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ENGR 110 / 112 – Design I

Design Process

Problem Definition

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What is Design in Engineering?

NSERC Definition of Design Engineering

Design engineering integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific *needs*. It is a *creative*, *iterative* and often *open-ended* process subject to *constraints* which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social or other pertinent factors.

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Engineering Design Terminology

Need – Description of an unsatisfactory situation.

Goal – It is a brief, general, and ideal response to the need. *How are we going to address this need?*

Objectives – Expressions of desired attributes and behavior that are quantifiable expectations of performance. They are usually expressed as *being* terms, *e.g., must be light, be safe, be recyclable, be inexpensive, be appealing, etc.*

Criteria – Attributes that are the basis for judging or deciding among design concepts, *e.g., cost, weight, etc.*

Metrics – Scales of the degree in which the objectives/criteria of our design are achieved, *e.g., portable computer, ultra-light 4pts, light 3pts, moderate 2pts, heavy 1pt.*

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Engineering Design Terminology

Constraints – Restrictions or limitations of the design performance parameters. They are clearly defined limits in the form of a binary choice *yes or no*, *e.g.*, *must not conduct electricity*, or a permissible range, *e.g.*, *must weigh less than 10lb*.

Functions – Services or actions that must be provided by the design or its components. They are generally expressed as *doing* terms (action verbs), *e.g.*, *must move*, *cut*, *show*, *insulate*, *support weight*, *manipulate*, *alert*, *etc.*

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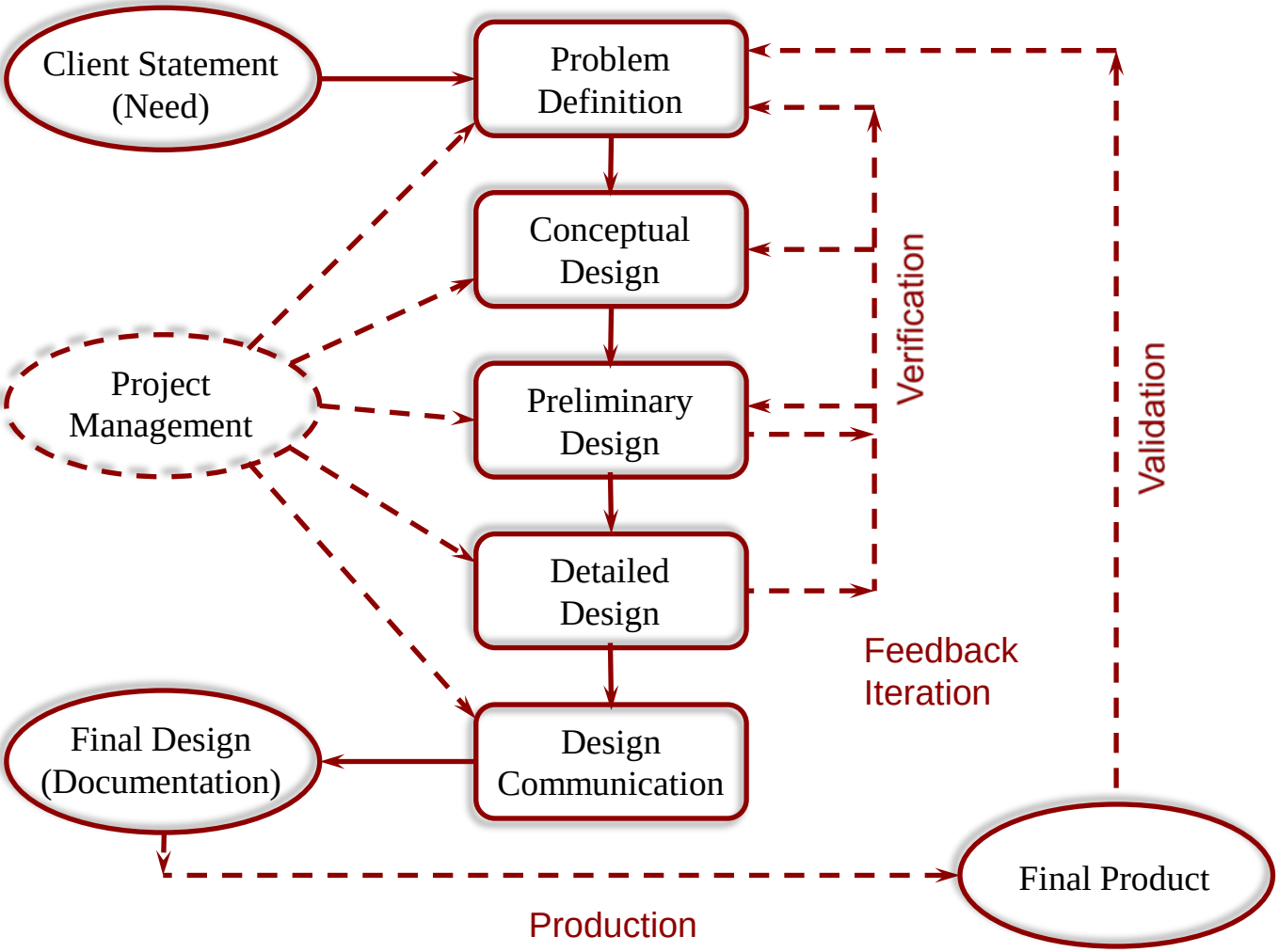
Engineering Design Process

The design process can be modeled in five main stages.



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Engineering Design

Design problems are *ill structured*. This implies that the solution to a problem cannot be found by applying a structured method, such as applying mathematic formulas or methods.

Design problems are *open-ended*. This implies that there are typically several acceptable solutions.

Design problems are *iterative*. The design process is not linear. In addition to the feedback loops (verification and validation) which are performed through testing, there are also continuous repetitions of the same methods even if they happen at different levels of the design process.

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Need Recognition

Problem Definition is a critical stage of the design process.

- Many design failures can be traced from an inadequate definition of the problem.
- Some failures are related to functionality, but other failures are related to the lack of understanding of the unsatisfactory situation as seen by the *client* or by the *users*.
- Failures appear later in the design process during testing or production, which can be costly in terms of money and time.
- It is critical to clarify what the design should achieve without committing to particular solutions.
- A key aspect of design is identifying a *client*'s unfulfilled description of the need.

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Clients

Who are the clients?

Clients could be individuals, companies, government, non-government organizations who identified a need and you are responsible of satisfying.

Clients could also be your supervisor, a branch in your organization, or even yourself (entrepreneurship).

On many occasions, there are different clients which could lead to tension based on different interpretations of the need.

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Client's Need

Any design project starts with the identification of a need as presented by a client.

It is important to keep focus on the overall definition of the client's need, without diverging to other problems.

However, client statements are generally incomplete, with errors, and biases.

On many occasions, the client describes the problem based on solutions or approaches rather than the need itself.

As a designer you must always question any statement made by the client, ask yourselves why?

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Stakeholders

In addition to the clients and the designers, there is another very important stakeholder: the *user or consumer*. The person or people who are going to use the product being designed.

Consumers play an important role in the design, because the product will not sell if the design does not meet their *needs*.

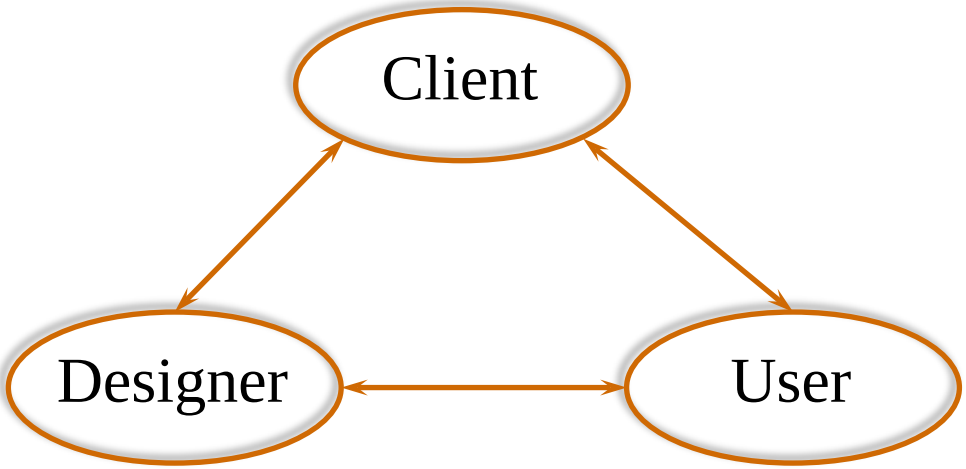

Figure 1. Stakeholder Triangle

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Business: Product Management

Understanding the role of the stakeholder is critical for any successful business. Shown below is a similar triangle from the business perspective.

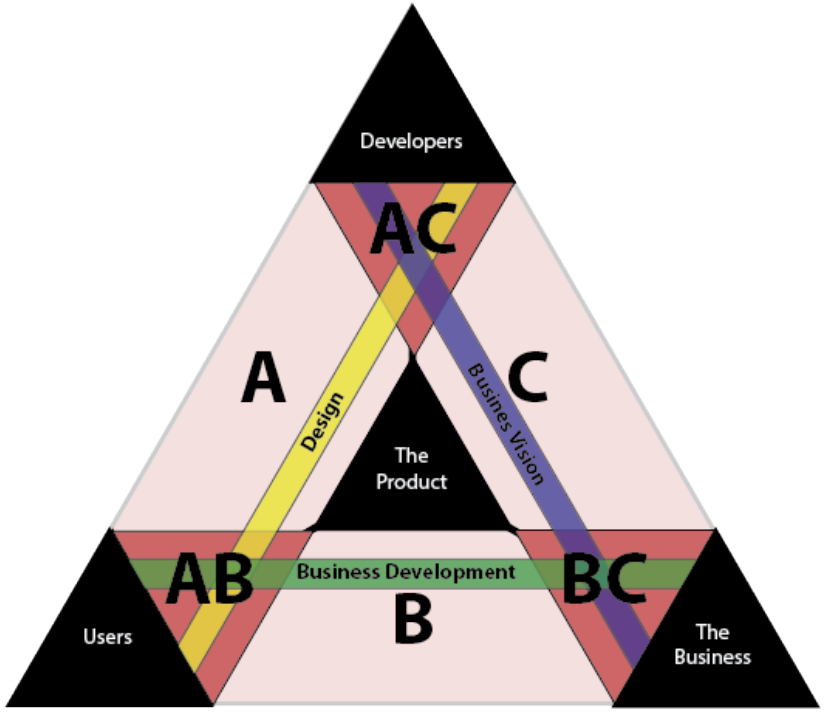

Figure 2. Product Management Triangle (retrieved Sept 2021)

The Product Management Triangle – Product Logic

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Stakeholders

The designer must understand what the client wants, but also the client must understand what the users actually need (market research) and communicate that to the designer.

As a designer you must recognize the importance of the users, as the success of the final product will be judge by them.

Design decisions often lead to tradeoffs, which may lead to conflictive obligations (ethic problems) between the client and user. For example, a reduction in the final cost may be achieved by using poor quality material, which could expose a safety risk to the user.

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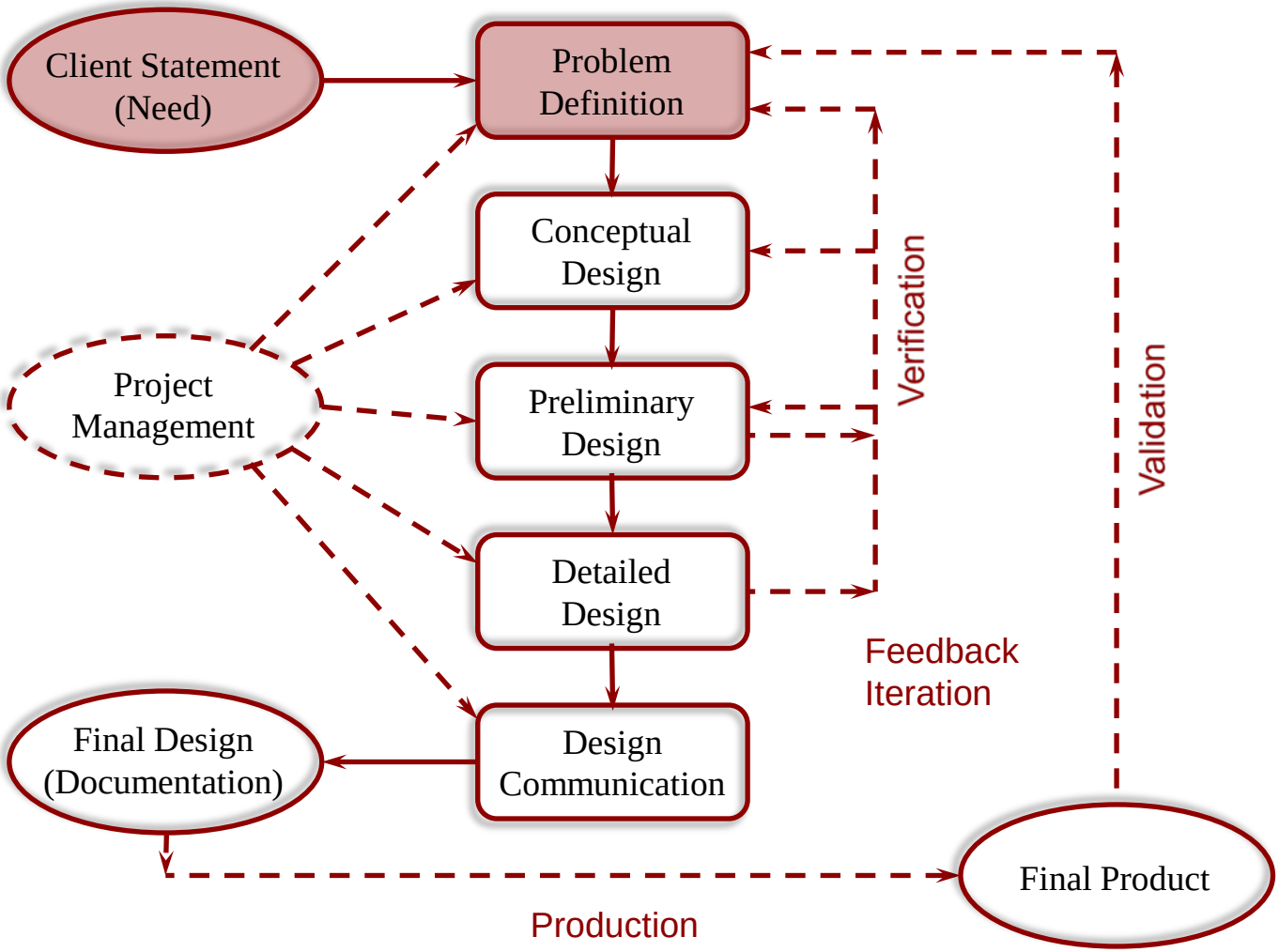
Engineering Design Process

The first stage of any design project is Problem Definition



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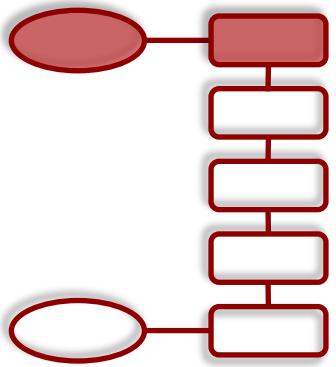
Problem Definition



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

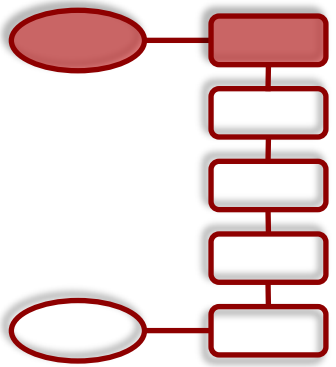
Outputs: *Revised problem statement*

List of final objectives (criteria)

List of final constraints

Weighted Criteria Tree

Problem Definition



- The client statements are short, with errors and biases.
- Generate a list of attributes with the following *means:*
  - Review literature
  - Ask questions to the client and stakeholders (users and experts)
  - Brainstorm to establish a list of attributes (objectives)
- Identify and organize objectives and constraints
- Build criteria trees
  - Convert objective list into criteria list
  - Order the list into sets of higher-level and lower-level objectives
  - Draw a tree of criteria with hierarchical relationships and links
- Quantify criteria
  - Set priorities (rank client's objectives): Pair-wise comparison chart
  - Weighted Criteria Tree

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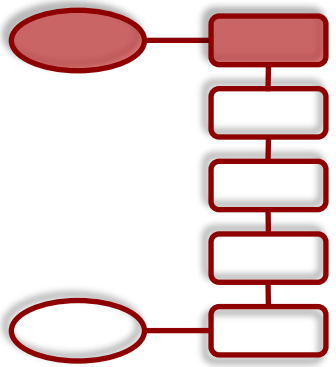
Problem Definition



- Methods for Problem Definition

Questioning – We will get a better understanding of our design project if we ask questions such as:

What should this technology or system do?

Is there a technology similar to this one on the market?

Can we improve an existing product by making it more competitive?

How are we going to do that?

Why do we want that?

What does that statement mean?

Can we modify some of the conditions given by the client?

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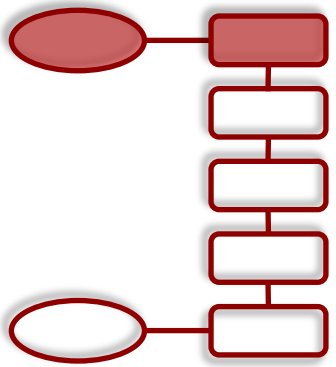
Problem Definition



Understanding the Need

The solutions that we develop depend upon how we define the need

Example of a need statement

I need a more efficient heating system for my house (currently electric baseboard)

- *What is the need?*
- *What is the unsatisfactory situation?*
- *Why is the electric heater inefficient?*
- *How do you measure efficiency?*
- *What are the options?*

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Problem Definition

Understanding the Need

The solutions that we develop depend upon how we define the need

Figure 2. Sources for heating U.S. Department of Energy

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Problem Definition

Understanding the Need

The solutions that we develop depend upon how we define the need

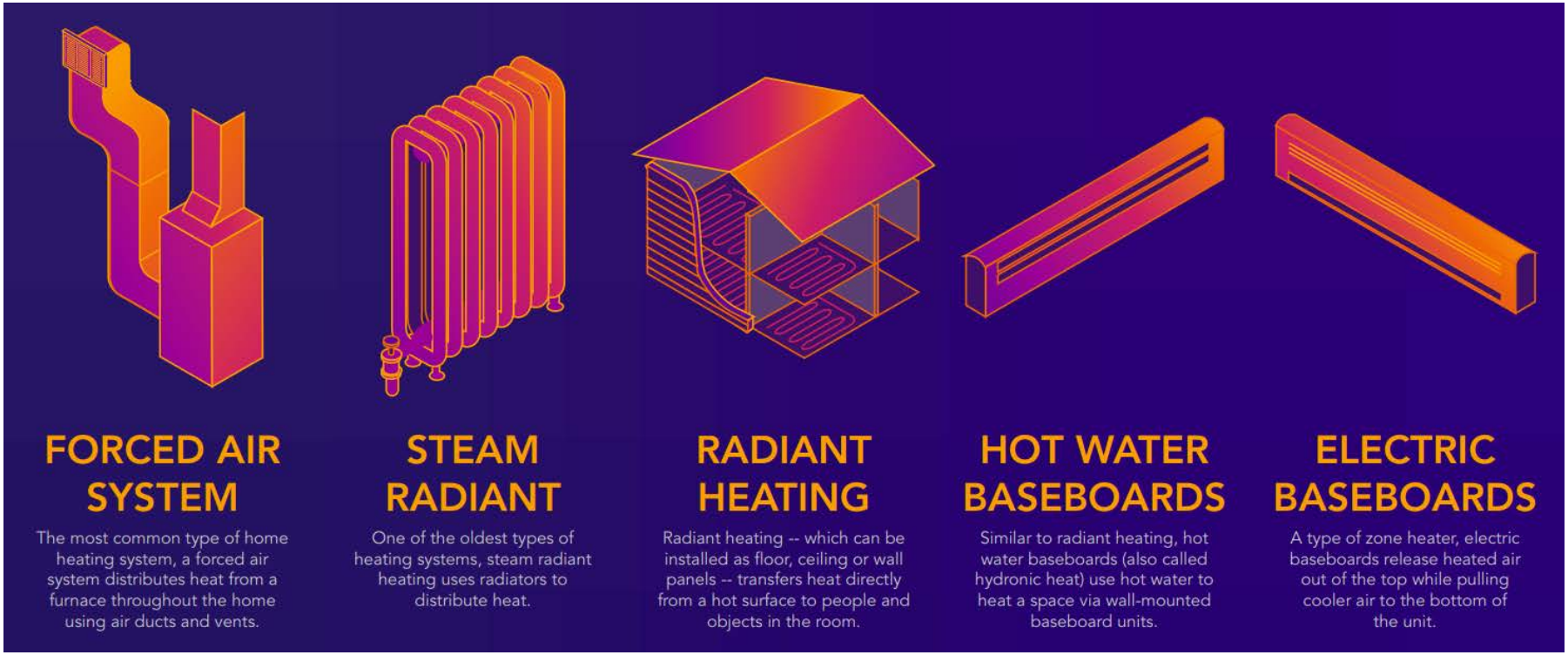
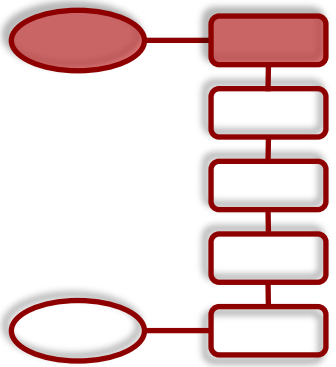


Figure 3. Heat distribution, U.S. Department of Energy

Problem Definition



Understanding the Need

The solutions that we develop depend upon how we define the need

Where do we start?

- Ask yourselves questions (individual and team activity)
- Ask the client questions
- Follow up with more questions that arise from responses to initials questions.
- Do your own research
- Think broadly first…then narrow down
- Avoid fixation on a single solution

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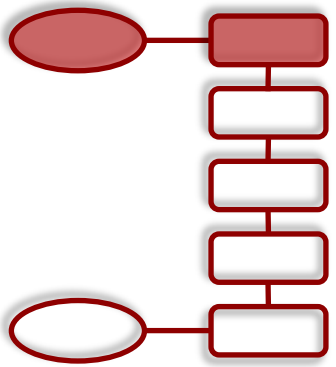
Problem Definition



Need – Description of an unsatisfactory situation.

Goal – It is a brief, general, and ideal response to the need.

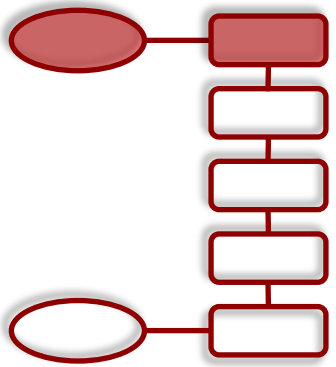
Perhaps, the unsatisfactory situation is that the annual heating bill is too high. Electric heaters are one of the most efficient systems at about 95-100% efficiency. Furnaces 60-98%, boilers 50-90%, and heat pumps 6.8-10 HSPF (Heating Seasonal Performance Factor). Replacing a system implies an additional cost.

Revised Need: My annual heating bill is too high

What possible "goals" could address this "need"?

- *Reduce heat loss*
- *Improve efficiency of heat source*

Problem Definition



Objectives – Expressions of desired attributes and behavior that are quantifiable expectations of performance.

Example (cont'd):

Need: My annual heating bill is too high
Goal: Reduce heating energy consumption

Possible Objectives:

- Reduce annual heating bill by 30%
- Reduce heat loss from windows by 40%
- Improve blower door test performance by 50%

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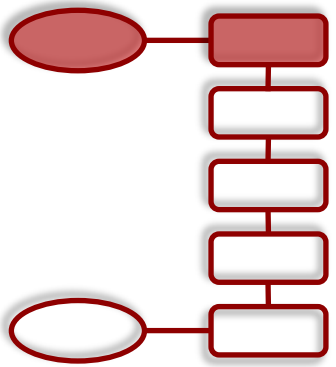
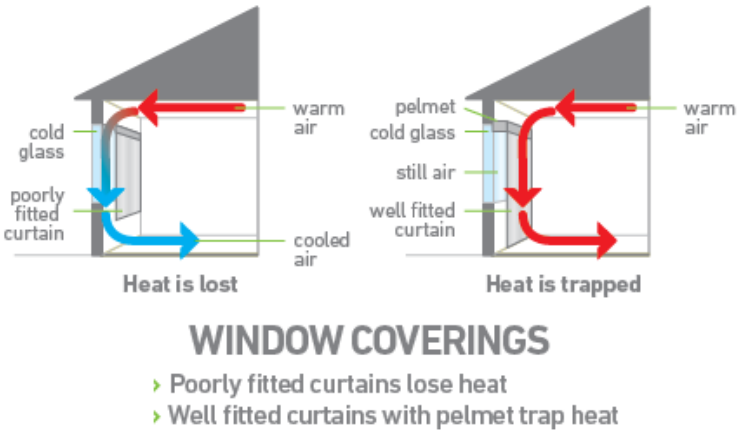
Problem Definition



Objective – Reduce heat loss from windows by 40%

How can we reduce the heat loss from windows?

- Replace windows (double- or triple-paned windows)
- Attach glazing (window) films to existing windows
- Cover windows with a well fitted curtain combined with a pelmet



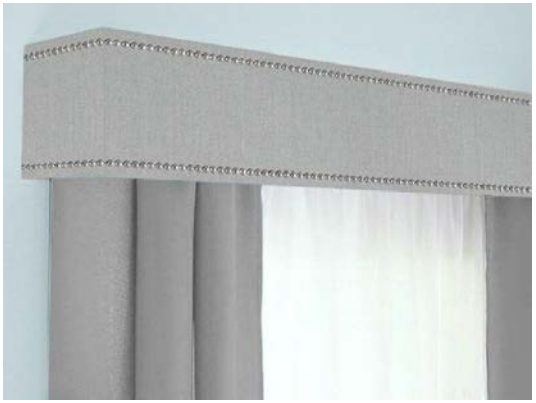


Figure 4. Sustainability Victoria, Australia link

Problem Definition

Objective – Improve blower door test performance by 50%

- A blower door test measures the airtightness of a building.
- It is a diagnostic tool for home energy audits.
- The fan draws air from the inside to the outside. The air then rushes back into the building through any cracks, gaps, or leaks.
- The auditor uses an infrared camera, that captures the temperature differences that are brought out with the blower door to identify sources of leakage.

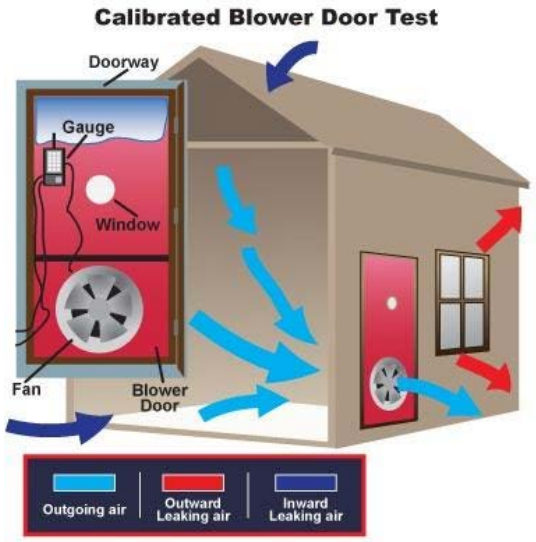


Figure 5. Blower Door Test link

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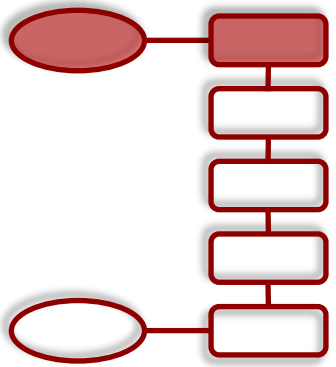
Problem Definition



Constraints – Restrictions or limitations of the design performance parameters, whether binary or a permissible range.

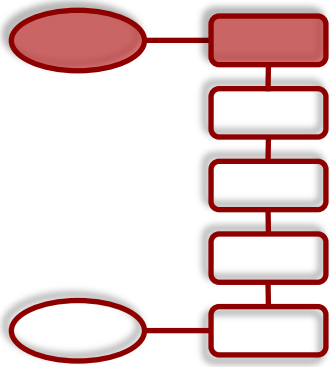
Example (cont'd):

Goal: Reduce heating energy consumption

Possible Constraints:

- Capital cost < $5,000
- Payback period < 10 yrs

Example from Textbook



Client :*"design a bottle for our new juice product"*.

We start questioning and generating a list of attributes.

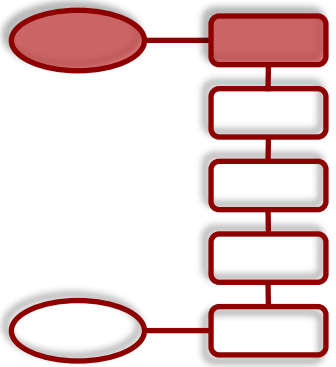
After talking to the client, marketing staff and clients there are many motivations for this new product:

- Plastic bottles and containers look alike
- The client has to deliver the product to diverse climates and environments
- Safety is a big issue for parents
- Market is very competitive
- Children need assistance to open their drinks
- Children always spill drinks
- Parents are concerned about the environment

Objectives

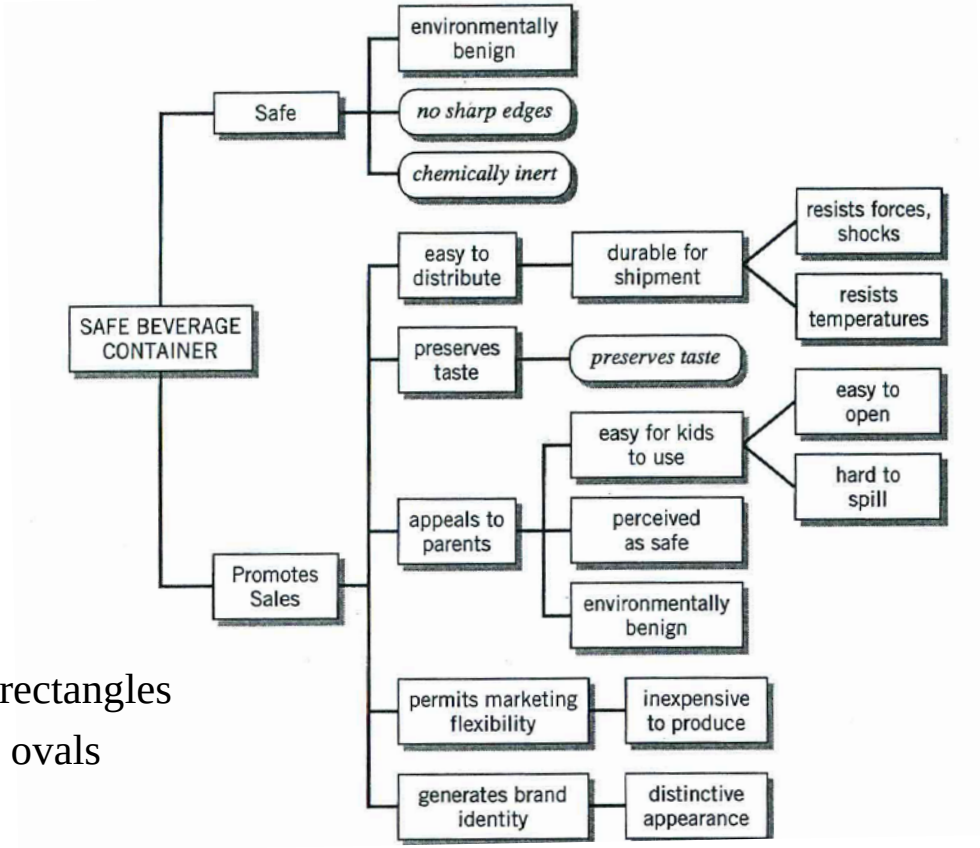
- Must be unique
- Must be resistant to forces and temperatures
- Must be safe
- Must be inexpensive and preserve taste
- Must be easy to open
- Must be hard to spill
- Must be environmentally friendly

Problem Definition



- Criteria Tree

  Convert the objectives into criteria (around 8 lower-level criteria in total). Organize them in a hierarchical structure.



Objectives in rectangles

Constraints in ovals

Note: Building a criteria tree requires multiple iterations.

Tip: Use sticky notes.

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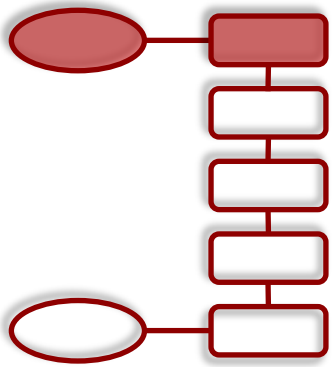
Problem Definition



- Rank the client's objectives (Pair-wise Comparison)

Goals	Environ. Benign	Easy to Distribute	Preserves Taste	Appeals to Parents	Market Flexibility	Brand ID	Score
Environ. Benign	••••	0	0	0	0	0	0
Easy to Distribute	1	••••	1	1	1	0	4
Preserves Taste	1	0	••••	0	0	0	1
Appeals to Parents	1	0	1	••••	0	0	2
Market Flexibility	1	0	1	1	••••	0	3
Brand ID	1	1	1	1	1	••••	5

(a) GRAFT's weighted objectives

Goals	Environ. Benign	Easy to Distribute	Preserves Taste	Appeals to Parents	Market Flexibility	Brand ID	Score
Environ. Benign	••••	1	1	1	1	1	5
Easy to Distribute	0	••••	0	0	1	0	1
Preserves Taste	0	1	••••	1	1	1	4
Appeals to Parents	0	1	0	••••	1	1	3
Market Flexibility	0	0	0	0	••••	0	0
Brand ID	0	1	0	0	1	••••	2

(b) BJIC's weighted objectives

While the GRAFT company is more interested in the look of the container and its distribution, the BJIC company is more concern about the environment and taste preservation.

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Problem Definition

- Weighted Criteria Tree

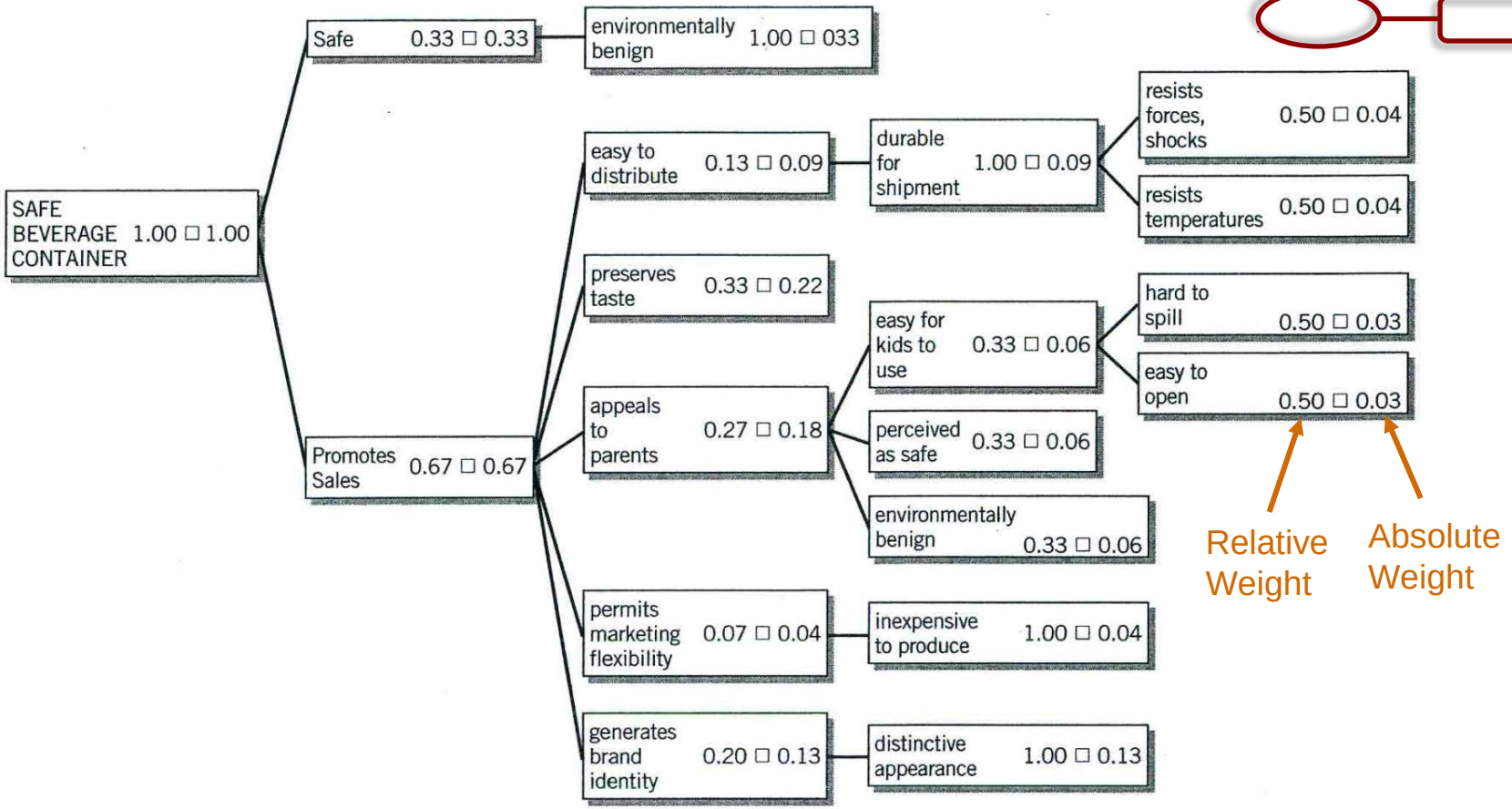

Figure 3.6 A weighted objectives tree for the design of a new beverage container, here reflecting the values of the BJIC company.

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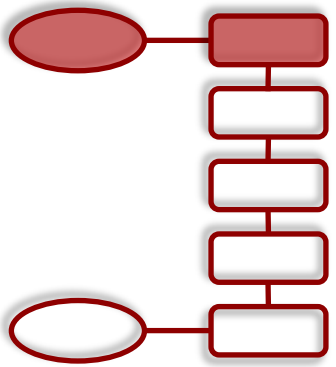
Problem Definition



- Revision of Problem Statement

  Client Statement:

  "Design a bottle for our new juice product."

  Revised Problem Definition Statement:

  "Design a safe method of packing and distributing our new children's juice product that preserves the taste and establishes brand identity to promote sales to middle income parents."