MP482
PRODUCT DEVELOPMENT AND DESIGN

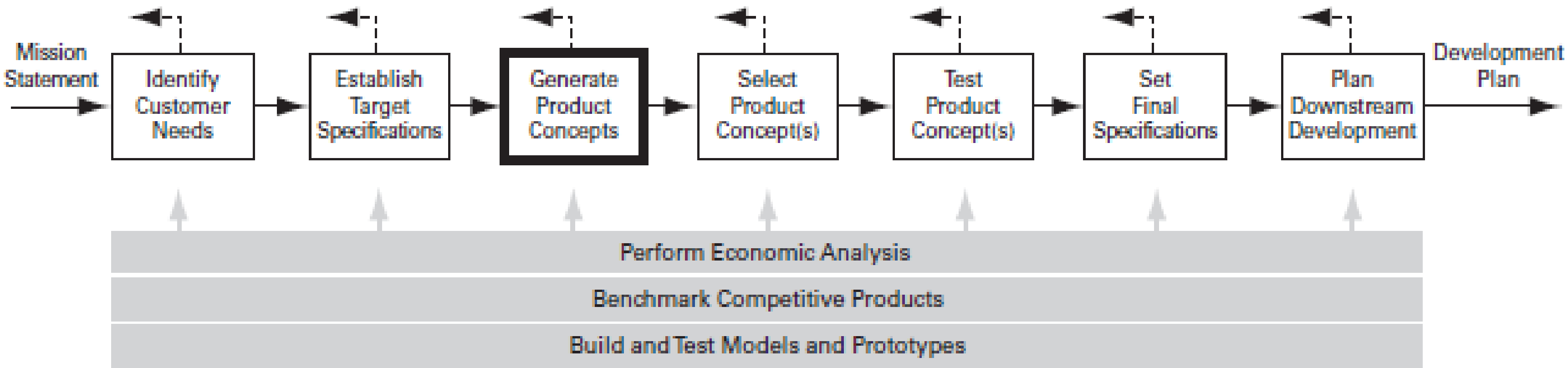
MODULE II

- Conceptual Design: Generation, selection & embodiment of concept. Product architecture. Industrial design: process, need.
- Robust Design: Taguchi Designs & DOE. Design Optimization

CONCEPT(PRODUCT CONCEPT)

- A product concept is an approximate description of the technology, working principles, and form of the product.
- It is a concise description of how the product will satisfy the customer needs.
- A concept is usually expressed as a sketch or as a rough three-dimensional model and is often accompanied by a brief textual description.
- Concept generation is relatively inexpensive and can be done relatively quickly in comparison to the rest of the development process

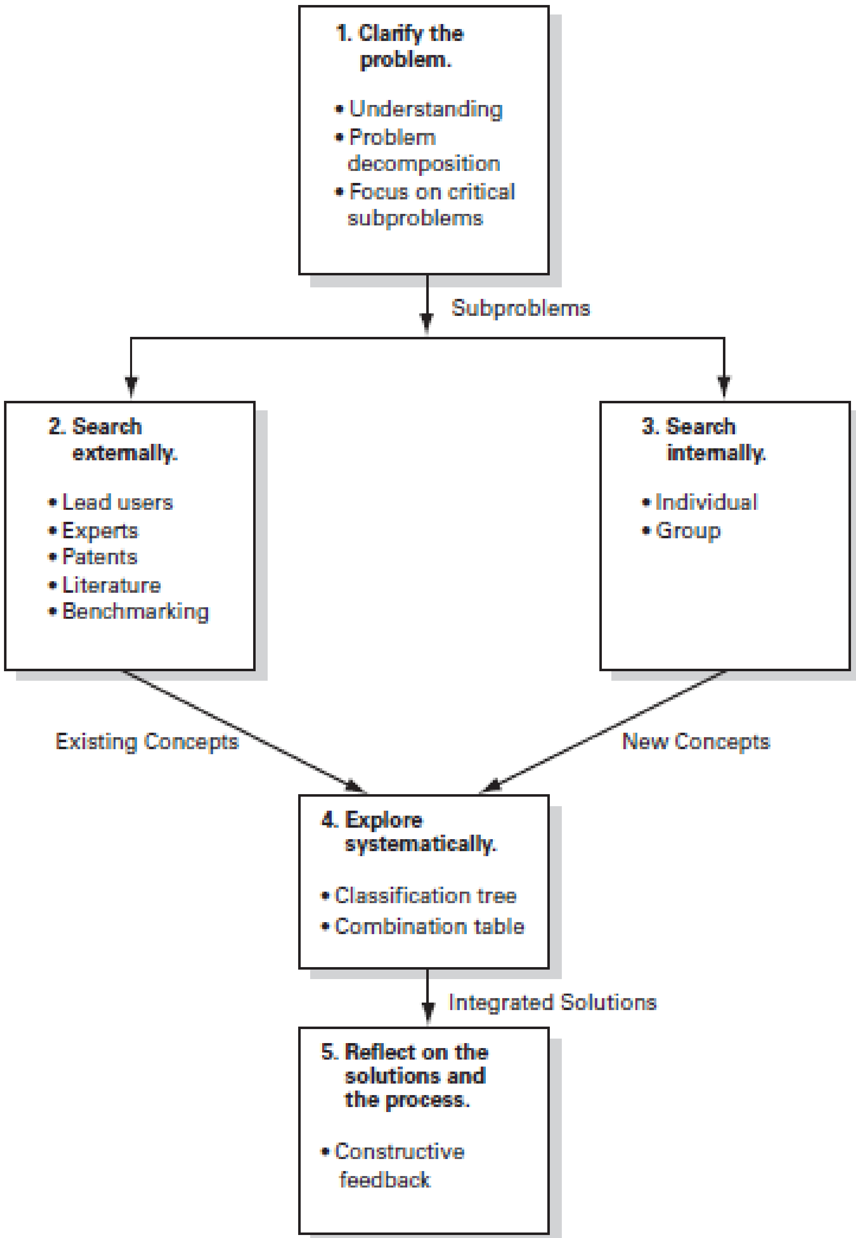
CONCEPT GENERATION



The concept generation process begins with a set of customer needs and target specifications and results in a set of product concepts from which the team will make a final selection.

Concept generation is almost always iterative

Five step concept generation method



- The method breaks a complex problem into simpler sub problems.
- Solution concepts are then identified for the sub problems by external and internal search procedures.
- Classification trees and concept combination tables are then used to systematically explore the space of solution concepts and to integrate the sub problem solutions into a total solution.
- Finally, the team takes a step back to reflect on the validity and applicability of the results, as well as on the process used.

Step 1: Clarify the problem

- Clarifying the problem consists of developing a general understanding and then breaking the problem down into sub problems if necessary.
- The mission statement for the project, the customer needs list, and the preliminary product specification are the ideal inputs to the concept generation process.
- Decompose a Complex Problem into Simpler Sub problems
- Eg: Document copier
- Decomposition may not be very useful for products with extremely simple functions. Eg:Paper clip

Step 1: Clarify the problem

- Dividing a problem into simpler sub problems is called *problem decomposition*.
- There are many schemes by which a problem can be decomposed.
  - Decomposition by functionality
  - Decomposition by sequence of user actions
  - Decomposition by customer needs.

Step 1: Clarify the problem: Functional Decomposition

- The first step in decomposing a problem functionally is to represent it as a single black box operating on material, energy, and signal flows,
- The next step in functional decomposition is to divide the single black box into sub functions to create a more specific description of what the elements of the product might do in order to implement the overall function of the product.
- Each sub function can generally be further divided into even simpler sub functions.
- The division process is repeated until the team members agree that each sub function is simple enough to workwith.
- A good rule of thumb is to create between 3 and 10 subn functions in the diagram

Step 1: Clarify the problem

- In some applications the material, energy, and signal flows are difficult to identify.
- In these cases, a simple list of the sub functions of the product, without connections between them, is often sufficient.
- Functional decomposition is most applicable to technical products, but it can also be applied to simple and apparently nontechnical products.

Step 1: Clarify the problem: Other Decomposition Approaches

- Decomposition by sequence of user actions
  - This approach is often useful for products with very simple technical functions involving a lot of user interaction.
- Decomposition by customer needs
  - This approach is often useful for products in which form, and not working principles or technology, is the primary problem.

Step 2:Search Externally

- External search is aimed at finding existing solutions to both the overall problem and the sub problems identified during the problem clarification step.
- external search occurs continually throughout the development process
- The external search for solutions is essentially an information-gathering process.
- Available time and resources can be optimized by using an expand-and-focus strategy:
- First *expand* the scope of the search by broadly gathering information that might be related to the problem and then *focus* the scope of the search by exploring the promising directions in more detail.

Step 2:Search Externally

- Five good ways to gather information from external sources:
  - Lead user interviews
    - *Lead users* are those users of a product who experience the needs months or years before the majority of the market benefit substantially from a product innovation
  - Expert consultation,
    - Experts may include professionals at firms manufacturing related products, professional consultants, university faculty, and technical representatives of suppliers.
  - Patent searches
    - Patents are a rich and readily available source of technical information containing detailed drawings and explanations of how many products work.
  - Literature searches
    - Published literature includes journals; conference proceedings; trade magazines; government reports; market, consumer, and product information; and new product announcements.
  - Competitive benchmarking.
    - *Benchmark Related Products* is the study of existing products with functionality similar to that of the product under development or to the sub problems on which the team is focused.

Step 3: Internal Search

- Internal search is the use of personal and team knowledge and creativity to generate solution concepts.
- Often called brainstorming, this type of search is internal in that all of the ideas to emerge from this step are created from knowledge already in the possession of the team.
- This activity may be the most open-ended and creative of any task in product development

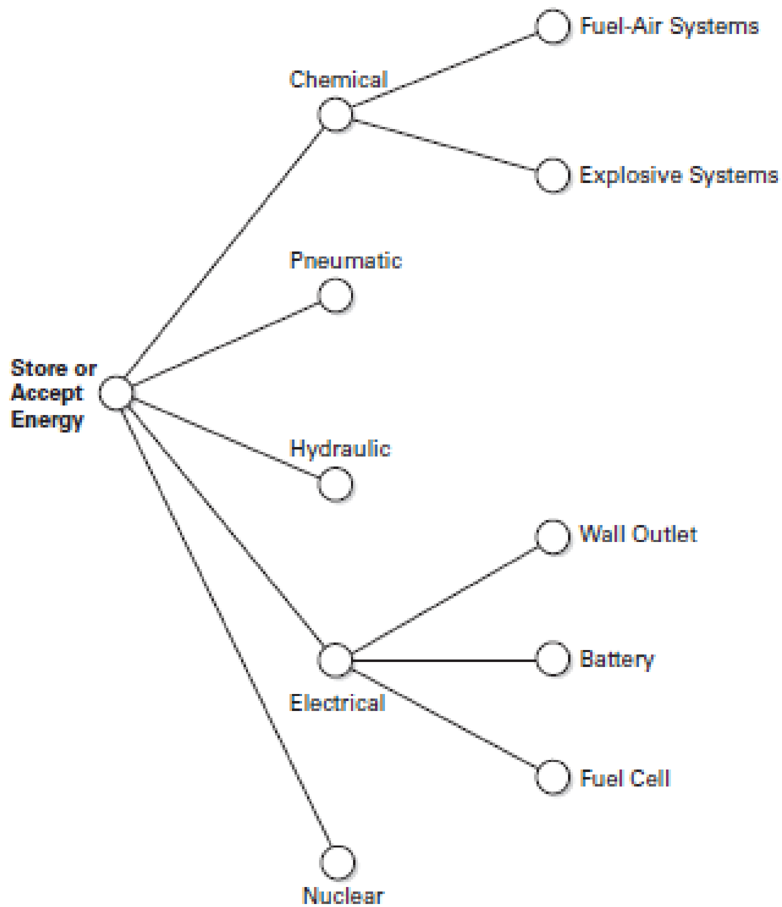
Step 4: Explore systematically

- As a result of the external and internal search activities, the team will have collected tens or hundreds of concept *fragments*—solutions to the sub problems.
- Systematic exploration is aimed at navigating the space of possibilities by organizing and synthesizing these solution fragments.
- There are two specific tools for managing this complexity and organizing the thinking of the team:
  - The *concept classification tree* and the *concept combination table*.
- The classification tree helps the team divide the possible solutions into independent categories.
- The combination table guides the team in selectively considering combinations of fragments.

Step 4: Explore systematically-Classification tree method

- Benefits of classification tree
  - The concept classification tree is used to divide the entire space of possible solutions into several distinct classes that will facilitate comparison and pruning.
  - Identification of independent approaches to the problem:
  - Exposure of inappropriate emphasis on certain branches

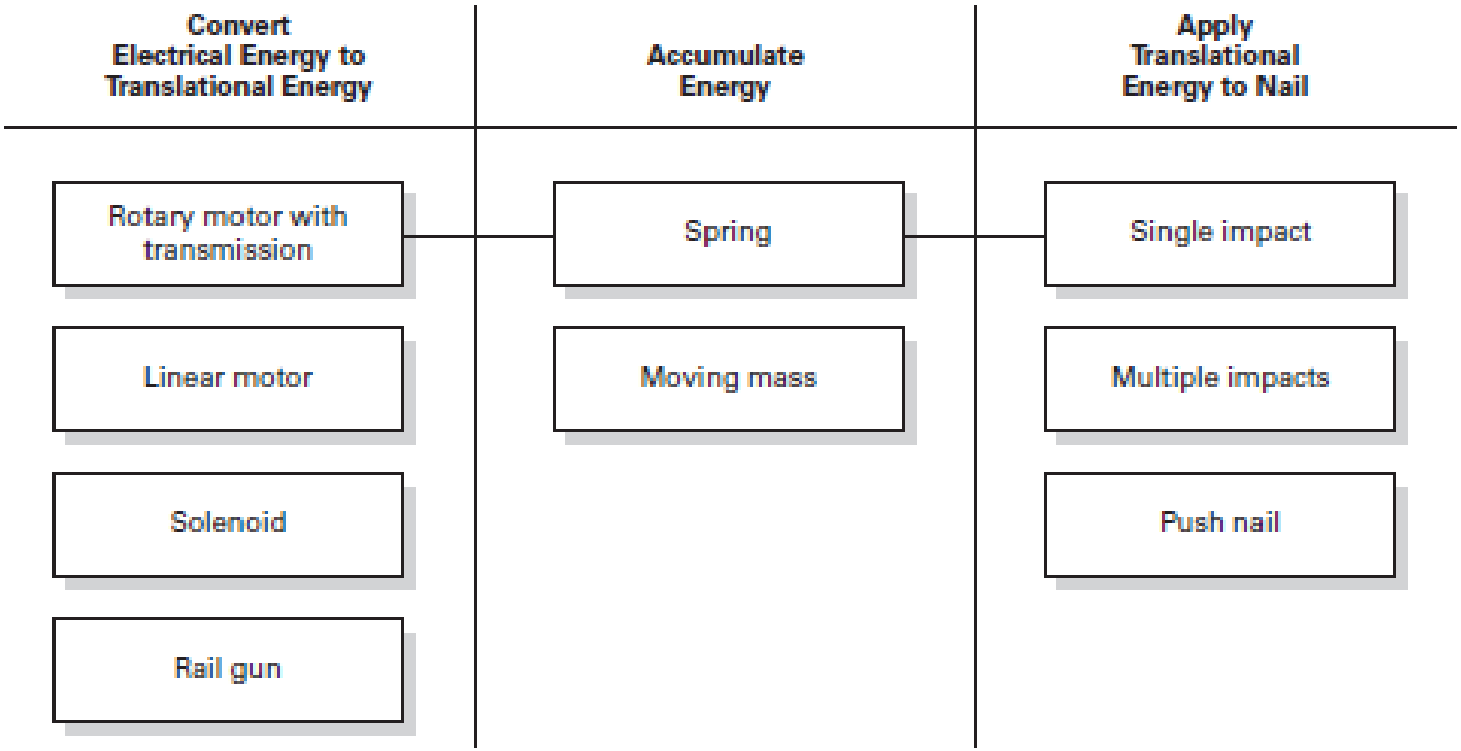
Step 4: Explore systematically- Classification tree method



Step 4: Explore systematically- Combination Table

- The concept combination table provides a way to consider combinations of solution fragments systematically.
- Potential solutions to the overall problem are formed by combining one fragment from each column.
- Two guidelines make the concept combination process easier.
  - First, if a fragment can be eliminated as being infeasible before combining it with other fragments, then the number of combinations the team needs to consider is dramatically reduced.
  - Second, the concept combination table should be concentrated on the sub problems that are coupled.

Step 4: Explore systematically- Combination Table



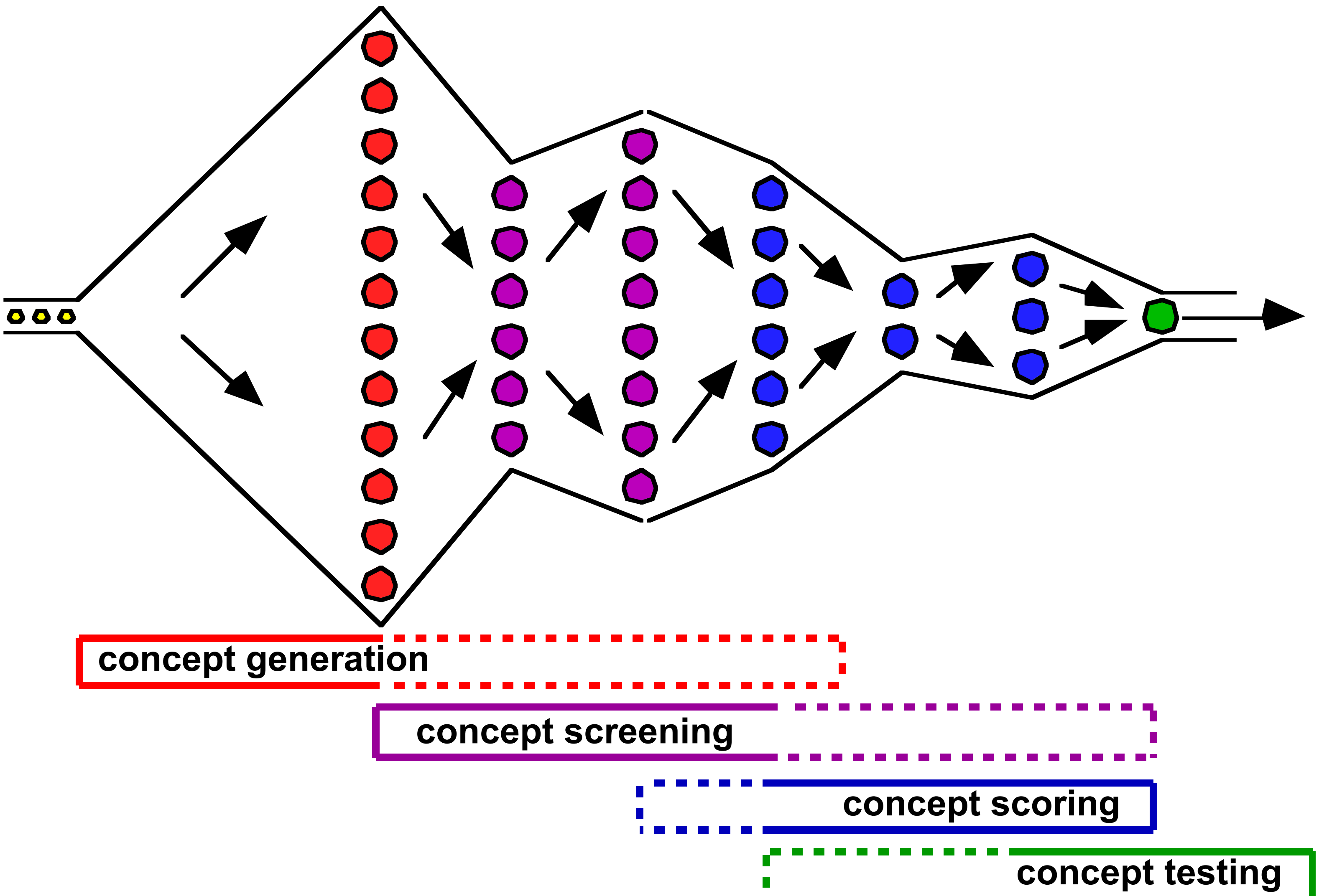
Step 5: Reflect on the Solutions and the Process

- Reflection should in fact be performed throughout the whole process.
- Is the team developing confidence that the solution space has been fully explored?
- Are there alternative function diagrams?
- Are there alternative ways to decompose the problem?
- Have external sources been thoroughly pursued?
- Have ideas from everyone been accepted and integrated in the process

Concept Selection

- *Concept selection* is the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development

Concept Development Funnel



Concept Selection

- Concept selection is a convergent process, it is frequently iterative and may not produce a dominant concept immediately.
- A large set of concepts is initially down to a smaller set, but these concepts may subsequently be combined and improved to temporarily enlarge the set of concepts under consideration.
- Through several iterations a dominant concept is finally chosen

Concept Selection Approaches

- External decision
  - By use of an external group of customers, clients, etc.
- Product champion & intuition
  - By an influential member of the development team
- Multi-voting
  - Asking each member to pick a number of concepts and pick the one with most votes.
- Pros and cons
  - The team list the strengths and weakness of each concept.
- Prototype and test
  - Build and test prototype for each concept and select based on the test data.
- Decision metrics
  - The team rates each concept against selection criteria with varying importance/weights.

Two stages of concept selection

- Concept screening (the Pugh concept selection method)
  - To quickly narrow the number of concepts and to improve the concepts
  - Screening is a quick, approximate evaluation aimed at producing a few viable alternatives.
- Concept scoring
  - Scoring is a more careful analysis of these relatively few concepts in order to choose the single concept most likely to lead to product success.
  - Weighs the relative importance of the selection criteria
  - Focus on more refined comparisons with respect to each criteria

Two Stage Concept Selection Method

- Both stages, concept screening and concept scoring, follow a six-step process that leads the team through the concept selection activity.
- The steps are:
  - Prepare the selection matrix.
  - Rate the concepts.
  - Rank the concepts.
  - Combine and improve the concepts.
  - Select one or more concepts.
  - Reflect on the results and the process.

Concept Screening

- Concept screening is based on a method developed by the late Stuart Pugh in the 1980s and is often called Pugh concept selection (Pugh, 1990).
- The purposes of this stage are to narrow the number of concepts quickly and to improve the concepts

Concept Screening Process

1. Prepare the Selection Matrix
   - Criteria on LHS and concepts on top of the matrix
   - Reference Concept
   - Weightings
2. Rate Concepts
   - Scale (– 0 +) or (1–5)
   - Compare to Reference Concept or Values
3. Rank Concepts
   - Sum Weighted Scores
4. Combine and Improve
   - Remove Bad Features
   - Combine Good Qualities
5. Select the Best Concept
   - May Be More than One
   - Beware of Average Concepts
6. Reflect on the Process
   - Continuous Improvement

Concept Screening Process: Step 1 Prepare the Selection Matrix

- The inputs (concepts and criteria) are entered on the matrix.
- The concepts are best portrayed by both a written description and a graphical representation
- The concepts are entered along the top of the matrix, using graphical or textual labels of some kind.
- The selection criteria are listed along the left-hand side of the screening matrix
- These criteria are chosen based on the customer needs
- The criteria includes from 5 to 10 dimensions.
- The selection criteria should be chosen to differentiate among the concepts.
- Each criterion is given equal weight in the concept screening method.
- After careful consideration, the team chooses a concept to become the benchmark, or *reference concept*, against which all other concepts are rated.
- The reference is generally either an industry standard or a straight forward concept with which the team members are very familiar

Step 2: Rate the Concepts

- A relative score of “better than” (+), “same as” (0), or “worse than” (–) is placed in each cell of the matrix to represent how each concept rates in comparison to the reference concept relative to the particular criterion.

Example:Concept Screening

	Concepts						
Selection Criteria	**A Master Cylinder**	**B Rubber Brake**	**C Ratchet**	**D (Reference) Plunge Stop**	**E Swash Ring**	**F Lever Set**	**G Dial Screw**
Ease of handling	0	0	–	0	0	–	–
Ease of use	0	–	–	0	0	+	0
Readability of settings	0	0	+	0	+	0	+
Dose metering accuracy	0	0	0	0	–	0	0
Durability	0	0	0	0	0	+	0
Ease of manufacture	+	–	–	0	0	–	0
Portability	+	+	0	0	+	0	0
Sum +'s	2	1	1	0	2	2	1
Sum 0's	5	4	3	7	4	3	5
Sum –'s	0	2	3	0	1	2	1
Net Score	2	–1	–2	0	1	0	0
Rank	1	6	7	3	2	3	3
Continue?	Yes	No	No	Combine	Yes	Combine	Revise

Step 3: Rank the Concepts

- After rating all the concepts, the team sums the number of “better than,” “same as,” and “worse than” scores and enters the sum for each category in the lower rows of the matrix.
- Net score can be calculated by subtracting the number of “worse than” ratings from the “better than” ratings
- Once the summation is completed, the team rank-orders the concepts.
- In general those concepts with more pluses and fewer minuses are ranked higher

Step 4: Combine and Improve the Concepts

- Consider if there are ways to combine and improve certain concepts. Two issues to consider are:
  - Is there a generally good concept that is degraded by one bad feature? Can a minor modification improve the overall concept and yet preserve a distinction from the other concepts?
  - Are there two concepts that can be combined to preserve the "better than" qualities while annulling the "worse than" qualities?
- Combined and improved concepts are then added to the matrix, rated by the team, and ranked along with the original concepts.
- In our example, concepts D and F could be combined to remove several of the "worse than" ratings to yield a new concept, DF, to be considered in the next round.
- Concept G was also considered for revision.

Step 5:Select One or More Concepts

- Once the team members are satisfied with their understanding of each concept and its relative quality, they decide which concepts are to be selected for further refinement and analysis.
- Based upon previous steps, the team will likely develop a clear sense of which are the most promising concepts.
- The number of concepts selected for further review will be limited by team resources (personnel, money, and time).

Step 6:Reflect on the Results and the Process

- All of the team members should be comfortable with the outcome.
- An explicit consideration of whether the results make sense to everyone reduces the likelihood of making a mistake and increases the likelihood that the entire team will be solidly committed to the subsequent development activities.

Concept Scoring

- Concept scoring is used when increased resolution will better differentiate among competing concepts.
- In this stage, the team weighs the relative importance of the selection criteria and focuses on more refined comparisons with respect to each criterion.
- The concept scores are determined by the weighted sum of the ratings

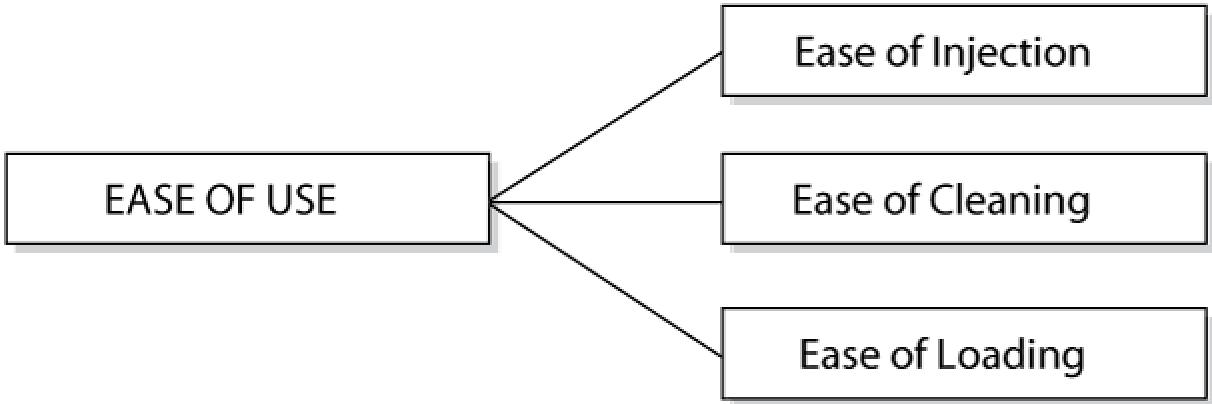
Concept scoring steps

1. Prepare a selection matrix, based on the selection criteria
2. Rate the concepts
3. Rank the concepts
4. Combine and improve concepts
5. Select one or more concepts
6. Reflect on the results and the process

Step 1: Prepare the Selection Matrix

- As in the screening stage, the team prepares a matrix and identifies a reference concept
- The concepts that have been identified for analysis are entered on the top of the matrix.
- The concepts have typically been refined to some extent since concept screening and may be expressed in more detail.
- In conjunction with more detailed concepts, the team may wish to add more detail to the selection criteria.
- The use of hierarchical relations is a useful way to illuminate the criteria.

Step 1: Prepare the Selection Matrix



From *Product Design and Development* by Karl Ulrich and Steven Eppinger (McGraw-Hill/Irwin)

Step 1: Prepare the Selection Matrix

- After the criteria are entered, the team adds importance weights to the matrix.
- Several different schemes can be used to weight the criteria, such as assigning an importance value from 1 to 5, or allocating 100 percentage points among them.

Step 1: Prepare the Selection Matrix

		Concept							
		A (Reference) Master Cylinder		DF Lever Stop		E Swash Ring		G+ Dial Screw+	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Ease of handling	5%	**3**	0.15	3	0.15	4	0.2	4	0.2
Ease of use	15%	**3**	0.45	4	0.6	4	0.6	3	0.45
Readability of settings	10%	2	0.2	**3**	0.3	5	0.5	5	0.5
Dose metering accuracy	25%	**3**	0.75	3	0.75	2	0.5	3	0.75
Durability	15%	2	0.3	5	0.75	4	0.6	**3**	0.45
Ease of manufacture	20%	**3**	0.6	3	0.6	2	0.4	2	0.4
Portability	10%	**3**	0.3	3	0.3	3	0.3	3	0.3
	Total Score	2.75		3.45		3.10		3.05	
	Rank	4		1		2		3	
	Continue?	No		Develop		No		No	

Step 2:Rate the concept

- As in the screening stage, it is generally easiest for the team to focus its discussion by rating all of the concepts with respect to one criterion at a time.
- Because of the need for additional resolution to distinguish among competing concepts, a finer scale is now used.
- Recommend a scale from 1 to 5:
- Another scale, such as 1 to 9, may certainly be used, but finer scales generally require more time and effort.
- To avoid scale compression, it is possible to use different reference points for the various selection criteria.
- Reference points may come from several of the concepts under consideration, from comparative benchmarking analysis, from the target values of the product specifications, or other means.

Step 2:Rank the concept

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

Step 3: Rank the Concepts

- Once the ratings are entered for each concept, weighted scores are calculated by multiplying the row scores by the criteria weights.
- The total score for each concept is the sum of the weighted scores:

$$S_j = \sum_{i=1}^{n} r_{ij} w_i$$

r_{ij} = raw rating of concept j for the ith criterion
w_i = weighting for ith criterion
n = number of criteria
S_j = total score for concept j

- Finally, each concept is given a rank corresponding to its total score

Step 4: Combine and Improve the Concepts

- As in the screening stage, the team looks for changes or combinations that improve concepts.
- Although the formal concept generation process is typically completed before concept selection begins, some of the most creative refinements and improvements occur during the concept selection process as the team realizes the inherent strengths and weaknesses of certain features of the product concepts.

Step 5: Select One or More Concepts

- Based on the selection matrix, the team may decide to select the top two or more concepts.
- These concepts may be further developed, prototyped, and tested to elicit customer feedback

Step 6: Reflect on the Results and the Process

- As a final step the team reflects on the selected concept(s) and on the concept selection process.
- Two questions are useful in improving the process for subsequent concept selection activities:
  - In what way (if at all) did the concept selection method facilitate team decision making?
  - How can the method be modified to improve team performance?

Concept Testing

- Further narrow the set of concepts under consideration,
  - based data gathered from potential customers in the target markets, rather than the judgments made by the development team
- Specific Objectives
  - Select one from multiple concepts,
  - Gather information on how to improve a concept, and
  - Estimate the sales potential of the product

Concept testing process

1. Define the purpose of the concept testing
2. Choose a survey population and sample size
3. Choose a survey format
4. Communicate the concept
5. Measure customer response
6. Interpret the results
7. Reflect on the results and the process

Define the purpose (step 1)

- Which of the alternative concepts should be pursued
- How can the concept be improved to better meet customer needs
- Approximately how much units are likely to be sold
- Should the development be continued

Choose a survey population and sample size (step 2)

1. The team should choose a survey population that mirrors the target market in as many ways as possible.
2. Sample size varies from a few to thousands
3. Factors affecting the sample size
   1. The stage of product development
   2. Cost to conduct survey
   3. Nature and intent of the survey
   4. Budget (amount) of the development project
   5. How possible to collect the intended information.
4. Possible to structure multiple surveys with different objectives at different stages.

Choose a survey format (step 3)

- Formats
  - Face to face interaction
  - Telephone
  - Postal mail
  - Electronic mail
  - Internet (a test site on the internet)
- Each has its pros and cons
- Each has its bias.

Communicate the concept (step 4)

- The choice of survey format is closely linked to the way in which the concept will be communicated.
- Communication means
  - Verbal description
  - Sketch
  - Photos and renderings
  - Storyboard (a series of images shown a temporal sequence of actions involving the products)
  - Video (allowing more dynamic than the story board)
  - Simulation
  - Interactive multimedia (video and simulation)
  - Physical appearance model (looks-like)
  - Working prototypes (works-like)

Communicating the Concept

- Verbal description
  - A verbal description is generally a short paragraph or a collection of bullet points summarizing the product concept.
  - This description may be read by the respondent or may be read aloud by the person administering the survey.
- ***Sketch:***
  - Sketches are usually line drawings showing the product in perspective, perhaps with annotations of key features

Communicating the Concept

- ***Photos and renderings:***
  - Photographs can be used to communicate the concept when appearance models exist for the product concept.
  - Renderings are nearly photo-realistic illustrations of the concept.
- ***Storyboard:***
  - A storyboard is a series of images that communicates a temporal sequence of actions involving the product.
- ***Video:***
  - Video images allow even more dynamism than the storyboard.
  - With video, the form of the product itself can be clearly communicated, as can the way in whichthe product is used.

Communicating the Concept

- ***Simulation:***
  - Simulation is generally implemented as software that mimics the function or interactive features of the product. Simulation would probably not be the ideal way to communicate the key features of a scooter, but in some other cases simulation can be effective.
- ***Interactive multimedia:***
  - Interactive multimedia combines the visual richness of video with the interactivity of simulation. Using multimedia, you can display video and still images of the product.
- ***Physical appearance models:***
  - Physical appearance models, also known a "looks-like" models, vividly display the form and appearance of a product. They are often made of wood or polymer foams and are painted to look like real products.

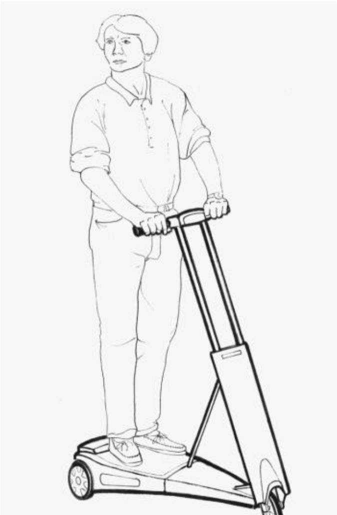
Communicate the concept (step 4)

	Telephone	Electronic Mail	Postal Mail	Internet	Face-to-Face
Verbal description	•	•	•	•	•
Sketch		•	•	•	•
Photo or rendering		•	•	•	•
Storyboard		•	•	•	•
Video				•	•
Simulation				•	•
Interactive multimedia				•	•
Physical appearance model					•
Working prototype					•

Communicating the Concept

- ***Working prototypes:***
- When available, working prototypes, or works-like models, can be useful in concept testing.
- However, the use of working prototypes is also risky.
- The primary risk is that the respondents will equate the prototype with the finished product.
- In some cases, prototypes perform better than the ultimate product

Communicating the Concept



Sketch

Rendering

Story Board

3D Model

Measure customer response (step 5)

- Measurement
  - Mere their preferences among alternative concepts
  - Understand why and how they respond to the product concepts
  - Attempt to measure purchase intent (the likelihood of buying)
  - But avoid aggressively promoting the product concepts
- Definitely would buy.
- Probably would buy.
- Might or might not buy.
- Probably would not buy.
- Definitely would not buy.

Interpret the results (Step 6)

- Q = N x A x P
  - Where P = Cd x Fd + Cp x Fp
    - Q = the quantity of the expected sales
    - N = the number of potential customers expected to buy
    - A = the fraction of these potential customers aware of the product and the product is available
    - P = the probability that the product is purchased if the customer is aware of it and it is available.
    - Fd = the the fraction of survey respondents indicating that they would definitely purchase
    - *F*p= is the fraction of survey respondents indicating that they would *probably purchase*
    - Cd(Calibration constants) = the percentage that those in Fd will actually buy (.1-.5)
    - Cp = the percentage that those in Fp will actually buy (0-.25)
- Be aware that sales also depends on
  - Words of mouth
  - Fidelity of the concept description
  - Pricing
  - Level of promotion

Step 7:Reflect on the results and the process

- The primary benefit of the concept test is in getting feedback from real potential customers.
- The team benefits from thinking about the impact of the three key variables in the forecasting model: (1) the overall size of the market, (2) the availability and awareness of the product, and (3) the fraction of customers who are likely to purchase.

Definition
– Product Architecture

- A product can be thought of in both functional and physical terms.
- The functional elements of a product are the individual operations and transformations that contribute to the overall performance of the product.
- Eg:For a printer, some of the functional elements are “store paper” and “communicate with host computer.
- The *physical elements* of a product are the parts, components, and subassemblies that ultimately implement the product’s functions.

Definition
– Product Architecture

- The physical elements of a product are typically organized into several major physical building blocks, which we call chunks.
- Each chunk is then made up of a collection of components that implement the functions of the product.
- The architecture of a product is the scheme by which the functional elements of the product are arranged into physical chunks and by which the chunks interact.

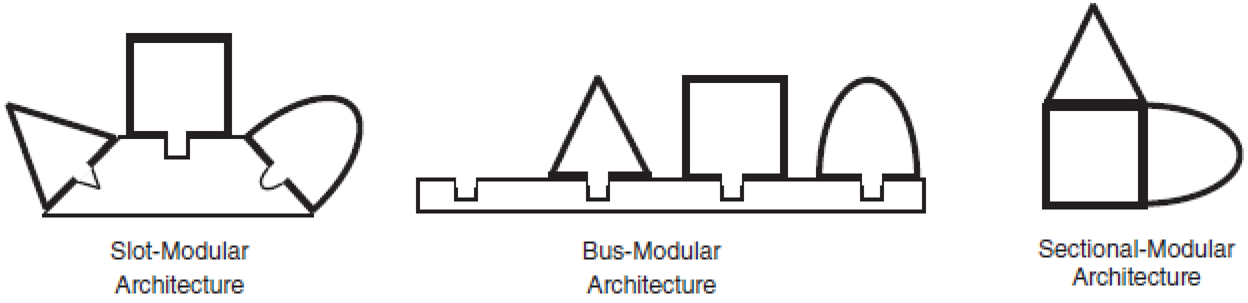
Modular vs. integrated architecture

- Modular
  - Chunks implement one or a few functional elements in their entirety (each functional element is implemented by exactly one physical chunks)
  - The interactions between chunks are well defined and are generally fundamental to the primary functions of the products.
- Integrated
  - Functional elements of the product are implemented using more than one chunk
  - A single chunk implements many functions.
  - The interaction between chunks are ill defined and may be incidental to the primary functions of the products.

Types of Modularity

- Modular architectures comprise three types: slot, bus, and sectional
- Each type embodies a one-to-one mapping from functional elements to chunks and well defined interfaces.
- The differences between these types lie in the way the interactions between chunks are organized

Types of Modularity



Types of Modularity

- Slot-modular architecture:
  - Each of the interfaces between chunks in a slot-modular architecture is of a different type from the others, so that the various chunks in the product cannot be interchanged.
- ***Bus-modular architecture:***
  - In a bus-modular architecture, there is a common *bus* to which the other chunks connect via the same type of interface.
- ***Sectional-modular architecture:***
  - In a sectional-modular architecture, all interfaces are of the same type, but there is no single element to which all the other chunks attach.

Factors affecting architecture modularity

- Product changes
- Product variety
- Component standardization
- Product performance
- Manufacturability
- Product development management

Factors affecting architecture modularity (product changes)

For modular architecture

- Allows to minimize the physical changes required to achieve a functional change

Reasons for product changes

- Upgrades(technological changes)
- add-ons(add components to basic unit)
- adaptation (adapt to different operation environments(220v and 110v power))
- wear (e.g., razors, tires, bearings)
- consumption (for example, toner cartridges, battery in cameras)
- flexibility in use (for users to reconfigure to exhibit different capabilities (many cameras can be used with different lens and flash options))
- re-use in creating subsequent products

Factors affecting architecture modularity (product variety)

- The range of products (models) concurrently available in the market
- Modular can vary without adding tremendous complexity to the manufacturing system.
- Eg:Watches

Factors affecting architecture modularity

- Component standardization
  - Use the same components in multiple products
  - Increase production volumes

Factors affecting architecture modularity

- Product performance (for integrated design)
  - Allow optimizing the performance for an individual integrated architecture.
  - Allow function sharing
    - Implementing multiple functions using a single physical element.
  - Allow for redundancy to be eliminated through function sharing and geometric nesting
    - Thus could lower the manufacturing cost

Factors affecting architecture modularity

- Manufacturability
  - DFM can be performed on the chunk-level but not across several chunks.
    - For example, minimize the total number of part counters.
  - Thus, it is more applicable to an integrated design.
- One important design-for-manufacturing (DFM) strategy involves the minimization of the number of parts in a product through *component integration*.

Factors affecting architecture modularity

- Product development management
  - Better for modular architecture
    - Each modular chunk is assigned to an individual or a small group
    - Known and relatively limited functional interactions with other chunks.
  - Not as easy for integrated architecture
    - Detailed designs will require close coordination among different groups.

Architecture Design Process

- Create a schematic of the product
- Cluster the elements of the schematic
- Create a rough geometric layout
- Identify the fundamental and incidental interactions.

Step 1:Creating a product schematic

- A *schematic* is a diagram representing the team's understanding of the constituent elements of the product.
- Create a schematic diagram representing the (physical or functional) elements of the product, using blocks, arrows, and other notations.
  - Flow of forces or energy
  - Flow of material
  - Flow of signal or data
- A good rule of thumb is to aim for fewer than 30 elements in the schematic, for the purpose of establishing the product architecture.
- If the product is a complex system, involving hundreds of functional elements, then it is useful to omit some of the minor ones and to group some others into higher-level functions to be decomposed later

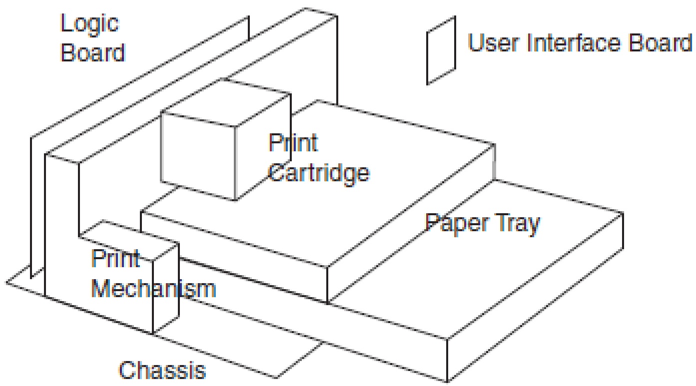
Step 2:Cluster the elements of the schematic

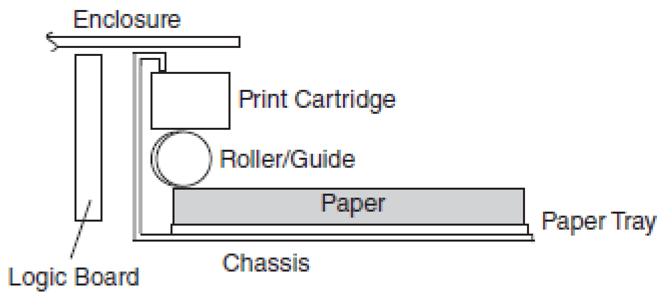
- The challenge of step 2 is to assign each of the elements of the schematic to a chunk
- At one extreme, each element could be assigned to its own chunk, yielding 15 chunks.
- At the other extreme, the team could decide that the product would have only one major chunk and then attempt to physically integrate all of the elements of the product
- Factors for considering clustering
  - Geometric integration and precision
  - Function sharing
  - Capability of vendors
  - Similarity of design or production technology
  - Localization of design (or part) change
  - Accommodating variety
  - Enabling standardization
  - Portability of the interfaces

Step 3:Creating a rough geometric layout

- A geometric system layout in
  - 2D or 3D drawings,
  - 2D or 3D graphics, or
  - Physical models.
- Creating a geometric layout forces the team to consider whether the geometric interfaces among the chunks are feasible and to work out the basic dimensional relationships among the chunks

Step 3:Creating a rough geometric layout

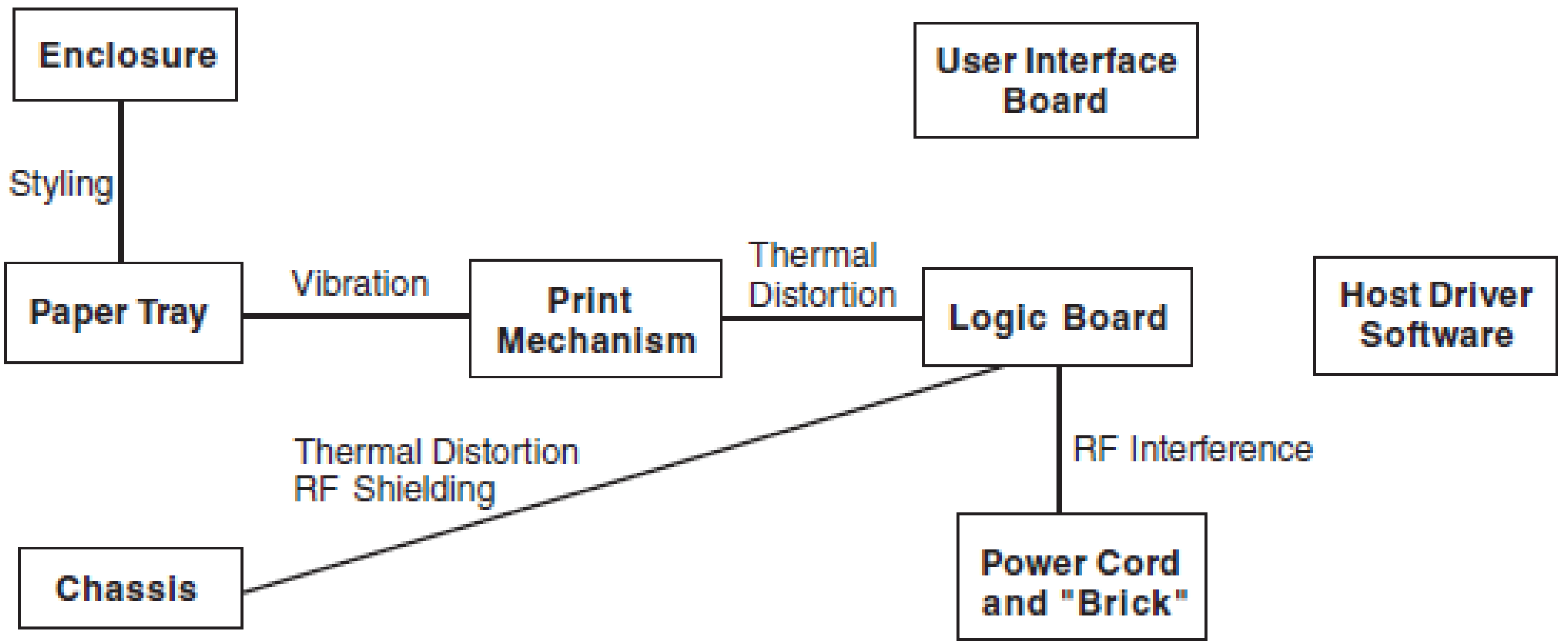




Step 4:Identify the fundamental and incidental interactions

- Fundamental interactions
  - Those which connect the building blocks, such as energy flows, material flows, and data flows.
  - First, *fundamental interactions* are those corresponding to the lines on the schematic that connect the chunks to one another.
  - For example, a sheet of paper flows from the paper tray to the print mechanism.
- Incidental interactions
  - Those that arise because of geometric arrangements of the building blocks, such as thermal expansion or heat dissipation.
  - For example, vibrations induced by the actuators in the paper tray could interfere with the precise location of the print cartridge in the x-axis.

Step 4:Identify the fundamental and incidental interactions



Industrial Design

- The Industrial Designers Society of America (IDSA) defines industrial design as “the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer.

Need of ID

- Dreyfuss (1967) lists five critical goals that industrial designers can help a team to achieve when developing new products:
  - ***Utility:*** The product's human interfaces should be safe, easy to use, and intuitive.
  - ***Appearance:*** Form, line, proportion, and color are used to integrate the product into a pleasing whole.
  - ***Ease of maintenance:***
  - ***Low costs:***.
  - ***Communication***

Need of ID

- The range of expenditures on ID is tremendous
- A convenient means for assessing the importance of ID to a particular product is to characterize importance along two dimensions: ergonomics and aesthetics.
  - (Note that we use the term *ergonomics* to encompass all aspects of a product that relate to its human interfaces)

Need of ID : Ergonomics Need

- **How important is ease of use?**
  - Ease of use may be extremely important both for frequently used products, such as an office photocopier, and for infrequently used products, such as a fire extinguisher.
  - Ease of use is more challenging if the product has multiple features and/or modes of operation that may confuse or frustrate the user.
- **How important is ease of maintenance?**
  - If the product needs to be serviced or repaired frequently, then ease of maintenance is crucial.
  - For example, a user should be able to clear a paper jam in a printer or photocopier easily.
- **How many user interactions are required for the product's functions?**
  - In general, the more interactions users have with the product, the more the product will depend on ID.

Need of ID:Ergonomics Need

- ***How novel are the user interaction needs?***

  A user interface requiring incremental improvements to an existing design will be relatively straightforward to design, such as the buttons on a new desktop computer mouse.

- ***What are the safety issues?***

  All products have safety considerations. For some products, these can present significant challenges to the design team.

  For example, the safety concerns in the design of a child's toy are much more prominent than those for a new computer mouse.

Need of ID: Aesthetics Need

- ***Is visual product differentiation required?***
  - Products with stable markets and technology are highly dependent upon ID to create aesthetic appeal and, hence, visual differentiation.
  - In contrast, a product such as a computer’s internal disk drive, which is differentiated by its technological performance, is less dependent on ID.
- ***How important are pride of ownership, image, and fashion?***
  - A customer’s perception of a product is in part based upon its aesthetic appeal.
  - An attractive product may be associated with high fashion and image and will likely create a strong sense of pride among its owners.
  - When such characteristics are important, ID will play a critical role in determining the product’s ultimate success.
- ***Will an aesthetic product motivate the team?***
  - A product that is aesthetically appealing can generate a sense of team pride among the design and manufacturing staff.

Industrial Design Process

- Investigation of customer needs.
- Conceptualization.
- Preliminary refinement.
- Further refinement and final concept selection.
- Control drawings or models.
- Coordination with engineering, manufacturing, and external vendors

Investigation of customer needs.

- The product development team begins by documenting customer needs
- Because industrial designers are skilled at recognizing issues involving user interactions, ID involvement is crucial in the needs process.
- While involvement of marketing, engineering, and ID certainly leads to a common, comprehensive understanding of customer needs for the whole team, it particularly allows the industrial designer to gain an intimate understanding of the interactions between the user and the product.

Conceptualization.

- Once the customer needs and constraints are understood, the industrial designers help the team conceptualize the product.
- During the concept generation stage engineers naturally focus their attention upon finding solutions to the technical sub functions of the product.
- At this time, the industrial designers concentrate upon creating the product’s form and user interfaces.
- Industrial designers make simple sketches, known as thumbnail sketches, of each concept.
- These sketches are a fast and inexpensive medium for expressing ideas and evaluating possibilities.

Preliminary refinement.

- In the preliminary refinement phase, industrial designers build models of the most promising concepts.
- Soft models are typically made in full scale using foam or foam-core board.
- They are the second-fastest method—only slightly slower than sketches—used to evaluate concepts.

Further refinement and final concept selection.

- At this stage, industrial designers often switch from soft models and sketches to hard models and information-intensive drawings known as *renderings*.
- Renderings show the details of the design and often depict the product in use.
- Drawn in two or three dimensions, they convey a great deal of information about the product.
- Renderings are often used for color studies and for testing customers’ reception to the proposed product’s features and functionality.

Control Drawings or Models

- Industrial designers complete their development process by making *control drawings* or *control models* of the final concept.
- Control drawings or models document functionality, features, sizes, colors, surface finishes, and key dimensions.
- Although they are not detailed part drawings (known as engineering drawings), they can be used to fabricate final design models and other prototypes.
- Typically, these drawings or models are given to the engineering team for detailed design of the parts. and assembly services.

Coordination with Engineering, Manufacturing, and External Vendors

- The industrial designers must continue to work closely with engineering and manufacturing personnel throughout the subsequent product development process.
- Some industrial design consulting firms offer quite comprehensive product development services, including detailed engineering design and the selection and management of outside vendors of materials, tooling, components and assembly services.