point on the surface is at a constant distance from the centre or axis. The roundness tolerance zone is the annular space between two co-planar, concentric circles.

Cylindricity

It is a combination of parallelism, straightness and roundness, applied to the surface of a cylinder. The Cylindricity tolerance zone is the annular space between two coaxial cylinders and its value is the radial distance between them.

Concentricity

It is the relationship between two cylinders, which have the same axis or common centre. Concentricity tolerance is the deviation of the axis from the true position.

Squareness

It is the condition where a line, plane or surface lies at 90 degrees to the another. It is the space between the two parallel lines or surfaces.

Parallelism

This is the condition where two lines or surfaces are separated by a uniform distance. Parallelism tolerances control the parallelism between the two lines or surfaces and the tolerance zone is the distance between them.

Angularity

It defines the position between two lines or surfaces which are nor parallel or perpendicular to each other.

Position

The positional tolerance controls the position between a feature and a datum or from another feature. The tolerance value is the specified deviation from the true position.

Symmetry

It is the feature where a feature is divided into identical parts by means of a line or plane. Symmetry tolerances control the area between the parallel lines or planes, which are parallel to the datum feature, and there value is the distance between them.

Circular Runout

It is the permissible variation of position of any point fixed on a surface, which occurs when a part is rotated through 360 degrees about its own axis. The resultant indications include errors of other characteristics without differentiating them. The combined errors must not exceed the stated tolerance value.

Total Runout

The difference between simple Runout and total Runout is that in the former, one measurement is taken during one revolution while in the later the measuring instrument is moved along the component during several revolutions.

Datum

A datum is the origin from which the location or geometric shape of features of a part are established. It is a theoretically perfect point, line or plane. Tolerance specifications will reference these datum.

Type of Tolerµ sance	Characteristics to be toleranced	Symbols
FORM	Straightness	—
	Flatness	▱
	Circularity (Roundness)	○
	Profile of any line	⌒
	Profile of any surface	⌓
ORIENTATION	Parallelism	//
	Perpendicularity	⊥
	Angularity	∠
LOCATION	Position	⌖
	Concentricity and coaxiality	◎
	Symmetry	⌯
RUNOUT	Simple runout	↗
	Total Runout	⌰

Table 4.2 Symbols of Toleranced Characteristics

Datum Reference Frame

Positioning the part with relation to three mutually perpendicular planes: the datum reference frame. This reference frame exist in theory only. In some cases a single datum may be sufficient. Features of size are often classified as datum features. Examples are: holes, slots, tabs and shafts. Placement of a datum feature symbol with a size dimension indicates that the feature of size is a datum feature.

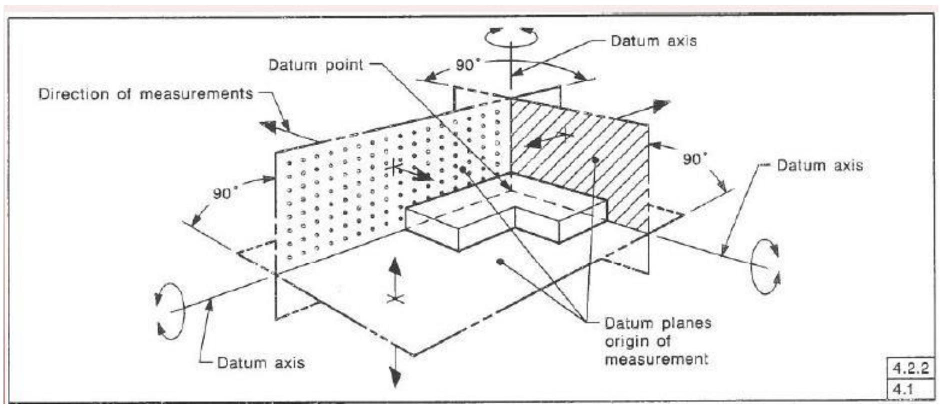


Figure 4.7 Datum Reference Frame

External Feature (Datum Call-Out)

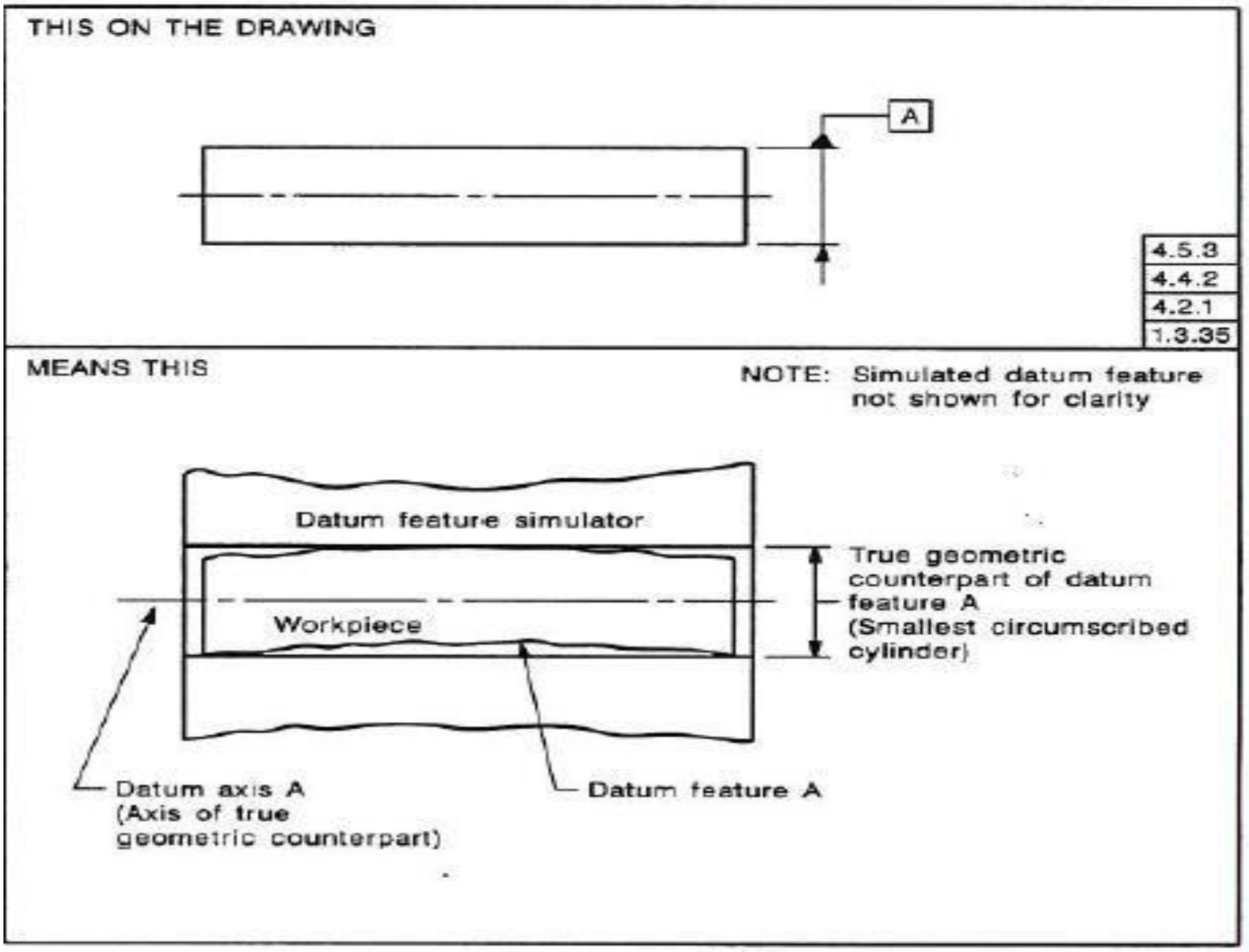


Figure 4.8: Primary External Datum Diameter-RFS

Internal Feature (Datum Call-Out)

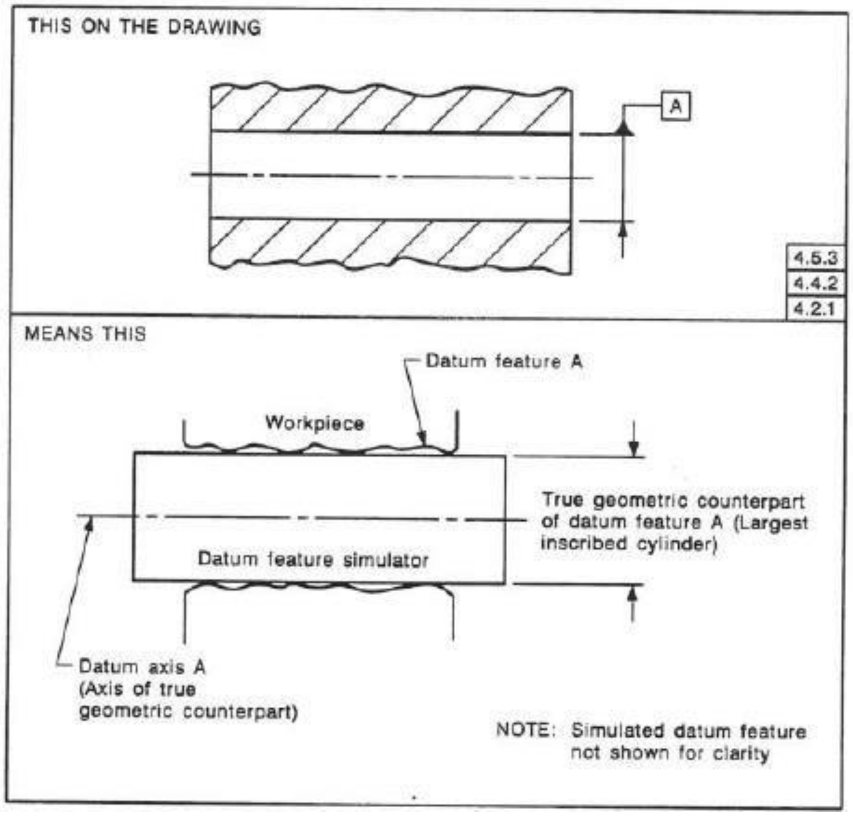


Figure 4.9: Primary Internal Datum Diameter-RFS

Tolerance Stack-Up

Product manufacturers utilize an organized flow of information to translate customer requirements into product requirements.

Tolerance Stack-Ups are vital to address mechanical fit and mechanical performance requirements. Mechanical fit is simply answering the question, “Do the parts that make up the assembly always go together?” Mechanical performance requirements would include the performance of mechanisms, like switches, latches, actuators, and the like. Other performance requirements could include optical alignments or motor efficiency. So what is a “stack-up”?

Tolerance stack-up calculations represent the cumulative effect of part tolerance with respect to an assembly requirement. The idea of tolerances “stacking up” would refer to adding tolerances to find total part tolerance, then comparing that to the available gap or performance limits in order. This process for mechanical requirements is generalized in the flow diagram below.

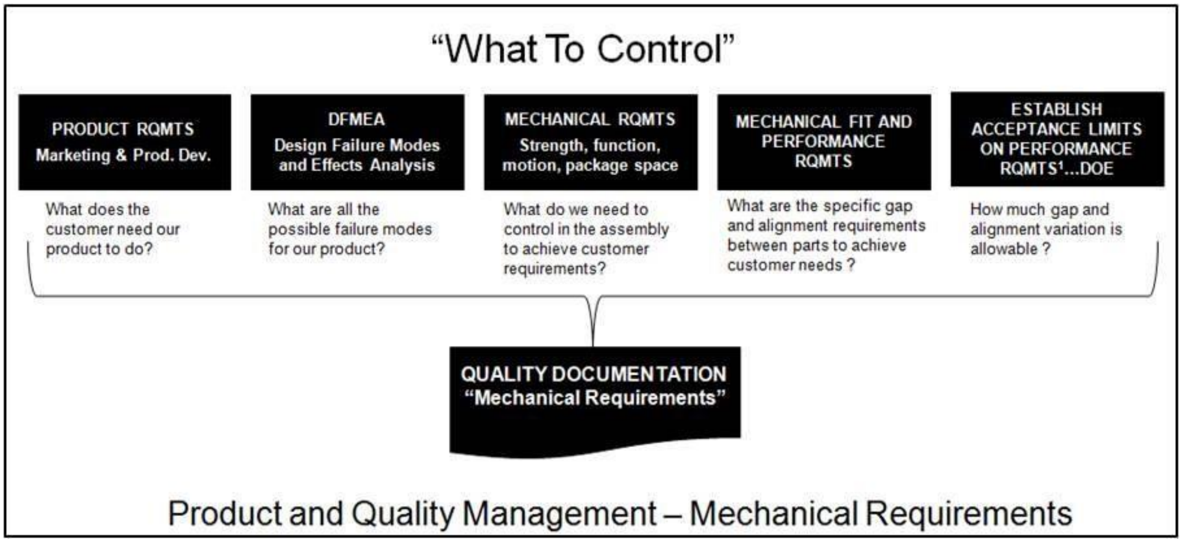


Figure 4.10 Product and Quality Management

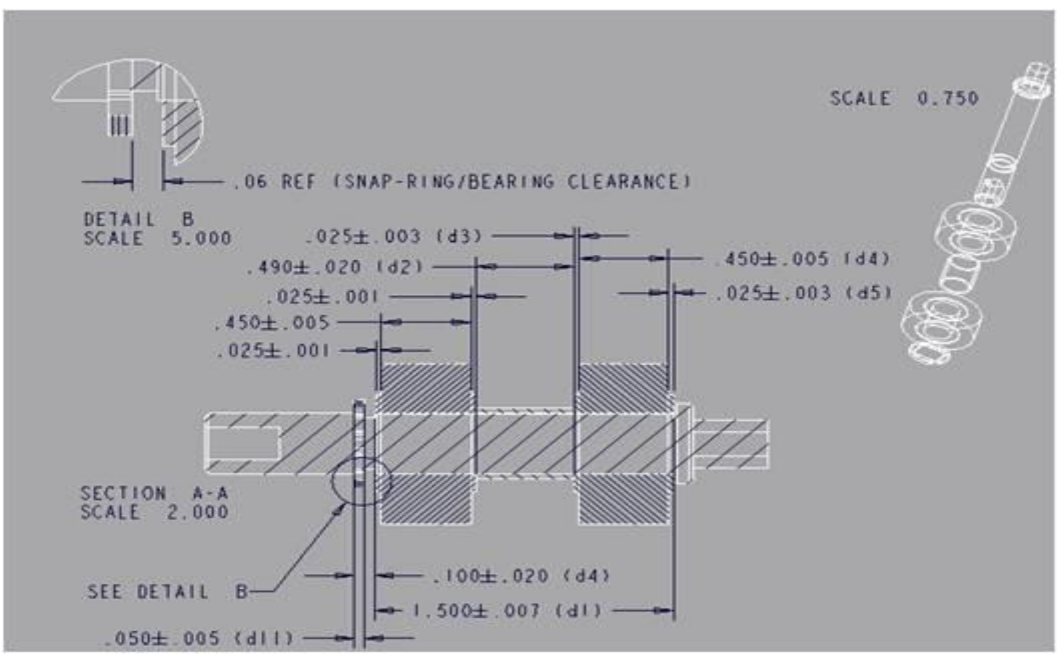


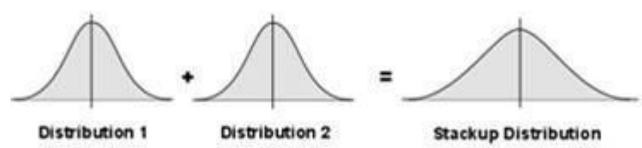
Figure 4.11 Tolerance Stackup

This simple comparison is also referred to as worst case analysis. Worst case analysis is appropriate for certain requirements where failure would represent catastrophe for a company. It is also useful and appropriate for problems that involve a low number of parts. Low being defined as three or four parts. Worst case analysis is most often done in a single direction, i.e. a 1D analysis. If the analysis involves part dimensions that are not parallel to the assembly measurement being studied, the stack-up approach must be modified since 2D variation such as angles, or any variation that is not parallel with the 1D direction, does not affect the assembly measurement with a 1-to-1 ratio.

Many companies utilize a statistical method for tolerance analysis. One approach involves a simple calculation using the RSS Method, Root-Sum-Squared. Instead of summing tolerances, as in worst-case analysis, statistical analysis sums dimension distributions. It is important to understand that the inputs values for a worst-case analysis are design tolerances, but the inputs for a statistical analysis are process distribution moments (e.g., standard deviation). Worst-case analysis (also called tolerance stack-up analysis) can be used to validate a design. Statistical analysis (also called variation analysis) can be used to predict the actual variation of an assembly based on the variation of the part dimensions. Comparing the assembly standard deviation to the assembly limits allow for the calculation of quality metrics like sigma, % yield, DPMU, etc. This approach requires distributions to be normal with all parts at the same quality level, i.e. +/- 3σ.

1D RSS:

$$\sigma_{ASM} = \left(\sum_{i=1}^{n} \sigma_i^{\,2} \right)^{1/2}$$



σ_i = Standard deviation of the *"ith"* dimension

Given the limitations of RSS, other methods for calculating assembly variation have been developed. One such method that is incorporated into CETOL 6 Sigma is called the Method of System Moments. This method eliminates the limitations stated above. Analyses of all complexities, i.e. 1D, 2D, and 3D, can be created with no restriction on distribution type or quality level. Companies can now do full Assembly Variation Analysis with tolerance analysis software.

Assembly variation analysis provides insight required to identify the key part characteristics, (KPCs) that must be controlled in order to produce a product that meets the expectation of the customer. The product development process should then become focused on defining and validating part manufacturing and assembly processes that are capable of achieving high producibility levels. Goals of Cpk = 1.67 for key features and Cp = 1.33 for non-key features are commonly quoted. Utilizing the insight for variation analysis allows design engineers to allocate tolerance budgets strategically. Critical features will be held to tighter tolerances. Looser tolerance can be applied to less important features. These decisions not only ensure product quality and performance, but also ensure manufacturability at the right price. The impact on the product development process can be huge.

Understanding Statistical Tolerance Analysis **Definition of Statistical Tolerance Analysis**

A statistical tolerance analysis is when you take the variation of a set of inputs to calculate the expected variation of an output of interest. In mechanical engineering, a product design is composed of multiple features, each with tolerance values that control the variable aspects of those features. Statistical tolerance analysis is used to understand how these tolerances contribute the various performance characteristics of the design.

1D Tolerance Stackup

The simplest form of tolerance analysis is the single direction, 1D Tolerance Stackup. A 1D Tolerance Stackup is created by creating a cross section of a model and adding the tolerance values for each feature in a straight line.The variation in each contributes to the overall output/outcome.

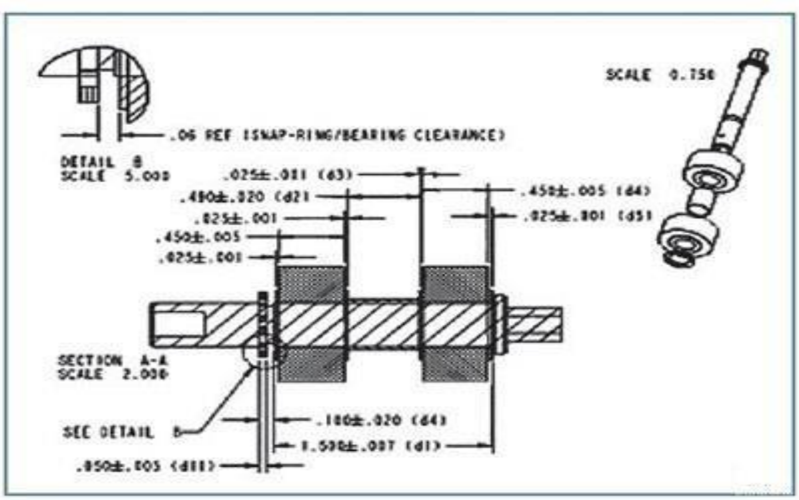


Figure 4.12 ID Tolerance Stackup

Worst-Case Analysis vs RSS (Root-Sum Squared) Statistical Analysis

In a Worst-Case Analysis, each dimension will have a minimum and maximum value that represents the range of acceptability for that dimension. Worst-Case answers the question, if I take the maximum range on each input, what is the maximum range for the measurement of interest or stackup? We are therefore dealing with the limits of acceptability and not probability.

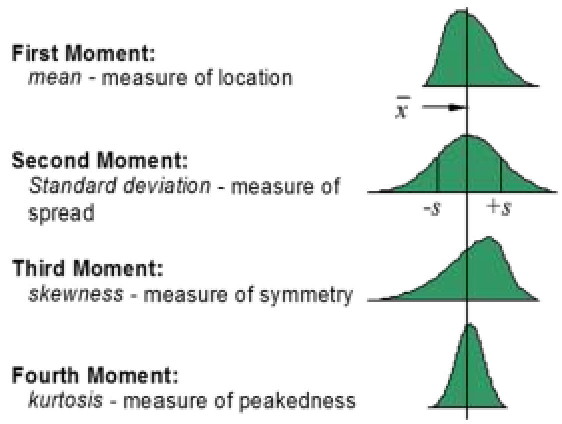
RSS (Root-Sum Squared) Statistical Analysis does not focus on the extreme values, but focuses on the distribution of the variation for each dimension. Each dimension will have a unique distribution of values based on the manufacturing process. Tool wear, operator differences, changes in material and environment all contribute to variation in the dimension value. Each dimension has its own distribution curve.

When you combine the probabilities for each dimension (each separate curve) you get the probability for the total and therefore the distribution curve of the total. Statistical analysis answers the question, given the distribution of variation on each dimension what is the probability that my performance characteristic will fall within defined acceptable limits. The limitation of RSS is that it assumes all inputs are normally distributed and all performance characteristics have a linear relationship with the dimension. These assumptions do not account for the breadth of conditions that exist in typical scenarios found in manufacturing.

Second Order Tolerance Analysis

Because manufacturing methods vary for different types of parts, the distribution moments or parameters change as well. RSS only uses standard deviation and does not include the higher moments of skewness and kurtosis that better characterize the effects tool wear, form aging and other typical manufacturing scenarios. Second Order Tolerance Analysis incorporates all distribution moments:

Second Order Tolerance Analysis is also needed to determine what your output is going to be when the assembly function is not linear. In typical mechanical engineering scenarios Kinematic adjustments and other assembly behaviors result in non-linear assembly functions. Second order calculations are much more complex so hand calculations are not advisable but the computation accuracy is greatly improved and becomes viable within a tolerance analysis software package.



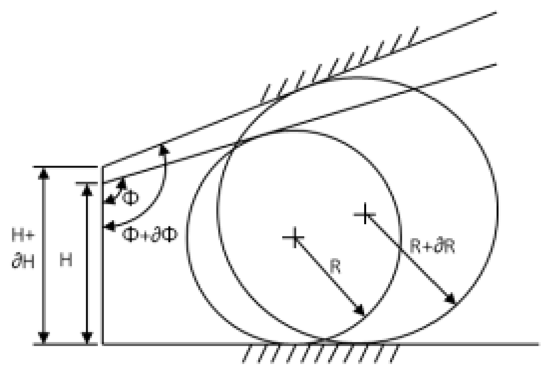


Figure 4.13 Summary of Statistical Tolerance Analysis for practical usage

The choice in tolerance analysis method is based on many factors, but the can be summarized as "Which method best matches the manufacturing and inspection process of the assembly". For simple fit problems, a 1D stack-up may be sufficient. RSS is sufficient for the small number of scenarios where the inputs are normal and the assembly relationships are linear. For all other scenarios, Second Order Tolerance Analysis is required to address the real world of manufacturing.

Tolerance Stack-Up

***Analysis:* Main Rules**

Start at the bottom and work up, or start at the left and work to the right. Always take the shortest route. Stay on one part until all tolerances are exhausted.

Step 1 : Identify the requirement that is to be analyzed.

Step 2 : Identify all dimensions and tolerances that contribute to the gap.

Step 3 : Assign each dimension a positive or negative value:

Up is positive Down is negative Right is positive Left is negative

Step 4 : Only one set of mating features creates the worst-case gap.

Step 5 : The analyst must deduce which geometric tolerance, location or orientation if either, contributes to the gap.

Step 6 : If your assumptions are wrong, your answer is wrong.

***Assembly Limits* General Aspects**

In the design and manufacture of engineering products a great deal of attention has to be paid to the mating, assembly and fitting of various components. In the early days of mechanical engineering during the nineteenth century, the majority of such components were actually mated together, their dimensions being adjusted until the required type of fit was obtained. These methods demanded craftsmanship of a high order and a great deal of very fine work was produced.

Present day standards of quantity production, interchangeability, and continuous assembly of many complex compounds, could not exist under such a system, neither could many of the exacting design requirements of modern machines be fulfilled without the knowledge that certain dimensions can be reproduced with precision on any number of components.

Modern mechanical production engineering is based on a system of limits and fits, which while not only itself ensuring the necessary accuracies of manufacture, forms a schedule or specifications to which manufacturers can adhere. In order that a system of limits and fits may be successful, following conditions must be fulfilled:

1. The range of sizes covered by the system must be sufficient for most purposes.
2. It must be based on some standards; so that everybody understands alike and a given dimension has the same meaning at all places.
3. For any basic size it must be possible to select from a carefully designed range of fit the most suitable one for a given application.
4. Each basic size of hole and shaft must have a range of tolerance values for each of the different fits.

5. The system must provide for both unilateral and bilateral methods of applying the tolerance.

6. It must be possible for a manufacturer to use the system to apply either a hole-based or a shaft-based system as his manufacturing requirements may need.

7. The system should cover work from high class tool and gauge work where very wide limits of sizes are permissible.

Nominal Size and Basic Dimensions

Nominal Size: A 'nominal size' is the size which is used for purpose of general identification. Thus the nominal size of a hole and shaft assembly is 60 mm, even though the basic size of the hole may be 60 mm and the basic size of the shaft 59.5 mm.

Basic Dimension: A 'basic dimension' is the dimension, as worked out by purely design considerations. Since the ideal conditions of producing basic dimension, do not exist, the basic dimensions can be treated as the theoretical or nominal size, and it has only to be approximated. A study of function of machine part would reveal that it is unnecessary to attain perfection because some variations in dimension, however small, can be tolerated size of various parts. It is, thus, general practice to specify a basic dimension and indicate by tolerances as to how much variation in the basic dimension can be tolerated without affecting the functioning of the assembly into which this part will be used.

Definitions

The definitions given below are based on those given in IS: 919

Shaft: The term shaft refers not only to diameter of a circular shaft to any external dimension on a component.

Hole: This term refers not only to the diameter of a circular hole but to any internal dimension on a component.

Basics of Fit

A fit or limit system consists of a series of tolerances arranged to suit a specific range of sizes and functions, so that limits of size may. Be selected and given to mating components to ensure specific classes of fit. This system may be arranged on the following basis:

1. Hole basis system
2. Shaft basis system.

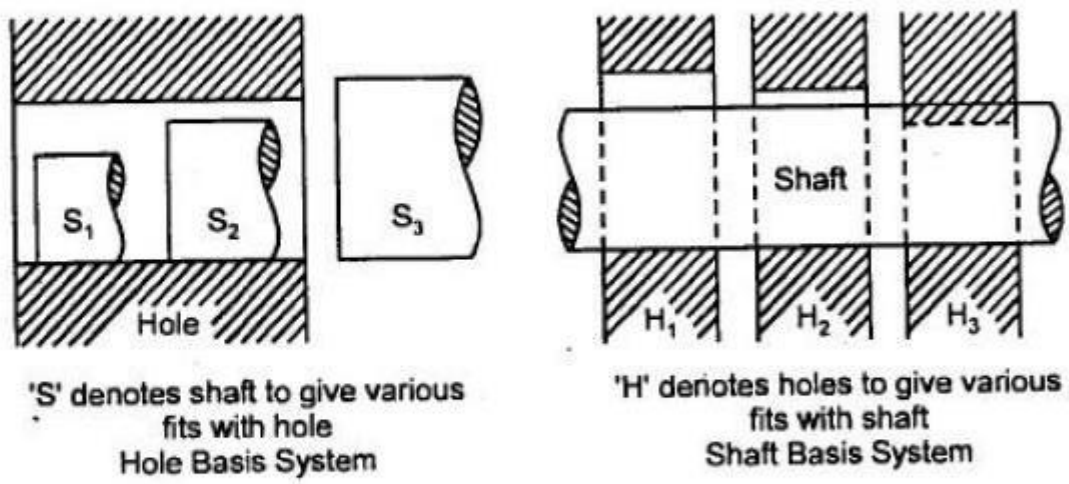


Figure 4.14 : Nominal and Basic Dimensions

***Hole basis system**:*

'Hole basis system' is one in which the limits on the hole are kept constant and the variations necessary to obtain the classes of fit are arranged by varying those on the shaft.

***Shaft basis system**:*

'Shaft basis system' is one in which the limits on the shaft are kept constant and the variations necessary to obtain the classes of fit are arranged by varying the limits on the holes. In present day industrial practice hole basis system is used because a great many holes are produced by standard tooling, for example, reamers drills, etc., whose size is not adjustable. Subsequently the shaft sizes are more readily variable about the basic size by means of turning or grinding operations. Thus the hole basis system results in considerable reduction in reamers and other precision tools as compared to a shaft basis system because in shaft basis system due to nonadjustable nature of reamers, drills etc. great variety (of sizes) of these tools are required for producing different classes of holes for one class of shaft for obtaining different fits.

Systems of Specifying Tolerances The tolerance or the error permitted in manufacturing a particular dimension may be allowed to vary either on one side of the basic size or on either side of the basic size. Accordingly two systems of specifying tolerances exit.

1. Unilateral system

2. Bilateral system.

In the unilateral system, tolerance is applied only in one direction.

Examples: ${}_{+0.02}40.0^{+0.04}$

$-0.0440.0^{-0.02}$

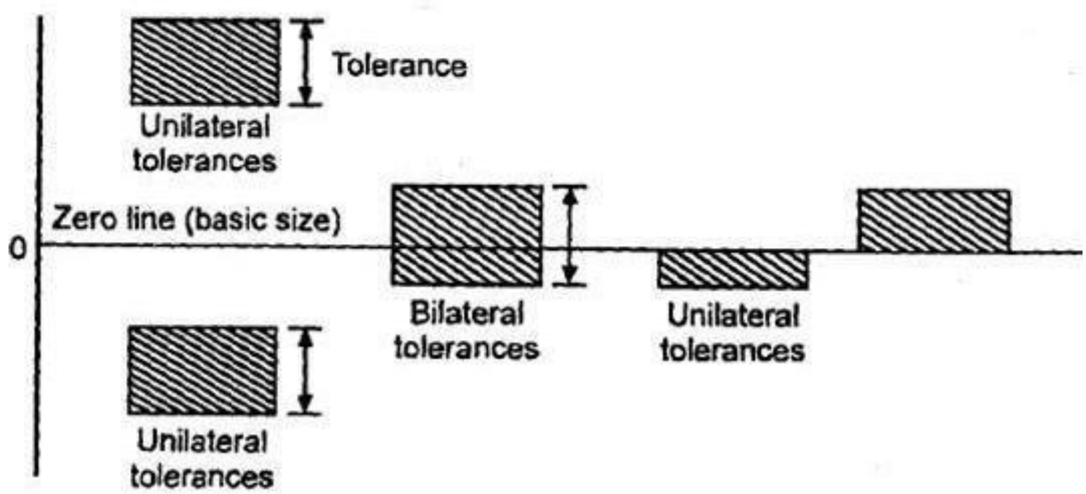


Figure 4.15: Types of Tolerances

In the bilateral system of writing tolerances, a dimension is permitted to vary in two directions.

Example: ${}_{-0.04}40.0^{+0.02}$

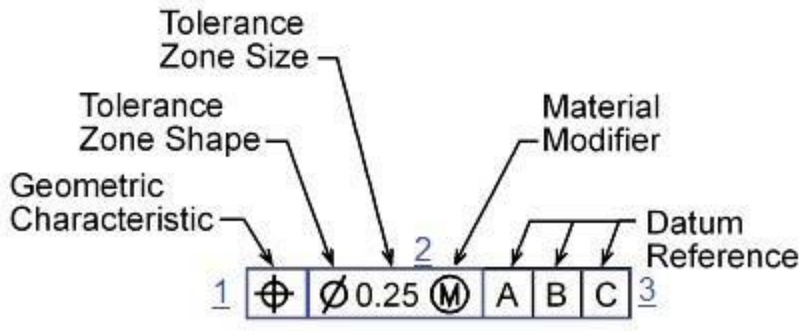
Feature Tolerances

Feature Control Frame

The Feature Control Frame is potentially the most useful tool in any geometric tolerancing system because it allows you to effectively use all of the geometric tolerancing symbols available to you.

A Feature Control Frame is a GD&T Tool that combines a Geometric Characteristic, the tolerance allowed (Tolerance Zone shape & Tolerance Zone Size), any material modifiers, and the datum feature references to create a geometric tolerance.

Feature Control Frames are a effective & compact method for providing clear & concise requirements for the many different features of your design. The Feature Control Frame can be broken down into three sections, shown here in blue.



The first box or section can contain any of the 14 different standard geometric tolerance symbols found above. In this example, the feature control frame includes a True Position Tolerance.

The next section contains the actual tolerance for the specific feature being Toleranced. In this example, the true position tolerance is 0.25 with an additional diameter symbol to indicate a circular tolerance zone at maximum material condition (M)

The third and final section indicates the datum references associated with the tolerance. In this example Datum A is the primary datum, Datum B is the secondary datum, and Datum C is the tertiary datum. This datum order is important because it standardizes the way the part is fixtured during inspection.

DESIGN FOR ENVIRONMENT

Introduction

Product Design for the environment is a design approach for reducing the impact of products on the environment. Products can have adverse impact on the environment through polluting processes and the consumption of large quantities of raw materials. The impact can be adverse also due to the consumption of large amounts of energy and difficulties during disposal. Because of this, one must consider a product’s entire life cycle, from creation through use through disposal.

In this life cycle, there are many events of creating pollution and many opportunities for recycling, remanufacturing, reuse, and reducing environmental impact. Simply designing a product to use nontoxic materials is not enough. Product designers must bring all ingenuity to bear on the challenging problem of developing efficient products.

To meet this challenge, designers must understand the process of life cycle assessment that adopts a total view by analyzing the entire life cycle of a product, process, package, material handling activity. Life cycle stages encompass extraction and processing of raw materials, manufacturing, transportation, and distribution; use/reuse/maintenance; recycling and composting; and final disposition.

Importance of DFE

Design for the environment is an important activity for a design team because environmental damage is greatly influenced in the early design phases. 80% of the environmental damage of a product is established after 20% of the design activity is complete. The design for environment is essentially due to three factors:

1. **Customer demand:**

   From the business viewpoint, the reason a design team should choose to complete design for the environment is that modern customers are now demanding products with least environmental impact. The world's population is becoming aware of society's influence; society is attempting to minimize its impact. Creating a product that impacts the environment less becomes a market advantage. For example, Xerox; Xerox has a commitment to be a waste-free company; as a part of its operations and its products, it will generate no waste material that cannot be recycled or remanufactured (Xerox, 2000). Xerox aims at 100% recyclable product.

2. **Government pressure:**

   Government agencies also enforce reduced environmental impact standards for products. Such regulatory pressure will only grow with time. Many countries now have for products such as packaging, computers, and transportation vehicles, complete with required recycling of the components.

3. **ISO requirement.**

   Standards are also being developed to support design for the environment as a practice. Underlying all of these activities are the market forces that demand design for the environment as a necessary part of modern product development.

Environmental Factors

It is important to understand pollution types, their range of impact, and what can be done in product development to reduce the impact of pollution. There are many guidelines developed to help industry understand and deal with its impact on the environment. Coalition for Environmentally Responsible Economies (CERES), as the CERES Principles, establishes objectives and guidelines to help companies maintain good environmental performance. These principles were adopted by the Exxon Corporation (March 24, 1989) and later adopted by hundreds of companies.

Outline of the objectives:

1. Companies will reduce the release of pollutants that endanger the earth.
2. Consistency of use of resources: Companies will use raw materials at a level where they can be sustained.
3. Companies will minimize waste wherever possible. When waste cannot be avoided, recycling will be adopted.
4. Companies will use environmentally safe energy and invest in energy conservation.
5. Companies will minimize health risk to employees and the community.
6. Companies will sell products that minimize environmental impact and are safe for consumers to use.
7. Companies will take responsibility through clean up and compensation for environmental harm.
8. Companies will disclose to employees and the community incidents that cause environmental harm or pose health and safety hazards.
9. At least one member of a company’s board will be qualified to represent environmental interests, and a senior executive for environmental affairs will be appointed.

10. Companies will conduct annual self-evaluations of progress in implementing these principles and make results of independent environmental audits available to the public.

11. Pollution can be organized by the scope of their environmental impact, from global to regional to local impacts.

Scope of Environmental Impact

Global Issues

There are pollution problems which exist on a global scale. These include concern over climate change, ozone depletion, and biodiversity loss. The concern over climate change is because of the probable consequences of possible large changes in the earth's climate due to increase in greenhouse gases. This is due to burning of fossil fuels which increase carbon dioxide levels in the atmosphere. From the product design point of view, developing products that use less energy will help mitigate this problem. Another global pollution concern is the depletion of the ozone layer. The ozone layer is a thin layer in the upper atmosphere that blocks ultraviolet radiation from reaching the Earth's surface. Fluorocarbon gases, from our industrial society, may also react with and reduce the ozone gas in this layer. From a product design viewpoint, developing products that do not make use of or release these harmful chemicals, either in use, manufacture, or disposal, will help to solve this problem. Minimizing biodiversity loss is another global environmental impact objective. Loss of habitat for different plant and animal species due to our expanding society can cause extinction of species. Developing products that use less new raw material will be useful.

Regional and Local Issues

Other environmental problems exist on a more regional level. These include problems of acid rain, where pollution by products in one region can cause acid rain in another region. Air pollution and smog also are regional problems. Water pollution, either in the ground water, river, bay, or ocean, is also a regional problem, often caused by herbicides and pesticides, in addition to suburban and urban street water run-off. Other contaminants can enter through streams and landfills as water pollution. Herbicides and pesticides are typical problem compounds whose amounts introduced to a regional area must be controlled. Many other chemical compounds that are used in products must similarly be understood and controlled

***Basic DFE Methods* Design Guidelines**

German, British and U.S. guidelines from a design point of view are available. These guidelines are simple and effective when implemented. After developing a concept, the guidelines should be consulted, every guideline questioned, and the underlying concepts modified to increase the guidelines' performance. During the embodiment and detail design phase, a guideline should again be consulted, so as to ensure that the product developed is compatible with these guidelines.

Product Structure Guidelines (General Electric)

1. Design a product to be multifunctional because it is more efficient than many unique function products.

2. Minimize the number of parts. Create multifunctional parts. This reduces disassembly time and resources.

3. Avoid separate springs, pulleys, or harnesses. Instead, embed these functions into parts. This reduces disassembly time and resources.

4. Make designs as modular as possible, with separation of functions. Allow options of service, upgrade, or recycling.

5. Design a reusable platform and reusable modules. This allows of service, upgrade, or recycling.

6. Locate unrecyclable parts in one subsystem that can be quickly removed. This speeds disassembly.

7. Locate parts with the higher value in easily accessible places, with an optimized removal direction. This partial disassembly for optimum return.

8. Design parts for stability during disassembly. Manual disassembly is faster with a firm working base.

9. In plastic parts, avoid embedded metal inserts or reinforcements. This creates the need for shredding and separation.

10. Access and break points should be made obvious. Specify remanufactured parts. Logical structure speeds disassembly and training. Stimulate demand for remanufacturing, reducing raw material consumption.

11. Design power-down features for different subsystems in a product when they are not in use. Eliminate unnecessary power consumption for idle components.

12. Lump individual parts with the same material. This eliminates the need for disassembly during recycling. Neighbour parts may be ground or melted as a group.

Material Selection Guidelines (G.E.)

1. Avoid regulated and restricted materials because they are high impact.

2. Minimize the number of different types of material. This simplifies the recycling process.

3. For attached parts, standardize on the same or a compatible material. Eliminate incompatible materials. This reduces the need for disassembly and sorting.

4. Mark the material on all parts. The value of many materials is increased by accurate identification and sorting.

5. Use recycled materials to stimulate the market for the material that has been recycled.

6. Use materials that can be recycled, typically ones as pure as possible (no additives). This minimizes waste; increase the end-of-life value of the product.

7. Avoid composite materials. Because composites are inherently not pure materials, and so not amenable to recycling.

8. Use high strength-to-weight materials on moving parts to reduce moving mass and therefore energy consumption. Use low-alloy metals that are more recyclable than high-alloy ones. More pure metals can be recycled into more varied applications.

9. If the same base metal can be used, different metals can be fastened. Aluminium, steel, and magnesium alloys are readily separated from shredder output and recycled.

10. Hazardous parts should be clearly marked and easily removed. Rapidly eliminate parts of negative value.

Labelling and Finish Guidelines

1. Ensure compatibility of ink where printing is required on parts to maintain maximum value of recovered material.

2. Eliminate incompatible paints on parts—use label imprints or even inserts. This is because many level-removal operations for paints cause part deterioration.

3. Use unplanted metals that are more recyclable than plated because some plating can eliminate recyclability.

4. Use electronic part documentation because these parts can be reused.

Fastening and Assembly Guidelines

1. Minimize the number of fasteners. Most disassembly time is fastener removal.

2. Minimize the number of fastener removal tools needed. Tool changing costs time.

3. Fasteners should be easy to remove. Save time in disassembly.

4. Fastening points should be easy to access. Awkward movements slow down manual disassembly.

5. Snap fits should be obviously located and able to be torn apart using standard tools. Because special tools may not be identified or available.

6. Try to use fasteners of material compatible with the parts connected. This enables disassembly operations to be avoided.

7. If two parts cannot be compatible, make them easy to separate. They must be separated to recycle.

8. Eliminate adhesives unless compatible with both parts joined. Many adhesives cause complete contamination of parts for material recycling.

9. Minimize the number and length of interconnecting wires or cables used. Flexible elements are slow to remove; copper contaminates steel, etc.

10. Connection can be designed to break as an alternative to removing fasteners. This is because fracture is a fast disassembly operation.

UNIT IV

DESIGN FOR MANUFACTURE AND ENVIRONMENT

S.No.	PART - A
1	List the general design principles for Design for Manufacturability
2	What is process capability?
3	What is a Feature tolerance?
4	What is mGeometric tolerances?
5	What is tolerance stacks?
6	Define design for environment.
7	What are the basic Design For Environment (DFE) methods?
8	What is the datum features?
9	List the global issues in DFE
10	What are the Design Guidelines in design for Environment?

S.No.	PART - B
1	Explain the design principles of manufacturabilty?
2	Describe the following: 1. Strength and Mechanical Factors for manufacturability

	2. Mechanism Selection 3. Process Capability for manufacturing
3	Explain about the feature and mGeometric tolerances?
4	Explain the design for the environment and objectives of environment?
5	Explain the basic DFE methods and design guide lines?

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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 5– INDUSTRIAL DESIGN – SME1310

Need for industrial design-impact in design process - investigation of customer needs - conceptualization - refinement- management of the industrial design process - technology driven products - user - driven products Integrating CAE, CAD, CAM tools

NEED FOR INDUSTRIAL DESIGN

Industrial design is a process of **design** applied to products that are to be manufactured through techniques of mass production. Industrial design is also to create and execute design solution for problems of form, function, usability, physical ergonomics, marketing, brand development, and sales.

But why is industrial design important in today's era?

Everyone has his or her requirement and for the requirement to be satisfied, an Industrial Designer makes his way in. Industrial designers develop products guided by the special requirements of their client and manufacturer. They prepare clear and concise recommendations through drawings, models and descriptions. Industrial designers improve as well as create, and they often work within multi-disciplinary groups that include management, marketing, engineering and manufacturing specialists.

The market is flooded with similar products, and the only thing that differentiates one brand of a particular good from another is its design. While products have always served a function, they are more and more carrying meaning. It is the role of good product design to effectively communicate that meaning to the consumer. It is vital for businesses that want to do well to listen to and respond to the needs and desires of consumers, providing creative and innovative product design.

Growing Urbanization is another reason why Industrial Design is important. As the society develops, a need for products in a more fashionable way according to the current trends arises and Industrial Designing helps fulfill those needs. India is one of the countries where industrial designing is developing rapidly. Many design schools offer courses on industrial designing in India.

Industrial Design is a fast growing field in designing and holds a very important place in the industry.

Impact in design process

The design process has a number of elements to it and each must be followed in order to get a design which is both aesthetically pleasing to the client and practical in its use.

- On-site visit
- Client consultation (design brief)
- Concept design drawings
- Client amendments

- Full working drawings completed

The on-site visit is essential for large projects for the designer to get an accurate feel for the project. At this time aspects of the land are taken into account and noted, for example, any views that can be exploited, the slope of the block and the orientation of the site.

All these factors can have a major influence on the design of the project and need to be carefully considered during the planning stage. At this stage it is a good idea to organise a site survey (contour survey) and soil test, as these can take time to complete.

The client consultation is greatly focussed on the client design brief (and this forms part of the contract). Now, a design brief can be a detailed document or as simple as a couple of notes.

This all depends on the complexity and scope of the project. For example, the level of detail of a design brief for a deck is going to be quite considerably less than that of a new home. For the purpose of this article we will be focussing on the process for a new home.

The first process to go through when developing a design brief is to identify all family members who are going to reside in the residence and analyse their specific requirements both socially and physically. This pertains to their relative stage in life and what needs they may have now and in the future. Once this has been determined it is than possible to work out the spaces that are required:

Number of bedrooms and the relationship between them

What type of living spaces are needed (informal, formal, media room, kids retreat, etc.)

How the kitchen is going to link the living spaces

The number of wet areas (bathroom, ensuite, powder room, laundry)

The houses entry and exit points and how they relate to the rest of the house

Size of garage and workshop (must accommodate cars, boats, toys)

The inclusion of storage (linen, store, attic)

The consideration of budget should also be a part of the design brief and a solid 'ball park' figure should be determined by the client before any particulars of the design are discussed. There is nothing worse than getting your heart set on a particular aspect of the design and then finding out it exceeds your budget. A visit to your local bank is usually a good place to start when determining your budget limitations.

With a detailed design brief a concept drawing can be produced incorporating all the necessary elements and needs of the clients. The concept plan consists of a floor plan to scale, a basic site plan positioning the building and a front elevation showcasing the proposed front façade. It is at this stage the client has the opportunity to amend the plans and change certain aspects of the design.

The concept drawings are then amended and presented to the client for one more review. This time the design and layout of the residence is finalised and the process proceeds to the final stage of documentation.

Documentation

In the documentation phase the working drawings are completed by Impact Design and Drafting this includes; site plan, floor plan, elevations, section, bracing, tie-down and timber schedule. These plans are sufficient for council submission. However, additional plans which are available include; construction details, internal elevations, electrical plan, slab plan and details of design features. Depending what service level was chosen by the client these additional plans may be included in the package.

Once all the plans have been completed it is than time to look at sourcing some external consultants that will be required to successfully achieve a building approval. Some of these consultants include engineers, private certifiers, town planners and interior designers (not required for council approval). Once again depending on what service level the client has chosen we at Impact Design and Drafting can organise the consultants and obtain a building approval from your respective council.

At Impact Design and Drafting we have extensive knowledge and experience in developing client's ideas into a completed project and we enjoy the design process. Some clients come to us with their own designs and we are happy to tweak the designs and finish the project for them as well. Just remember designing your new home, renovation or addition is meant to be fun and enjoyable so let your creativity flow.

investigation of customer needs

An innovative product doesn't come from a law passed by the government. It also doesn't come from venture capitalists looking for a higher return on an investment. Innovation comes from identifying customers' needs and providing solutions that meet those needs.

Companies like Uber, Airbnb, and Intuit understand this. Uber's success, for example, has come not from building new, better taxis, but from seeing — and then solving — people's transportation problems.

Although you might not be working on the next Airbnb, Uber, or even a product you think is exciting, like business software, or temperature controls, understanding and identifying customer needs may lead to a revolutionary innovation. After all, Nest revolutionized the rather mundane industry of thermostats and changed how everyone heats and cools houses.

STARTING WITH EXISTING DATA

You most likely have existing data at your fingertips. Review past surveys, customer interviews, and customer-support call logs. There's no point in funding an extensive and expensive research campaign if the data you need is already collected.

Save the budget for data you don't have and more advanced questions you need answered.

INTERVIEWING STAKEHOLDERS

Why not begin with the data you don't have to pay for: the collective knowledge stakeholders have. Start with sales and support teams. They know the product and the customer. They often have a list of feature requests, bug reports, and enhancements straight from the customer's mouth.

Combine these to generate a preliminary list of requirements. Look for patterns, but don't automatically dismiss one-offs look to corroborate them with findings from other methods.

MAPPING THE CUSTOMER PROCESS

If you know your customer's process, map it out.

For example, before Uber, to get a ride you called a taxi company, waited to reach a dispatcher, waited for a car to be dispatched, hoped the driver would find you, and hoped you had enough cash when you reached your destination.

With Uber, you open your smartphone and summon the nearest car with one tap; you already know how far away the car is because you can see it in real time on a map. The driver also sees your location so he or she can come right to you. The figure shows a simple process map comparing these experiences.

Figure 5.1 Process Map

MAPPING THE CUSTOMER JOURNEY

A customer journey map is a visualization of the process a customer goes through when engaging with a product or service. It takes process mapping to a new level by including multiple phases and touch points a person goes through from prospect to loyal customer. It's a document meant to unify fragmented efforts and identify points of friction and opportunities for improvement.

Finding and fixing the pain points in a customer's journey isn't just about damage control: It's also about the innovation that comes from fixing the pain.

CONDUCTING "FOLLOW ME HOME" RESEARCH

"Follow me home" research relies on observation by literally following a customer home or to work. You follow a customer to her workplace, spending the day watching her do her job. You observe process pain points and then look for opportunities for improvement.

For example, during a "follow me home" exercise, a team of researchers at Intuit noticed that retail customers were exporting their transactions from their point-of-sale cash registers into QuickBooks to manage their books. This step took time and sometimes led to failure and frustration. The innovative solution? Developers integrated QuickBooks into a cash register and eliminated the export step for customers and created a new version called QuickBooks Point of Sale (POS).

INTERVIEWING CUSTOMERS

Go right to the source: Ask customers what problems they have and what features they want. Even when customers can't articulate their needs clearly, you can often gain insights that lead to successful innovations.

Use the "Five Whys" technique to help you discover what needs people don't even know they have, needs that no one has recognized before: Keep asking why until you get at the root cause of the problem and not a symptom. (It's called "Five Whys" because you often have to go through five levels before you get to the point where you can make a change that addresses the problem.)

CONDUCTING VOICE OF CUSTOMER SURVEYS

Voice of Customer surveys collect data, from email or from a pop-up on a website, about the attitudes and expectations of existing or prospective customers. Use a mix of open- and closed-ended questions to see what produces the most useful data.

Although customers aren't necessarily good at identifying their needs, this type of survey often yields data from which you can discern customer goals, challenges, problems, and attitudes, and then recommend opportunities for improvement.

ANALYZING YOUR COMPETITION

Consider using research firms that might present a more objective face to customers who engage with your organization and its competition. Consider using the SWOT rule: Identify your competitors' strengths, weaknesses, opportunities, and threats. You can use a SWOT for a brand, product, or even an experience.

Define the competition both narrowly and broadly. Don't just look at your competition in the same industry, but other industries as well.

ANALYZING CAUSE-AND-EFFECT RELATIONSHIPS

No one will disagree that it's usually good to think positively, but sometimes, negative thinking can solve problems more effectively. Through observations, surveys, and other data sources, you may find problems that are actually just symptoms of other root cause problems.

Task failures, errors, and long task times are usually the symptoms of multiple underlying problems. These can be problems in the interface or a disconnection with the user's goals. Through the process of asking "Why?" multiple times and segmenting different causes, you can help identify and address root problems in the user experience.

RECORDING EXPERIENCES THROUGH DIARY STUDIES

Sometimes opportunities reveal themselves over time. One cost-effective longitudinal method is a diary study. Ask participants to record problems, frustrations, positive experiences, or thoughts at intervals throughout a day, week, or even a year. This can be low tech, with customers writing their experiences and thoughts down on paper and mailing it in, or high tech, in which you send text messages or emailed surveys to customers at particular intervals.

Because you're asking your customer to do the data collection for you, be sure you have targeted questions and clear hypotheses you want to test with all the data that gets collected.

Expect a good percentage of customers to drop out or not be 100% diligent about filling out their diaries. Still, any information you can garner is better than no information at all. After all, you can't fix what you don't know about.

MANAGEMENT OF THE INDUSTRIAL DESIGN PROCESS

When launching new products, it is essential to progress through the product development stages quickly and efficiently, from initial concept through to finished product.

In this specialization, you will learn to effectively manage the product creation process and to communicate with a variety of target groups, both internal and external (i.e. clients and suppliers).

While the product development manager is not always directly involved in a product's design, he or she needs to be aware of various design techniques in order to successfully lead multi-disciplinary design teams. This may include generating a product development plan, drafting recommendations for the organization of a product's development, organizing a feasibility study and optimizing a product's life cycle.

TECHNOLOGY DRIVEN PRODUCTS

As innovation can take an infinite variety of forms, so its underlying insights can be derived from a great many different sources. Technology-driven innovation usually originates in scientific discoveries and in hundreds of years of accumulated technical know-how. These combined forces of science and technology drive ever greater specialization in the spheres of knowledge. When new technologies make the transition from the scientific domain to realization in technology, inventors and corporate R&D groups, companies compete to develop commercial applications.

In the early decades of industrialization the development of new technology was itself often a key source of competitive advantage. Consequently, companies invested heavily in R&D projects that produced new products in every sector of the economy. In some areas, this remains true today; pharmaceutical and bio-tech companies actively search for new genes, molecules and delivery systems; computer chip manufacturers are constantly refining the processes of design and manufacture in the endless pursuit of greater

performance and smaller size; materials scientists in many fields are searching for higher performance and lower price, the twin hallmarks of innovation. Similar efforts characterize every other high-tech field.

Critical Success Factor

For companies that do not compete in the high tech sector, the development and deployment of technology is also a critical success factor, but here the role of technology is largely in operations, because technology is critical to every aspect of coordination, communication and management in today's markets. For these companies (the vast majority), technology is completely embedded in how people work and improvements in technology applications can be a significant source of differentiation.

For example, FedEx relies on one of the largest and most sophisticated information technology operations in the U.S. to get packages to their destinations overnight, while allowing customers to track a shipment's every step along the way. Similarly, supply chain management and automation at Wal-Mart was one of the company's early competitive strengths and they remain so today. At major banks, millions of credit card transactions are processed each day; the pattern recognition software systems that search for fraud are run on massive computers that analyze terabyte-sized data files.

Technology Providers and Appliers

For companies that are heavy users of technologies that are not their end product, technology itself has nevertheless become a significant domain for innovation; technology-driven innovation, therefore, is central to their competitive position just as it is in high tech manufacturing. In this context, technology-driven innovation refers to the interplay between technology providers and technology appliers, and addresses the complex innovation dynamics that emerge when they work together to bring new capabilities into reality.

Discovering and deploying useful new technologies is a serious commitment for technology-driven innovation companies because of the competitive advantages that can be achieved. Managing the supply chain, managing millions of customer relationships or financial transactions, managing massively complex manufacturing sites are all critical functions that absolutely depend on technology. As technology advances new modes of operation have to be worked out, which calls forth a collaborative process of innovation between suppliers and users.

There is an ironic aspect to this – because technology is so pervasive, because access to it hardly varies from continent to continent and because its root purpose is almost always to increase efficiency, the acquisition and deployment of technology has itself become a force of commoditization. Commonly-available technology (including computers, communications gear, new materials and new methods) are all being applied globally to improve operations, to lower costs and lower prices, and to drive the process of commoditization deeper into all aspects of economic activity.

Generally, therefore, today's technologies drive commoditization in nearly every sector of the economy – unlike in the 19th and 20th centuries, when innovation in technology was a source of competitive differentiation.

There is one exception to this trend, and that is in the creation of knowledge and the use of knowledge in services, which is often a source of differentiation through forces such as personalization, customization, and the aggregation and re-purposing of data, information and knowledge. It is for this reason that many of the most innovative companies of the last two decades are business model innovators, companies that do not innovate in the development of technology, but rather in its application in services and distribution, companies like FedEx and Wal-Mart as well as Starbucks, Home Depot, Zara, Amazon and even Nike.

User driven products

What is user driven content?

User driven content is information that has been heavily influenced by the opinions, thoughts and ideas of individuals. The notion is that customers are no longer spectators but collaborative partners in business development. Today, customers are more empowered then ever as they actively initiate conversations, shape and manage the flow of data related to products and services across a wide range of communication channels. Gone are the days when the expert team of brand managers, marketers and product designers spend countless hours around the conference room table discussing ways to get inside the customer's head. A user driven framework of product development recognizes that the customer is a key component within the design and development process.

User driven content: Implications for business strategy. Customer-centric companies understand that the only way to develop good products is to incorporate customer feedback into every critical phase of the design and delivery process. Their design teams take advantage of early customer input or feedback to develop and test products faster and correct design flaws more efficiently. They also recognize that collecting quality user driven data, especially during the early phases, can increase sales, customer retention and brand loyalty. Finally, user driven product development increases bottom-line results by eliminating costly product redesigns and re-launches.

Create user driven products with OneDesk

OneDesk understands that only a well-structured cross-functional collaboration between departments will produce high value products. That is why includes easily customizable project management tools that put your entire company on the same page, so you can get organized and get the job done efficiently.

Equip your team with the right tools to gather useful data, listen to the ideas and concerns, and incorporate product suggestions from your customers. This will give your team a positive direction and empower them to produce products that will surprise and delight your customers.

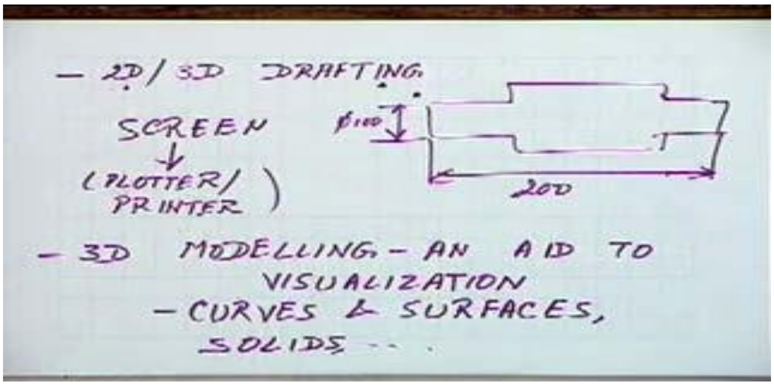
INTEGRATING CAE, CAD, CAM TOOLS

Before we go on to the any of those activities, I first want to briefly describe what is normally referred to as computer aided design. In computer aided design we basically talk of integrating computer science techniques with or integrating computer science techniques for engineering design. What that means is any kind of use of computers in the design activity is referred to as computer aided design. This includes a wide variety of usage, this includes a wide variety of techniques that are used some are computer graphics techniques, some are simply using computer as programming tools. We will see what are the different activities that can come under these or what are the different computer science techniques or computer techniques which have been used under the design domain.

This use would include use of both hardware as well as software. When you are talking of hardware different kinds of hardware have been used in terms of the screens that you have, the input devices like I think you all familiar with the mouse. The other input devices maybe a ball or maybe a light pen, there are other output devices like plotters. So different kinds of hardware are relevant which are specifically meant for CAD activities. Different kinds of software which have been developed which are different kinds of modelling software we will be talking of that in detail.

Then if you talk of different numerical techniques, numerical methods, when I talk of numerical methods I include optimization, I even include the normal programming or instead of talking of automation we just program a particular activity where we are using the computer as a number crunching machine.

All those activities are what I include under numerical methods. They can include matrix multiplication or where very large matrices are involved, they can include solution of partial differential equations, they can include optimization techniques all these are what I cover under numerical methods.



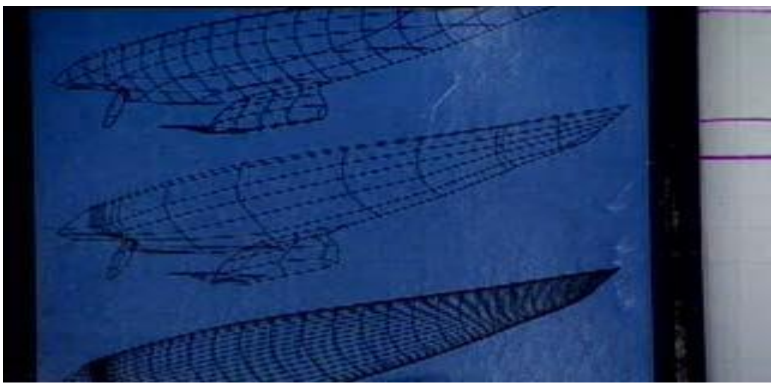
When you talk of CAD after numerical methods, the next thing that is normally including under CAD is what is referred to as drafting which is either 2 D or 3 D drafting. When we say drafting

what we mean is the normal drawing work that is done. You have all done a course on engineering drawing. Whatever drawing you do on a drawing board, the same instead of doing it on the drawing board you do it on a computer that means if you have to draw lets take a very simple example if I want to draw the shaft and I want to give it a dimension something like this and maybe some length over here which is let's say, if I want to give it a set of dimensions like this I can make a engineering drawing out of this on the drawing board. Instead of using the drawing board I can do the same thing on the computer using Auto CAD or using some other drafting package. This drawing consists of a set of lines that have been draw here, the set of arrow heads, the set of text that has been written and so on. In this each entity is a line or an arc if you are drawing or if you have an arc over here that will be an arc, so each entity is a line or an arc.

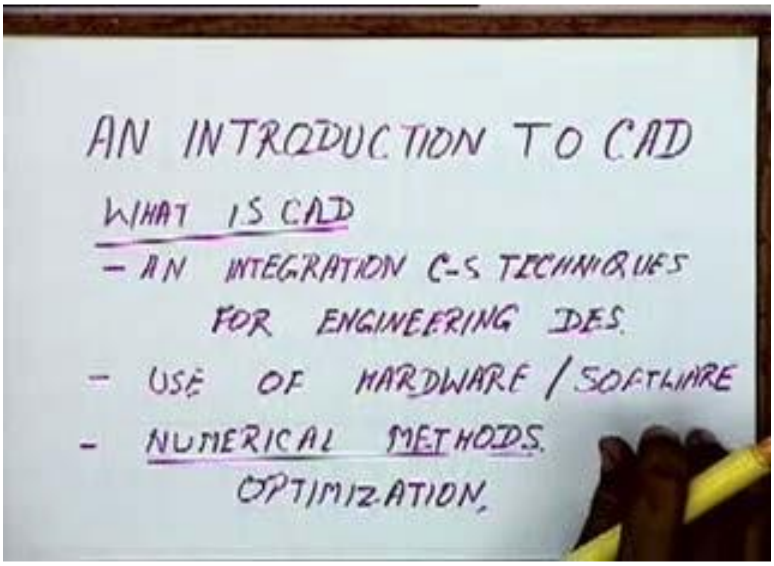
An entity is a not the complete shaft, we don't have the concept of a shaft right now, we have just drawn a set of line in a set of arcs. This is what we mean by drafting. These lines can be 2 dimensional lines or they can be 3 dimensional lines but they are essentially lines and arcs. And we use these lines and arcs to make a complete figure on the computer. Once we make a complete figure on the screen, from the screen I can take a printout using maybe a plotter or a printer. So that is where CAD specific hardware comes into picture. We have specific hardware meant for plotting, we have specific hardware meant for printing. The screen will normally be a high resolution screen like a VGA monitor or something like that and the basic application is the drafting application that we were talking about. So this is 2 D or 3 D drafting.

The other kind of activities that are normally included in CAD is what we call as 3 D or even 2 D modelling. When you are taking of 3 D modelling, we essentially talk of representing this object. Now if we are talking of shaft over here, we are talking of representing this object as a three dimensional object. If we have it as a three dimensional object let's take this pen, I took this example yesterday also. If I talk of this pen and I represent it as a three dimensional object on the computer, I can take views from any angle. If you are taking a front view you can take a front view like this, if you want to take a top view you can take a top view. If you want to take an isometric that is a view roughly at this angle or something like this, you can also get an isometric view. If you want to take sections, you can take sections. So you represent it as a 3 D model and then take different sections, different views, get the different views and then dimension them accordingly so this is what you mean by 3 D modelling. I will just show you some of the slides from these texts. Can you see it on the monitor?

Now in this you will find a complete scene which has been modeled on the computer. You see a dining table which has been set, different objects which have been placed. Now each of these objects has been modeled using some of these techniques. We were able to use this model to visualize what the table would look like. Here it’s a flight simulator, we are able to use this model to see what the scene is like, what are the different objects there and so on, to see it from different angles and to get a feel of the actual situation. We can have some more examples.



These are objects of different shapes but modeled using different techniques. This model looks very different from the model that you have just saw. In this the surfaces have been modeled by a mesh of wires, it's a wire mesh kind of model, wire mesh kind of display that is being used but this is also a 3 D model, it's a 3 D modelling technique which has been used here. So the other CAD activity is 3 D modelling and this is a major part of what we mean by computer aided design. Often people refer to this as drafting as computer aided design



Some people even refer to just numerical methods also being computer aided design because even in numerical methods you are using the computer as an aid for designing but the major part this activity of computer aided design comes under this realm of 3 d modelling. When you are talking of modelling, it is an essentially an aid to visualization. You want to visualize the object from different angles see different corners, see whether different parts are interfering or not that is what we mean by an aid to visualization. So modelling, we use as an aid to visualization then when you talking of modelling, we are trying to model the different curves and surfaces.

If you are modelling a complete solid, you also have to model the curves and surfaces that come on it. For example in this object you are seeing the surfaces which form this solid. If you want to represent this solid, we also have to represent the curves and surfaces which from a part of the solid. So when we talking of 3 D modelling it is not just representing the solid as such, you also have to represent the curves and surfaces which constitute that solid or which define that solid. So under 3 D modeling, we represent curves, surfaces, solids and so on, all this comes under 3 D modeling.

Now once we have represented a 3 D model, the next question that comes up is that what do we do with the 3 model. one we have already said we will use it for visualization, you want to visualize the object on the screen, it will help us give a feel of the situation and we will able to see whether different parts are interfering, whether the particular part in motion is interfering with something else or not and such things. So one use is visualization but another very important use of these CAD models is in analysis. Once we have the model of a particular object, we should be able to analyze it for the different forces that are acting on it the different forces, the different displacements that the object will be going through and so on.

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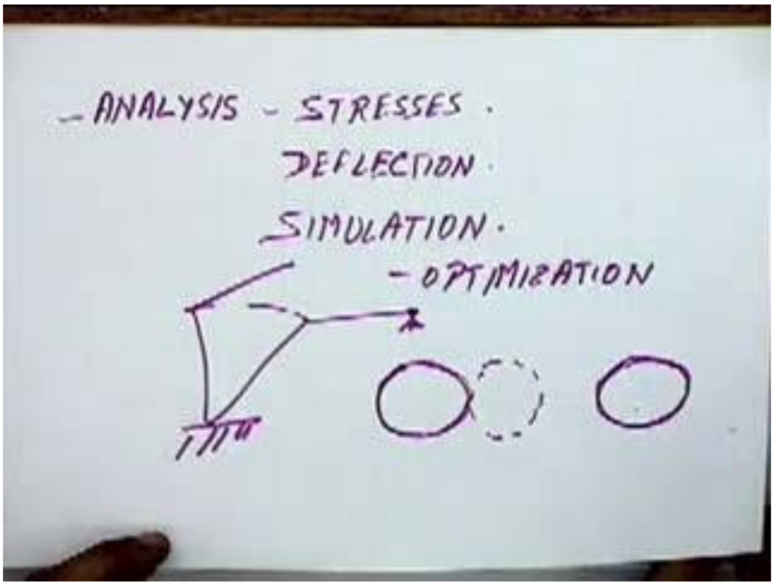
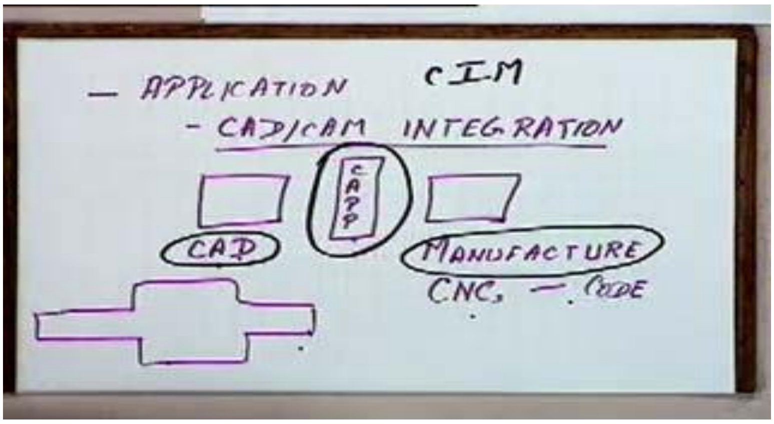


Now this analysis can be analysis for stresses, you can analyze it for deflections. We can also when we are talking of analysis we can actually simulate the objects in actual use that means by simulation what we mean is let's say if we have a simple mechanism like this maybe it's a part of a robot arm or something like that with some maybe gripper attached to here. Now this robo arm is moving in space, from this position maybe it goes to some position like this, the path that I take this link rotates like this along with that this link is also rotating simultaneously



We want to be able to visualize how this object, how this mechanism would move in actual space. So we want to simulate its motion and then actually animate it on the screen and see how the motion will take place. So that is what we mean by simulation, we want to simulate the motion of an object. In very important application of this kind of analysis is let’s say if we have one object, this object can be very complex object maybe car or a bus and we have another object which is maybe another car or maybe a two wheeler or something like that, they meet in a head on collision.

Once they will collide there will be some deformations, there will some forces on the passengers, there will be some stresses on them, stresses on the different parts of the body so we want to estimate, we want to see what will happen in the crash that is crash simulation that is also another type of analysis. All that can be done if we have a model of each of these objects, if we have some representation for this object, some representation for this object, if we have some representation for this set of links for this robo and so on. So all this comes under computer aided design.

We are using the computer as a tool for designing each of these objects and we essentially modelling these objects first then using it for analysis using special tools for each of these kinds of analysis. And of course in another analysis, we have already mentioned optimization. If we have the model of an object, we can use it for optimization, we can use it for optimizing the size or weight and so on for different criteria. So the model that is created that model can be used for any of these activities.

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Other than analysis an important application of these CAD models is applications of CAD models are in the areas of what we call as CAD CAM integration. In CAD CAM integration essentially we are talking of let's say this is an initial stage what we call as CAD where we are developing the model, we are analyzing the model and finally designing a particular object then we have the manufacturing stage. Within the manufacturing stage let's say we have a set of CNC machines, this object has to be manufactured on the CNC machine.

For manufacturing this object on the CNC machine, for this CNC the CNC code has to be generated, has to be written down. This code will depend on the object that has been modeled; it will depend on the set of manufacturing steps that have to be carried on. If we have the model for an object, we can use that model to generate this code and to get an interface, to have automatic interface between CAD and CAM that means directly by a CAD model let's say if we are talking of a shaft, if this shaft is represented internally in a proper manner then from this representation of this shaft, from the model of this shaft we can directly get the NC code that will be required to make it. We will be able to generate a process plan, between CAD and CAM we will have a stage called what is to referred to as computer aided process planning. For making a process plan for this, the CAD model that has been made that will form the input for that. So CAD models will form an input for computer aided process plan and will also be used for generating the NC code.

In case if we are talking of an integrated manufacturing environment, in the integrated manufacturing environment, this CAD CAM integration plays a very vital role. So under the applications this CAD CAM interface and of course computer aided process plan, these form a very major application for the CAD models. In fact there is a whole area which is normally referred to as CIM computer integrated manufacturing. It refers to CAD, it refers to the process plan that is being generated and it refers to the manufacturing stage. This complete stage, this complete cycle comes as a part of CIM computer integrated manufacturing. There are other aspects also to CIM, we won't get into that but the CAD model that has been created forms the basic links for each of these stages in CIM. If you talking of an integrated manufacturing environment, the CAD model is the starting point.

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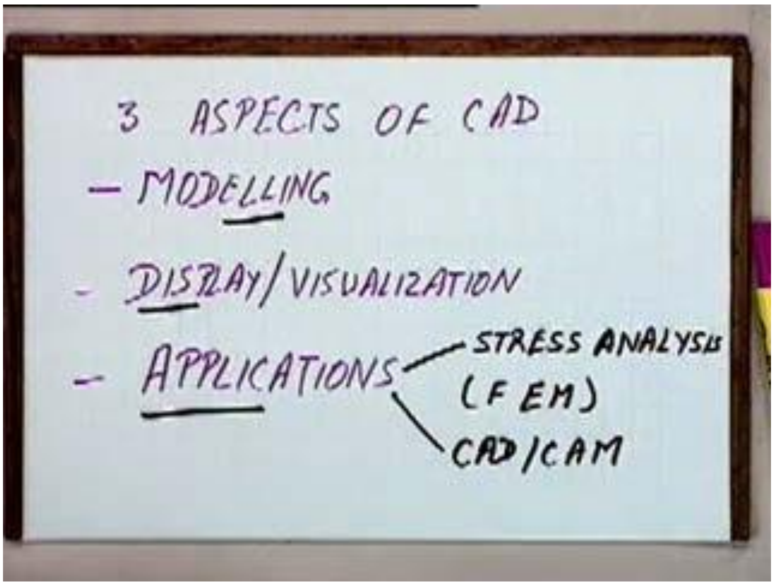

So if we summarize from this the three important aspects, the first important aspect is what we refer to as modelling. The second is what we refer to as the display or visualization. You have modelled an object, you want to display it, we want visualize it and the third is what we refer to as applications.

The applications would be CAD CAM applications, stress analysis applications, CAD simulation applications and so on. In addition to these we have also mentioned numerical methods as an important part of CAD. Quite often CAD is referred to as numerical methods and optimization but as a part of this course, we will not be touching upon this part. In this course we will essentially be talking of computer aided design as starting from a CAD model, we will be talking of modelling and its applications. We will not be going into numerical methods optimization and other such techniques. This course is going to talk mainly of computer aided design as consisting of modeling, as consisting of its use and display and applications. The applications or the main application that will be talking of would be stress analysis and we will be talking of the finite element method and the other application would be CAD CAM integration which we might touch upon. So these are the three different aspects of CAD which we will be touching upon as a part of this course. We will briefly see what are the different activities that come under each of these three.

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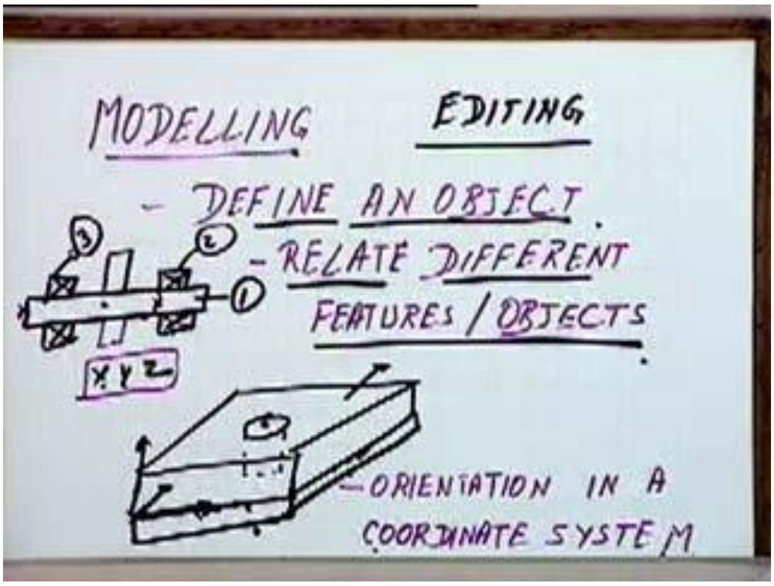

So when we are talking of modelling, under modelling the first thing that we want to do is to define an object. We take a simple object, we want to define it on the computer, we want to define it using some modelling techniques. The first thing that modelling deals with is how to define an object, that is going to be the first important part of modelling. When we are talking of defining an object, we were essentially saying that we want to relate the different features; I will just the different features of an object relate different features or relate different objects.

For instance if you consider this shaft, now this shaft is supported on a set of bearings. When you want to model this complete system, we have to define this shaft as one object, this bearing as the second object and this bearing maybe as a third object and in addition to that there might be some mountings on it maybe there is a gear here or a chain and sprocket here or something like that and something else connected on the other end, so there might be different objects connected on them. When we you are modelling this complete scenario, each of these objects would first be defined.

Then we have to define the relationship between these objects that means this shaft is next to this bearing and is touching it on this surface. So let's say if for this object we are defining this as an origin and for this bearing maybe we are taking this as the origin for this bearing. We will like to define that this bearing is located at a particular xyz value with respect to this origin so that defines a relationship between this bearing and this shaft. This relationship is a geometric relationship with respect to adjacency, with respect to which object is next to the other object and so on. It defines the geometric location of the two objects with respect to one another.

Similarly if you are talking of this mounting which can be a let's say chain and sprocket or a gear, we will have to define this sprocket whose origin is here is at a certain location with respect to this point. This is what we mean by we have to relate different objects; we have to relate them with respect to one another. Relate different features let's say if you are talking of a simple block like this, on this block let's say we have a through hole, this hole is a feature on this block. We will have to relate that this block let's say whose origin is at this location, this is the origin this hole this feature is at a particular orientation with respect to this origin at a particular distance.

This hole is at let's say this face, on the top face. This hole is a vertical hole and is a through hole. All this information has to be available when you are talking of defining this objects that is what you mean when you say relate different features. This hole is one feature, this top face of this object is the second feature, you have to relate the two together saying that this face is next to this hole.

The basic idea that I want to convey right now is that when you are trying to relate the different feature and objects, a lot of information has to be stored in that model. So when you are talking of modelling that includes a lot of information, is not just defining this object as maybe a block, a lot of information goes into it. So unless we are able to relate these features, we will not be able to use this object in any situation.

Unless I know that this hole is at the so and so location is a vertical whole and is a through hole, unless I known all this I cannot get the manufacturing sequence for it. For finding of the manufacturing sequence for making a hole, I need to know the location I need to know the direction of the hole and I need to know how deep it is. So unless all that is known to me, I will not be able to use this model for any realistic propose that is why we say that when we are talking of defining an object, we have to relate different features of the object. And another thing related to this that I have already mentioned is that we have to talk of orientation in a coordinate system.

We define a coordinate system that let’s say this is the origin for the shaft, this is the origin for the bearing, the two are or this origin is at a location xyz with respect to this origin, all that is with respect to a particular coordinate system. So whenever we are talking of modelling you are doing that with respect to a particular coordinate system, you have to define a coordinate system and give all our dimensions with respect to that system. And then once a model has been made in any say design situation, the model will never be static, meaning that the model will change from time to time.

I have made this model but then I find you know the thickness of this plate is too small, so now I want to increase the thickness so I want to go and make a change. The moment I want to make any change that means let’s say I want to change the thickness. In this figure I will have to increase this size, this size, make this change, this change and rub out all these. If I am doing on the drawing board I will have to make all these changes.

So when I am talking of making these changes, we refer to this process as a process of editing, editing an existing model or making changes in an existing model.

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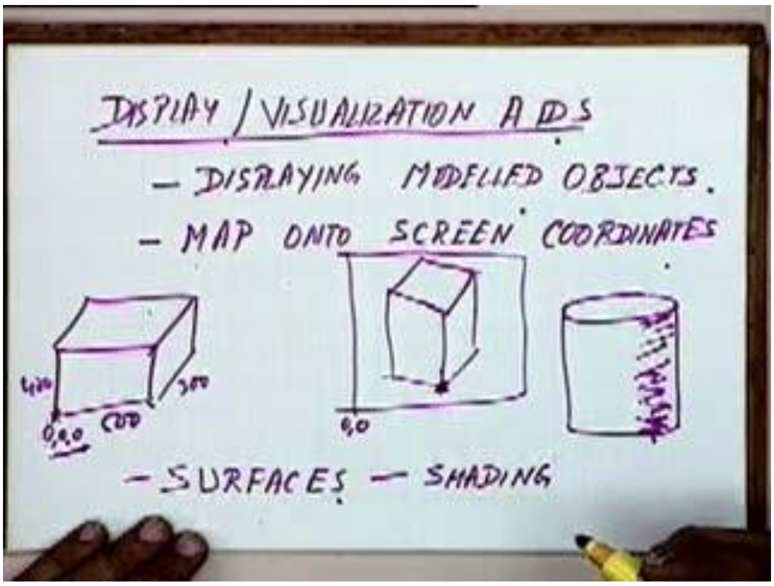


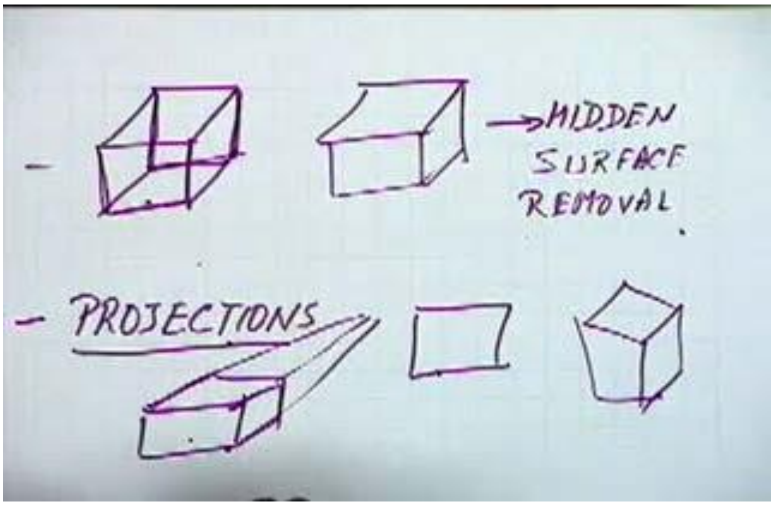
So once a model is available then we talk of what I refer to as display or visualization aids. When you are talking of display, we are talking of displaying model objects. When you are talking of displaying the model objects what we basically want to do, if this object we want to map it onto screen coordinates. That means if you have a simple block like this the block let's say for this block I am taking this as the origin, the width is maybe 500, height is 400 and the depth is maybe 300.

If I am taking a particular view in which maybe let's say an isometric view something like this. Now this view has to be drawn on the screen. So, on the screen the orientation of the location of each of these points has to be defined. So on this screen if I am taking this as my 0 0, I have to decide this 0 0 0 over here has to map to which point on this screen. That means every point of this block has to be mapped down to a screen location that is what we mean by mapping onto screen coordinates.

If I am able to map every point on this block then I can draw the object on the screen. So when we are talking of displaying a visualization of that object, we are basically talking of taking the model object, for each and every point we find a corresponding point under screen coordinates that is what you mean by display. In this display if we have surfaces then these surface might have to be shaded.

If I have a simple cylinder like this, for an engineering view of this cylinder I need not bother, I can just take a front view and a top view and make my three orthographic views but for visualization I might like to get a shaded view. If I am taking a shaded view it will look something like this depending on where the light is placed. So when you are talking of displaying I should be able to take any object and display it on the screen, show it on the screen depending on what is the location of my light source, what is the nature of the surface whether it reflects a lot of light or whether it is a diffusing kind of surface and so on.

So when you are displaying surfaces, we will talk of issues like shading and we will talk of what is referred to as hidden surface removal.



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If I am trying to make a view of a simple block, I am displaying all the surfaces this is what the view would look like. And it is easy to see that this view is confusing, it is not easy to make out which surface is in the front which surface is at the back. I can’t make out whether this surface is in front or whether this surface is in front. So normally we like to remove the hidden surfaces, the surfaces at the back which are not visible, the edges which are not visible we like to remove those lines and edges. So instead of drawing it like this, we like to draw it just like this. This should improve the clarity of the presentation, it will help in visualization.

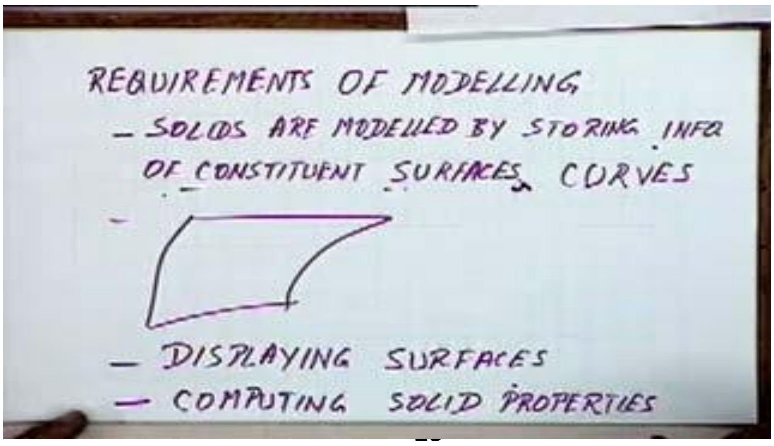
So when we are talking of display, we like to remove hidden lines. This is normally referred to as hidden line removal or hidden surface removal. Then when we are talking of display, we will also like to talk of projections. If I take an orthographic view or a front view, simple front view of this object, I will get a rectangle. If I take an isometric view, I will get a view which would be something like this. If I take maybe perspective view, I will get a view which would be something like this.

If I have modelled this object that is if I have given the geometric description of each of the surfaces and each of the edges, if all that information is available with the computer I should be able to generate any of these views depending on the direction from which I am looking, depending on my specifications given. I should be able to do these projections. We will be seeing methods for each of these tasks. We will see how projections can be obtained, we will see how hidden surfaces can be removed, we will see how simple display of lines and curves can be done. We will also see how the shading can be done, all these techniques we will be covering as the part of this course.

So from all this we can conclude that if we are talking of modelling, modelling has different requirements. The first is that solids are modelled or have to be modelled by storing information of constituent surfaces. If I have any solid, I cannot represent the solid unless I am able to represent the surfaces because my different features will be on the surfaces. If I have a hole or if I have slot, if I have glove they will all be on the surfaces. So all my surfaces will play an important role in defining the solids, so we say that solids are modelled by storing information of constituent surfaces.

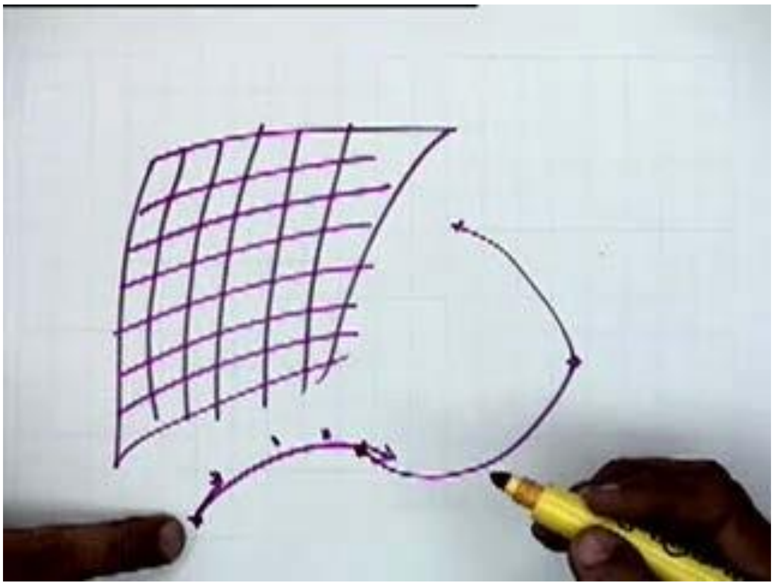
Similarly when we are talking of displaying surfaces, we will also have to talk of curves. If I have surface like this, I cannot represent this surface unless I am able to represent the edges of this surface. So if I am talking of surfaces, curves are also equally important. Then if I am representing or if I am storing information of with respect to surfaces and curves this would help us in firstly displaying these surfaces. Now this would help in displaying surfaces that means if I have to display any object, how do I display a solid? The only I can display the solid is by displaying all the boundary surfaces. In the simple example when I am trying to display this solid, what I am basically doing is I am displaying each of these surfaces one after another, so I cannot display a solid unless I am able to display the surfaces. So storing information of constituent surfaces is going to help us in displaying the surfaces. It will also help us in computing solid properties.

What we mean by solid properties? For this object, if I want to find out the weight of this object or if I want to find out the volume of this object, the moment of inertia of this object I should be able to do that. I cannot do that unless I know what are the bounding surfaces. If I know the bounding surfaces I can find out the weight, I can find the moment of inertia and so on. So this information is going to be important in computing the solid properties. Then I have already mentioned that solids are modelled by storing information



surfaces and surfaces will be modelled by storing the information on the curves. So this relationship between solids and curves is well represented by this diagram.

Are you able to see it clearly? [Conversation between Student and Professor – Not audible (00:44:41 min)] Essentially what it says is if you want to represent any volume, a volume is delimited by or is bounded by a set of surfaces. Surfaces can be either plane surfaces that is planes or they can be warped surfaces, warped surfaces or curved surfaces. Whether they are plane surfaces or whether they are warped surfaces, their boundary will be different kinds of curves. So if you have a curve can be a boundary for a warped surface or it can be a boundary of a plane surface. We can also have a family of curves which define a surface, a network of curves or a set of curves which define a surface.



For instance if we take a set of curves like this, we say this is an family of curves. One set of maybe cubic curves in one direction, another set of cubic curves in the second direction and this defines a surface patch. So we can have a network of curves or we can have patches which can define a warped surface or which can define a three dimensional surface. A curve can consist of a set of curve segments. What you mean by a set of curve segments? We have a curve from one point to a second point then we have a different kind of curve from this point to the next point and in another kind of curve from here to here and so on. So a curve can consist of a set of curve segments like this, so curves can consist of a set of curve segments and curve segments would be defined by end points, end points or the geometric properties.

So if you want to represent a solid or volume, this solid or volume will be represented by surfaces which are represented by curves which are in turn represented by curve segments which consist of points. If we have to describe solid modelling techniques, we cannot describe them unless you have some idea of how to represent curves and surfaces. The basic method of representing any solid is always going to have methods of representing curves and surfaces embedded in it. So the basic idea is that when we talk of modelling surfaces or modelling solids before that we will be talking of curves and surfaces and their modelling techniques. So in this course we will first talk of different methods of, when we talk of modelling we will first be talking of different methods of representing curves, different methods of representing surfaces and then we will talk of different methods of representing solids. [Conversation between Student and Professor – Not audible (00:48:35 min)] What is your question again? You defined curve segments being defined by end points. That is to say curves may essentially lines.

I am glad to you have put that question. Actually instead of end points I should have said control points that is the better way of saying that. If we have a curve starting from this point, ending at this point, here if I just specify two points, I can only have a straight line between them but if I have a set of control points, I can have a set of points here. This is the set of control points which define this curve then I can have a curve either a cubic curve or a higher degree polynomial curve depending on the modelling technique I am using. If I am using five points or if I am using ten points, I will have a curve of the corresponding degree. So the curve will be modelled not just by the end points but by a set of control points or if I am just giving the end points and also be specifying something in addition to that maybe the direction of the tangent over here or some such related information. Maybe I will specify the direction of the tangents plus I will specify that this is the second degree curve then maybe end point, just end point would be sufficient.

But the basic idea in this figure is that if I have to represent a curve segment, I cannot do that without storing the relevant points in line. The relevant points will be the set of control points including end points, including some other information in terms of tangents and so on. So here it won't just be the end point or the start point and the end point but it will be also be a set of control points which will be important for every curve. Any other question? So if they are no more questions then I will end now and we will start from this point in the next class.

UNIT V

INDUSTRIAL DESIGN

S.No.	PART - A
1	What is the need for Industrial design?
2	What is an investigation of customer needs?
3	Define Conceptualization in Product Design.
4	Define Refinement in Industrial Design.
5	What do you mean by technology driven products?
6	Define Computer Aided Engineering (CAE)
7	Define Computer Aided Design (CAD)
8	Define Computer Aided Manufacturing(CAM).
9	How Industrial design will provide impact in the product design process?
10	What is the management of industrial design process?

S.No.	PART - B
1	Explain the need for Industrial design with example.
2	Explain the steps in Industrial design process.
3	Explain the Investigation of customer needs in Industrial design.
4	Explain the conceptualization and refinement in industrial design?
5	Differentiate technology and user driven product and explain with example.