HSE Teachers’ Workshop
Design and Project Management

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Summer 2009
Today’s Focus

• Engineering design
  – as a process

• Project management
  – in a usable form
What engineers do ...

Problem → Solution
What engineers do …

Problem  Design  Solution
Design in an engineering context

• Design is a process
• Modeled in many different ways
• Involves the use of tools
Engineering Design Process

A Linear Model
(Not very realistic)

Engineering Design Process

A Cyclic Model – a much better view

Start (Define the Problem) → Gather Information → Define Criteria → Choose a Strategy → Develop Alternate Solutions

Choose a Strategy → Model and Analyze → Test and evaluate

Test and evaluate → Revise

Revise → Does solution meet requirements?

Yes → Documentation of Fabrication Specifications

No → Gather Information
Engineering Design Process

A Cyclic Model

**Problem Definition**

- Start (Define the Problem)
- Gather Information
- Define Criteria
- Revise
- Does solution meet requirements?
- Yes
  - Documentation of Fabrication Specifications
- No

Choose a Strategy

- Develop Alternate Solutions
  - Build a Prototype
- Model and Analyze
  - Test and evaluate
  - Does solution meet requirements?
Engineering Design Process

A Cyclic Model

- Start (Define the Problem)
- Gather Information
- Define Criteria
- Revise
- Does solution meet requirements?
- Yes
  - Documentation of Fabrication Specifications
- No
  - Choose a Strategy
  - Conceptual Design
    - Develop Alternate Solutions
    - Build a Prototype
  - Model and Analyze
  - Test and evaluate
  - Does solution meet requirements?
  - Yes
    - Documentation of Fabrication Specifications
Engineering Design Process

A Cyclic Model

Start (Define the Problem) → Gather Information → Define Criteria → Choose a Strategy → Develop Alternate Solutions

Choose a Strategy → Develop Alternate Solutions → Build a Prototype

Build a Prototype → Model and Analyze → Test and evaluate

Test and evaluate → Does solution meet requirements?

Does solution meet requirements? → Revise → Gather Information

Gather Information → Define Criteria → Choose a Strategy

Choose a Strategy → Develop Alternate Solutions → Build a Prototype

Documentation of Fabrication Specifications → Does solution meet requirements?

Yes → Documentation of Fabrication Specifications → Does solution meet requirements?

No → Does solution meet requirements?
Engineering Design Process

A Cyclic Model

Start (Define the Problem) → Gather Information → Define Criteria

Choose a Strategy → Develop Alternate Solutions

Does solution meet requirements?

No → Choose a Strategy

Yes → Build a Prototype → Model and Analyze

Test and evaluate → Revise

Documentation of Fabrication Specifications → Detailed Design
Engineering Design

• Is a cyclic process
  — real-life design does not happen in a linear sequential way

• Requires tools and procedures
  — we need to know how to use those tools

• Has its own language
  — we need to understand that language
Engineering Design Process

A Cyclic Model

Realm of our design focus

Start (Define the Problem)

Gather Information

Define Criteria

Choose a Strategy

Develop Alternate Solutions

Build a Prototype

Yes

Does solution meet requirements?

Revise

Model and Analyze

Test and evaluate

Documentation of Fabrication Specifications
Group Work

• See worksheet and its key
Design Criteria (a.k.a. Objectives)

- Attributes the solution should have
- From a manufacturing viewpoint
- We need weights for the criteria
- We need metrics for Criteria
- The “right” criteria, weights, and metrics are the bases of a good Decision Matrix
# Decision Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Design A</th>
<th>Design B</th>
<th>Design C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate for A1</td>
<td>Score for A1</td>
<td>Rate for B1</td>
</tr>
<tr>
<td>Criterion 1</td>
<td>Rate for A2</td>
<td>Score for A2</td>
<td>Rate for B2</td>
</tr>
<tr>
<td>(weight1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion 2</td>
<td>Rate for A3</td>
<td>Score for A3</td>
<td>Rate for B3</td>
</tr>
<tr>
<td>(weight2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion 3</td>
<td>Rate for A4</td>
<td>Score for A4</td>
<td>Rate for B4</td>
</tr>
<tr>
<td>(weight3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(weight4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score Totals</td>
<td>Sum of A scores</td>
<td>Sum of B scores</td>
<td>Sum of C scores</td>
</tr>
</tbody>
</table>

Score = Rate x weight

Design with highest sum wins!!
Design Tools

- Objective tree
- Pair-wise comparison chart
- Metrics for Criteria
- Decision Matrix
Design Tool Use

• To organize **Criteria** (a.k.a. **Objectives**)  
  – Use an Objective Tree

• To assign **Weights** to Criteria  
  – Use a Pair-wise Comparison Chart

• To **Rate** Alternate Designs for a given Criterion  
  – Use the metric for the criterion to decide on a rating
Where does all this get you?

- To a **Decision Matrix** that is generated according to real engineering design procedures instead of guesswork
**Tool: The Objective Tree**

- Objective Trees help us organize our design objectives (criteria), so that we can use the objectives in other tools.
- Objective trees should be solution independent.
  - Stop when functions and implementations (*which are not objectives*) begin to appear

**Tool: Pair-wise Comparison Chart**

Used to help us **weight** our objectives

- Compare only objectives emanating from a common node at the same sub-level in the objective tree
- Directly compare two objectives: in the cost row, compare cost to portability, to usefulness, and to durability, and then add the results
  
  Use 1 = more important, 0 = less important, 0.5 if equally important (rare)

- Compare higher-level objectives first
- Know whose perspectives are being assessed.

Results give an approximate subjective judgment of relative value and importance (i.e., **weight**) rather than a strong meaningful measurement

Example pair-wise Comparison Chart for marketability of the ladder.

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Cost</th>
<th>Portability</th>
<th>Usefulness</th>
<th>Durability</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>N/A</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Portability</td>
<td>1</td>
<td>N/A</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Usefulness</td>
<td>1</td>
<td>0</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Durability</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

Tool: Metrics for the criteria (objectives)

Use metrics to *measure* how well a design alternative achieves the objective, then rate the designs using those measurements (e.g., use a scale of 1-5 with higher ratings being better).

Good metrics are essential to rate the design alternatives.

• To develop metrics
  – Identify units and scale of something appropriate to measure about the objective (e.g., $$, kg, or subjective)
  – Identify the way to measure the designs in those units (tests, surveys)
  – Determine if the measurement is feasible (remember, the designs are only conceptual at this point)
Characteristics of a “Good Metric”

• It measures the criterion
• It’s capable of the appropriate level of precision or tolerance
• It’s repeatable
• It’s expressed in understandable units of measure
• It promotes clear interpretation
# Decision Matrix

<table>
<thead>
<tr>
<th>Criteria (weight)</th>
<th>Designs</th>
<th>Design A</th>
<th>Design B</th>
<th>Design C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rate for A1</td>
<td>Score for A1</td>
<td>Rate for B1</td>
</tr>
<tr>
<td>Criterion 1</td>
<td></td>
<td>Rate for A2</td>
<td>Score for A2</td>
<td>Rate for B2</td>
</tr>
<tr>
<td>(weight1)</td>
<td></td>
<td>Rate for A3</td>
<td>Score for A3</td>
<td>Rate for B3</td>
</tr>
<tr>
<td>Criterion 2</td>
<td></td>
<td>Rate for A4</td>
<td>Score for A4</td>
<td>Rate for B4</td>
</tr>
<tr>
<td>(weight2)</td>
<td></td>
<td>Sum of A scores</td>
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<td>Criterion 3</td>
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<td></td>
</tr>
<tr>
<td>(weight3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criterion 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(weight4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Score = Rate x weight  
Design with highest sum wins!!
Now let’s clarify some confusing terms… these two items are very different things in design

**design criterion**  *n*: *Designer chosen* characteristic of the solution that is related to the problem, such as durability, size, or weight, and used as an evaluation factor. aka “**Objective**”

Plural: design criteria

**design constraint**  *n*: An *imposed* limit or boundary placed on the design solution by an external source, such as nature or your boss.
Good design does not just happen!

• Managing design involves addressing
  – Scope of the project
  – Schedule
  – Spending

• Project management tools help specify
  – What must be done
  – Who must do it
  – When it must be done
Tools for Project Management

• Work Breakdown Structure (WBS)
  – A hierarchical breakdown of project tasks

• Team Calendar or Timeline
  – Mapping of major project deadlines and schedules

• Management Plan
  – Assignment of task responsibility to people, with internal team deadlines

• Gantt Chart
  – Graphical representation of the timing (start to finish) of project tasks
Work Breakdown Structure (WBS): The decomposition of tasks into smaller manageable subtasks

- Organized around basic design process tasks:
  - Understand problem
  - Analyze function requirements
  - Generate alternatives
  - Evaluate alternatives
  - Select
  - Document design process
  - Manage design process
  - Communicate design

- When breaking an item into subtasks, if it can’t be broken down into at least two subtasks, then it does not need to be broken down

- If you cannot determine how long a task will take or who will do the task, break it down further

- All tasks or activities that consume resources (time) should be included in the WBS explicitly or as a known component of another task
Team Calendars and Timelines

- Include
  - Externally imposed deadlines
  - Routine or recurring events (meetings)
  - Major deadlines team commits to

- Review and update regularly
Project Management

- **Management Plan:**
  - The equitable division of specific tasks among team members.
  - This list of tasks should be well defined, have a specifics person assigned to it, and have a team determined internal deadline.
# Management Plan

<table>
<thead>
<tr>
<th>Task</th>
<th>Person</th>
<th>Responsibility</th>
<th>Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Management plan &amp; timeline memo</td>
<td>A. Monte</td>
<td>Timeline, memo</td>
<td>9/30/07</td>
</tr>
<tr>
<td></td>
<td>K. Torrey</td>
<td>Management plan</td>
<td></td>
</tr>
<tr>
<td>2 Interviews of previous ENG1101 students, sketches of design concepts, and vehicle selection matrix memo</td>
<td>A. Monte</td>
<td>One interview, one sketch, selection matrix</td>
<td>10/25/07</td>
</tr>
<tr>
<td></td>
<td>K. Torrey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Spring analysis memo</td>
<td>A. Monte</td>
<td>Memo</td>
<td>10/30/07</td>
</tr>
<tr>
<td>4 Mathematical model of mousetrap car memo</td>
<td>K. Torrey</td>
<td></td>
<td>10/30/07</td>
</tr>
<tr>
<td>5 Design project test day</td>
<td>A. Monte</td>
<td>Bring car to class</td>
<td>11/14/07</td>
</tr>
<tr>
<td></td>
<td>K. Torrey</td>
<td>Bring rough draft to class</td>
<td>11/20/07</td>
</tr>
<tr>
<td>6 Final design report</td>
<td>A. Monte</td>
<td>Bring final report to class</td>
<td>11/24/07</td>
</tr>
</tbody>
</table>

- Same tasks as on your timeline
- Shows who is in charge of what tasks
- Shows when the team can expect to review the task work
Timeline (Gantt Chart)

- Same tasks as on your timeline
- Shows when the tasks start, finish, and how they overlap – and overlap is critical
Summary

• Engineering design:
  – A cyclic process
  – with its own language (criteria/constraints)
  – and tools (decision matrix)

• Project management:
  – A work breakdown structure
  – A timeline calendar with major external deadlines
  – A management plan with internal team deadlines
  – A Gantt chart to visualize the team’s management plan
Extra Slides

• How do we get candidate designs?
Tool: Morphological Charts—“Morph charts”

• Help us define our design space – the number and the kinds of alternate solutions that are possible through different approaches.

• Example – Think about designing a new beverage container.
  – What must the container do (functions)?
  – How will it do those things (means)?
Example morph chart for design of new beverage container

<table>
<thead>
<tr>
<th>Function</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contain liquid</td>
<td>can</td>
</tr>
<tr>
<td>Allow drinking access</td>
<td>screw cap</td>
</tr>
<tr>
<td>Display product information</td>
<td>labels</td>
</tr>
</tbody>
</table>

How did we build this morph chart?
List the design functions in the left-most column, and put the means to achieve the functions in the columns to the right.

How many alternate designs paths do we get from this chart?
Maximum = $4 \times 4 \times 2 = 32$, but some of these are not feasible (e.g., a can with an unfolding top) and must be excluded. We can expand our design space by adding more functions or means for the container, and we can shrink our design space by eliminating any means that will not allow the design to meet constraints.

Design Space Adjustments ...

If our morph chart gives us an overwhelming number of alternatives for our project:

• we can pick a general approach to pursue and not consider other paths – this is called “Choosing a strategy” in our cyclic model.

• we can reduce the number of alternatives by
  – excluding all incompatible alternatives (e.g., a can with an unfolding top)
  – applying design constraints to eliminate means