UNIT-1

Introduction to Product Design and Development

Dr. Dhiren R. Patel

What is Product ?

- A *product* is something sold by an enterprise to its customers.

What is Product Development ?

- *Product development* is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product.

DEFINITION OF PRODUCT DESIGN

- Product design deals with conversion of ideas into reality and, as in other forms of human activity, aims at fulfilling human needs.
- A designer does not usually produce the goods or services which immediately satisfy consumer's needs. Rather, he produces the prototype which is used as a sample for reproducing the particular goods or services as many times as required.
- A design may be of a pattern on upholstery or of a dress in the world of fashion.
- If the producer believes that a sufficient number of customers will be satisfied by the product, then mass production of the item or service may be taken up by the production department.
- In the course of production, an error made by the producer in manufacturing an item may lead to its rejection; but an error in design, which will be repeated in all products, may lead to an economic misadventure of enormous proportions.
- The designer's responsibility is therefore serious.

What is Product Design?

- Product Design deals with *form* and *function* of a product.

1. *Form Design* – is associated with product's shape.
2. *Functional design* – is associated with product's working.

PRINCIPLES OF GOOD PRODUCT DESIGN

From customer prospective

- It should function correctly
- It should have required standard of reliability
- Easy to operate
- It should have easy accessibility for servicing
- It should obtain good space utilization
- Should have pleasant appearance
- Should be reasonably priced

From Manufacturer prospective (for making adequate profit)

- Easy to manufacture
- Use of standard components
- Well designed with minimum number of parts
- Minimum number of operations
- Easy to pack and distribute

DESIGN BY EVOLUTION

- In the past, designs used to evolve over long spans of time.
- change reduced the risk of making major errors.
- The circumstances rarely demanded analytical capabilities of the designer.
- This was *design by evolution*.
- Development of the bicycle from its crank operated version to its present day chain and sprocket version over a period of about a century is a typical example of design by evolution.

The disadvantages of evolutionary design are:

Unsuitability for mass production:

- An evolved design is rather crude and is more oriented towards design by masses for Production by masses (Gandhian philosophy) rather than mass production.
- It is acceptable at village level but unacceptable at urban level.

Difficulty in modification:

- A design by evolution is shaped by demands of time.
- On the other hand, design by invention and creative process uses sophisticated tools and techniques such as CAD (Computer-Aided Design) workstation.
- The CAD workstation helps generate a large number of design alternatives within minutes.

Inability to tap new technologies:

- A new technology can result in a totally new design based on a different working principle as compared with evolutionary design which relies heavily on small modifications in an existing design.
- It is well known that the new technology has made artisans and craftsmen of certain categories redundant.

DESIGN BY INNOVATION

- Following a scientific discovery, a new body of technical knowledge develops rapidly; the proper use of this discovery may result in an almost complete deviation from past practice.
- Every skill, which the designer or the design team can muster in analysis and synthesis, is instrumental in a totally novel design.

Examples of design by innovation are:

1. Invention of laser beam which has brought about a revolution in medical and engineering fields. Laser based tools have made surgical knife in medicine and gas cutting in engineering obsolete.

2. Invention of solid state electronic devices resulting in miniaturization of electronic products, which has made vacuum tubes obsolete.

ESSENTIAL FACTORS OF PRODUCT DESIGN

(i) Need.

A design must be in response to individual or social needs, which can be satisfied by the technological status of the times when the design is to be prepared.

In mathematical logic, **realizability** is a collection of methods in proof theory used to study constructive proofs and extract additional information from them.

(ii) Physical realizability. A design should be convertible into material goods or services, i.e., it must be physically realizable. The technique for determining the physical realizability is termed, design tree approach. In this approach (Fig. 1.1(a))., the success of a design concept depends on the success of its subproblems, say *Q*1 and *Q*2. Let *D*11, *D*l2, ... represent alternative solutions of *Q*1 and *D*21, *D*22 represent alternative solutions of *Q*2, and so forth.

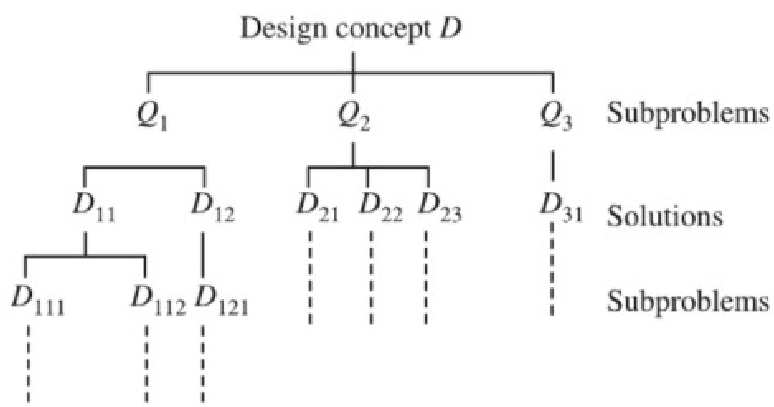
The probability equations are:

$P(D) = P(Q1)\,P(Q2)$ (1.1)

$P(Q1) = P(D11 \text{ or } D12) = P(D11) + P(D12) - P(D11)P(D12)$ (1.2)

$P(Q2) = P(D21 \text{ or } D22) = P(D21) + P(D22) - P(D21)P(P22)$ (1.3)

- The probability values of *D*11, *D*12, *D*2l, and *D*22 should be estimated from practical considerations.



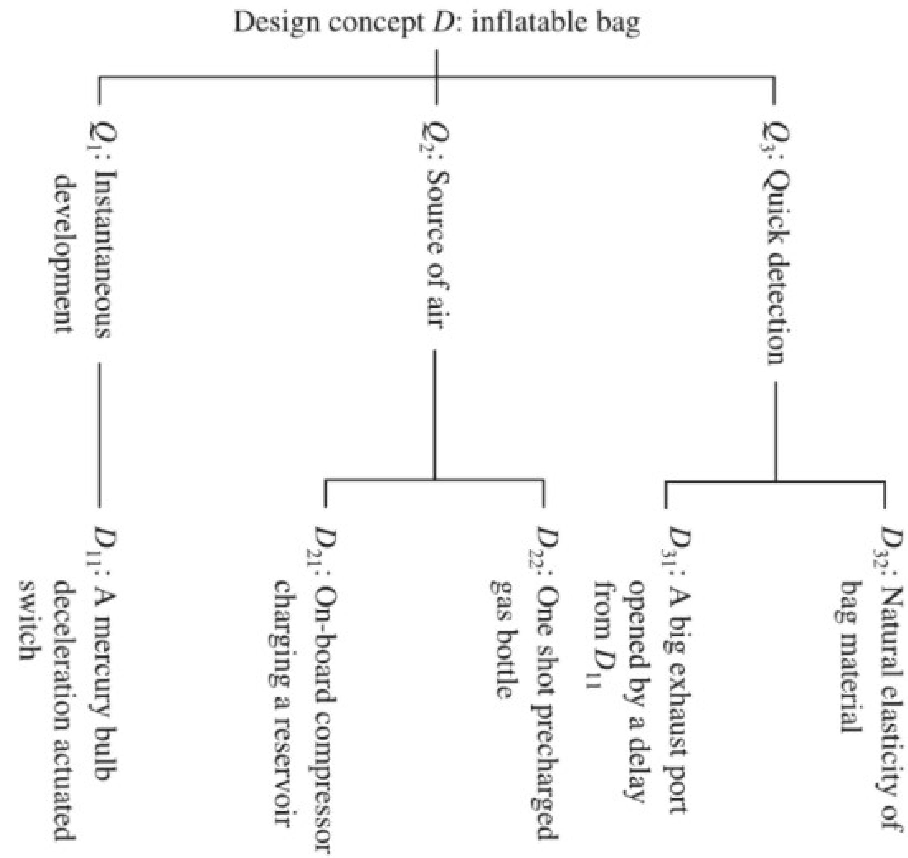
(a) Design tree for a design concept *D*

Fig. 1.1 Contd.

- An example of development of device for combating automobile head-on crash is also illustrated in Fig. 1.1(b).

(a) Design tree for a design concept *D* **Fig. 1.1** Contd.

(b) Design tree for protection device in automobile head on crash **Fig. 1.1** Determination of physical realizability through use of design tree.



(b) Design tree for protection device in automobile head on crash

Fig. 1.1 Determination of physical realizability through use of design tree.

(iii) Economic worthwhileness.

- The goods or services, described by a design, must have a utility to the consumer which equals or exceeds the sum of the total costs of making it available to him.
- For example, a bulb with luminous intensity 3 and life 4 on a ten-point scale has a lower utility than a bulb with luminous intensity 2.5 and life 5.

(iv) Financial feasibility.

- The operations of designing, producing and distributing the goods must be financially supportable, i.e., a design project should be capable for being funded by suitable agencies or people.
- The method for assessment of financial feasibility could be 'Net present value' which states that the present worth of cash flows in the project when added up during the useful life of the product should be greater than the initial investment for the project.

(v) Optimality.

- The choice of a design concept must be optimal amongst the available alternatives; the selection of the chosen design concept must be optimal among all possible design proposals.
- Optimal design, in theory, strives to achieve the best or singular point derived by calculus methods.
- In the context of optimization under constraints for mechanical strength, minimum weight and minimum cost are usually taken up as criteria for optimization.

(vi) Design criterion.

- Optimality must be established relative to a design criterion which represents the designer's compromise among possibly conflicting value judgements which include those of the consumer, the producer, the distributor, and his own.

(vii) Morphology.

- Design is progression from the abstract to the concrete.
- This gives a chronologically horizontal structure to a design project.
- The three phases of design are:

1. **Feasibility study phase**
2. **Preliminary design phase**
3. **Detailed design phase**

as indicated in Fig. 1.2.

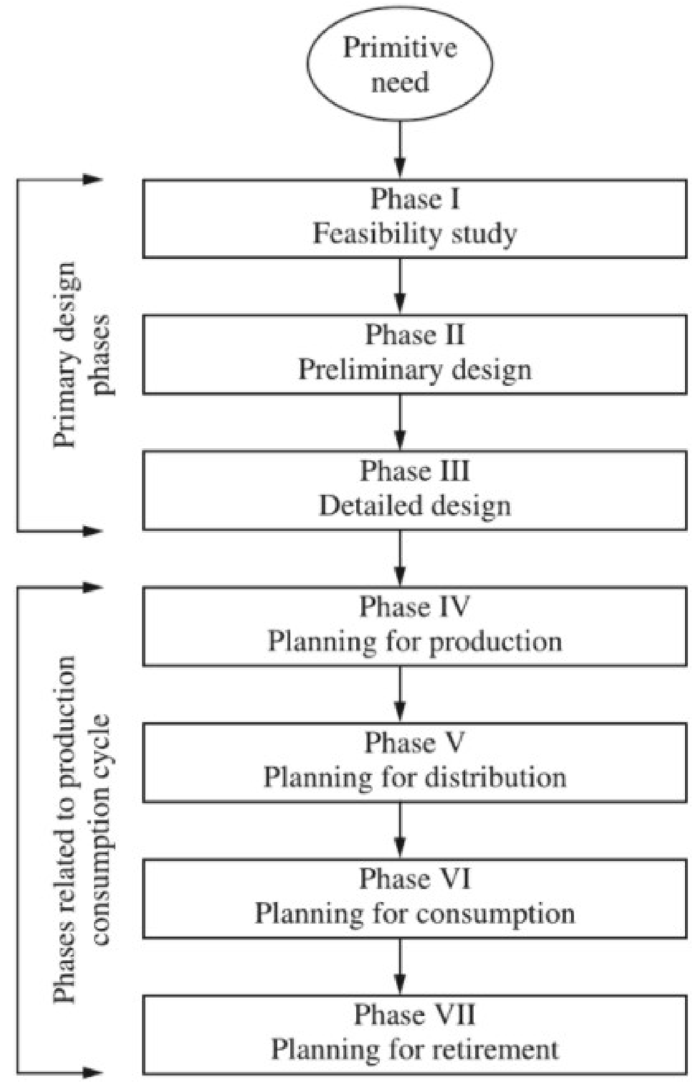


Fig. 1.2 Morphology of design process.

(viii) Design process.

- Design is an iterative problem-solving process.
- This gives a vertical structure to each design phase.
- The iterative nature of design is owing to feedback from existing design and improvement with further information in the form of technological, financial and creativity inputs. This is indicated in Fig. 1.3.

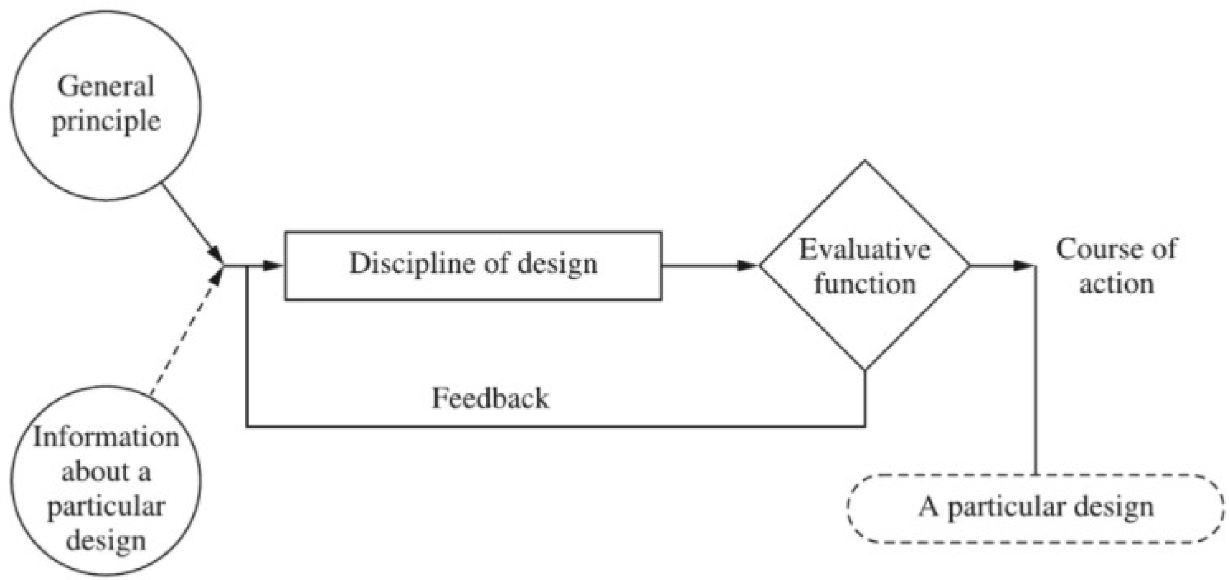


Fig. 1.3 Iterative nature of design process.

(ix) Subproblems.

- During the process of solution of a design problem, a sublayer of subproblems appears; the solution of the original problem is dependent on the solution of the subproblems.
- The "Design Tree" of Fig 1.1 reveals the concept of subproblems.

(x) Reduction of uncertainty.

- Design is derived after processing of information that results in a transition from uncertainty, about the success or failure of a design towards certainty.
- Each step in design morphology from step (i) to step (x) enhances the level of confidence of the designer.

(xi) Economic worth of evidence.

- Information gathering and processing have a cost that must be balanced by the worth of the evidence, which affects the success or failure of the design.
- Authentic information should be gathered to make the design project a success.
- Today, information is regarded as a resource which is as valuable as money, manpower and material.

(xii) Bases for decision.

- A design project is terminated when it is obvious that its failure calls for its abandonment.
- It is continued when confidence in an available design solution is high enough to indicate the commitment of resources necessary for the next phase.

(xiii) Minimum commitment.

- In the solution of a design problem at any stage of the process, commitments which will fix future design decisions must not be made beyond what is necessary to execute the immediate solution.
- This will allow maximum freedom in finding solutions to subproblems at the lower levels of design.
- A model of design problem, subproblems etc. is developed through a *design tree* (see Fig. 1.1).

(xiv) Communication.

- A design is a description of an object and prescription for its production; it will exist to the extent it is expressed in the available modes of communication.
- The best way to communicate a design is through drawings, which is the universal language of designers.
- Three dimensional renderings or cut-away views help explain the design to the sponsor or user of the design.
- The present day impact of computer aided modelling and drafting has resulted in very effective communication between the designer and the sponsor.

THE THREE S's

- The three S's refer to standardization, simplification, and specialization—three related subjects which are at the root of any economic analysis of product design. The three S's can be defined as follows:
- ***Standardization*** is the process of defining and applying the "conditions" necessary to ensure that a given range of requirements can normally be met with a minimum of variety and in a reproducible and economic manner on the basis of the best current techniques.
- Reduction is the essence of standardization: The effect of variety reduction on production and set-up times is shown in Fig. 2.2. It has attained so much importance that ISO 9000 system of International Standards has now become a synonym for quality and prestige. Several industries are aiming at achieving this standard to be able to compete globally.

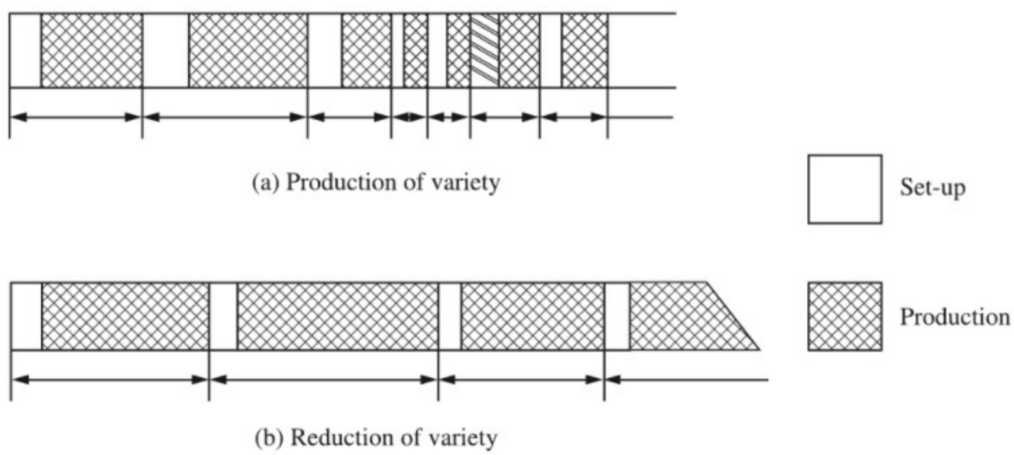


Fig. 2.2 Effect of simplification and variety reduction on set-up and production cycle times.

- ***Simplification*** is the process of reducing the number of types of products within a definite range.
- It is also an attempt to reduce variety.
- ***Specialization*** is the process whereby particular firms concentrate on the manufacture of a limited number of products or types of products.
- Specialization often is a result of one's aim to monopolize the market.
- The three processes are usually linked together and develop as a logical sequence.
- From a wide range of requirements it is first necessary to short out the essential features, define them, and then work out in a scientific manner the minimum variety required to meet these essentials. This is a process of standardization, and it is mainly an engineering process.
- Within a given range, whether covered by standards or not, a process of simplification can be carried out with a view to reducing the variety of products or materials that are produced or purchased. This is both an economic and an engineering process, and specialization is one of its natural outcomes.

STANDARDIZATION

Standardization covers a wide field of activity.

These activities include:

1. Physical dimension and tolerances of components within a defined range.
2. Rating of machines or equipment (in units of energy, temperature, current, speed, etc.).
3. Specification of physical and chemical properties of materials.
4. Methods of testing characteristics or performances.
5. Methods of installation to comply with minimum precautionary measures and convenience of use.

- The first three categories relate to limitation of the number of sizes or grades and some aspects of quality, one of the important aims being interchangeability of components or assemblies.
- Adherence to standards of raw materials is one of the fundamentals of product design since any deviation from the standards in this respect may cause a substantial increase in the cost of materials.
- Industry is rich with examples in which the designer specifies "special" materials whereas the standard grades can do just as well.
- Standardization and interchangeability impose certain limitations on the designer and demand high skill and effort in planning.
- It is easy enough when designing a new component to decide that no standard really meets the special requirements of the case in hand and that a part has to be specified.
- What designers seem to forget is that one of the purposes of standards is to provide solutions to relieve them of the task of having to solve afresh some basic problem, and thereby allow them more time to concentrate on the broader aspects of the design.

- Another prerequisite of interchangeability is the precision required in the manufacturing process in order to obtain production within the specified tolerances.
- This implies that production control has to be tightened so that any deviation from the given standards will be immediately noticed and appropriate action can be taken to avoid the process getting out of control.

Standardization has, however, many advantages, some of which may be briefly listed now:

1. Reduction of material waste and obsolescence.
2. Concentration of effort in manufacturing: hence, simplification and specialization.
3. Reduction in inventories, both of materials, and semifinished and finished products.
4. Reduction in book-keeping and other paper work.
5. Lowering the grades of skill required in manufacture and assembly.
6. Reduction in price: hence expansion of the market.
7. Reduction in repair and maintenance costs.

SIMPLIFICATION

- Simplification is a constant source of disagreement between the marketing department and the production personnel.
- A production engineer prefers little variety, minimum set-up, and long runs.
- Simplification enables the production department to improve planning, achieve higher rates of production and machine utilization, and simplify control procedures.
- The salesman, on the other hand, strives to satisfy the customer by giving him a choice or by offering him the nearest to what he wants.
- The pros and cons of simplification are given in the following tabular representation:

Pro-Simplification	*Pro-Variety*
• Reduce inventories of materials and finished products. • Reduce investment on plant and equipment. Save storage space. • Simplify planning and production methods. Simplify inspection and control. • Reduce required technical personnel. • Reduce sales price. • Shorten or eliminate order queues.	• Satisfy a wide range of demand. • Enable better contact with the market to study its tastes and requirements. • Avoid losing orders for more salable products because the customer directs all his orders to other vendors. • Create demand.

- Perhaps the **last point** in favor of variety deserves further clarification.
- Some sales people claim that variety encourages consumption and that, especially where consumer goods are concerned, the psychological effect of plenty creates demand.
- Further, market research by some firms seems to suggest that in some cases similar products tend to capture roughly the same portion of a given market.
- The prospects of increasing total demand on the one hand and the firm's portion of the market on the other, may have been the main causes for boosting variety to the extent found nowadays in industry.
- From the customer's point of view, this is a very unsatisfactory state of affairs.
- A flood of variety pleases the customer, who ceases in many cases to appreciate the fine distinction between similar products and has either to make a haphazard choice or to invest effort, time and study (and quite often money) to enable him to make an intelligent choice.

- This is undesirable for the firm as well.
- Apart from missing all the advantages listed above, when simplification is applied, an analysis of the market sometimes shows that variety has long exceeded the saturation point and that an increase in variety will not even be noticed in the market.
- Also, the division of the market between a large number of products (in fact, too large) makes each portion so small that prices have to be kept at high levels to avoid losses.
- When a great variety exists, a sales analysis can be made to establish the salability of the products.
- When the accumulated sales income is plotted against die number of products offered for sale, it is often revealed that a comparatively small number of products contributes substantially to the total sales (Fig. 2.3).

- This is sometimes referred to in industry as the “25% to 75%” relationship because in many cases it was found that 25% of the products brought in 75% of the income, although in some extreme cases, studies revealed as small as 10 to 90% relationships.
- This leads to unnecessary drain of the firm’s efforts, which should be directed to promoting the more profitable products.
- A more desirable situation is when responsibility for income is more evenly distributed between products, i.e., when the curve is “flat” as the lower curve in Fig. 2.3 shows, which is achieved through reduction of variety.

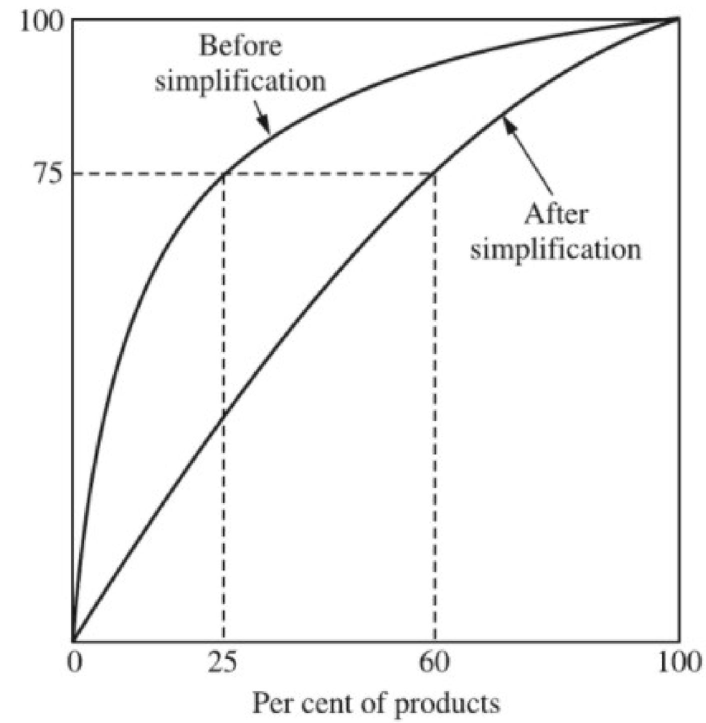


Fig. 2.3 Effect of simplification on Pareto diagram (ABC diagram).

Ergonomic design or product design for human use

- *Ergonomic designs:* Until recently, products were designed with technical feasibility and cost as main criteria.
- The difficulty in operation and control of cars, aircrafts and other devices of previous generations was at the root of many accidents.
- Limited visibility, difficult to read for unsafe operation and at times loss of life.
- **Designing products and machines to adapt them to human characteristics is the domain of *ergonomics*.**
- Ergonomics has experiences impressive growth since World War II.

- ***Ergonomics*** or ***human factors engineering*** is the science of fitting tasks to man.
- The word "Ergonomics" is derived from the Greek words *ergon* and *nomos,* meaning **"work"** and **"natural laws",** respectively.
- Ergonomics and human factors engineering are synonymous and cover a very wide field, including the human operator and his working environment.
- The areas of study covered under human factors engineering are **one group comprising Anatomy, Physiology and Psychology**, and the **other group consisting of engineering sciences such as Physics, Mathematics, Materials Science and Design**.
- Human factors engineering brings together two groups of specialists: those who know about **machines and processes**, and those who know about **human capabilities**.
- Thus, human factors engineering is the **link** between **engineering sciences and social sciences.**

- The role of human factors in product and equipment design assumes importance in three respects:

1. Man, as occupant of space, i.e. to operate a machine, the human operator should have adequate space, as dictated by human body dimensions or anthropometry.

2. Man, as reader of display from the machine. That is, based on the display data, man processes the data and takes action.

3. Man, as one who takes action through operating controls which form a part of the machine.

- Thus, man acts as applicator of force and controls the machine.
- It will be obvious that human engineering in design should consider application of forces and study of displays and controls.

HUMAN BEING AS APPLICATOR OF FORCES

- Energy is converted into useful work by the human motor system.
- The body can be regarded as a set of rigid members: the part of the limbs between joints, the main parts of the trunk and head.
- All these parts are quite heavy in relation to the available forces.
- Thus, available forces may be wasted in moving the parts of the body.
- Two consequences follow from this. ***First,* action will not be efficient if the direction of force is such that the limb or any other part of the body is moving against the force of gravity. *Second,* the most effective way of generating forces is to use the muscles and joints to get the body in a position such that use of body weight is made to overcome forces.**

Fig. 11.1 (a) Aspects of weight distributions, (b) Lifting and carrying.

- For example, in lifting a weight off the ground, if the body and head are moving upwards against gravity as the weight is lifted, then most of the available force will be wasted within the body.
- Correspondingly, if a worker is required to exert a downward force, for instance, to fit an object into its surrounding part, then this task might well be accomplished more easily, from a standing rather than a sitting position.

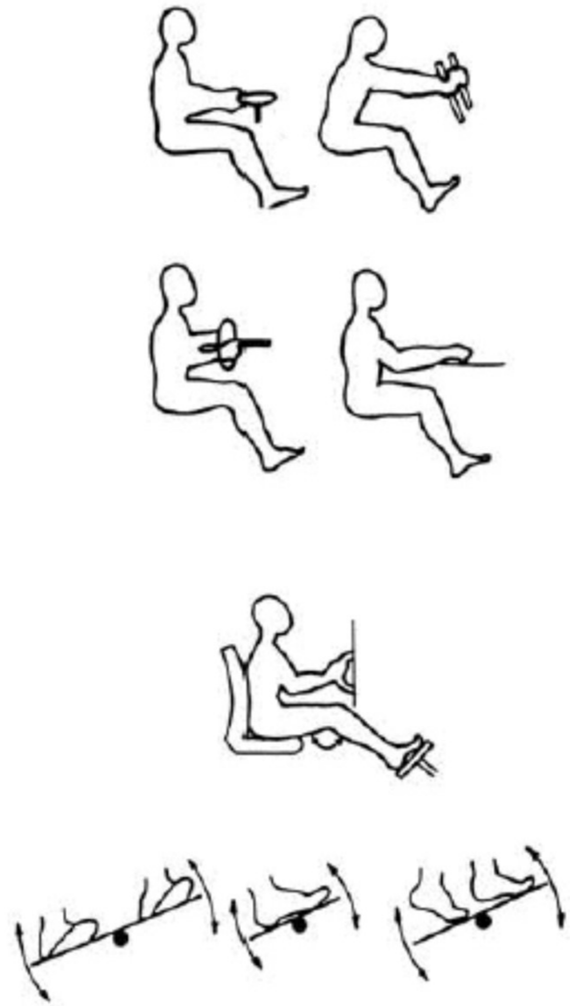
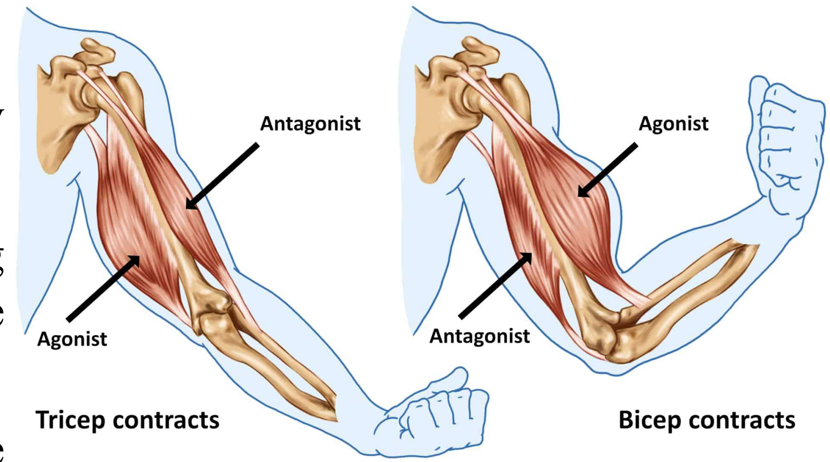


Fig. 11.2 (a) Use of hand controls and (b) Use of pedals (stable foot rest required).

(i) Momentum.

- One other way in which body masses can be utilized is by the provision of forces from momentum.
- The force exerted is proportional to the mass of the moving part, as also to the relative velocity of the limb and the object on which the force is to be exerted.
- Machine operators are trained to use momentum to operate handwheels, etc.
- To achieve precision in limb movement, a worker uses two sets of muscles about each joint—those involved in causing the required movement (the agonists), and a complementary group opposing the movement (the antagonists).
- This is the best way to achieve high precision.
- Assuming that these two sets of muscles are required, the greatest precision will be achieved when the limbs are in the middle part of their total path of movement.



AGONIST (Prime Mover)	ANTAGONIST
Biceps	Triceps
Deltoids	Latissimus Dorsi
Pectoralis Major	Trapezius/Rhomboids
Rectus Abdominis	Erector Spinae
Iliopsoas	Gluteus Maximus
Quadriceps	Hamstrings
Hip Adductor	Gluteus Medius
Tibialis Anterior	Gastrocnemius

(ii) Muscle contraction and energy release

- Economy and spread of effort occur within a muscle.
- All muscles consist of a large number of fibers and bundles of fibers that can be regarded as motor units.
- The greater the force, or the faster the movement, the greater will be the number of motor units involved.
- A slight change in the movement of a particular joint may result in a drastic change in the order, number and identity of motor units involved.

(iii) Isometric application of forces and isotonic action

- In mechanics, the principle that no work is done unless a force moves its point of application is used.
- The human operator is certainly capable of work, either by **isometric (static)** muscle action or by **isotonic action**, in which there is limb movement.
- Isometric activity probably is superior in reaction sensitiveness as it is called *kinesthetic feedback.*
- In kinesthetic feedback, the operator receives more information feedback from the feel of what he is doing than from observing the results of the activity.
- Isotonic action, in which muscle fibers are moving in relation to each other, facilitates the blood flow and thereby the supply of oxygen and the removal of waste products.
- Thus, for **maximum precision, isometric action is often best**, but **for maximum power output and for postponing fatigue, isotonic action is superior.**

Modern Approaches to Product Design

- In recent years the competition between American and Asian (mainly Japanese) corporate world has given rise to two important and novel approaches to Product Design.
- The first approach is ***concurrent design*** while the second approach is ***quality function deployment.***

CONCURRENT DESIGN

- Development from concept to product requires the consideration of four basic elements.
- Central to this concept is the function of the product. Related to the function are the shape, material, and production techniques used to manufacture and assemble the product.
- Concurrent design is the simultaneous planning of the product and the process for producing it.
- Prior to the 1980s, team formation was not a preferred idea, and many designers worked in isolation.
- The role of manufacturing was to build what the designer conceived, improve the manufacture and assembly of the product.
- A certain industry survey showed that **60 per cent** of all manufactured parts were not made exactly as represented in the drawings.
- The reasons varied: (a) The drawings were incomplete. (b) The parts could not be made as specified. (c) The drawings were ambiguous (unclear). (d) The parts could not be assembled if manufactured as drawn.

- Many of these problems have since been overcome by **evolution of the design team** and of the **philosophy of concurrent design**.
- The process of translating from concept to a manufacturable product is **rarely** accomplished now by the designer alone.
- Generally, a team comprising a **design engineer**, a **manufacturing engineer** and a **materials engineer** plays a major role in supporting the chief designer.
- There are too many materials and manufacturing processes available for the designer to be able to make good decisions without the help of specialists.

The Design Team

- Design is both a **private, individual experience** and a **social, group experience**.
- The ability to recall previous designs from memory and to synthesize partial concepts together to form new ideas is unique to an individual designer.
- However, since most design projects are large and require knowledge in many areas, they are generally accomplished by teams of engineers with varying views and backgrounds.
- We now provide a list of individuals who may fill a role on a product design team.
- Their inclusion on the design team will vary from product to product, and their titles will vary from company to company.
- Each position on the team will be described as if filled by one person, but for large design projects, there may be many persons filling that role.

(i) Product design engineer.

- The major design responsibility is carried by the product design engineer.
- He must be certain about the needs for the product are clearly understood and that engineering requirements are developed and met by the product.
- This usually requires both **creative and analytical skills**.
- The design engineer should bring knowledge about the design process and about specific technologies to the project.
- The person who fills this position usually has a four-year engineering degree.
- However, especially in smaller companies, he may be a designer who has extensive experience in the product area.

(ii) **Marketing manager or product marketing manager.**

- In many companies the marketing manager has the ultimate responsibility for the development of the product and represents the **major link between the product and the customer.**
- Because the product manager is accountable for the success of the product in the market, he is also often referred to as the *marketing manager* or the *product marketing manager.*
- The product manager also represents the interests of sales and service.

(iii) **Production engineer.**

- It is not possible for the design engineer to have the necessary know-how about **production processes**.
- This knowledge is provided by the person who must have a grasp not only of in-house manufacturing capabilities, but also of what the industry as a whole has to offer.

(iv) **Design detailer.**

- In many companies the design engineer is responsible for specification development, planning, conceptual design, and the early stages of product design.
- The project is then turned over to detailers (often called designers), who finish **detailing the product and developing the manufacturing and assembly documentation.**
- Detailers usually are those who have passed two-year technology courses.

(v) **Testing engineer.**

- The testing engineer aids the design engineer in developing test apparatus, performing experiments, and gathering data in the development of the product.
- The insights gained from the technician's hands-on experience are usually invaluable.

(vi) **Materials engineer.**

- In some products the choice of materials is **forced by availability**.
- In others, materials may be designed to **fit the needs of the product**.
- The more a product moves away from the use of known, available materials, the more a materials specialist is needed as a member of the design team.
- Many suppliers actually provide design assistance as part of their services.

(vii) **Quality control specialist.**

- A quality control (QC) specialist has training in techniques for measuring a statistically significant sample to determine **how well it meets specifications**.
- This inspection is done on incoming raw material, incoming products from vendors, and products manufactured in-house.

(viii) **Industrial designer.**

- Industrial designers are responsible for how a product looks and how well it interacts with human users; they are the stylists who have a background in fine arts and in human factors analysis.
- They often **design the scope** within which the engineer has to work.

(ix) **Assembly engineer.**

- While the production engineer involved in making the components from raw materials, the assembly manager is responsible for **putting the product together**.
- Concern for the assembly process is an important aspect of product design in modern times.

(x) **Supplier's representative.**

- Very few products are made entirely inside one factory.
- Usually there will be many suppliers of both **raw material and finished goods**.
- Often it is important to have critical suppliers on the design team because the success of the product may be highly dependent on them.

Benefits from Concurrent Design Approach

- The application of a concurrent design approach results in reducing product design and development time and speeds the product to market.
- A recent example is that of the Reliance Industries where involvement of design team reduced the premarket time from 120 days to 14 days.
- Today this approach is also termed the ***Business Process Reengineering (BPR)*** approach.
- Michael Hammer and Champy, in their pioneering work* have cited design process carried out as a concurrent engineering by Eastman Kodak Ltd., Rochester, USA to meet the high quality and smaller lead times of their competitor Fuji Corporation of Japan. They have met with some success.

QUALITY FUNCTION DEPLOYMENT (QFD)

- QFD is the latest approach to product design.
- It essentially consists of converting customer's need statement (which is usually qualitative) into technical specifications.
- For example, a user of automobile insists upon "easy closure" of the door.
- This voice of the customer enables the design task force to derive the specifications of door closing mechanism in terms of kilograms of force required for the mechanism.
- QFD enables organizations to be proactive rather than reactive in QC.
- QFD involves

(a) the customer,

(b) what the customer wants, and

(c) how to fulfill the customer's wants.

- The first step of a QFD exercise is to objectively determine what group or groups constitute the customer base.
- For the design engineer, this implies answering the question: Who will benefit from the successful production or implementation of this product or program?
- Once the customers have been identified, the wants of each customer or customer group must be determined.
- In QFD terminology, these are commonly referred to as the WHATs (i.e. What does the customer want?).
- These WHATs can be ascertained by either interviewing representatives of the customer group, through survey, or mailing questionnaire based on the knowledge and judgement of the QFD team participants.

- As stated by Robert Hall in his book, *Attaining Manufacturing Excellence,* design engineers are greatly maligned for concentrating so much on the technical aspects of design, yet giving so little thought to how everything fits together.
- Through the structured QFD process, these engineers are forced to first consider what the customer wants, then the means of achieving that end.
- When defining the WHATs in a QFD exercise, it is important to use the same terms and phrase as would the customer.
- The best way to do this is through an interview/questionnaire process.
- As is often the case, time and budgetary constraints may prevent this approach.
- However, the QFD team must be able to empathize with the customer so as to correctly identify what the customer demands of the product.

- Next, the QFD team must determine a means by which to satisfy these WHATs In QFD terminology, these will be the 'HOWs', and will consist of the items or attributes of the product or program under development.
- When formulating a program strategy, the HOWs will constitute many of the action agendas in the strategic plan.
- The WHATs and HOWs are now ready for entry into the QFD matrix.
- This matrix table, often referred to as an A-l quality table, is a simple table of rows in which the WHATs are recorded and columns used to record the HOWs (see Table).

Example. Gearbox top cover—GBS 40 Tata Truck.

Customer demands (WHATs) — Technical requirement / Customer requirement	*Integral casting*	*Reduce finger length*	*Reduce bush length*	*Redesign interlock pin*	*Increase diameter cable hole*	*Reshape checkplate and lug*	*Provide thick gasket*
Ease of assembly	9	3					
Easy of manufacturing	9			3		3	
Ease of gear shifting	1	9	3	3	3	3	
Ease of maintenance	9						1
Economy	9		1			3	
Low weight	9	1	1				
No leakage	3						9

Table: Simple QFD matrix—quality characteristics

- After meeting the three objectives, QFD transitions from a qualitative to a quantitative methodology.
- The QFD team assigns numeric values of 1.5, 1.2 and 1.0 to each of the WHATs, with 1.5 going to the most important WHAT, 1.2 to the second most important, and 1.0 to all others.
- These values are referred to as the *sales points* and reflect the relative importance of these customer demands.
- The next step is to determine the correlation between each HOW and WHAT in the matrix.
- The following correlation and values are used:

❑Possible correlation 1

❑Some correlation 3

❑Strong correlation 9

- Many cells within the matrix will receive no value, indicating no correlation.
- Each WHAT must also be analyzed and assigned a B value from 1 (for relatively low importance) to 5 for most important.
- These values should be recorded within the QFD matrix in the "Ratio of importance" column (see Table).

Cell value = Relationship weightage × *DW*
e.g. 243 = 9 × 27

Quality characteristic (HOWs)

Customer Demands (WHATs)

Technical requirement / Customer requirement	Integral casting	Reduce finger length	Reduce bush length	Redesign interlock pin	Increase dia cable hole	Reshape checkplate and lug	Provide thick gasket	*T*	*B*	*N*	*P*	*A*	*C*	*AW*	*DW*
Ease of assembly	9/243	3/81						324	4	3	4	0.75	1.5	4.5	27
Ease of manu-facturing	9/81			3/27		3/27		135	2	3	4	0.75	1	1.5	9
Ease of gear shifting	1/27	9/243	3/81	3/81	3/81	0.3/81		(594)	5	3	5	0.6	1.5	4.5	27
Ease of maintenance	9/108						1/12	120	2	4	4	1	1	2.0	12
Economy	9/99		1/11			3/33		143	3	2	4	0.5	1.2	1.8	11
Low weight	9/81	1/9	1/9					99	3	2	4	0.5	1	1.5	9
No leakage	3/15						9/45	60	1	3	4	0.75	1	0.75	5
Column weight	(654)	333	101	108	81	141	57			Totals					100
Function weight	44	22	7	7	5	9	1	100							

Relationship: Strong 9
Medium 3
Weak 1
Sales points = 1.5, 1.2, or 1.0
AW = $A \times B \times C$
$A = P/N$

Note: T = total
B = rate of importance
N = company now
P = plan
A = ratio of improvement
C = sales point
AW = absolute weight
DW = absolute weight

Table: Quality Table

- Next, an objective evaluation of the current performance of the organization in meeting each WHAT should be done, and a realistic projection as to where the organization will be in a given period of time has to be carried out.
- The ratings range from 1 (very poor) to 5 (very good).
- These values are recorded in the QFD matrix under the headings of "company now" and "Plan", respectively.
- The final steps are the basic task of number crunching.
- The "Ratio of improvement" should be calculated by dividing each WHATs "Company now" score into its "Plan" score.
- The absolute weight of each WHAT is then calculated as follows:

$AW = A \times B \times C$

Where, AW = absolute weight, A = ratio of improvement, B = ratio of importance, C = sales point

- Once all WHATs have been similarly calculated, the demanded weight is computed by normalizing the column of absolute weights.
- The WHATs with the largest demanded weights represent the most critical customer demands.
- A similar exercise yields the corresponding critical HOWs.
- In order to quantify the HOWs, the demanded weights of each corresponding WHAT is multiplied by the correlation factor previously recorded in the cells of the matrix.
- By summing the column, and again normalizing the sums of all columns, the most significant HOWs are derived.
- As can be seen from Table - 2, integral casting is the most important design change, and ease of gear shifting is the most important "WHAT".
- Necessary implementation at the shopfloor should be done as a part of continual quality improvement of products.

- Though the mechanics of QFD are reasonably simple, its application enforces a rigour of planning and detail from its users.
- Participants in a QFD exercise must be capable of viewing the product from the vantage point of the customer.
- In order to do this, it is often advantageous to personalize the exercise by imagining yourself as a particular person within the customer group, then answering the question, “What do I want?” as you feel that the customer would.

Implementation of QFD in production.

A four-fold strategy for production engineering division can be emphasized as follows:

1. *Establish* a single center for the integration and dissemination of tools to support the concurrent engineering process needed for QFD implementation on the shopfloor.

2. *Develop* and validate analytical tools which increase the quality and quantity of information available to support the development of systems needed for incorporating the change in product or process.

3. Reduce the time and effort required to develop and transform systems into production by eliminating nonvalue adding activities.

4. Broaden the technology base by providing the ability to rapidly produce critical items for test, evaluation, and field trials.

- The aim is to either locate or develop knowledge base or other tools related to the production function, evaluate its effectiveness and utility to other groups, then promote the transfer of this technology throughout the departments.
- The desired result is a more efficient and cost effective means for all organizations involved in the production process to share their collective knowledge and resources between various industries.

Types of Design

1. **Adaptive design.**

- This design requires only minor modification usually in size alone.
- The level of creativity needed is negligible because only adaptation of existing design is essential.
- Some authors call it adaptive design even if the changes are more but original design concept is same.

2. **Variant design.**

- This is a design approach followed by companies who wish to serve product variety to satisfy varying customer tastes. For examples, Hero Honda: CD 100, CD Deluxe, Passion and Splendor are variant designs.

3. **Creative design.**

- The most demanding design effort and creativity is needed when a totally new product is to be designed.

4. Configuration design.

- Configuration design helps in synthesis, analysis and choice of best combination of parts.
- In the detailed design phase Step 5 is to verify that the different components and subassemblies fit very well to form the final product.
- Configuration design is represented in the form of special assembly drawings to ‘prove’ the success (or failure) of the assembly.
- Configuration design differs from detail design in the sense that layout drawing are made in configuration drawings.
- They cannot be used for the preparation of process planning.
- Detailed drawings in orthographic projections are essential for fixing operations essential to produce final product.
- Concept of obtaining various configuration for computers is often cited as example of configuration design.

5. Modular design.

- The use of ‘modules’ or building blocks for assembling and producing a variety of products is termed modular design.
- It will be recalled how furniture companies enable the production of a wide range of racks, etc. as end products by assembly of different modules.
- The advantage of modular design over integral design is lower inventory, better flexibility, lower cost, etc.

6. Redesign.

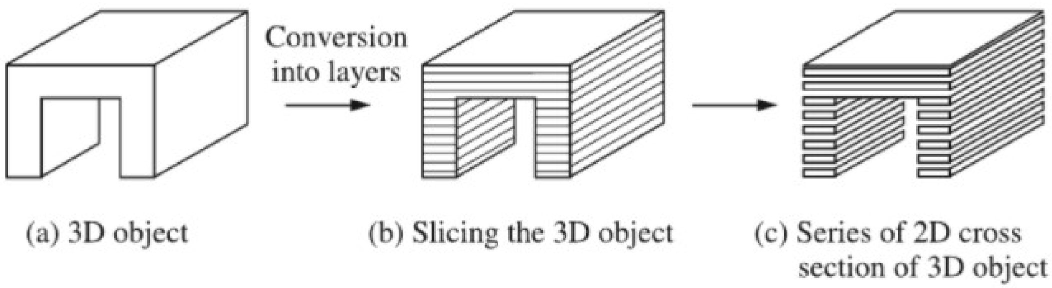
- Much more frequently, engineering design is employed to improve an existing design.
- The task may be to redesign a component in a product that is failing in service, or to redesign a component so as to reduce its cost of manufacture.
- Often redesign is accomplished without any change in the working principle or concept of the original design.
- When redesign is achieved by changing some of the design parameters, it is often called variant design.

RAPID PROTOTYPING

- During product design, physical models called *prototypes* are prepared and evaluated as a part of design evaluation.
- Conventional prototype manufacture is a very time-consuming process involving all stages of manufacture such as process planning, machining, and assembly, in addition to production planning.
- Due to the delay caused by the conventional prototyping procedure, R&D people in industry and academics started looking for some strategy which could enable the conversion of a 3D computer model to a 3D prototype form.
- Thus, the need of industry to reduce time to market resulted in the unique concept of rapid prototyping.

Principle of Rapid Prototyping

- In the rapid prototyping process, the 3D object is sliced into several 2D sections on a computer.
- This simplifies 3D part producing process to 2D layer manufacture.
- By 'gluing' the produced layers, the desired part can be produced directly from its geometric model.
- Thus, rapid prototyping consists of two steps; **Data preparation and Model production.**



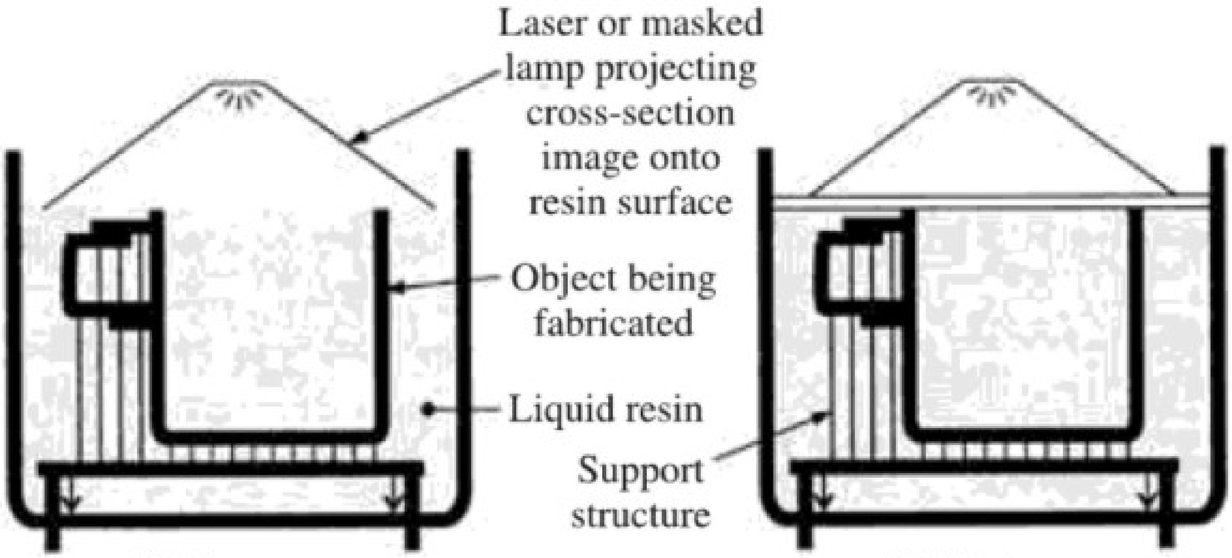
- Advantage of additive fabrication is taken in rapid prototyping.
- Sometimes, apart from the basic material, one more material to support basic material is needed.
- After the model is complete, the supporting material is removed.
- The various processes and corresponding material are tabulated and shown in Table.

S.No.	*Process*	*Material*
1.	Stereolithography	Photosensitive polymer
2.	Selective laser sintering	Thermoplastic powders
3.	Fused deposition modelling	Eutectic materials, polymers
4.	Laminated object modelling	Paper
5.	Solid ground curing	Various materials
6.	Injket printing	Various materials

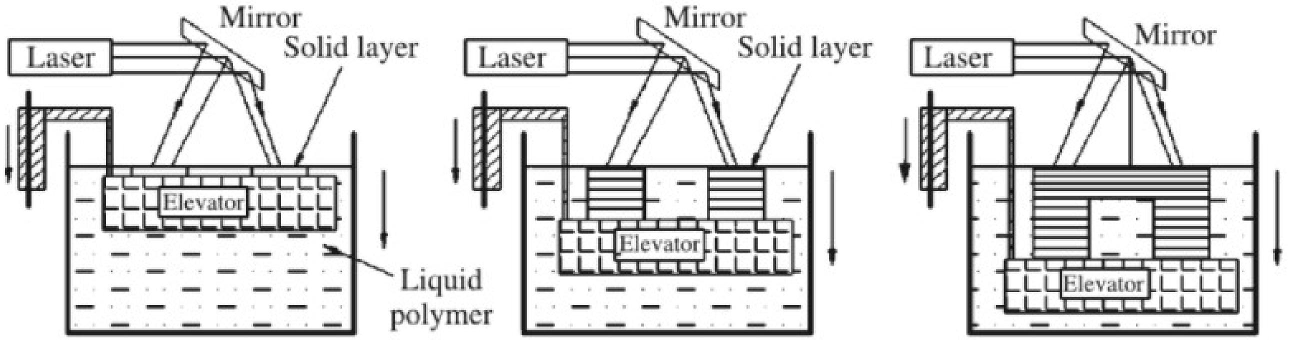
Rapid Prototyping Technologies

(1) Stereolithography

- In this technology, the part is produced in a vat containing a liquid which is a photo-curable resin acrylate (see Fig. (a)).
- Under the influence of light of a specific wavelength, small molecules are polymerized into larger solid molecules.
- The SLA machine creates the prototypes by tracing the layer cross-sections on the surface of liquid polymer pool with a laser beam.
- In the initial position the elevator table in the vat is in the topmost position.
- The laser beam is driven in *x*- and *y*-directions by program driven mirrors to sweep across the liquid surface so as to solidify it to a designed depth (say, 1 mm).
- In the next cycle, the elevator table is lowered further.
- This is repeated until the 3D model is created.
- Figure (b) shows a modified design in which a contact window allows the desired area to be exposed to light, masking the area which remains liquid.



(a) Open type (b) Mask type



(a) Stage I – Elevator initial high position (b) Stage II – Elevator intermediate high position (c) Stage III – Elevator lowest position

(2) Photomasking technique or solid ground curing

This method has certain unique features:

1. A mask is generated by electrostatically charging a glass plate with a negative image of cross section of the part.

2. In the meantime, a thin layer of liquid polymer is spread across the surface of the work plane.

3. The mask plate with negative image of the cross-section slice is positioned over the thin polymer layer and exposed under the ultraviolet laser lamp for two seconds.

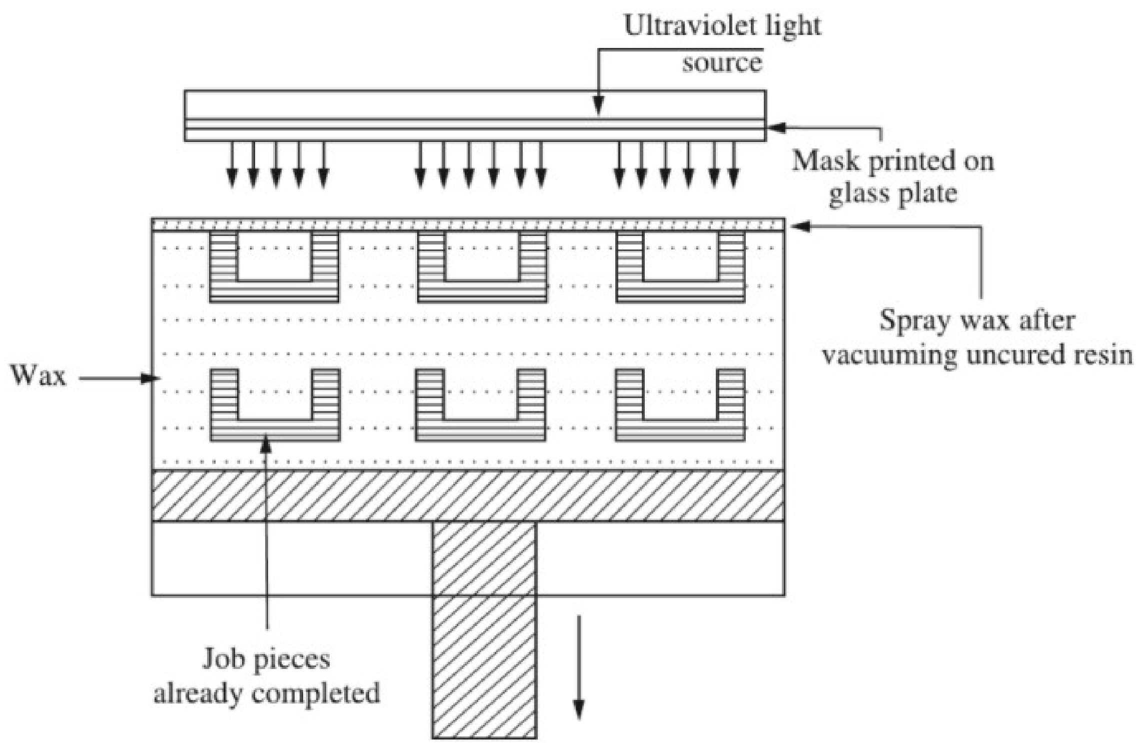
- All the parts of the exposed photopolymer layer are solidified with one exposure.
- However, the area shaded by the mask is left in a liquid form and is wiped off with vacuum suction head and replaced by hot wax which acts as a support to the solidified polymer layer.

4. A face mill makes the surface of wax and polymer flat and to desired thickness.

5. The above four steps are repeated until the final model which is embedded in wax is obtained.

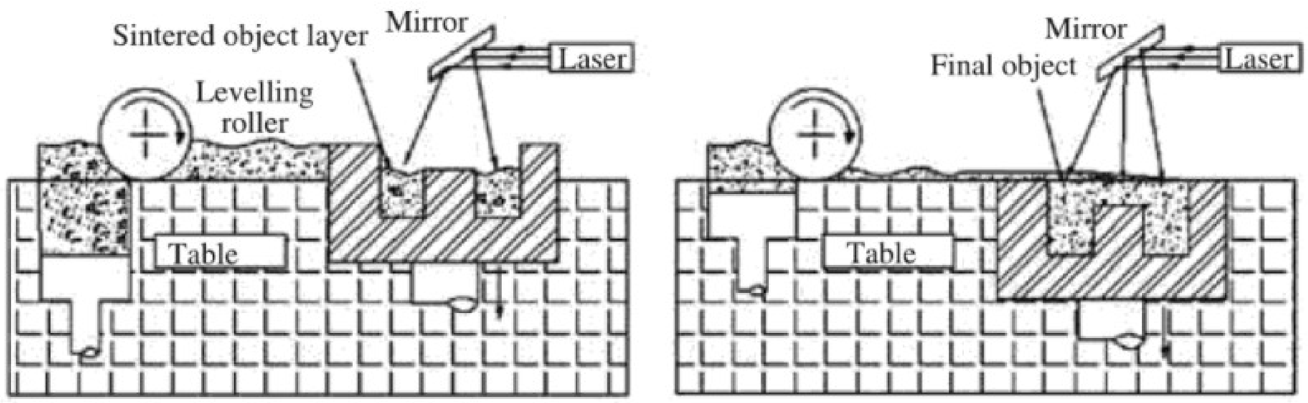
- The wax can be removed.

solid ground curing



(3) Selective laser Sintering (SLS)

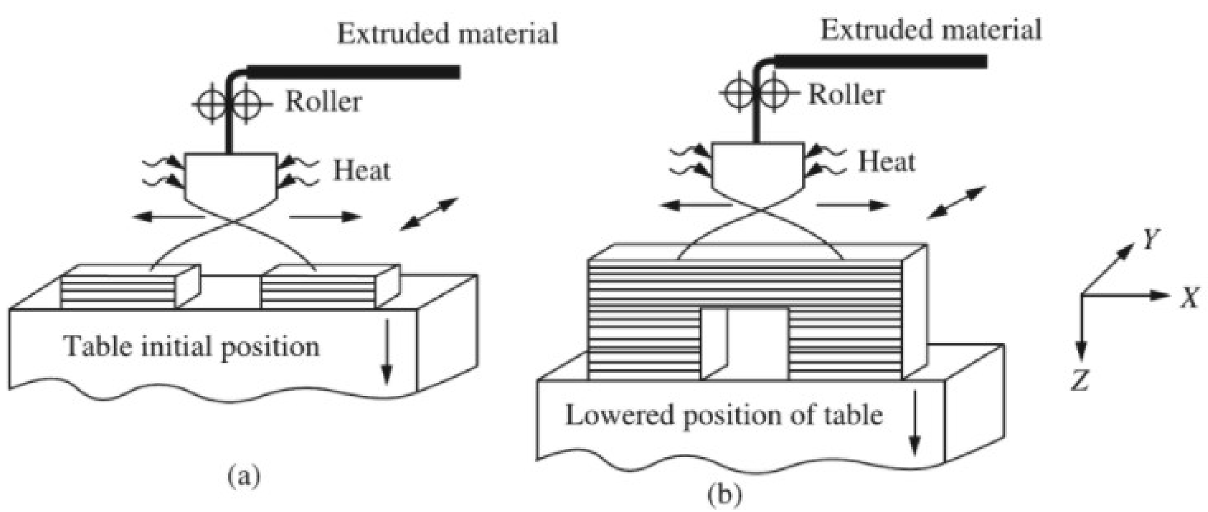
- In the SLS process, a thin layer of powder is applied at the workplace with a roller.
- Carbon dioxide laser is often used to sinter successive layers of powder (instead of liquid resin).
- Particles of 50 mm diameter, are molten by laser beam.
- Solidified layer is lowered in powder bed by piston and new layer is spread over the surface (Fig.).



(a) Initial position of piston (b) Final position of piston

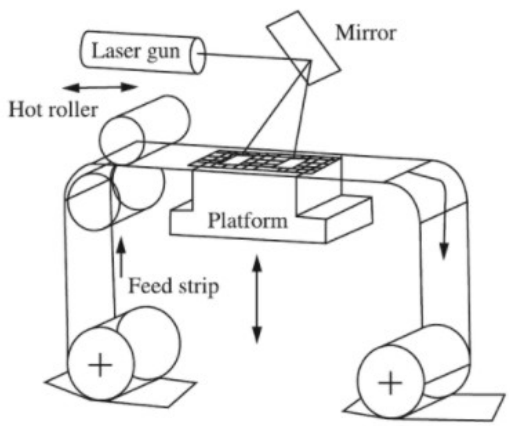
(4) Fused deposition modelling

- In the FDM process, a spool of thermoplastic filament feeds into a heated FDM extrusion head. The *x*- and *y*-movements of the FDM head are controlled by a computer so that the exact outline of each cross-section of the prototype is obtained. Each layer is bonded to the earlier layer by heating. This method is ideal for producing hollow objects.
- The process has been compared with a baker covering the cake with decorations. The heated thermoplastic material filament coming out of the conical hopper is deposited in *X* and *Y* direction under the instruction from computer. The table is lowered in *Z* direction of each cycle of deposition.

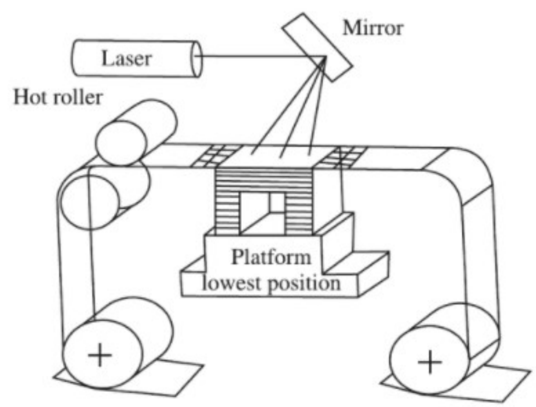


(5) Laminated object manufacturing (LOM).

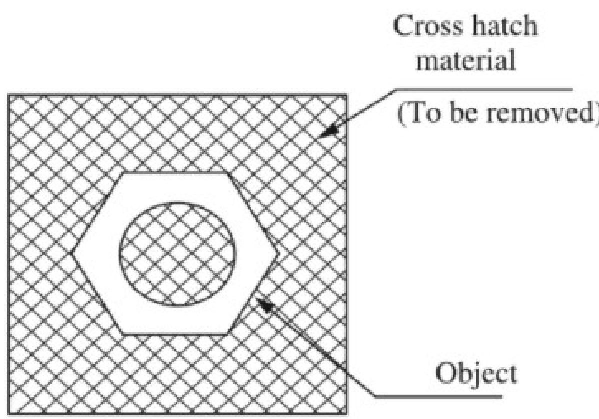
- The LOM process is especially suited for producing parts from bonded paper, plastic, metal, etc. A laser beam cuts the contour of part cross-section. Several such sections, when glued or welded, yield the prototype.
- In this process, laser beam cuts contour of each layer and glue activated by hot roller presses the layers together. The cross hatch material remaining in the final object is removed later on. For example, if the object is an octagonal prism with a circular hole in the middle, the cross hatched material remaining attached to the object is removed after the process is complete. This is shown in Figs.



(a) Initial position of plateform



(b) Final position of platform



Job piece obtained by LOM

(6) Ballistic particle manufacturing (BPM)

- The BPM system uses piezo-driven inkjet mechanism to shoot droplets of molten materials, which cold weld together on a previously deposited layer.
- A layer is created by moving the droplet nozzle in *x*- and *y*-directions.
- After a layer is formed, the baseplate lowers a specified distance and a new layer is created on top of the previous one.
- Finally, the model is created.

(7) Three-dimensional (3D) printing

- Three-dimensional printing was developed at the MIT (USA).
- This technique also uses an inkjet printing head with a binder material to bind ceramic and other powders which are spread by a roller prior to application of the binder gun.