Mechanical Design/Product Design Process

Several Major Steps:
• Define project and its planning
• Identify customers (users) and their needs
• Evaluate existing similar products (benchmarking)
• Generate engineering specifications & target values
• Perform conceptual design
  (Functional Modeling Approach)
• Perform concept evaluations
• Develop product/prototype
• Evaluate product for performance and cost

Sources:
Planning for the Design Project

Before launching into a detailed design process for a product, at least three things needed to be planned out first.

1. Identify types of Design Projects
   - Minor variation of an existing product
   - Improvement of existing product
   - Development of a new product
     (a) for a single or small run
     (b) for mass production

2. Form a Design Teams
   - Available members and resources

3. Develop a Project Plan
   - Identify the Tasks
   - State the Objectives for each Task
   - Estimate the Resources (Personnel, Time, etc.) needed to Meet the Objectives
   - Develop a Sequence for the Tasks
   - Estimate the Product Development Costs
Understand the Problem and Develop Engineering Specifications

Quality function deployment (QFD) -- technique to generate engineering specifications. It is used to develop the House of Quality for the product.

Important
“What” needs to be designed first,
Then concern about “How” the design will look and work.
With this approach, QFD sets the foundation for generating concepts.
There are 8 steps in QFD technique:
(Forms House of Quality)

1. Identify the Customers (Who?)
2. Determine the Customers’ Requirements (What?)
   - Kano Model of Customer Satisfaction
     - Basic Quality
     - Performance Quality
     - Excitement Quality
3. Determine Relative Importance of the Requirements (Who vs. What?)
4. Identify and Evaluate the Competition (Now vs. What?)
5. Generate Engineering Specifications (How will the Customers’ Requirements be met?)
6. Relate Customers’ Requirements to Engineering Specifications (How to measure What?)
7. Set Engineering Targets (How much is good enough?)
8. Identify Relationships between Engineering Requirements (How are the Hows dependent on each other?)
**Functional Decomposition & Concept Generation**

Important customer requirements are concerned with the functional performance desired in the product. These requirements become the basis for the concept generation techniques.

- Functional Decomposition is designed to refine the functional requirements,
- Concept Variant Generation helps in transforming the functions into concepts.

**Functions** tell what the product must do (Action Verb). The techniques support a divergent-convergent design philosophy. This philosophy expands a design problem into many solutions before it is narrowed to one final solution.
**Function** tells what the product must do, whereas the form or structure tells how the product will do it.

**Function** can be described in terms of the logical flow of energy (including static forces), material, or information.

The flow of Energy – type of energy in electromechanical systems including Mechanical, Electrical, Thermal, Fluid, etc.), by their action in the system.

The flow of Material – 3 types: (1)Through flow the system (material-conservative process). The terms associated with through-flow are position, lift, hold, support, move, translate, rotate, guide, etc. (2) Diverging flow are dividing the materials such as disassemble or separate. (3) Converging flow are assembling or joining materials. Such as mix, attach, position relative to, etc.

The flow of Information – usually in the form of mechanical signals, electrical signals. Generally the information is used as part of an automatic control system or to interface with a human operator.

The goal of the **functional modeling techniques** is to decompose the problem in terms of the flow of energy, material, and information for a detailed understanding.
4 basic steps in applying the Functional Decomposition technique to generate design functions:

(1) Find the Overall Function That Needs to be Accomplished
- State the “most important” function.

(2) Create Subfunction Descriptions
- Decompose the main function into subfunctions (what needs to happen?).
- Include known flows (material, energy, info.).
- Note operating sequence.

(3) Put Subfunction in Order
- To order the functions in step (2) to accomplish the overall function in step (1).
- The order must be logical and in time sequence.
- Redundant subfunctions must be recombined.

(4) Refine Subfunctions
- To decompose the subfunction structure as fine as possible.
- Until the function can be fulfilled by existing objects
Basic Methods of Generating Concepts:

1 Brainstorming as a source of ideas
2 Using the 6-3-5 Method
3 Use of Analogies in Design
4 Use of Extremes and Inverses
5 Finding ideas in Reference Books and Trade Journals, Patents, etc.
6 Using Experts to help generate concepts

Patent Searches Websites:

http://www.uspto.gov/patft/index.html
http://www.delphion.com/home
http://gb.espacenet.com/
In the 1990s, 2 logical methods for developing concepts evolved. 

**TRIZ** – “The Theory of Inventive Machines”. The method makes use of CONTRADICTIONS and INVENTIVE PRINCIPLES.

Contradictions are engineering “trade-offs” – when something gets better, forcing something else to get worse. Using the TRIZ method, the goal is to find the major contradiction that is making the problem hard to solve. Then use TRIZ’s 40 inventive principles to generate ideas for overcoming the contradictions. Altshuller found that there are 40 inventive principles underlying all patents.

**Axiomatic Design**

Axiomatic design was developed by Professor Nam Suh of MIT in an effort to make the design process logical. Axiomatic design is based on the relationships between 4 design domains: Customer, Function, Physical, and Process.
Morphological Method for generating concepts (How?) from functions:

Make sure the functions are refined as much as possible.

(1) Develop Concepts from each function
   - Concepts are the means of providing each function.
   - To develop as many means of accomplishing the function as possible.

(2) Combine Concepts
   - To select one concept for each function and combine the selected ones into a single design.
   - The goal is to generate different designs for further evaluation later.
Techniques for Concept Evaluation:

Evaluation Based on Feasibility Judgment

- three reactions
  (a) not feasible (reason why)
  (b) might work if something else happens (conditional)
  (c) worth considering

- Based on “gut feeling” – a comparison made with prior design experience and design knowledge.
Evaluation Based on Technology-Readiness Assessment

- Absolute comparison with state-of-the-art capabilities. (Matured Technology)
- Six measures to determine a technology maturity
  (a) Can the technology be manufactured with known processes?
  (b) Are the critical parameters (such as dimensions, material properties, or other features) that control the function identified?
  (c) Are the safe operating latitude (limits) and sensitivity of the parameters known?
  (d) Have the failure modes been identified?
  (e) Does hardware exist that demonstrates positive answers to the above 4 questions?
  (f) Is the technology controllable throughout the products life cycle?
Evaluation Based on Go/No-Go Screening
- Customer requirement must be transformed into a question to be addressed to each concept. Answer with Yes or Maybe (Go) or No (No-Go).
- If a concept has only a few no-go responses, it may be worth modified rather than being eliminated.

Evaluation Based on a Basic Decision Matrix method (Pugh’s method)
- It provides a means of scoring each concept relative to another in its ability to meet customer requirements.

Five Steps to this method:
(a) Choose the customer requirements (criteria) for comparison
(b) Develop relative importance weightings
(c) Select the alternative concepts to be compared (on same level of abstraction)
(d) Generate scores using S, +, - (let one of the “best” concepts be the datum)
(e) Compute the total score
Design/Product Evaluation for Performance and Cost

• Evaluation for Design Robustness

The word “robust” in design usually refers to final products that are of high quality because they are insensitive to manufacturing variation, operating temperature, wear, and other uncontrolled factors so that performance is maintained.

• Evaluation for Design Reliability

• Evaluation for Design Manufacturing

• Evaluation for Design Assembly
Robust Decision Making

The word “robust” in design usually refers to final products that are of high quality because they are insensitive to manufacturing variation, operating temperature, wear, and other uncontrolled factors.

“Robust” here refers to decisions that are as insensitive as possible to the uncertainty, incompleteness, and evolution of the information that they are based on.

Satisfaction = belief that an alternative meets the criteria
Belief = knowledge + confidence
• A belief map is a tool to help designers picture and understand evaluation of concepts. A belief map organizes two dimensions of belief: knowledge and confidence.

• Knowledge is “a measure of the information held by a decision-maker about a feature of a concept defined by a criterion (target).” If the required information was not known to the designer, then the probability is 0.5 (50/50 chance of getting the right answer), if fully known, then it would be 1.

• Confidence can be associated with probabilities. If there is confidence that the concept fully meets the target stated in the criteria, then the probability is 1 (100%). Probability is 0 if the alternative fails to meet the target at all.

Evaluation based on an **Advanced Decision Matrix**
Similar to the Basic Decision Matrix but described the difference in step 4 and 5.

i.e. Evaluate alternatives
    Compute satisfaction
Product liability is the special branch of law dealing with alleged personal injury or property or environmental damage resulting from a defect in a product.

Three difference charges of Negligence can be brought against designers in product liability cases:

1. The product was defectively designed (Not follow commonly accepted standards)
2. The design did not include proper safety devices (either, inherent, added-on, or warning)
3. The designer did not foresee possible alternative uses of the product. (e.g. lawn mower for trimming branches)

Other charges of negligence (not in control of the designers) are:
1. The product was defectively manufactured
2. The product was improperly advertised (use for wrong intent)
3. The instruction for safe use of the product was not given.