ENGR 110 / 112 – Design I

Design Process

Functional Analysis

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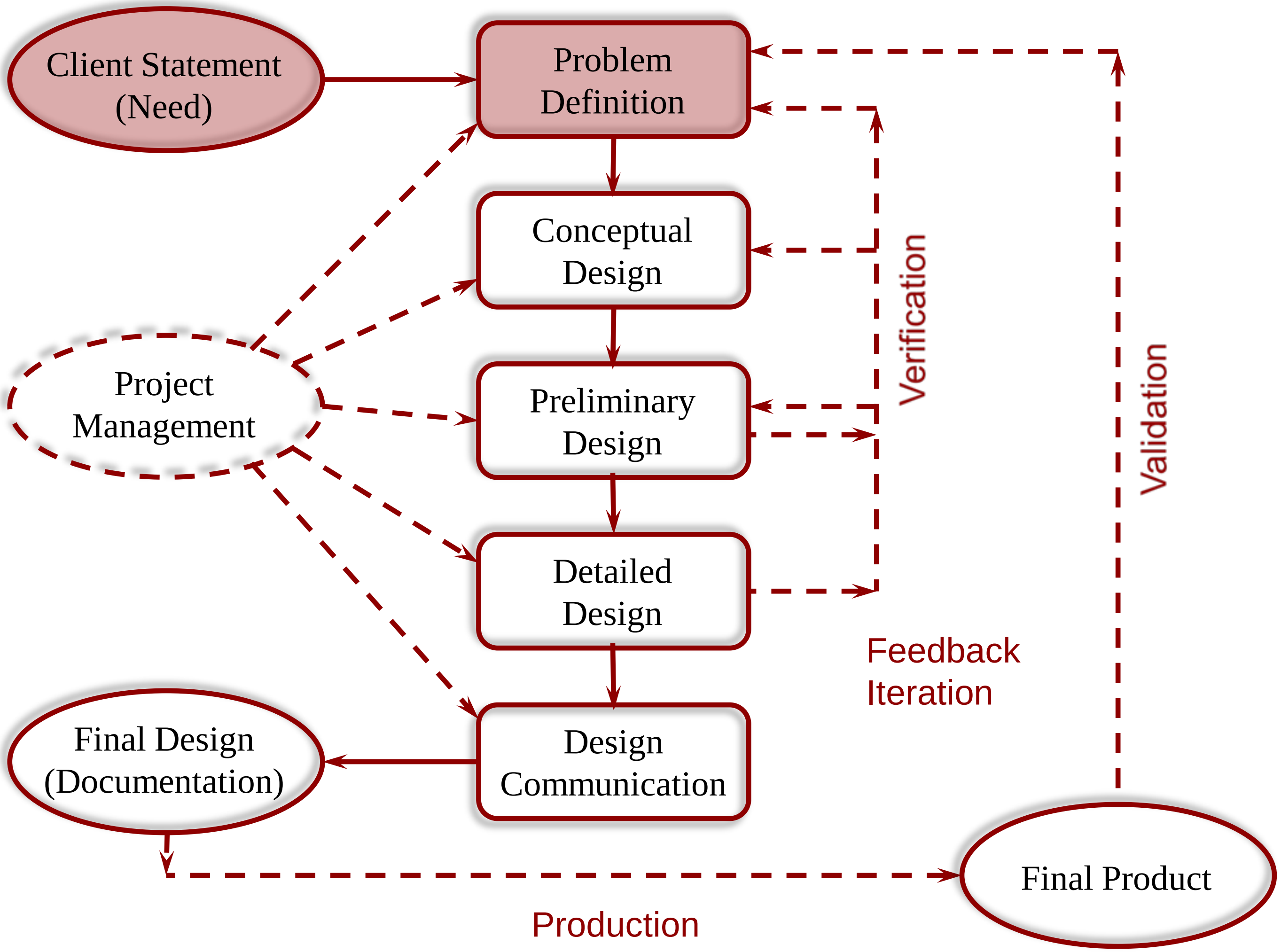
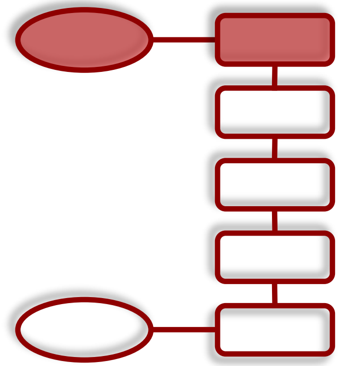
Engineering Design Process

The first stage of any design project is Problem Definition



Problem Definition Summary



The problem is defined by understanding the client’s need. This involves gathering information needed to develop a clear statement of what the client wants.

Input: *Client Statement*

Tasks: *i) Clarify design objectives*

ii) Establish metrics for those objectives (criteria)

iii) Identify constraints

iv) Revise client’s problem statement

Outputs: *Revised problem statement*

List of final objectives (criteria)

List of final constraints

Weighted Criteria Tree

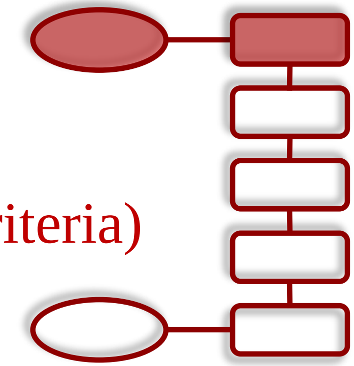
Example

Assume you are married with three children, and you have the *need* to buy a new vehicle.

Based on your requirements, you identify a number of *desired attributes*

- You want space for your family and perhaps a few more seats, for friends of your children, parents, in-laws, etc.
- You want a car that is fuel efficient
- You want to use it for camping, off-road trips, etc.
- You want a vehicle that has resale value
- You want a vehicle that is comfortable, reliable, safe, spacious, and aesthetically appealing
- You are planning to keep the car for about 15 years
- You have a budget of $40K
- You want a car that is easy to maintain

Example



The next step is to identify Constraints and Objectives (Criteria)

- You want space for your family and a few more seats, for friends of your children, in-laws, etc.
- You want a car that is fuel efficient
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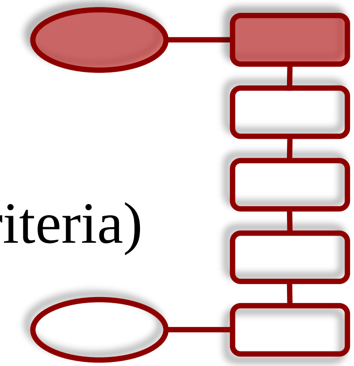
Example



The next step is to identify Constraints and Objectives (Criteria)

Constraints:

Passenger needs:	Must have a third row
Expected usage:	Must be AWD (all-wheel drive)
Budget	Must be less than $40K

Objectives:

Reliable	Easy to Drive	Safe
Fuel-Efficient	High Comfort	Features
Easy to Maintain	Resale Value	Large Cargo
Spacious	Aesthetically Appealing	Good Torque
Low cost of Parts	Good Horsepower	Fast

Example

Structure Objectives and Create Criteria Tree

- New Vehicle
  - Comfort
  - Cargo Space
  - Cost
    - Purchase Value
    - Resale Value
  - Safety
  - Vehicle Performance
    - Reliable
    - Engine Performance
    - Fuel Economy
  - Service Cost

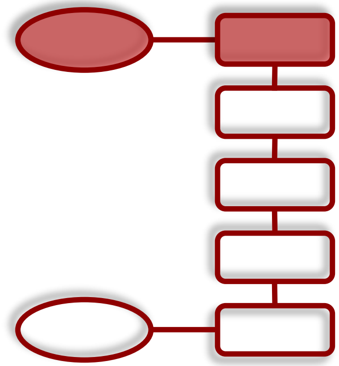
Consider seating comfort, room, leg, maneuverability, audio features

If possible, combine criteria. Eliminate criteria that might not be so important; for example, here aesthetics was eliminated.

Horsepower, Torque, Speed, etc.

Maintenance, cost of parts, etc.

Example



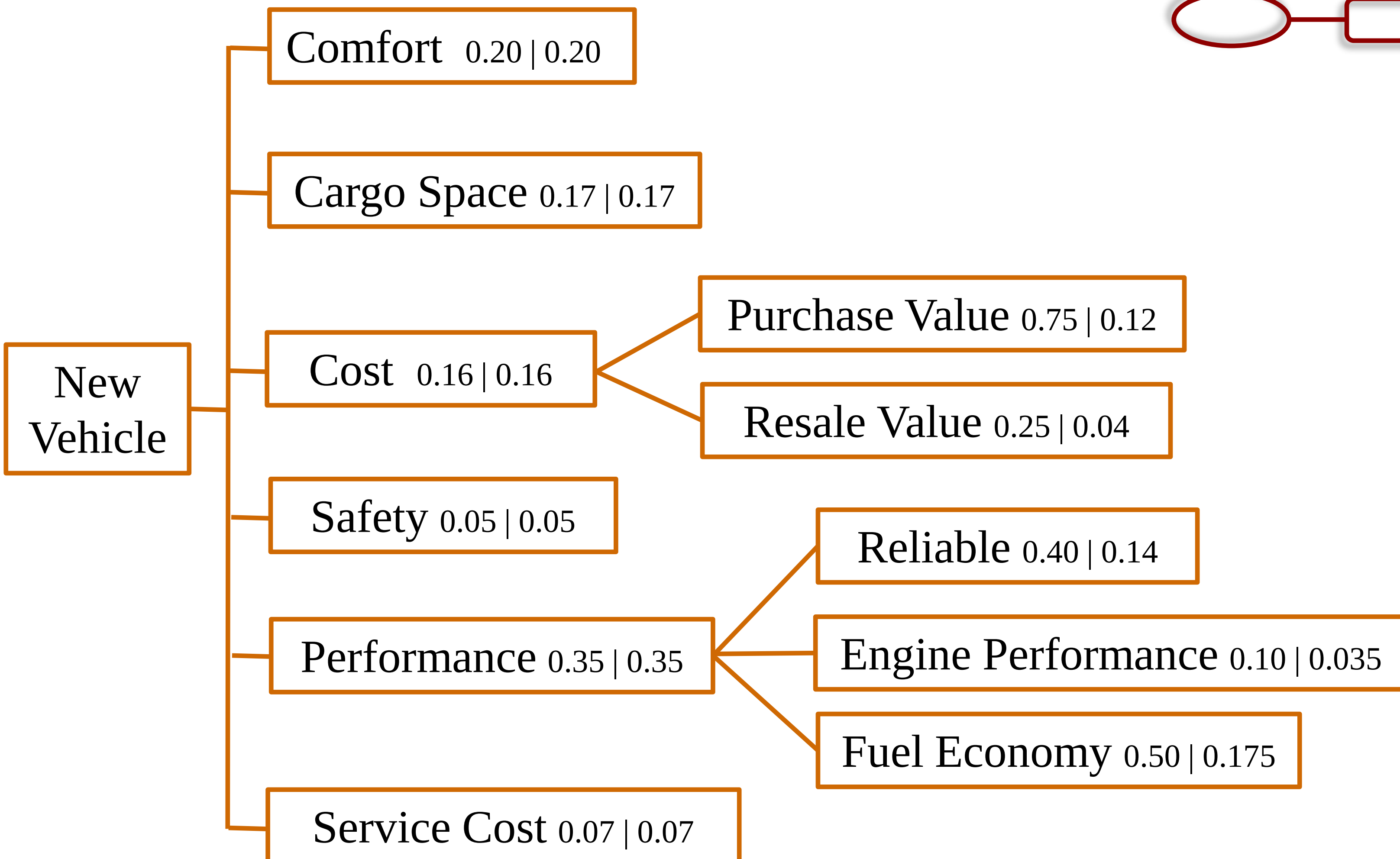
Rank objectives (Pair-wise Comparison)

Assign a 1 if the row criteria is more important than the column criteria

	Comfort	Cargo	Cost	Safety	Performance	Service	Total
Comfort	-	1	1	1	0	1	4
Cargo	0	-	1	1	0	1	3
Cost	0	0	-	1	0	1	2
Safety	0	0	0	-	0	0	0
Performance	1	1	1	1	-	1	5
Service	0	0	0	1	0	-	1

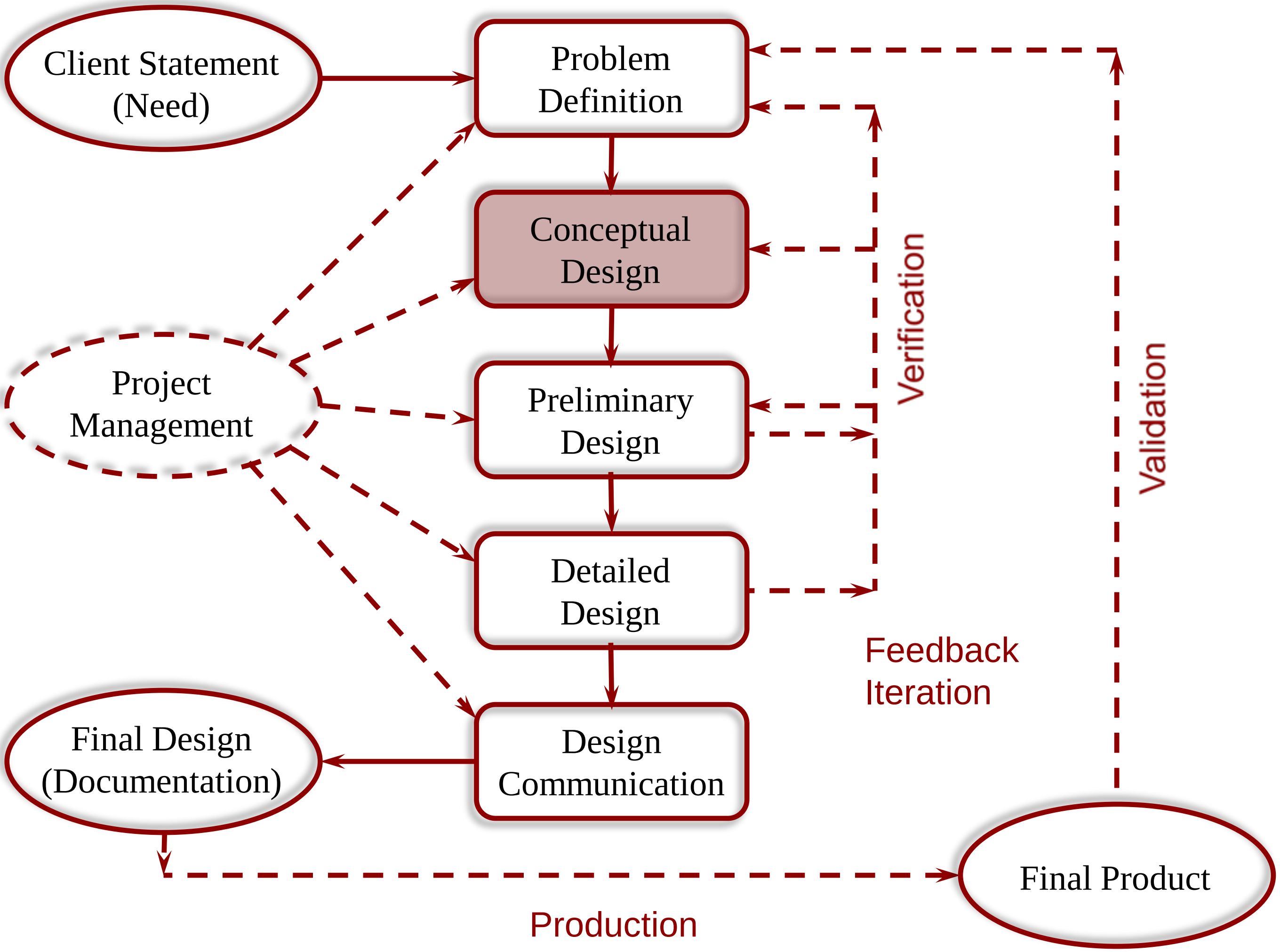
Example

Weighted Criteria Tree

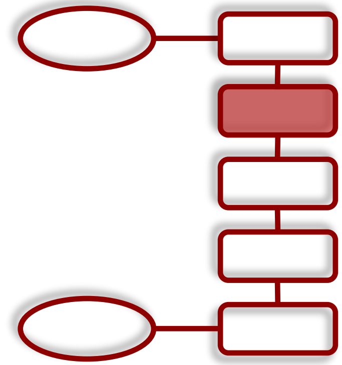


Engineering Design Process

The design process can be modeled in five main stages.



Conceptual Design



Here we generate concepts of alternative designs.

Input: *Revised problem statement*

List of final objectives (criteria)

List of final constraints

Tasks: *v) Establish functions*

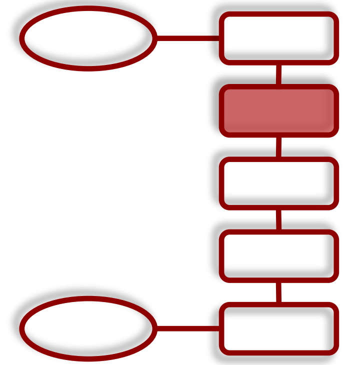
vi) Establish requirements or specifications

vii) Generate alternative designs

Outputs: *Design and Functional Specifications*

Alternative conceptual designs

Conceptual Design



Functional Analysis (identification of functions)

- Enumeration
- Black Boxes and Transparent Boxes
- Dissection and Reverse Engineering
- Function-Means Tree

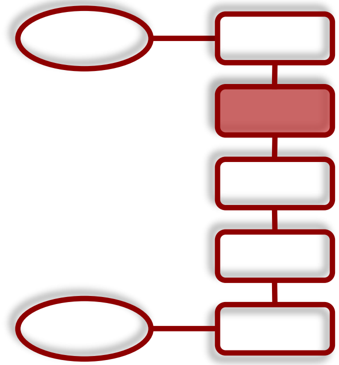
Generating Design Ideas

- Morphological Charts

Specifications

- Functional
- Design
- Performance

Functional Analysis



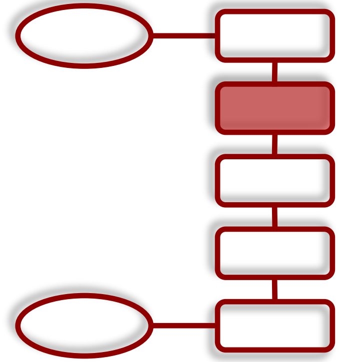
Function Enumeration

Create a list of all the functions that the product does. A method to generate this list is to imagine what would happen if it did not exist.

Recalling the beverage container, it must do the following:

- *Contain liquid*
- *Have an easy access to the liquid*
- *Close container after opening*
- *Resist forces due to extreme temperature*
- *Resist forces induced by handling / stacking*
- *Identify the product*

Functional Analysis



Black Boxes and Transparent Boxes

A black box is simply a graphic representation of the system or product being designed, with inputs shown on the left entering the box and outputs shown on the right leaving the box.

Questions might arise from this representation: What happens to the input? Where does this output come from?

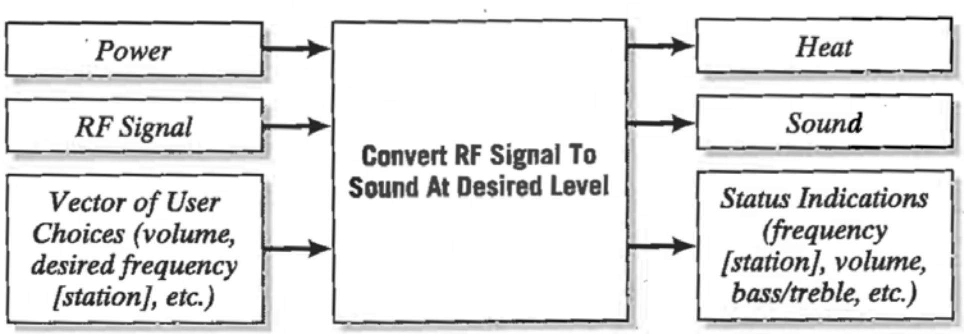


FIGURE 4.1 (a) This is a black box for the radio. Notice that all the inputs and outputs are somehow related in the single, top-level function. We call this top-level function a *basic function*. If we want to know how the inputs are actually transformed into the outputs, we need to remove the cover on the black box.

Functional Analysis

Black Boxes and Transparent Boxes

A transparent box unveils a number of other functions that are interacting within the system. This method allows us to identify functions that could be attained with different *means*.

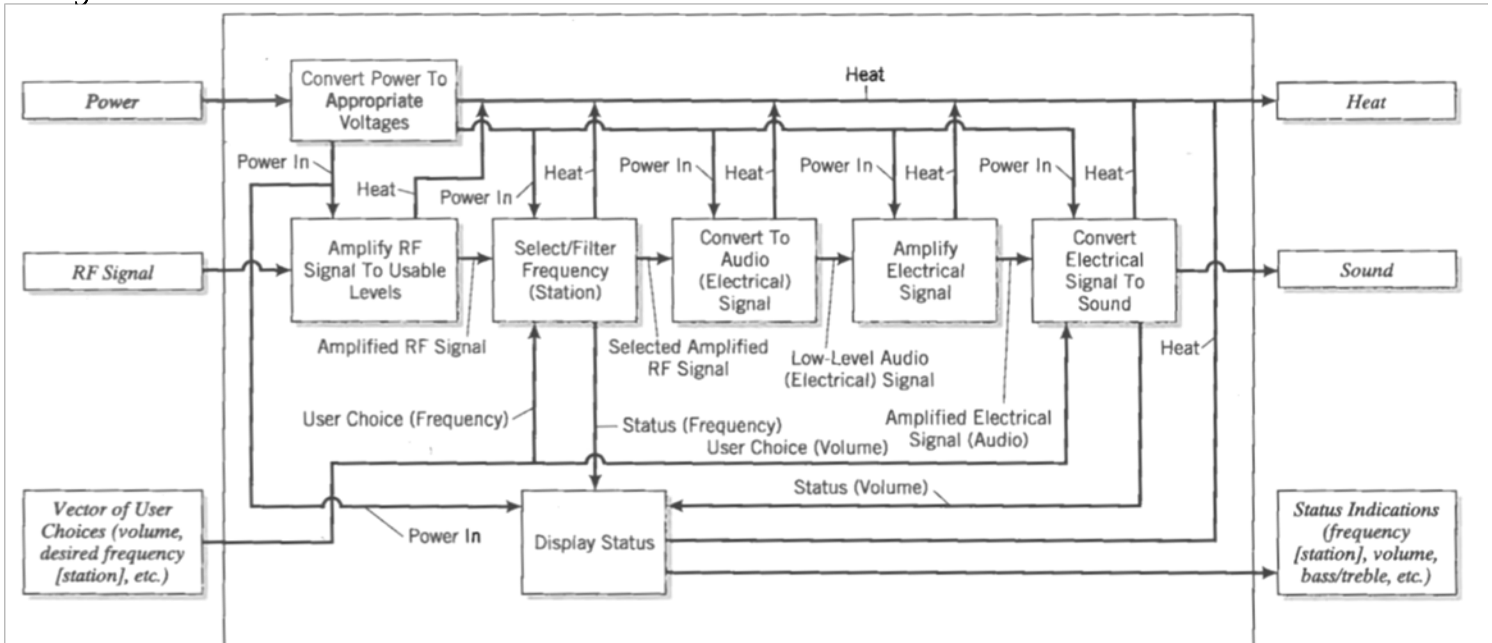
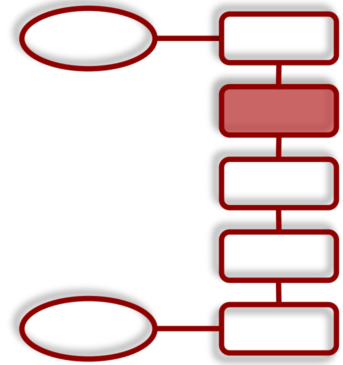


FIGURE 4.1 (b) The cover on the black box has been removed, or made transparent. Notice that in order to transform the inputs into outputs, a large number of secondary functions are required. If our design responsibilities (or our curiosity) demanded it, we could also remove the covers on some or all of these functions. Notice also that this design calls for the heat to be allowed out of the box on its own. In many designs, we would add a specific function, "dissipate heat," and then decide on a strategy for doing so.

Functional Analysis



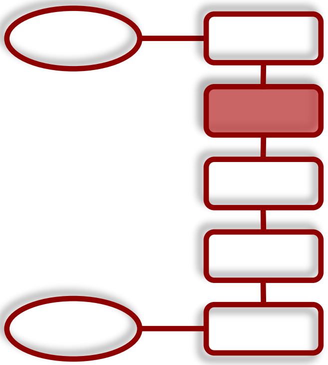
Reverse Engineering

Reverse engineering is the process of gaining knowledge or design information from a product and using this information to reproduce the product or anything related to the extracted information.

The process involves disassembling a product or a system (mechanical device, electronic component, computer program, etc.) and analyzing its components and find out how it functions. Keep in mind that

- The reversed engineered product might have had other objectives or goals
- Do not limit your design to the functions and means that were found on the product being reverse engineered

Functional Analysis



Functions-Means Tree

Consider the “functions” as ***what you must do***.

Consider the “means” as ***how you might do it***.

The Function-Means Tree allows you to dissect the problem into multiple levels of functions (primary, secondary, etc.)

> *Breaking down the problem into smaller problems is critical to understand better the problem and to generate different concepts. Divide and conquer!*

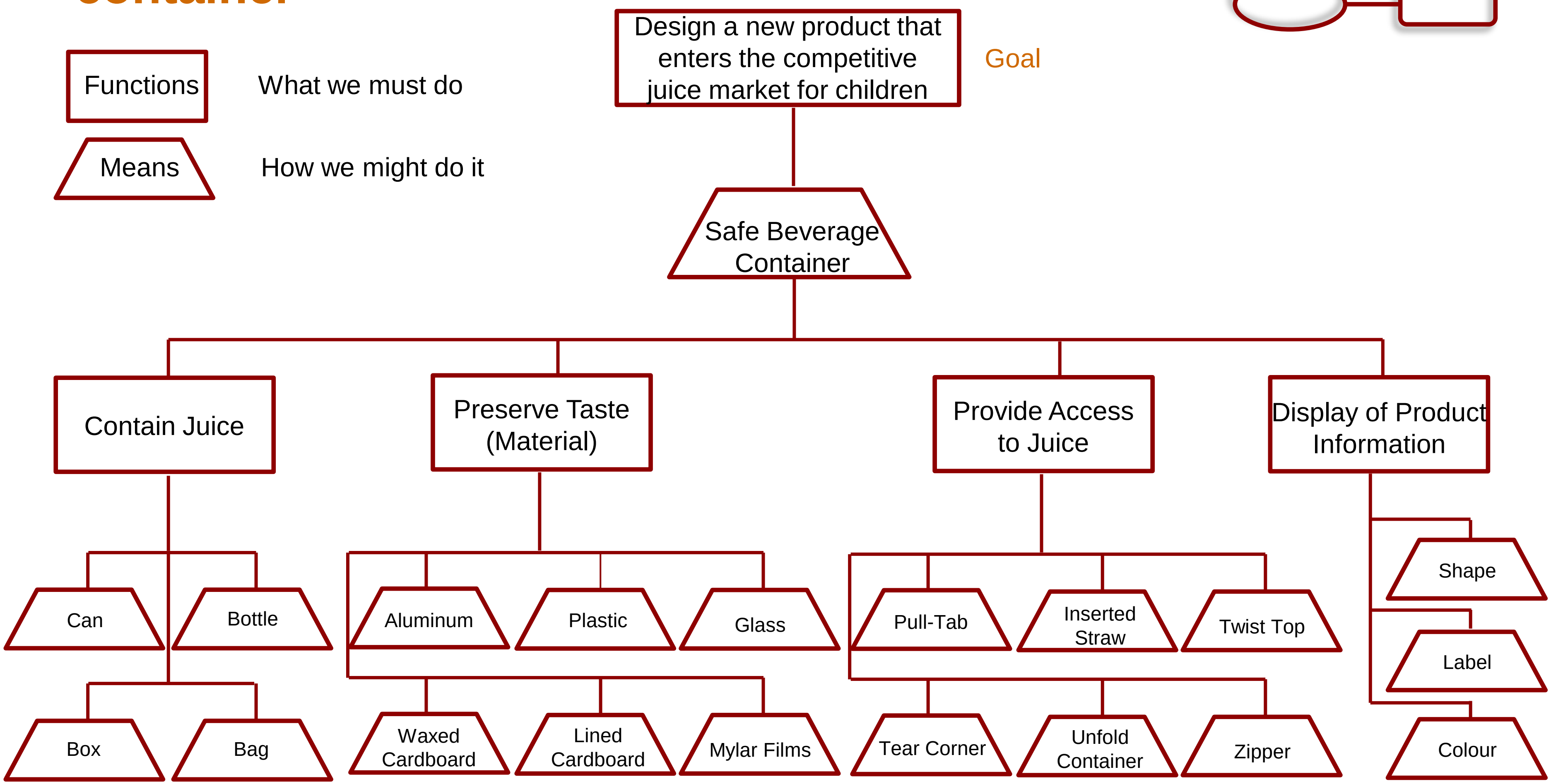
Each function will be isolated and a number of means to achieve it will be proposed.

Example

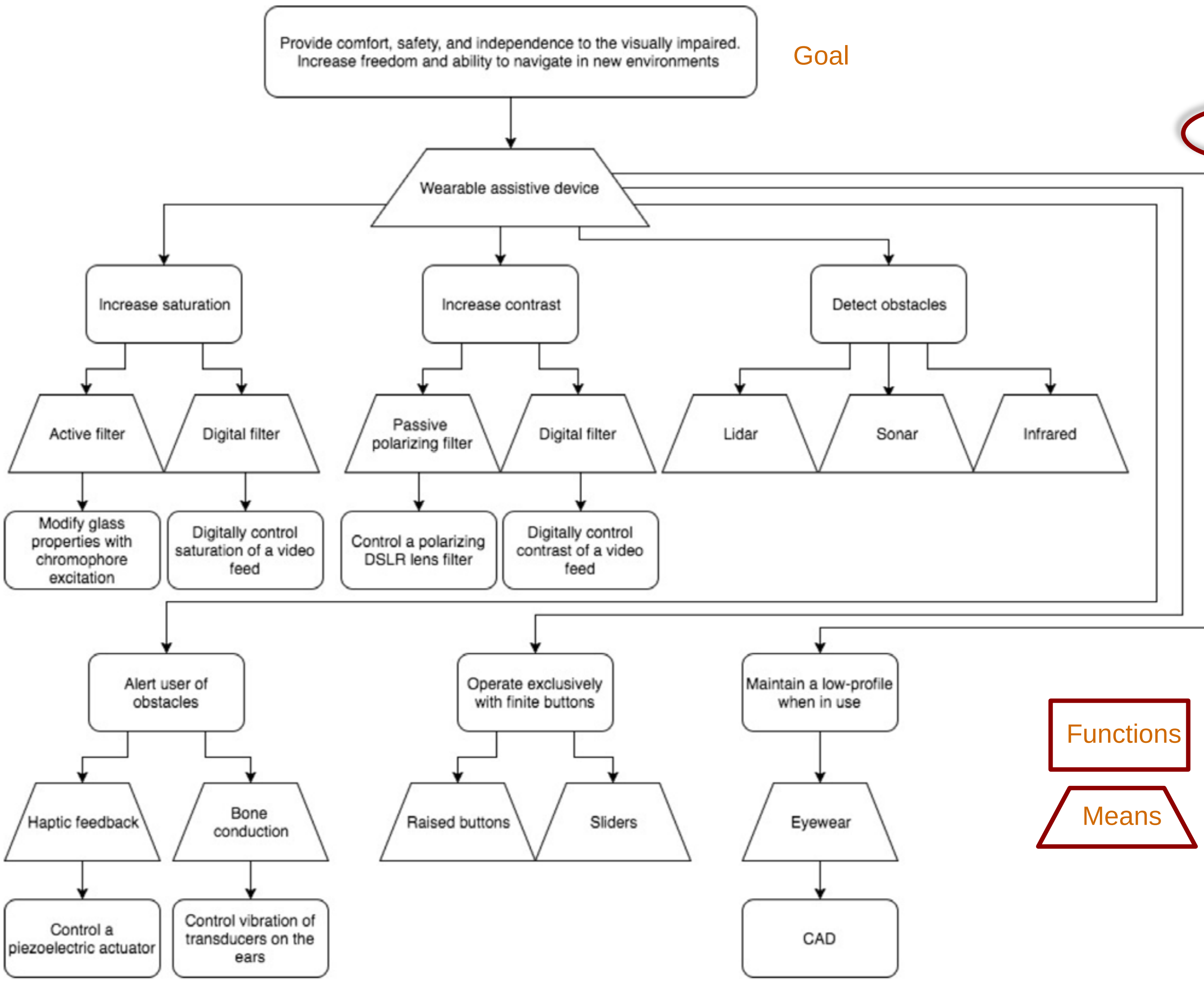
Micropropagation of Blueberry Plants

Functional Analysis

Example of a function-means tree for the juice container



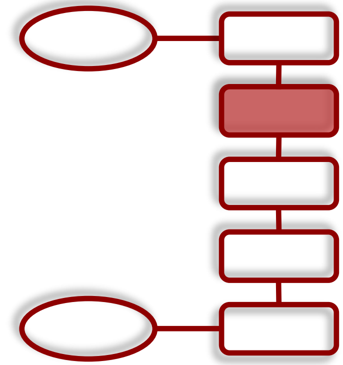
Example



Functions — What we must do

Means — How we might do it

Specifications



There are three types of requirements or specifications: Functional Specifications, Design Specifications and Procedural Specifications:

Functional Specifications: It characterizes the desired behavior or performance of the designed product or system.

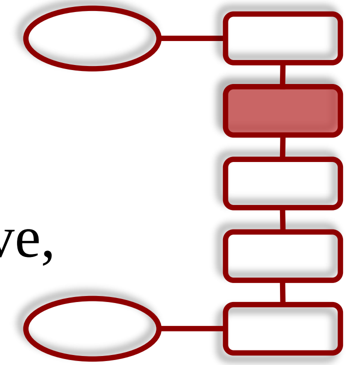
Functions describe what the product ***must do*** in order to realize the stated objectives.

"A step on a ladder is safe if it will support 300 lbs."

LOAD CAPACITY*	DESCRIPTION	CSA CODE	ANSI CODE
200 lbs./91 kg	Household - Light Duty	Grade 3	Type III
225 lbs./102 kg	Tradesman and Farm - Medium Duty	Grade 2	Type II
250 lbs./113 kg	Construction and Industrial - Heavy Duty	Grade 1	Type I
300 lbs./136 kg	Construction and Industrial - Heavy Duty	Grade 1A	Type IA
375 lbs./170 kg	Construction and Industrial - Heavy Duty	Grade 1AA	Type IAA

*Includes user and materials

Specifications



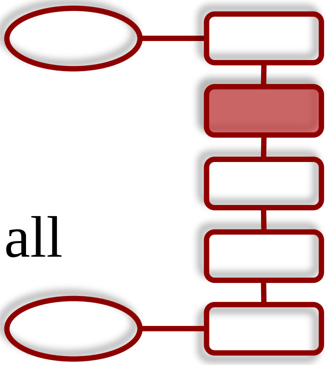
Design Specifications: These specifications are prescriptive, as they specify values of attributes that the designed product must meet to be successful. Design Specifications are associated with the verb ***to be***.

"A step on a ladder is safe if it must be made from Grade A fir, the spacing between steps shall not be less than 8in nor more than 18in, and each step must be attached to the frame in a full-width groove slot at each end"

Procedural Specifications: These specifications identify specific procedures or methods to be used in calculating the attributes or behaviors.

"A step on the ladder is safe if its maximum bending stress is computed from $\sigma_{max} = {}^{Mc}/_{I}$ and is such that σ_{max} does not exceed σ_{allow}".

Specifications

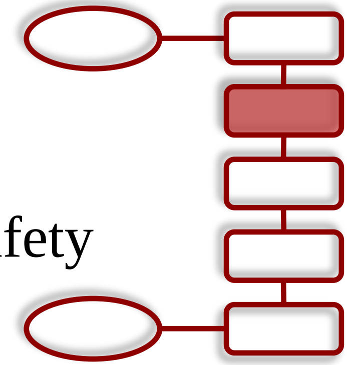


In general, specifications are very large documents that list all the requirements for each category (General, Mechanical, Electrical, Safety, etc.)

The document should be structured in a way that is easy to be accessed. It is recommended to have the following structure:

- **Scope**: What is this document for?
- **Intended Audience**: Team, Supervisors, Client
- **Classification Scheme**: Classify specifications with tags. Each company uses their own notation for the tags.

Example



Following the example of the ladders, the Occupational Safety and Health Administration of the US, uses the following standards to define the specifications of commercial ladders.

Link

Part 1926 – Safety and Health Regulations for Construction

Subpart 1053 – Ladders

Tag: 1926.1053(a)(1)(i)

a – Defines whether general (a) or use (b)

1 – Lists the categories of the specifications, 1, 2, 3, etc.

i - Lists the specifications for that particular category.

Example

1926.1053(a)*General*. The following requirements apply to all ladders as indicated, including job-made ladders.

1926.1053(a)(1)Ladders shall be capable of supporting the following loads without failure:

1926.1053(a)(1)(i)Each self-supporting portable ladder: At least four times the maximum intended load, except that each extra-heavy-duty type 1A metal or plastic ladder shall sustain at least 3.3 times the maximum intended load. The ability of a ladder to sustain the loads indicated in this paragraph shall be determined by applying or transmitting the requisite load to the ladder in a downward vertical direction. Ladders built and tested in conformance with the applicable provisions of appendix A of this subpart will be deemed to meet this requirement.

1926.1053(a)(1)(ii)Each portable ladder that is not self-supporting: At least four times the maximum intended load, except that each extra-heavy-duty type 1A metal or plastic ladders shall sustain at least 3.3 times the maximum intended load. The ability of a ladder to sustain the loads indicated in this paragraph shall be determined by applying or transmitting the requisite load to the ladder in a downward vertical direction when the ladder is placed at an angle of 75 1/2 degrees from the horizontal. Ladders built and tested in conformance with the applicable provisions of appendix A will be deemed to meet this requirement.

1926.1053(a)(1)(iii)Each fixed ladder: At least two loads of 250 pounds (114 kg) each, concentrated between any two consecutive attachments (the number and position of additional concentrated loads of 250 pounds (114 kg) each, determined from anticipated usage of the ladder, shall also be included), plus anticipated loads caused by ice buildup, winds, rigging, and impact loads resulting from the use of ladder safety devices. Each step or rung shall be capable of supporting a single concentrated load of at least 250 pounds (114 kg) applied in the middle of the step or rung. Ladders built in conformance with the applicable provisions of appendix A will be deemed to meet this requirement.

1926.1053(a)(2)Ladder rungs, cleats, and steps shall be parallel, level, and uniformly spaced when the ladder is in position for use.

….

1926.1053(b)*Use*. The following requirements apply to the use of all ladders, including job-made ladders, except as otherwise indicated:

1926.1053(b)(1)When portable ladders are used for access to an upper landing surface, the ladder side rails shall extend at least 3 feet (.9 m) above the upper landing surface to which the ladder is used to gain access; or, when such an extension is not possible because of the ladder's length, then the ladder shall be secured at its top to a rigid support that will not deflect, and a grasping device, such as a grabrail, shall be provided to assist employees in mounting and dismounting the ladder. In no case shall the extension be such that ladder deflection under a load would, by itself, cause the ladder to slip off its support.

1926.1053(b)(2)Ladders shall be maintained free of oil, grease, and other slipping hazards.

… (continues)