Design & Manufacturing

ENGINEERING DESIGN PROCESS

Prof Sachin Pande

SECAB I E T Vijaypur

- 9880160233

Engineering Design Process

DESIGN

Product design deals with conversion of ideas into reality and, as in other forms of human activity, aims at fulfilling human needs.

> *Design is a plan for arranging elements in such a way as best to accomplish a particular purpose.*

Generally speaking, it is the process of envisioning and planning the creation of objects, interactive systems, buildings, vehicles, etc. It user-centered, i.e. users are at the heart of the design thinking approach. It is about creating solutions for people, physical items or more abstract systems to address a need or a problem.

CHECKLISTS FOR ENGINEERING PROBLEMS

A checklist is a type of informational job aid used to reduce failure by compensating for potential limits of human memory and attention. It helps to ensure consistency and completeness in carrying out a task.

In engineering design of a chemical process plant there can be several checklists. Some examples for engineering design checklists are as follows:

- Checklist for Process Flow Diagram
- Checklist for Piping & Instrumentation Diagrams
- Checklists for Equipment Data Sheet (e.g. Pumps. Tanks, Vessels, Compressors, Mixers, Dryers, Package Items etc.)
- Checklists for Instrument Data Sheets (Flow meters, Pressure Measurement, Temperature Measurement, Analytical Instruments etc.)
- Checklist for Vendor Data Analysis
- Checklist for Piping Isometrics and GA Drawings
- Checklist for Electrical Single Line Diagrams
- Checklist for Instrument Loop Diagrams

DESIGN BY EVOLUTION

In the past, designs used to evolve over long spans of time. The leisurely pace of technological 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.

Disadvantages of evolutionary design

- **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:

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

DESIGN CHECK FOR CLARITY, SIMPLICITY AND SAFETY

Assuming there's already a product-market fit, what are some qualities that make a product fun and delightful to use? What in a product, apart from its fundamental usefulness, creates a sublime experience?

Simplicity

In the context of user-experience, simplicity refers to the ease of using a product. Its often used as an overarching term to describe a product that's not just easy to use but also efficient, and delightful.

When designers write about simplicity its often perceived to be about the simplistic, and minimalist visual style. Simplicity described here is not about visual styling but about the substantive content — core functionality, features, and behaviour.

However, simplicity by itself is rarely the complete solution. To make a product understandable, designers look for clarity.

Clarity

Focussing on Simplicity helps the designer decide on what to include in a product while Clarity helps define how to present it. Clarity is about organising the content in a manner that conveys the desired message and leads to desired actions by the user. Clarity is the quality of being intelligible.

"Confusion and clutter are the failures of design, not attributes of information."

Elegance

In the dictionary, elegance is defined as the quality of being graceful and stylish in appearance or manner. In reality, of the three qualities discussed here, Elegance is perhaps the most difficult to define. Its because it relates not to the intellect but to a deeper feeling or emotion. Elegance is achieved when all components come together in a balanced way to make the whole just right. The feeling is similar to watching Roger Federer play tennis or the legendary Sachin Tendulkar play cricket.

Safety

Safety in Design means "the integration of control measures early in the design process to eliminate or, if this is not reasonable practicable, minimise risks to health and safety throughout the life of the structure being designed."

A defect free or *fail-safe design* is one that will not lead to accidents, in the case of functional failures. Since a functional repair is much cheaper than a damage from an accident, fail-safe designs are recognized as superior and necessary in many products. Take power steering as an example. Most power steering systems are designed so that the wheels can still be controlled without the power booster. If the fluid pump fails or the engine stalls, the car can still be steered.

Factor of safety is the ratio of strength to load. Strength is a characteristic of the machine component: the maximum force it can bear. The load is the actual force imparted to the component, when the machine operates. The strength of a component may vary, because of uncertainties in 'material properties and finishing processes. The load may exceed the estimated load, when the machine is missed. A factor of safety larger than 1 leaves a margin for an overload, and for the discrepancy between what is calculated and what actually happens. Sometimes, a factor of safety as large as 10 is used, because the estimation of strength and load is extremely inaccurate. Since excess strength results in material wastage, a better engineering practice is to obtain an accurate evaluation of the strength and the load, and to use a small factor of safety.

DESIGN FOR ASSEMBLY/DESIGN FOR MANUFACTURABILITY

Design for Assembly is a process by which products are designed with ease of assembly in mind. If a product contains fewer parts it will take less time to assemble, thereby reducing assembly costs. In addition, if the parts are provided with features which make it easier to grasp, move, orient and insert them, this will also reduce assembly time and assembly costs. The reduction of the number of parts in an assembly has the added benefit of generally reducing the total cost of parts in the assembly. This is usually where the major cost benefits of the application of design for assembly occur.

Two notable examples of good design for assembly are the *Sony Walkman* and the *Swatch* watch. Both were designed for fully automated assembly. The Walkman line was designed for "vertical assembly", in which parts are inserted in straight-down moves only. The Sony SMART assembly system, used to assemble Walkman-type products, is a robotic system for assembling small devices designed for vertical assembly.

ESSENTIAL FACTORS OF PRODUCT DESIGN

- Need (will be discussed later in detail)
- Morphology (will be discussed later in detail)
- Communication (will be discussed later in detail)
- Physical reliability A design should be convertible into material goods or services, i.e. it must be physically realizable.
- **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.
- **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.
- **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 ail 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.
- **Design criterion** Optimality must be established relative to a design criterion which represents the designer's compromise among possibly conflicting value judgments which include those of the consumer, the producer, the distributor, and his own.
- **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.

- **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.
- **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.
- **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.

NEED AND NEED ANALYSIS

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

Put simply; whereas Requirements analysis focuses on the elements needed to be represented in the system, **needs analysis** focuses on the requirements related to the goals, aspirations and needs of the users and/or the user community and feeds them into the system requirement analysis process. The main purpose of needs analysis is the user's satisfaction.

As it focuses on the needs of the human, *needs analysis* is not limited to addressing the requirements of just software, but can be applied to any domain, such as automotive, consumer product or services such as banking. Although it is not a business development tool, it can be used to help in the development of a business case.

Types of Customer Needs

- **Direct Needs:** Customers have no trouble declaring them clearly when asked. (Example: Watch should show the right time, Water bottle must be easy to hold etc.)
- **Latent Needs:** Not directly expressed by customers; needs probing. (Example: Hidden needs (High-end mobile phones should never be broken no matter how abusive the drop or fall is!)
- **Constant Needs:** Intrinsic to the task of the product, and will always be there. (Example: Intrinsic to the product – Data storage space in servers/computers)
- **Variable Needs:** Not constant, may go away if a suitable techno-solution is available. (Example: Digital photography eliminates a customer need for long film storage life)
- **General Needs:** Applies to all customers, i.e., heating facility in cars in the entire USA. (Example: Compliance to National standards, safety etc.)
- **Niche Needs:** Apply only to a selected customer. (Example: A/C in the car in the UK because it is a cold country for the most part of the year, The car should have bulletproof feature)

Need Statement

There can be extreme variability in description, interpretation, and assessment of need statement. The simple statement of need has thus to be carefully examined by asking following questions ?

- What is the origin ?
- Why is it felt to be a need ?
- Whose need is it ?
- When and for how long will it be needed ?
- Does it conflict with other needs ?

Examples of need statements are

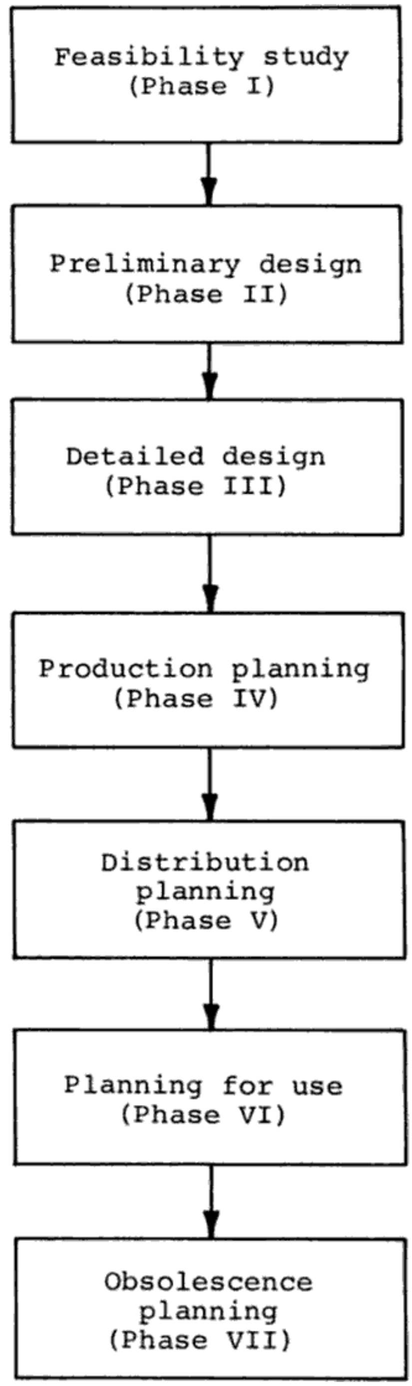
- **The need statement for bicycle**. A device for a common person to travel reasonable distance comfortably with least effort. Of course, the initial cost should be low, be as light as possible, have adequate life, be easy to maintain, etc.
- **The need statement for voltage stabilizer**. A solid state, noiseless electrical device of adequate power rating to provide continuously an output at constant voltage, accepting the input power at varying voltage between the limits of ..... volts. The indications for input and output voltage levels may be provided.
- **The need statement for personal computer**. A computing device to accept-input data, manipulate it according to a set of instructions, and provide the desired output on CRT and printer.

Steps to analyse the needs for a project/product

- Main emphasis should be on the needs of the end user directly.
- The market trends in past, present and future may be analysed thoroughly.
- There should be no bias, prejudices or preconceptions of the analysis.
- The needs should be measured against the abilities to satisfy them.
- The needs should be translated into a statement of goals, considering the resources, constraints and judging criterion.

MORPHOLOGY OF DESIGN (THE SEVEN STEPS)

Design is progression from the abstract to the concrete. This gives a chronologically horizontal structure to a design project. The **seven phases of design** proposed by **Asimow** are: Feasibility study phase, preliminary design phase, and detailed design phase, as indicated in figure.



Of the seven phases, the first three phases belong to design, and the remaining four phases belong to production, distribution, consumption and retirement.

Phase I - Feasibility Study

It is done to

- To demonstrate that the original need has current existence.

- To explore the design problem and identify elements like parameters, constraints, major design criteria etc.
- To conceive a number of possible solutions.
- To sort out potentially useful solutions on the basis of physical reliability, economic worthwhileness, and financial feasibility

Phase II - Preliminary Design

Establishes which the best design concept is. Various steps involved Preliminary design are;

- To subject each alternative solution to order of magnitude analysis until one is proved to be the best.
- To initiate synthesis studies for establishing the fineness of the range within which the major design parameters must be controlled.
- To study how the design will meet consumer's taste, how it will match with products of competitors, whether scarce and critical raw materials will continue to be available, rate of obsolescence.
- The rate of deterioration of performance with corrosion, wear fatigue, etc.
- To test the critical aspects of the design in order to validate the design concept and provide information for subsequent phases.

Phase III-Detailed Design

The detailed design phase begins with the concept evolved in the preliminary design. Its purpose is to furnish the engineering description of a tested and producible design. It furnishes the engineering description of a feasible design.

Various steps of Detailed design are;

- To develop an overall, provisional synthesis as a master layout.
- To prepare specifications of components.
- To initiate experimental design by constructing models to check out untried ideas.
- To test prototypes and using information obtained as basis of redesign and refinement.

Phase IV - Planning the Production Process

The above-mentioned three phases were particularly in the area of engineering design; much of the responsibility for phase 4 will be shared with other areas of *management*.

A new battery of skills, those of tool design and production engineering, come into play.

The production planning phase involves many steps which will vary in form and detail according to the particular industry. The following shortened list is typical of the mass production industries:

1. **Detailed process planning** is required for every part, subassembly and the final assembly. The information is usually displayed on process sheets, one for each part of subassembly. The process sheet contains a sequential list of operations which must be performed to produce the part. It specifies the raw material, clarifies special instructions, and indicates the tools and machines required. This step is particularly important, because design features that lead to difficulties in production are revealed. Such difficulties should have been minimized earlier by timely consultations between product designers and tool designers. Similarly, questions about materials should have been resolved by consultation with metallurgists.
2. **Design of tools and fixtures**: This design work proceeds generally from the information developed in the operations analysis on the process sheets.
3. Planning, specifying or designing new production and plant facilities.
4. **Planning the quality control system**
5. **Planning for production personnel**: Job-specifications are developed, standard times are determined, and labour costs estimated.
6. **Planning for production control**: Work schedules and inventory controls are evolved. Standard costs for labour, materials, and services are established and integrated with the accounting system.
7. **Planning the information-flow system**: The information necessary for transmission of instructions and provision of feedback for control is determined. Appropriate forms and records are designed and integrated with computers when available. How patterns and routines are established.
8. **Financial planning**: Usually, large sums of money are required to initiate production of a new product. The source of the financing must be carefully established, and the means and rate of recovering the capital determined.

Phase V - Planning for Distribution

Production is the first process in the production-consumption cycle. The second is *distribution.* The purpose of this phase is to plan an effective and flexible system of distribution of the designed goods. The short list we now give is indicative of the planning for distribution.

- Designing the packaging of the product
- Planning the warehousing systems
- Planning the promotional activity
- Designing the product for conditions arising in distribution

Phase VI - Planning for Consumption

Consumption is the third process in the production-consumption cycle. As a process, it occurs naturally after distribution. The purpose of this phase is to incorporate in the design, adequate service features and to provide a rational basis for product improvement and redesign. Design for consumption must consider the following factors:

- Design for maintenance
- Design for reliability
- Design for safety
- Design for convenience in use
- Design for aesthetic features
- Design for operational economy
- Design for adequate duration of services
- Obtain service data that can provide a basis for product improvement, for next generation designs.

Phase VII - Planning for Retirement

The fourth process in the production-consumption cycle is the disposal of the retired product. For large an semi-permanent installations, the mere removal may pose difficult engineering problems, as for example, the demolition of a tall building closely surrounded by buildings on either side. Sometimes, the impact on a new design is more immediate as when an old structure or system must be replaced by a. new one with minimum disruption of normal operations.

Designing for retirement, according to Asimow, must consider the following aspects:

- Designing to reduce the rate of obsolescence by taking into account the anticipated effects of technical developments.
- Designing physical life to match anticipated service life.
- Designing for several levels of use so that when service life at higher level of use is terminated, the product will be adaptable for further use with a less demanding level.
- Designing the product so that reusable materials and long-lived components can be recovered.
- Examining and testing of service-terminated products in the laboratory to obtain useful design information.

MORPHOLOGY VS. ANATOMY OF DESIGN

Morphology

The consideration of the product life from its conception to retirement

- Needs Analysis
- Feasibility Study
- Preliminary Design
- Detailed Design
- Production
- Distribution

- Consumption
- Retirement

Anatomy of Design

It includes

- Detailed examination of the engineers
- actions as he/she identifies and solves the
- problem
- Problem statement and formulation
- Information collection
- Modelling
- Value statement
- Synthesis of alternatives
- Analysis and testing
- Evaluation
- Decision
- Optimisation
- Iteration
- Communication

COMMUNICATION

It must always be kept in mind that the purpose of the design is to satisfy the needs of a customer or client. Therefore, the finalized design must be properly communicated, or it may lose much of its impact or significance. The communication is usually by **oral presentation** to the sponsor as well as by a **written design report**.

Surveys typically show that design engineers spend 60 percent of their time in discussing designs and preparing written documentation of designs, while only 40 percent of the time is spent in analyzing and testing designs and doing the designing. Detailed engineering drawings, computer programs, 3-D computer models, and working models are frequently among the “deliverables” to the customer.

Different types of communication designs

- **Graphic Design** Graphic design is a form of visual communication that has certain goals which can be achieved through proper graphics designing. It involves aesthetically expressing the concepts by using various graphics tools. Graphics Designing entails to creating a layout and choosing the right images, symbols and words to express a message.
- **Data Visualisation** Data visualization is also a form of visual communication whereby the information and data are represented in a graphical form. The elements which play a key role in data visualization are maps, charts and graphs. These elements help the viewer to easily understand the data’s pattern, trends or outliners. Today a large amount of data is available at everyone’s disposal. However, it needs to be analyzed for better decisions with proper visualization tools.
- **Interaction Design** Today digital products like applications have become so popular these are being used as powerful tools to spread message and information. There are

different elements of digital products and each element interacts with the user in a different way. Interaction design refers to a designing approach whereby designers focus on the ways a product & its elements will interact with the users. Through the interactive design of digital products, the necessary information is communicated to the end users.

- **Art and Illustrations** Rather than the oral means of communication, messages can be conveyed best through graphics, illustrations, photographs or pictograms.
- **Visual Identity** Visual identity refers to symbols, logos, shapes or other visual elements that different brands use in order to act as their identity. These are easy to remember and whenever a person witnesses the logo of a brand, he/she can correlate it with the brand.
- **Writing & Editing** Different newspaper articles, promotional content, blogs, articles, fiction novels, journals, and informational documents are a great way of communicating a message. Thus, communication design also includes creating content in such a way that it meets its intended goals.

Factors for Effective Communication

- **Presentation**. When a message has too much information, or when it is conveyed in a way that the receiver cannot understand, then that message is ineffective. Communication needs to be condensed down to essential facts and then put into a form that the receiver can understand in order for it to be effective. Once the message is received and understood, then a detailed discussion regarding the topic can begin.
- **Channels**. A communication system is only as effective as its ability to deliver the message, according to the educational resource Management Study Guide. The structure of an organization has a profound effect on the effectiveness of organizational communication. By creating clear communication channels that are understood and upheld by the entire organization, you can significantly increase the effectiveness of your company's communication.
- **Completeness**. For a message to be effective it needs to be complete. While it is important to keep your message concise, you also need to be certain that all pertinent information is included each time you communicate. Prepare to have a discussion with someone by studying the topic at hand. This will allow you to be able to present all of the information needed to get a resolution.
- **Medium**. Effective communication is done through the right mediums. If it is a short and quick message, then a written medium such as a memo or email would be sufficient. Topics that require longer and more detailed discussion should be done in person or over the phone. Choosing the wrong medium can cause problems with message retention. Discussing the details of a contract in person without using a written back-up means that the information may get lost or forgotten. Selecting the

right communication medium has an influence on the effectiveness of a communication.

TECHNICAL REPORTS

A formal technical report usually is written at the end of a project. Generally, it is a complete, stand-alone document aimed at persons having widely diverse backgrounds. Therefore, much more detail is required than for the memorandum report.

The outline of a typical professional report 5 might be:

Cover letter (letter of transmittal): The cover letter is provided so that persons who might receive the report without prior notification will have some introduction to it.

Title page: The title page includes names, affiliations, and addresses of the authors.

Executive summary (containing conclusions): The summary is generally less than a page in length and contains three paragraphs. The first briefly describes the objective of the study and the problems studied. Paragraph two describes your solution to the problem. The last paragraph addresses its importance to the business in terms of cost savings, improved quality, or new business opportunities.

Table of contents, including list of figures and tables.

Introduction: The introduction contains the pertinent technical facts that might be unknown to the reader but will be used in the report.

Technical issue sections (analysis or experimental procedures, pertinent results, discussion of results):

- The experimental procedure section is usually included to indicate how the data were obtained and to describe any nonstandard methods or techniques that were employed.
- The results section describes the results of the study and includes relevant data analysis. Any experimental error allowances are included here.
- The discussion section presents data analysis analyzing the data to make a specific point, develop the data into some more meaningful form, or relate the data to theory described in the introduction.

Conclusions: The conclusion section states in as concise a form as possible the conclusions that can be drawn from the study. In general, this section is the culmination of the work and the report.

References: References support statements in the report and lead the reader to more in-depth information about a topic.

Appendixes: Appendixes are used for mathematical developments, sample calculations, etc., that are not directly associated with the subject of the report and that, if placed in the main body of the report, would seriously impede the logical flow of thought. Final equations developed in the appendixes are then placed in the body of the report with reference to the appendix in which they were developed.

BRAINSTORMING

Brainstorming is the *most widely known creative method for idea generation.* This is a method for generating a large number of ideas, most of which will subsequently be discarded, but with perhaps a few novel ideas being identified as worth following up. It is normally conducted as a small group session of about 5-12 people.

The group of people selected for a brainstorming session should be diverse including a wide range of expertise and even laypeople if they have some familiarity with the problem area. The group must be non hierarchical, although one person does need to take an organizational lead. The role of the group leader in a brainstorming session is to ensure that the format of the method is followed, and that it does not degenerate into a round table discussion. In response to the initial problem statement, the group members are asked to spend a few minutes-in silence-writing down the first ideas that come into their brains. After the ideas have been written down by all the members, then these ideas are analysed one by one so that best of the ideas may be identified and selected out from a huge pile of ideas, generated during the session.

The essential rules of the brainstorming are :

- No criticism is allowed during the session.
- A large quantity of ideas is wanted.
- Seemingly crazy ideas are quick welcome.
- Keep all ideas short and snappy
- Try to combine and improve on the ideas of others.

Brainstorming originated in advertising as a way of discovering new methods of promotion. It is a useful technique now extensively practiced as part of value engineering, but it has two drawbacks. An obvious difficulty is the gathering together of a group at a specific time. The bulk of design results as a consequence of other design work. It is not uncommon for a designer to have to speculate several times in one day and to arrange brainstorming groups at such frequent intervals is not a very practical proposition. As a consequence, brainstorming is normally reserved for the major problems and for those where a solution eludes the designer. A second difficulty is keeping the specification accurately in mind and still maintaining an informal atmosphere. Situations can occur where the line of thought is allowed to drift away from the specification to such an extent that whilst most of the solutions may satisfy the requirement, they include those features which not appropriate to the specification.

Advantages of brainstorming technique

- It is possible to refine ideas of different people for a better solution to the problem.
- It allows people to use maximum creativity to find solutions.
- It increase harmony among people in reaching to feasible solution.

- The person participating may not be highly qualified or consultant but may find a solution.
- This method is easy to understand and not a complicated technique.
- Generated ideas and solutions may be used elsewhere also.

Disadvantages of brainstorming technique

- Some dump ideas may also be accepted for evaluation.
- Overlapping of ideas is possible.
- Some emotional and environmental mental blocks re possible e.g. unease with chaos, fear of criticism and perpetuation of incorrect assumptions.

PRODUCT AND MARKET

First, it is necessary to establish that the proposed product will fulfill a demand in the market, what it is supposed to do, and the services it can offer are both desirable and acceptable. If no consumption is expected, it is futile to go ahead with product design.

The demand for the product in the market may already exist, and its volume can then be assessed by market research and sales figures for similar products. Demand can also be created with the introduction of a new product either by filling in a gap in the market or by offering new attributes, such as novelty, form and shape, or some other specific quality. The volume of such a demand is more difficult to forecast. Market research is a useful tool in these cases.

The volume of demand is a function of several factors, such as trends, cyclic effects, seasonal effects etc., some of which are closely related to local conditions and are sometimes difficult to define *or* measure. It is therefore essential for an enterprise to keep in touch with the market and "feel" its trends, especially when this market is remote and different in character from the local one.

Another relevant question related to product design is: should the customer get what he wants or should he be served with what he needs?

In practice, product design is a result of compromise between infinite variety on one hand and the designer’s concept of the ideal design on the other. In order to selling this compromise to potential customer, the management opts for an advertising campaign.

PRODUCT CHARACTERISTICS

The various relationships in design have already been illustrated in given figure. Now it can be seen how market research starts driving the 'design-production-consumption' cycle. Needs analysis generates **functional requirement** which in turn generates specification for product development.

Apart from the functional aspects, other aspects, termed **standards of performance**, e.g. cost durability, dependability, and ergonomics, are essential inputs to product development.

Production design which considers incorporation of production into the design is another important aspect of design, and development.

Aesthetics or considerations of product appearance usually enter product design at a later stage rather than at the development stage. After the product design is complete, the subsequent steps are prototype production and later on, batch or mass production. The next step involves the actual selling of the product to the appropriate market. From the market, the feedback loop too needs analysis is complete.

Functional aspect

When the marketing possibilities have been explored, the functional scope of the product has to be carefully analyzed and properly defined. Sometimes, functional aspects are multiple, and usage of the product can be left to the customer's choice. A steam iron is a case in point. The additional function of dampening the cloth when required, prior to or during ironing, is incorporated in the steam iron, the main functions of which is to iron the cloth. The customer can decide whether and when to exploit this characteristic of the apparatus.

There is a trend to offer functional versatility of the product, thereby increasing the range of applications and sometimes combining several tools in one. A mixer, for example, allows for a large number of attachments to be added for a variety of duties. It is labelled as a "kitchen machine" to enhance its positioning. Basically, the mixer housing contains a power unit and a speed regulator, but it has to be so designed as to serve all the attachments, and the customer has to decide and define for himself the functional scope to be compatible with his needs, his taste and his pocket.

Operational aspect (Ergonomic considerations)

After determining the functional aspect, the operational aspect has to be considered. Not only must the product function properly, it must be easy to handle and easy to operate. Sometimes it has to be adaptable to various operational conditions. The designer's problem becomes all the more critical with the rising trend for increased versatility because this characteristic implies using basic attachments as elements for building suitable combinations for specific purposes.

Consideration of *human factors* is very important since every design is to be used or controlled by human beings. A good designer should always seriously think of the man-machine system. Efficiency of any system to a great extent depends on the comfort of human operator and as such it becomes essential to keep in view the limitations of the human operator. The ease with which he does the various operations - moving of levers, seeing dials and receiving other signals, the fatigue that human body gathers while doing these operations, the environmental conditions, heat, noise, humidity, safety considerations etc., need serious consideration. The subject dealing with human aspects of design and his working environment is known as *ergonomic design*.

Ergonomics is an activity which has developed from work study and the aim is to improve the working environment such that the operator fatigue and strain is reduced, and the efficiency as a whole is improved. Ergonomics is also defined as the study of the relation between man and his occupation, equipment and environment, and particularly the application of anatomical, physiological and psychological knowledge to the problems arising there from. It applies knowledge of the human body and mind to industrial problems. Many of the problems encountered in the ergonomic design of machines and controls are found in the design of workplace layouts (place to house operator). Efficiency of operator is directly dependent on the design of workplace. Workplace should be so proportioned that it suits a chosen group of people. If possible, adjustments on seat heights, etc. be provided to accommodate operators of different height.

The optimum conditions have been established by the research methods based upon which the following basic principles have been evolved which should be considered by designer for a system involving operator:

- As far as possible the designer should aim for *'sitting position at work'*. When it is impossible to consider the sitting position due to the nature of work, then only standing position should be considered.
- All the unnatural body positions should be avoided for reduction of body fatigue.
- For tiring work such as holding a weight with arm stretched; supports lined with soft rubber or felt should be provided for elbows, and arms and hands.
- Since continuous Use of one hand leads to fatigue, both the arms should be used, as far as possible.
- The height of working area should be properly chosen both for sitting and standing postures of the body.
- Most frequent movements of hands should be as close to the body as possible. Working implements, levers, hand grips etc. and work layout in the sitting condition should be arranged accordingly.
- The working load on limbs of human body should not exceed their load carrying capacities.
- Adequate light should be provided on the working area, but glare should be avoided.
- Knobs, levers, push buttons should be properly designed.

Ease of maintenance and durability

These are two factors closely related to the selection of materials and class of workmanship and hence to the design of the product and the economical analysis of its cost. Quality is not always a simple characteristic to define, but durability and dependability are two factors that often determine quality and have to be carefully considered by the designer. *Durability* is defined mainly by the length of the service life or endurance of the product under given working conditions. Selection of good materials alone does not guarantee the durability of a product. The actual service life of a match or a rocket motor maybe rather limited, but that does not mean that materials for these articles may be of low quality. An additional criterion, therefore, has to be considered, that of *reliability*, or the capability of the product to do its job. In the case of matches, for instance, reliability may be related to the number of sticks in a box, and while the manufacturer is eager to reduce this number to a minimum, he need not choose the very best raw materials to ensure that not even one match will fail. Dependability of rocket motors, however, may be more rigidly defined, and quality materials are chosen in spite of the short active life envisaged for them in some applications. The **standard of performance** and specifications of different products should be assessed with caution.

Another aspect of durability is that of *maintenance and repair*. The amount of repair and preventive maintenance required for some products is closely related to quality and design policy. This is of particular importance when the equipment is supposed to operate continuously and when any repair involves a loss of running time.

Aesthetic aspect

In what way does the appearance of a product affect its design? In most cases where the functional scope, durability and dependability have already been defined, the aesthetics aspect is mainly concerned with moulding the final shape around the basic skeleton. Functional shape is a concept in its own right among designers. Those who believe in functional shape argue that compatibility of function with shape is logical and should therefore be accentuate. A standard lamp is first and foremost a lamp and not a butterfly, and there is nothing wrong with its looking like a lamp. This approach is illustrated in previous figure. In this approach, the aesthetic aspects are examined at the design stage, after all the other aspects of the proposed product have been analyzed.

In some cases, aesthetics is the governing factor in design and completely dominates it. This is especially true. for many consumer goods or fashion goods.

Whereas styling is a dominant factor in product design, it is often used as a means to create demand. In such products, appearance is the sole reason for purchase of the product. Changes in fashion and taste, evolution of form, and the introduction of new ideas quickly replace previous designs. If the market is turbulent and eager to discard outdated designs in favour of new ones, styling becomes a race against time, a race that determines the salability of the product.

Aesthetic moulding, especially when governed by selection of material, colour, texture and sometimes even a line, has great economic advantages, since great variety can be achieved at a comparatively low cost.

Product Development

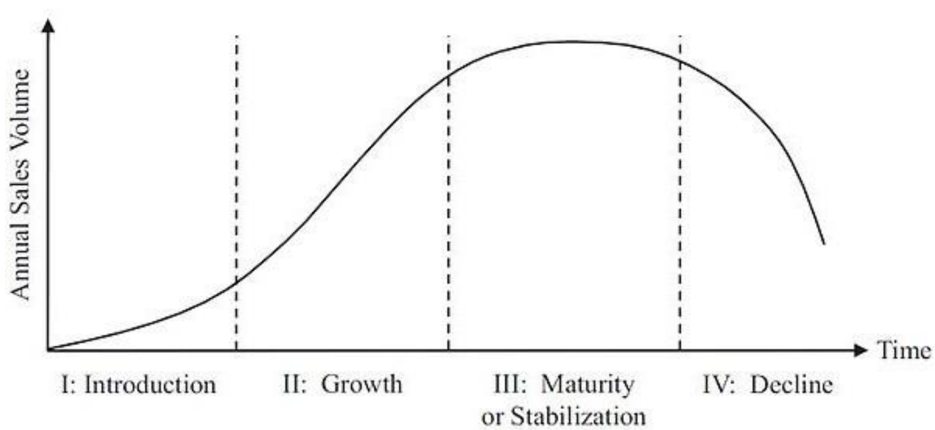
New product development is a crucial process for the survival of firms, especially small businesses. The small business environment today is very dynamic and competitive. For small enterprises to withstand competition from multinationals, they have to continuously update their products to conform to current trends.

Five phases guide the new product development process for small businesses.

- **Idea Generation**. This is the initial stage where a business sources for ideas regarding a new product. Some of the sources for new product ideas include the business customers, competitors, newspapers, journals, employees and suppliers. This stage is crucial as it lays the foundation for all the other phases, the ideas generated shall guide the overall process of product development.
- **Screening**. The generated ideas have to go through a screening process to filter out the viable ones. The business seeks opinions from workers, customers and other businesses to avoid the pursuit of costly unfeasible ideas. At the end of the screening process, the firm remains with only a few feasible ideas from the large pool generated.
- **Concept Development**. The enterprise undertakes research to find out the potential costs, revenues and profits arising from the product. The business conducts a SWOT analysis to identify the strengths, weakness opportunities and threats existing in the market. The market strategy is set out to identify the product's target group.
- **Product Development and Commercialization**. Product development entails the actual design and manufacture of the product. Development commences with the manufacture of a prototype that facilitates market testing. Based upon the results of the tests, the business owner decides on whether to undertake large-scale production or not. Favourable results precede large-scale production and commercialization. The business launches its promotion campaign for the new product. Ergonomics & human factors of design

PRODUCT LIFE CYCLE

A new product progresses through a sequence of stages from introduction to growth, maturity, and decline. This sequence is known as the **product life cycle** and is associated with changes in the marketing situation, thus impacting the marketing strategy and the marketing mix. The product revenue and profits can be plotted as a function of the life-cycle stages as shown in the graph below:



Introduction Stage

In the introduction stage, the firm seeks to build product awareness and develop a market for the product. The impact on the marketing mix is as follows:

- Product branding and quality level is established, and intellectual property protection such as patents and trademarks are obtained.
- Pricing may be low penetration pricing to build market share rapidly, or high skim pricing to recover development costs.
- Distribution is selective until consumers show acceptance of the product.
- Promotion is aimed at innovators and early adopters. Marketing communications seeks to build product awareness and to educate potential consumers about the product.

Growth Stage

In the growth stage, the firm seeks to build brand preference and increase market share.

- **Product** quality is maintained and additional features and support services may be added.
- **Pricing** is maintained as the firm enjoys increasing demand with little competition.
- **Distribution** channels are added as demand increases and customers accept the product.
- **Promotion** is aimed at a broader audience.

Maturity Stage

At maturity, the strong growth in sales diminishes. Competition may appear with similar products. The primary objective at this point is to defend market share while maximizing profit.

- **Product** features may be enhanced to differentiate the product from that of competitors.
- **Pricing** may be lower because of the new competition.
- **Distribution** becomes more intensive and incentives may be offered to encourage preference over competing products.
- **Promotion** emphasizes product differentiation.

Decline Stage

As sales decline, the firm has several options:

- Maintain the product, possibly rejuvenating it by adding new features and finding new uses.

- Harvest the product - reduce costs and continue to offer it, possibly to a loyal niche segment.
- Discontinue the product, liquidating remaining inventory or selling it to another firm that is willing to continue the product.

The marketing mix decisions in the decline phase will depend on the selected strategy. For example, the product may be changed if it is being rejuvenated, or left unchanged if it is being harvested or liquidated. The price may be maintained if the product is harvested, or reduced drastically if liquidated.

STANDARDIZATION

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 current techniques.

Standardization covers a wide field of activity. These activities include:

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

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

- Reduction. of material waste and obsolescence
- Concentration of effort in manufacturing: hence, simplification and specialization
- Reduction in inventories, both of materials, and semi finished and finished products
- Reduction in book-keeping and other paper work
- Lowering the grade of skill required in manufacture and assembly
- Reduction in price: hence expansion of the market
- Reduction in repair and maintenance costs

SPECIFICATION

For a particular application, the user must decide on the performance required depending on his application and then check with the manufacturer's specification whether his requirements can be met by the product manufactured by the company.

A specification must be clearly written so that all the necessary information on important characteristics is shown without other confusing details.

Performance specification is a detailed statement of the characteristics and parameters of a device/machine/process when operating under stated environmental conditions. It enables selection of well defined product.

Test specification is a document used within a manufacturing plant which details the tests, with limits of measured values, that must be made on all production models.

Standard specifications are issued by national authorities for the guidance of manufacturers and users of equipment. These cover the glossaries of terms and symbols, dimensional standards, performance specifications, standard methods of test, and codes of practice.

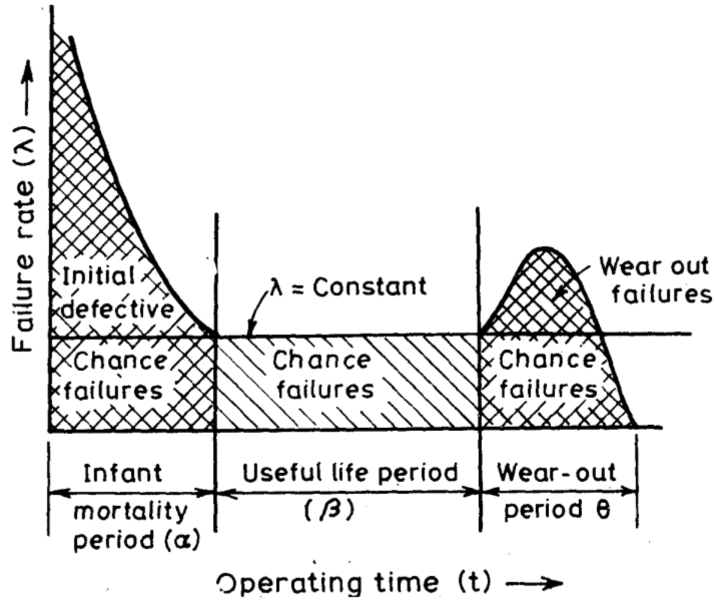
Specifications are used when designing a new product. The necessary information on the product to be designed is transmitted to the designer through the specification. Writing the specification thus deserves special attention and care. Good specifications can be developed by considering/ following points:

- Use plain and simple English. Avoid ambiguous phrases.
- Ascertain accuracy of specification.
- It should be flexible to incorporate improvements without difficulty.
- It should be ensured that specification is reasonable for stated tolerances.
- Reference to standard documents should be minimised.
- It should be ensured that the specification is complete and concise.
- It should include limitations during erection, manufacturing constraints etc.

RELIABILITY

Every product that is designed, fabricated and used has a finite life. After some time, there comes a time when the product ceases to perform the design function effectively. This is all quite predictable, since we can calculate, at least approximately, the wear rates etc. And because of this predictability it does not pose a very serious problem to the designer who can always design for a life longer than that needed for the particular application.

What worries the designer is however another kind of failure called 'chance failures'. A designer knows only too well that no matter how carefully he designs, some piece will fold up before its expected life. If we plot failure rate on y axis and operating time on x axis, we obtain a curve as shown in figure.



Bath tub life characteristic curve for product reliability

Fresh pieces have a relatively high rate of failure because of the undetected manufacturing errors that result in a defective product being passed at the inspection stage. This defective product fails quite early in the life tests. After this initial phase (infant stage or *early failure stage*), the product settles down and renders useful services. During this period (*useful life period*) too, some product fails because of a chance failure, but the rate of failure is relatively low. After the useful life 'β', the surviving units fail quite rapidly again because they are beginning to wear out.

The *chance failure* rate during the middle zone is of concern to the designer. He can guard against the first type of failures by suitable designing, but these apparently is no protection against chance failures in the middle zone except making the rate of failures in this zone as low as possible.

A study for reliability concentrates on the study of the zone of chance failures. Research in this area has shown that these chance failures are governed by the laws of stochastic processes. This permits constructing mathematical models of this phase and drawing conclusions about the reliability of a product or a system.

General Reliability Model

$$R = e^{-(t/\theta)^{\beta}}$$

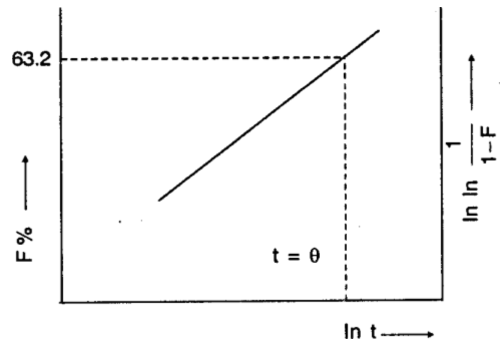
The values of β and θ are estimated through life testing of the equipment. In this test, a random sample is drawn and the failure number and corresponding time are recorded. We have

$$R = 1 - F = e^{-(t/\theta)^{\beta}}$$

$$\therefore \quad \ln \frac{1}{1-F} = \beta \ln t - \beta \ln \theta$$

where R is reliability and F is components failing during test.

The results of the life test, i.e. F% (percentage of components failing during test) versus time t are plotted on a special graph paper called *Weibull probability paper*.

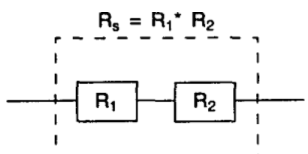


The slope of the line of best fit gives us β.

The time taken for 63.2% of the samples to fail is the characteristic life θ.

Reliability of Series System

See following figure.

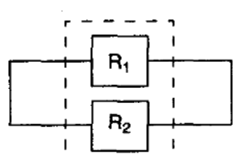


In a series system, the probability of survival depends on the survival of both the components. From the theorem of multiplication of probabilities, $R_s = R_1 \times R_2$.

In this case, it can be shown that MTBF (mean time before failure) for experimental is $1/(\lambda_1 + \lambda_2)$ where λ_1 and λ_2 are failures rates of elements 1 and 2 respectively.

Reliability of Parallel System

See following figure.



The probability of failure of component 1 = $(1 - R_1)$. The probability of failure of component 2 = $(1 - R_2)$.

Hence probability of failure of both components = $(1 - R_1)(1 - R_2)$

Hence the probability survival of both the components = system reliability. Since $(1 - R_1)(1 - R_2)$ is the probability of failure of both units in parallel, the probability of survival of both the units is

$$R_p = (1-(1-R_1)(1-R_2)).$$

If $R_1 = R_2$ then

$$R_p = \left[1-(1-R_1)^2\right].$$

Thus

$$MTBF = \left(\frac{1}{\lambda} + \frac{1}{2\lambda}\right)$$

Example

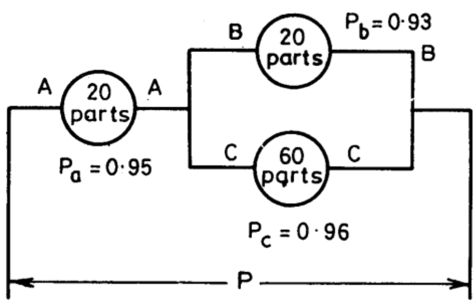
An equipment consists of 100 parts, of which 20 parts are connected functionally in series, which in turn are connected in series to the parallel branches of 60 and 20 parts, the individual parts in 60 and 20 being connected in series. The reliability of each part in the three groups is 0.95, 0.96 and 0.93 respectively. Find overall reliability of the equipment.

Solution

See the following figure.

Since reliability of each part in first group of 20 parts is 0.95.

i.e. $P_a = 0.95$



Overall reliability of all 20 parts connected in series

$$P_{AA} = P_a^{20} = 0.95^{20} = 0.358$$

Similarly $P_{BB} = 0.93^{20} = 0.240$

And $P_{CC} = 0.96^{20} = 0.0863$

Unreliability of groups BB and CC will be

$$(1-P_{BC}) = (1-P_{BB})(1-P_{CC})$$

$$= (1-0.240)(1-0.0863) = 0.760 \text{ x } 0.914 = 0.695$$

or reliability of branch BB and CC is

$$P_{BC} = 1 - 0.695 = 0.305$$

Overall reliability of equipment

$$P = P_{AA} \text{ x } P_{BC} = 0.358 \text{ x } 0.305 = 0.109$$

Problem

(i) In a system there are 10 components in series each with a reliability factor of 0.95. What is the overall reliability of system?

Answer: 0.5987

(ii) If each of the 10 components is in parallel, and has individual reliability factor of 0.30 only, what is the system reliability?

Answer: 0.97175

Example (AMIE S94)

(i) It the failure rate of and equipment has been established as 20 failures during every 1000 hours of operation, calculate MTBF.

(ii) In series of computers, the reliability of each is given as R_A = 90%, R_B = 80% and R_C = 70%. Find out the reliability of the system.

Solution

(i) $$\text{MTBF} = \frac{\text{no of hours of operation}}{\text{no. of failures}}$$

$$= \frac{1000}{20} = 50 \text{ hours}$$

(ii) For series configuration, Reliability of system

= product of reliability of each component

= R_A x R_B x R_C = 0.9 x 0.8 x 0.7

= .504

= 50.4%

Example (AMIE S94)

Calculate the probability of survival of a piece of equipment that is to operate for 500 hours and which consists of four sub-assembly system having following MTBF's:

Sub-system A - MTBF = 5000 hours

Sub-system B - MTBF = 3000 hours

Sub-system C - MTBF = 15000 hours

Sub-system D - MTBF = 15000 hours

Solution

Reliability of a system = $e^{-No.of hours/MTBF}$

Thus reliability of four systems

$$R_A = e^{-500/5000} = 0.9048$$

$$R_B = e^{-500/3000} = 0.846$$

$$R_C = e^{-500/15000} = 0.9672$$

$$R_D = e^{-500/15000} = 0.9672$$

If sub assemblies are in series, then system reliability will be

$$= R_A x R_B x R_C x R_D$$

= 0.9048 x 0.846 x 0.9672 x 0.9672

= 0.716

If assemblies are in parallel, then system unreliability will be

$$= (1 - R_A)(1 - R_B)(1 - R_C)(1 - R_D)$$

$$= (1 - 0.9052)(1 - 0.846)(1 - 0.9672)(1 - 0.9672)$$

= 0.0000158

Hence reliability for parallel system

= 1 - unreliability

= 1 - 0.0000158 = 0.9999842

Example (AMIE S94)

(i) During the inspection of wooden tables, the average number of defects is found to be 9, establish the control limits. (ii) if the standard deviation in the inspection data comes out to be 4, compute the control limits.

Solution

(i) Average number of defects $\bar{C} = 9$

∴ Upper control limit = $\bar{C} + 3\sqrt{\bar{C}} = 9 + 3\sqrt{9} = 18$

and lower control limit = $\bar{C} - 3\sqrt{\bar{C}} = 9 - 3\sqrt{9} = 0$

(ii) Standard deviation = 4

Hence average number of defects = $\overline{C}$ = (standard deviation)^2 = 4^2 = 16

$\therefore$ Upper control limit = $\overline{C} + 3\sqrt{\overline{C}} = 16 + 3\sqrt{16} = 28$

and lower control limit = $\overline{C} - 3\sqrt{\overline{C}} = 16 - 3\sqrt{16} = 4$

MAINTAINABILITY

Maintainability is the probability that, when maintenance action is initiated under staled conditions, a failed system will be restored to operable condition within a specified time. System maintainability can be improved by providing accessible test points, built-in test equipment, built-in diagnostic aids, training the operating personnel, and providing spare pans and equipment for incorporating repairs.

TAGUCHI METHOD OF ROBUST DESIGN OF PRODUCTS

Robust Design method, also called the *Taguchi Method*, pioneered by *Dr. Genichi Taguchi*, greatly *improves* engineering productivity. By consciously considering the noise factors (environmental variation during the product's usage, manufacturing variation, and component deterioration) and the cost of failure in the field the Robust Design method helps ensure customer satisfaction. Robust Design focuses on improving the fundamental function of the product or process, thus facilitating flexible designs and concurrent engineering. Indeed, it is the most powerful method available to reduce product cost, improve quality, and simultaneously reduce development interval.

To ensure or guarantee customer satisfaction, the Robust Design approach takes into account both (i) The *noise* considered as the variation from environmental to manufacturing and component failure, and (ii) The *cost* considered as the rate of deterioration in the area. It is a technique for performing experiments to look into processes or investigate on processes where the end result depends on several factors such as inputs and variables without having a mind-numbing and inefficient or too costly operation with the use of possible and feasible mixture of values of the said variables. With a systematic choice of variable combination, dividing their individual effects is possible.

The Robust Design method or the Taguchi approach makes it possible for engineers to:

- Improve processes and products which are intended under a broad variety of consumer's circumstances in their life cycle and making processes reliable and products durable
- Capitalize and get the most out of robustness by developing the planned function of a product by improving and expanding insensitivity to factors of noise which somehow discredit performance
- Alter and develop formulas and processes of a product to arrive at the performance desired at a reduced cost or the lowest rate possible but, at the shortest turnaround or time frame
- Make designs easier and processes at a reduced cost

The Robust Design follows a crucial methodology to ensure a systematic process to attain a good output. Below are the *five* primary tools used in the Robust Design approach:

- P-Diagram is used to classify the variables associated with the product into noise, control, signal (input), and response (output) factors.
- Ideal Function is used to mathematically specify the ideal form of the signal-response relationship as embodied by the design concept for making the higher-level system work perfectly.
- Quadratic Loss Function (also known as Quality Loss Function) is used to quantify the loss incurred by the user due to deviation from target performance.
- Signal-to-Noise Ratio is used for predicting the field quality through laboratory experiments.
- Orthogonal Arrays are used for gathering dependable information about control factors (design parameters) with a small number of experiments.

The following are the 4 main steps in Robust Parameter method:

- **Problem Formulation**. This step would incorporate the identification of the main function, development of the P-diagram, classifying the best function and signal to noise or S/N ratio, and planning or strategizing the experiments. The tests or experiments would involve altering the noise, control as well as the signal factor logically and efficiently utilizing orthogonal arrays.
- **Gathering of Data**. This is the stage where experiments or tests are performed in either simulation or hardware. Having a full-scale example of the product for experimentation purposes is not considered necessary or compulsory in this step. What's important or significant in this stage is to have a vital model or example of the product which satisfactorily encapsulates the design idea or concept. As a result, experiments or tests can be performed at a low cost or economically.
- **Factor Effects Analysis**. This is the stage where results or outcome of the control factors are estimated and such results are evaluated to identify and classify the most favourable arrangement of the control variables or factors.
- **Prediction/Confirmation**. This is the stage wherein predicting the performance or operation of the product model under the most favourable arrangement of the control variables or factors to confirm best conditions is done. After which, experiments are done under such conditions as well as comparing the results observed with the underlying predictions. If the outcome or results of the experiments done corresponds with the predicted results or predictions, final results are then implemented. However, if predictions do not match with the final results, the steps need to be repeated.

A lot of companies worldwide have saved millions of dollars or even hundreds of millions just by using the Taguchi approach.