Design for Manufacturing

Teaching materials to accompany:
Product Design and Development
Chapter 11
Karl T. Ulrich and Steven D. Eppinger
Product Design and Development
Karl T. Ulrich and Steven D. Eppinger

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1. Introduction
2. Development Processes and Organizations
3. Product Planning
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6. Concept Generation
7. Concept Selection
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9. Product Architecture
10. Industrial Design
11. Design for Manufacturing
12. Prototyping
13. Product Development Economics
14. Managing Projects
Product Development Process

Planning → Concept Development → System-Level Design → Detail Design → Testing and Refinement → Production Ramp-Up

How can we emphasize manufacturing issues throughout the development process?
Design for Manufacturing Example: GM 3.8-liter V6 Engine
Understanding Manufacturing Costs

Manufacturing Cost

Components
  - Standard
    - Raw Material
  - Custom
    - Processing
    - Tooling

Assembly
  - Labor
  - Equipment and Tooling

Overhead
  - Support
  - Indirect Allocation
Definition

- Design for manufacturing (DFM) is a development practice emphasizing manufacturing issues throughout the product development process.
- Successful DFM results in lower production cost without sacrificing product quality.
Three Methods to Implement DFM

1. Organization: Cross-Functional Teams

2. Design Rules: Specialized by Firm

3. CAD Tools: Boothroyd-Dewhurst Software
Design for Assembly Rules

Example set of DFA guidelines from a computer manufacturer.

1. Minimize parts count.
2. Encourage modular assembly.
3. Stack assemblies.
4. Eliminate adjustments.
5. Eliminate cables.
6. Use self-fastening parts.
7. Use self-locating parts.
8. Eliminate reorientation.
9. Facilitate parts handling.
10. Specify standard parts.
Design for Assembly

• Key ideas of DFA:
  – Minimize parts count
  – Maximize the ease of handling parts
  – Maximize the ease of inserting parts

• Benefits of DFA
  – Lower labor costs
  – Other indirect benefits

• Popular software developed by Boothroyd and Dewhurst.
  – [http://www.dfma.com](http://www.dfma.com)
To Compute Assembly Time

\[
\text{Handling Time} + \text{Insertion Time} = \text{Assembly Time}
\]
Method for Part Integration

• Ask of each part in a candidate design:
  1. Does the part need to move relative to the rest of the device?
  2. Does it need to be of a different material because of fundamental physical properties?
  3. Does it need to be separated from the rest of the device to allow for assembly, access, or repair?
• If not, combine the part with another part in the device.
Videocassette DFM Exercise

- 2 billion worldwide annual volume
- 7 major producers of 1/2” cassette shells
- JVC licenses the VHS standard
  - dimensions, interfaces, light path, etc
- VHS cassette shells cost ~$0.25 each
- What is a $0.01 cost reduction worth?
DFM Strategy is Contingent

Corporate Strategy

Product Strategy

Production Strategy

DFM Strategy
Concept Generation

Teaching materials to accompany:

*Product Design and Development*

*Chapter 6*

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Concept Development Process

1. Identify Customer Needs
2. Establish Target Specifications
3. Generate Product Concepts
4. Select Product Concept(s)
5. Test Product Concept(s)
6. Set Final Specifications
7. Plan Downstream Development
8. Development Plan

- Perform Economic Analysis
- Benchmark Competitive Products
- Build and Test Models and Prototypes
Concept Generation Example: Power Nailer
Concept Generation Process

- Clarify the Problem
  - Problem Decomposition
- External Search
  - Lead Users
  - Experts
  - Patents
  - Literature
  - Benchmarking
- Internal Search
  - Individual Methods
  - Group Methods
- Systematic Exploration
  - Classification Tree
  - Combination Table
- Reflect on the Process
  - Continuous Improvement
Concept Generation Exercise: Vegetable Peelers
Vegetable Peeler Exercise:
Voice of the Customer

- "Carrots and potatoes are very different."
- "I cut myself with this one."
- "I just leave the skin on."
- "I'm left-handed. I use a knife."
- "This one is fast, but it takes a lot off."
- "How do you peel a squash?"
- "Here's a rusty one."
- "This looked OK in the store."
Vegetable Peeler Exercise: Key Customer Needs

1. The peeler peels a variety of produce.
2. The peeler can be used ambidextrously.
3. The peeler creates minimal waste.
4. The peeler saves time.
5. The peeler is durable.
6. The peeler is easy to clean.
7. The peeler is safe to use and store.
8. The peeler is comfortable to use.
9. The peeler stays sharp or can be easily sharpened.
Problem Decomposition: Function Diagram

**INPUT**
- Energy (?)
- Material (nails)
- Signal (tool "trip")

**OUTPUT**
- Energy (?)
- Material (driven nail)
- Signal (?)

**Hand-held nailer**
- Store or accept external energy
- Convert energy to translational energy
- Apply translational energy to nail

**INPUT**
- Energy
- Nails
- "Trip" of tool

**OUTPUT**
- Driven nail

**Components:**
- Store nails
- Isolate nail
- Trigger tool
- Sense trip

**Materials and Signals:**
- Energy (?)
- Signal (tool "trip")
- Material (nails)
External Search:
Hints for Finding Related Solutions

- Lead Users
  - benefit from improvement
  - innovation source
- Benchmarking
  - competitive products
- Experts
  - technical experts
  - experienced customers
- Patents
  - search related inventions
- Literature
  - technical journals
  - trade literature
Capture Innovation from Lead Users: Utility Light Example
Capture Innovation from Lead Users: Utility Light Example
Internal Search:
Hints for Generating Many Concepts

- Suspend judgment
- Generate a lot of ideas
- Infeasible ideas are welcome
- Use graphical and physical media
- Make analogies
- Wish and wonder
- Solve the conflict
- Use related stimuli
- Use unrelated stimuli
- Set quantitative goals
- Use the gallery method
- Trade ideas in a group
Systematic Exploration: Concept Combination Table

<table>
<thead>
<tr>
<th>Convert Electrical Energy to Translational Energy</th>
<th>Accumulate Energy</th>
<th>Apply Translational Energy to Nail</th>
</tr>
</thead>
<tbody>
<tr>
<td>rotary motor w/ transmission</td>
<td>spring</td>
<td>single impact</td>
</tr>
<tr>
<td>linear motor</td>
<td>moving mass</td>
<td>multiple impacts</td>
</tr>
<tr>
<td>solenoid</td>
<td></td>
<td>push nail</td>
</tr>
<tr>
<td>rail gun</td>
<td></td>
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</tr>
</tbody>
</table>
Concept Testing

Teaching materials to accompany:

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*Chapter 8*

Karl T. Ulrich and Steven D. Eppinger

Product Design and Development
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Product Development Process

Planning
Concept Development
System-Level Design
Detail Design
Testing and Refinement
Production Ramp-Up

Qualitative Concept Testing
Quantitative Concept Testing
Concept Development Process

Mission Statement → Identify Customer Needs → Establish Target Specifications → Generate Product Concepts → Select Product Concept(s) → Test Product Concept(s) → Set Final Specifications → Plan Downstream Development → Development Plan

- Perform Economic Analysis
- Benchmark Competitive Products
- Build and Test Models and Prototypes
Concept Testing is Used for Several Purposes

• Go/no-go decisions
• What market to be in?
• Selecting among alternative concepts
• Confirming concept selection decision
• Benchmarking
• Soliciting improvement ideas
• Forecasting demand
• Ready to launch?
Concept Testing Process

- Define the purpose of the test
- Choose a survey population
- Choose a survey format
- Communicate the concept
- Measure customer response
- Interpret the results
- Reflect on the results and the process
Concept Testing Example:
emPower Electric Scooter
Scooter Example

• Purpose of concept test:
  – What market to be in?

• Sample population:
  – College students who live 1-3 miles from campus
  – Factory transportation

• Survey format:
  – Face-to-face interviews
Communicating the Concept

- Verbal description
- Sketch
- Photograph or rendering
- Storyboard
- Video
- Simulation
- Interactive multimedia
- Physical appearance model
- Working prototype
Verbal Description

• The product is a lightweight electric scooter that can be easily folded and taken with you inside a building or on public transportation.

• The scooter weighs about 25 pounds. It travels at speeds of up to 15 miles per hour and can go about 12 miles on a single charge.

• The scooter can be recharged in about two hours from a standard electric outlet.

• The scooter is easy to ride and has simple controls — just an accelerator button and a brake.
Sketch
Rendering
3D Solid CAD Model
Appearance Model
Working Prototype
Beta Prototype
Video
Animation
Interactive Multimedia
Live Demonstration
Survey Format

• PART 1, Qualification
  – How far do you live from campus?
    • <If not 1-3 miles, thank the customer and end interview.>
  – How do you currently get to campus from home?
  – How do you currently get around campus?

• PART 2, Product Description
  – <Present the concept description.>
Survey Format

• PART 3, Purchase Intent
  – If the product were priced according to your expectations, how likely would you be to purchase the scooter within the next year?

- I would definitely not purchase the scooter.
- I would probably not purchase the scooter.
- I might or might not purchase the scooter.
- I would probably purchase the scooter.
- I would definitely purchase the scooter.

“second box”
“top box”
Survey Format

- **PART 4, Comments**
  - What would you expect the price of the scooter to be?
  - What concerns do you have about the product concept?
  - Can you make any suggestions for improving the product concept?

- **Thank you.**
Interpreting the Results: Forecasting Sales

\[ Q = N \times A \times P \]

- \( Q \) = sales (annual)
- \( N \) = number of (annual) purchases
- \( A \) = awareness \( \times \) availability (fractions)
- \( P \) = probability of purchase (surveyed)

\[ = C_{\text{def}} \times F_{\text{def}} + C_{\text{prob}} \times F_{\text{prob}} \]

“top box”

“second box”
Forecasting Example: 
College Student Market

- N = off-campus grad students (200,000)
- A = 0.2 (realistic) to 0.8 (every bike shop)
- P = 0.4 x top-box + 0.2 x second-box
- Q =
- Price point $795
Forecasting Example: Factory Transport Market

- N = current bicycle and scooter sales to factories (150,000)
- A = 0.25 (single distributor’s share)
- \( P = 0.4 \times \text{top-box} + 0.2 \times \text{second-box} \)
- \( Q = 150,000 \times 0.25 \times [0.4 \times 0.3 + 0.2 \times 0.2] \)
  \[
  = 6000 \text{ units/yr}
  \]
- Price point $1500
emPower’s Market Decision: Factory Transportation

Still walking?
Production Product
Sources of Forecast Error

- Word-of-Mouth Effects
- Quality of Concept Description
- Pricing
- Level of Promotion
- Competition
Discussion

• Why do respondents typically overestimate purchase intent?
  – Might they ever underestimate intent?
• How to use price in surveys?
• How much does the way the concept is communicated matter?
  – When shouldn’t a prototype model be shown?
• How do you increase sales, Q?
• How does early (qualitative) concept testing differ from later (quantitative) testing?
Managing Complex System Development Projects

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Sloan School of Management
Engineering Systems Division
Leaders for Manufacturing Program
System Design and Management Program

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http://web.mit.edu/dsm
Session Outline

• Motivation: Managing Project Structure
  – Concurrent Engineering in the Large

• Design Structure Matrix
  – Information Flow Modeling
  – Task-Based DSMs
  – Sequencing Analysis
  – Example: Semiconductor Development

• Managing Design Iterations
  – Solving Coupled Issues Faster
  – Example: Instrument Cluster

• Systems Integration
  – Organization-Based DSM
  – System Architecture-Based DSM
  – Example: Engine Development

• DSM Web Site
Industrial Examples and Research Sponsors

DELPHI  
Pratt & Whitney  
VOLVO AERO  
BOEING  
FIAT  
HP  
Intel  
ABB  
Kodak  
GM  
Ford  
ITT Industries
Concurrent Engineering

*in the Small*

- Projects are executed by a cross-disciplinary team (5 to 20 people).
- Teams feature **high-bandwidth** technical communication.
- Tradeoffs are resolved by mutual understanding.
- “Design and production” issues are considered simultaneously.
Concurrent Engineering in the Large

- Large projects are organized as a network of teams (100 to 1000 people).
- Large projects are decomposed into many smaller projects.
- Large projects may involve development activities dispersed over multiple sites.
- The essential challenge is to integrate the separate pieces into a system solution.
- The needs for integration depend upon the technical interactions among the sub-problems.
Sequencing Tasks in Projects

Three Possible Sequences for Two Tasks

Dependent (Series)

Independent (Parallel)

Interdependent (Coupled)
- We can represent the important task relationships.
- It is difficult to understand large, complex diagrams.
The Design Structure Matrix: An Information Exchange Model

Interpretation:
- Task D requires information from tasks E, F, and L.
- Task B transfers information to tasks C, F, G, J, and K.

Note:
- Information flows are easier to capture than work flows.
- Inputs are easier to capture than outputs.
The Design Structure Matrix

(Partitioned, or Sequenced)

Note:
Coupled tasks can be identified uniquely.
The display of the matrix can be manipulated to emphasize certain features of the process flow.
Semiconductor Development Example

1. Set customer target
2. Estimate sales volumes
3. Establish pricing direction
4. Schedule project timeline
5. Development methods
6. Macro targets/constraints
7. Financial analysis
8. Develop program map
9. Create initial QFD matrix
10. Set technical requirements
11. Write customer specification
12. Develop program map
13. Develop test plan
14. Develop validation plan
15. Build base prototype
16. Functional modeling
17. Design rule check
18. Generate masks
19. Verify masks in fab
20. Life testing
21. Infant mortality testing
22. Mfg. process stabilization
23. Develop field support plan
24. Thermal testing
25. Confirm process standards
26. Final certification
27. Volume production
28. Prepare distribution network
29. Delivers product to customers

- = Information Flows  ■ = Planned Iterations  ○ = Unplanned Iterations  □ = Generational Learning
How to Create a Task-Based Design Structure Matrix Model

1. Select a process or sub-process to model.
2. Identify the tasks of the process, who is responsible for each one, and the outputs created by each task.
3. Lay out the square matrix with the tasks in the order they are nominally executed.
4. Ask the process experts what inputs are used for each task.
5. Insert marks representing the information inputs to each task.
6. Optional: Analyze the DSM model by re-sequencing the tasks to suggest a new process.
7. Draw solid boxes around the coupled tasks representing the planned iterations.
8. Draw dashed boxes around groups of parallel (uncoupled) tasks.
9. Highlight the unplanned iterations.
Design Iteration

• Product development is fundamentally iterative — yet iterations are hidden.

• Iteration is the repetition of tasks due to the availability of new information.
  – changes in input information (upstream)
  – update of shared assumptions (concurrent)
  – discovery of errors (downstream)

• Engineering activities are repeated to improve product quality and/or to reduce cost.

• To understand and accelerate iterations requires
  – visibility of iterative information flows
  – understanding of the inherent process coupling
**Instrument Cluster Development**

**Delco**

- Casing Design
- Wiring Layout
- Lighting Details
- Tooling
- Hard Prototype
- Testing

**Supplier**

- Casing Design
- Lighting Details
- Wiring Layout
- Soft Prototype
- Testing
- Revision
- Hard Tooling

**Slower Design Process**
- Several planned iterations
- Usually one unplanned iteration

**Faster Design Process**
- Fewer planned iterations
- Planned revision cycle
- No unplanned iterations
Lessons Learned: Iteration

- Development is inherently iterative.
- An understanding of the coupling is essential.
- Not everything should be concurrent in concurrent engineering.
- Iteration results in improved quality.
- Iteration can be accelerated through:
  - information technology (faster iterations)
  - coordination techniques (faster iterations)
  - decreased coupling (fewer iterations)
- There are two fundamental types of iteration:
  - planned iterations (getting it right the first time)
  - unplanned iterations (fixing it when it’s not right)
Decomposition, Architecture, and Integration

**Decomposition** is the process of splitting a complex system into sub-systems and/or components.

**System architecture** is the resulting set of interactions among the components.

**Integration** is the process of combining these sub-systems to achieve an overall solution.

System integration needs are determined by the chosen decomposition and its resulting architecture.

We map the structure of interactions in order to plan for integration.
Organization DSM Application: Engine Development

- Site: General Motors Powertrain Division
- Product: “new-generation” engine
- Structure: 22 PDTs involved simultaneously
Decomposition of the Engine Development Project

**22 PDTs**
- Engine Block
- Cylinder Heads
- Camshaft/Valve Train
- Pistons
- Connecting Rods
- Crankshaft
- Flywheel
- Accessory Drive
- Lubrication
- Water Pump/Cooling
- Intake Manifold
- Exhaust
- E.G.R.
- Air Cleaner
- A.I.R.
- Fuel System
- Throttle Body
- EVAP
- Ignition System
- Electronic Control Module
- Electrical System
- Engine Assembly

**PDT composition**
- 1 product release engineer
- 1 CAD designer
- 3 manufacturing engineers
- 2 purchasing representatives
- 2 casting engineers
- machine tool supplier
- 1 production control analyst
- 1 financial planner
- production personnel
## PDT Interactions

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<tbody>
<tr>
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</tr>
</tbody>
</table>

**Frequency of PDT Interactions**

- **Daily**
- **Weekly**
- **Monthly**
System Team Assignments

**Short Block**
- Engine Block
- Crankshaft
- Flywheel
- Pistons
- Connecting Rods
- Lubrication

**Valve Train**
- Cylinder Heads
- Camshaft/Valve Train
- Water Pump/Cooling

**Induction**
- Intake Manifold
- Accessory Drive
- Fuel System
- Air Cleaner
- Throttle Body
- A.I.R.

**Emissions/Electrical**
- Exhaust
- E.G.R.
- E.V.A.P.
- Electrical System
- Electronic Control
- Ignition
Lessons Learned: Integration

- Large development efforts require multiple activities to be performed in parallel.
- The many subsystems must be integrated to achieve an overall system solution.
- Mapping the information dependence reveals an underlying structure for system engineering.
- Organizations can be “designed” based upon this structure.
System Architecture Example: P&W 4098 Jet Engine

- 9 Systems
- 54 Components
- 569 Interfaces

Design Interfaces:
- Spatial, Structural
- Energy, Materials
- Data, Controls
Lessons Learned: Product/System Architecture

- Hierarchical system decompositions are evident.
- System architecting principles are at work.
- There is a disparity between known interfaces and unknown interactions.
- Integrating elements may be functional and/or physical.

**Hypothesis: Density of known interactions—**

- **novel**
  - sparse

- **experienced**
  - dense

- **mature**
  - clustered
### Types of DSM Models and Analysis

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Analysis Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
<td>Sequencing, Iteration, Overlapping</td>
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<tr>
<td>Parameter</td>
<td>Clustering</td>
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<tr>
<td>Organization</td>
<td></td>
</tr>
<tr>
<td>Component</td>
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</table>
MIT
Design Structure Matrix
Web Site

http://web.mit.edu/dsm

• Tutorial
• Publications
• Examples
• Software
• Contacts
• Events
Managing Projects

Teaching materials to accompany:

Product Design and Development
Chapter 14

Karl T. Ulrich and Steven D. Eppinger
Product Development Process

Planning → Concept Development → System-Level Design → Detail Design → Testing and Refinement → Production Ramp-Up

Project management is necessary throughout the development process.
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Two Phases of Project Management

- Project Management
  - Project Planning
  - Project Control
The Design Structure Matrix: An Information Exchange Model

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• Inputs are easier to capture than outputs.

Donald V. Steward, Aug. 1981
*IEEE Trans. on Eng'g Mgmt.*
The Design Structure Matrix

(Partitioned, or Sequenced)

Task Sequence

Note:
Coupled tasks can be identified uniquely.
The display of the matrix can be manipulated to emphasize certain features of the process flow.
<table>
<thead>
<tr>
<th>Responsible</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Management</td>
<td>Approve product architecture/configuration</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Define extended layout team</td>
</tr>
<tr>
<td>Systems</td>
<td>Determine project quality objectives</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Establish the need for prototypes</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Establish prototype specifications</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Establish DMU, PMU and prototypes to be developed</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Prepare activity/resource plan</td>
</tr>
<tr>
<td>Systems</td>
<td>Approve layout team leader's activity/resource plan</td>
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<tr>
<td>Planning</td>
<td>Verify the feasibility of the LO team's plan with other plans</td>
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<tr>
<td>Systems</td>
<td>Approve no. of DMU, PMU and prototypes to be developed</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Verify that planning phase is complete</td>
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<tr>
<td>Platform Director</td>
<td>Authorize go-ahead to next phase</td>
</tr>
<tr>
<td>Concurrent Engineering</td>
<td>Provide CAD models in PDM</td>
</tr>
<tr>
<td>Styling Center</td>
<td>Provide style models</td>
</tr>
<tr>
<td>Concurrent Engineering</td>
<td>Convert non-standard CAD models</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Construct DMUs from CAD models</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Verify DMU completeness</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Review issues document from past project</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Define volumes for new components</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Construct DMU for the verification process</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Request missing CAD models</td>
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<tr>
<td>Concurrent Engineering</td>
<td>Provide missing CAD models in PDM</td>
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<tr>
<td>Core Layout Team</td>
<td>Verify DMU using checklist # 80195</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Verify style compatibility</td>
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<tr>
<td>Core Layout Team</td>
<td>Prepare alternate solutions</td>
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<tr>
<td>Core Layout Team</td>
<td>Analyze issues with appropriate members of the layout team</td>
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<tr>
<td>Extended Layout Team</td>
<td>Verify overall DMU with all stakeholders</td>
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<tr>
<td>Core Layout Team</td>
<td>Update issues document</td>
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<tr>
<td>Concurrent Engineering</td>
<td>Modify CAD models</td>
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<td>Styling Center</td>
<td>Modify styling</td>
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<td>Core Layout Team</td>
<td>Modify component positioning in DMU</td>
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<tr>
<td>Top Management</td>
<td>Select two models of style</td>
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<tr>
<td>Core Layout Team</td>
<td>Freeze DMU (STEP1)</td>
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<tr>
<td>Layout TL/Production Test</td>
<td>Define information required for assembly process</td>
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<tr>
<td>Core Layout Team</td>
<td>Specify component connectivity constraints</td>
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<tr>
<td>Concurrent Engineering</td>
<td>Perform detail design for component connectivity</td>
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<tr>
<td>Production Technology</td>
<td>Verify assembly feasibility</td>
</tr>
<tr>
<td>Safety Center</td>
<td>Verify safety objectives</td>
</tr>
<tr>
<td>Vehicle Maintenance</td>
<td>Verify vehicle maintenance feasibility</td>
</tr>
<tr>
<td>Layout Team Leader</td>
<td>Establish/communicate modifications to be done</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Freeze DMU (STEP 2)</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Verify that all critical CAD models are present</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Prepare reference list of CAD drawings for prototyping</td>
</tr>
<tr>
<td>Testing</td>
<td>Build prototypes for design validation (DV1)</td>
</tr>
<tr>
<td>Road Testing</td>
<td>Run experiments on prototypes</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Verify project quality objectives</td>
</tr>
<tr>
<td>Platform Director</td>
<td>Authorize go-ahead to next phase</td>
</tr>
<tr>
<td>Core Layout Team</td>
<td>Freeze DMU (STEP 3)</td>
</tr>
</tbody>
</table>
• Simple network diagrams are easy to understand.
• We cannot represent the coupled/iterative task relationships.
Start with a sequential/parallel network. Use 50/50 task duration estimates. Compute the critical path, noting resources. Insert feeder and project buffers as safety. Ideal buffers are 50% of path duration. Monitor buffer status. Reduce buffers when tasks overrun.

Project Management Example:
Kodak Cheetah Microfilm Cartridge
Three Fundamental Activity Relationships

(a) Sequential
- Receive and Accept Specification
- Concept Generation/Selection
- Design Beta Cartridges

(b) Parallel
- Design Beta Cartridges
- Produce Beta Cartridges
- Develop Testing Program
- Test Beta Cartridges

(c) Coupled
- Test Beta Cartridges
- Design Production Cartridge
- Design Mold
- Select Assembly Equipment
- Design Assembly Tooling

Example: Kodak Cheetah Microfilm Cartridge
PERT Chart and Critical Path

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Receive and Accept Specification</td>
<td>2</td>
</tr>
<tr>
<td>B Concept Generation/Selection</td>
<td>4</td>
</tr>
<tr>
<td>C Design Beta Cartridges</td>
<td>8</td>
</tr>
<tr>
<td>D Produce Beta Cartridges</td>
<td>8</td>
</tr>
<tr>
<td>E Develop Testing Program</td>
<td>5</td>
</tr>
<tr>
<td>F Test Beta Cartridges</td>
<td>2</td>
</tr>
<tr>
<td>G Design Production Cartridge</td>
<td>2</td>
</tr>
<tr>
<td>H Design Mold</td>
<td>2</td>
</tr>
<tr>
<td>I Design Assembly Tooling</td>
<td>4</td>
</tr>
<tr>
<td>J Purchase Assembly Equipment</td>
<td>10</td>
</tr>
<tr>
<td>K Fabricate Molds</td>
<td>6</td>
</tr>
<tr>
<td>L Debug Molds</td>
<td>2</td>
</tr>
<tr>
<td>M Certify Cartridge</td>
<td>2</td>
</tr>
<tr>
<td>N Initial Production Run</td>
<td>2</td>
</tr>
</tbody>
</table>

Task Dependencies:

- A → B → C → D
- E → F → G → H
- I → K → L → M → N

Critical Path: A → B → C → D → G → H → K → L → M → N
**Design Structure Matrix**

**TASK**

- Receive and Accept Specification
- Concept Generation/Selection
- Design Beta Cartridges
- Produce Beta Cartridges
- Develop Testing Program
- Test Beta Cartridges
- Design Production Cartridge
- Design Mold
- Design Assembly Tooling
- Purchase Assembly Equipment
- Fabricate Molds
- Debug Molds
- Certify Cartridge
- Initial Production Run

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
</tr>
</thead>
<tbody>
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<td>X</td>
</tr>
</tbody>
</table>

- Sequential Tasks
- Parallel Tasks
- Coupled Tasks

Example: Kodak Cheetah Microfilm Cartridge
Tasks for Cooking Dinner

Wash and cut salad vegetables (15 minutes)
Toss the salad (2 minutes)
Set the table (8 minutes)
Start the rice cooking (2 minutes)
Cook rice (25 minutes)
Place the rice in a serving dish (1 minute)
Mix casserole ingredients (10 minutes)
Bake the casserole (25 minutes)
Bring the food to the table (2 minutes)
Call the family for dinner (1 minute)
Group Assignment

Part 1
• Prepare a baseline project schedule for cooking the dinner. Show the schedule in Gantt chart form.
• You will need to identify the dependencies among the tasks. State your assumptions.

Part 2
• Prepare an accelerated project schedule.
• Explain why you believe that the accelerated project is feasible. What are the risks?
Product Specifications

Teaching materials to accompany:

*Product Design and Development*
*Chapter 5*

Karl T. Ulrich and Steven D. Eppinger
Product Design and Development
Karl T. Ulrich and Steven D. Eppinger

Chapter Table of Contents
1. Introduction
2. Development Processes and Organizations
3. Product Planning
4. Identifying Customer Needs
5. Product Specifications
6. Concept Generation
7. Concept Selection
8. Concept Testing
9. Product Architecture
10. Industrial Design
11. Design for Manufacturing
12. Prototyping
13. Product Development Economics
14. Managing Projects
Concept Development Process

- **Mission Statement**
- **Identify Customer Needs**
- **Establish Target Specifications**
- **Generate Product Concepts**
- **Select Product Concept(s)**
- **Test Product Concept(s)**
- **Set Final Specifications**
- **Plan Downstream Development**

**Perform Economic Analysis**

**Benchmark Competitive Products**

**Build and Test Models and Prototypes**

**Target Specs**
Based on customer needs and benchmarking

**Final Specs**
Based on selected concept, feasibility, models, testing, and trade-offs
The Product Specs Process

• Set Target Specifications
  – Based on customer needs and benchmarks
  – Develop metrics for each need
  – Set ideal and acceptable values

• Refine Specifications
  – Based on selected concept and feasibility testing
  – Technical modeling
  – Trade-offs are critical

• Reflect on the Results and the Process
  – Critical for ongoing improvement
Product Specifications Example:
Mountain Bike Suspension Fork
Start with the Customer Needs

<table>
<thead>
<tr>
<th>#</th>
<th>NEED</th>
<th>Imp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The suspension reduces vibration to the hands.</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>The suspension allows easy traversal of slow, difficult terrain.</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>The suspension enables high speed descents on bumpy trails.</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>The suspension allows sensitivity adjustment.</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>The suspension preserves the steering characteristics of the bike.</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>The suspension remains rigid during hard cornering.</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>The suspension is lightweight.</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>The suspension provides stiff mounting points for the brakes.</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>The suspension fits a wide variety of bikes, wheels, and tires.</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>The suspension is easy to install.</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>The suspension works with fenders.</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>The suspension instills pride.</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>The suspension is affordable for an amateur enthusiast.</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>The suspension is not contaminated by water.</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>The suspension is not contaminated by grunge.</td>
<td>5</td>
</tr>
<tr>
<td>16</td>
<td>The suspension can be easily accessed for maintenance.</td>
<td>3</td>
</tr>
<tr>
<td>17</td>
<td>The suspension allows easy replacement of worn parts.</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>The suspension can be maintained with readily available tools.</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>The suspension lasts a long time.</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>The suspension is safe in a crash.</td>
<td>5</td>
</tr>
</tbody>
</table>
## Establish Metrics and Units

<table>
<thead>
<tr>
<th>Metric #</th>
<th>Need #s</th>
<th>Metric</th>
<th>Imp</th>
<th>Units</th>
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<tbody>
<tr>
<td>1</td>
<td>1,3</td>
<td>Attenuation from dropout to handlebar at 10hz</td>
<td>3</td>
<td>dB</td>
</tr>
<tr>
<td>2</td>
<td>2,6</td>
<td>Spring pre-load</td>
<td>3</td>
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</tr>
<tr>
<td>3</td>
<td>1,3</td>
<td>Maximum value from the Monster</td>
<td>5</td>
<td>g</td>
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<tr>
<td>4</td>
<td>1,3</td>
<td>Minimum descent time on test track</td>
<td>5</td>
<td>s</td>
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<tr>
<td>5</td>
<td>4</td>
<td>Damping coefficient adjustment range</td>
<td>3</td>
<td>N-s/m</td>
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<tr>
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<td>5</td>
<td>Maximum travel (26in wheel)</td>
<td>3</td>
<td>mm</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>Rake offset</td>
<td>3</td>
<td>mm</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>Lateral stiffness at the tip</td>
<td>3</td>
<td>kN/m</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>Total mass</td>
<td>4</td>
<td>kg</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>Lateral stiffness at brake pivots</td>
<td>2</td>
<td>kN/m</td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>Headset sizes</td>
<td>5</td>
<td>in</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>Steertube length</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td>13</td>
<td>9</td>
<td>Wheel sizes</td>
<td>5</td>
<td>list</td>
</tr>
<tr>
<td>14</td>
<td>9</td>
<td>Maximum tire width</td>
<td>5</td>
<td>in</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>Time to assemble to frame</td>
<td>1</td>
<td>s</td>
</tr>
<tr>
<td>16</td>
<td>11</td>
<td>Fender compatibility</td>
<td>1</td>
<td>list</td>
</tr>
<tr>
<td>17</td>
<td>12</td>
<td>Instills pride</td>
<td>5</td>
<td>subj</td>
</tr>
<tr>
<td>18</td>
<td>13</td>
<td>Unit manufacturing cost</td>
<td>5</td>
<td>US$</td>
</tr>
<tr>
<td>19</td>
<td>14</td>
<td>Time in spray chamber w/o water entry</td>
<td>5</td>
<td>s</td>
</tr>
<tr>
<td>20</td>
<td>15</td>
<td>Cycles in mud chamber w/o contamination</td>
<td>5</td>
<td>k-cycles</td>
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<tr>
<td>21</td>
<td>16,17</td>
<td>Time to disassemble/assemble for maintenance</td>
<td>3</td>
<td>s</td>
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<td>22</td>
<td>17,18</td>
<td>Special tools required for maintenance</td>
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<td>list</td>
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<td>23</td>
<td>19</td>
<td>UV test duration to degrade rubber parts</td>
<td>5</td>
<td>hours</td>
</tr>
<tr>
<td>24</td>
<td>19</td>
<td>Monster cycles to failure</td>
<td>5</td>
<td>cycles</td>
</tr>
<tr>
<td>25</td>
<td>20</td>
<td>Japan Industrial Standards test</td>
<td>5</td>
<td>binary</td>
</tr>
<tr>
<td>26</td>
<td>20</td>
<td>Bending strength (frontal loading)</td>
<td>5</td>
<td>MN</td>
</tr>
</tbody>
</table>
Metrics Exercise:
Ball Point Pen

Customer Need:
The pen writes smoothly.
## Link Metrics to Needs

<table>
<thead>
<tr>
<th>Need</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reduces vibration to the hands</td>
<td>Attenuation from dropout to handlebar at 10 Hz</td>
</tr>
<tr>
<td>2. Allows easy traversal of slow, difficult terrain.</td>
<td>Spring pre-load</td>
</tr>
<tr>
<td>3. Enables high speed descents on bumpy trails.</td>
<td>Maximum value from the Monster</td>
</tr>
<tr>
<td>4. Allows sensitivity adjustment.</td>
<td>Minimum descent time on test track</td>
</tr>
<tr>
<td>5. Preserves the steering characteristics of the bike.</td>
<td>Dampling coefficient adjustment range</td>
</tr>
<tr>
<td>6. Remains rigid during hard cornering.</td>
<td>Maximum travel (26in wheel)</td>
</tr>
<tr>
<td>7. Is lightweight.</td>
<td>Rake offset</td>
</tr>
<tr>
<td>8. Provides stiff mounting points for the brakes.</td>
<td>Lateral stiffness at the tip</td>
</tr>
<tr>
<td>9. Fits a wide variety of bikes, wheels, and tires.</td>
<td>Lateral stiffness at brake pivots</td>
</tr>
<tr>
<td>10. Is easy to install.</td>
<td>Total mass</td>
</tr>
<tr>
<td>11. Works with fenders.</td>
<td>Lateral stiffness at brake pivots</td>
</tr>
<tr>
<td>12. Instills pride.</td>
<td>Steertube length</td>
</tr>
<tr>
<td>13. Is affordable for an amateur enthusiast.</td>
<td>Wheel sizes</td>
</tr>
<tr>
<td>14. Is not contaminated by water.</td>
<td>Maximum tire width</td>
</tr>
<tr>
<td>15. Is not contaminated by grunge.</td>
<td>Time to assemble to frame</td>
</tr>
<tr>
<td>16. Can be easily accessed for maintenance.</td>
<td>Fender compatibility</td>
</tr>
<tr>
<td>17. Allows easy replacement of worn parts.</td>
<td>In-stills pride</td>
</tr>
<tr>
<td>18. Can be maintained with readily available tools.</td>
<td>Time in spray chamber w/o water entry</td>
</tr>
<tr>
<td>19. Lasts a long time.</td>
<td>Cycles in mud chamber w/o contamination</td>
</tr>
<tr>
<td>20. Is safe in a crash.</td>
<td>Time to disassemble/assemble for maintenance</td>
</tr>
<tr>
<td></td>
<td>Special tools required to degrade rubber parts</td>
</tr>
<tr>
<td></td>
<td>UV test duration to degrade rubber parts</td>
</tr>
<tr>
<td></td>
<td>Monster cycles to failure</td>
</tr>
<tr>
<td></td>
<td>Japan Industrial Standards test</td>
</tr>
</tbody>
</table>

### Metric Details

- Spring pre-load: Attenuation from dropout to handlebar at 10 Hz
- Maximum value from the Monster: Spring pre-load
- Minimum descent time on test track: Dampling coefficient adjustment range
- Dampling coefficient adjustment range: Maximum travel (26in wheel)
- Maximum travel (26in wheel): Rake offset
- Rake offset: Lateral stiffness at the tip
- Lateral stiffness at the tip: Lateral stiffness at brake pivots
- Lateral stiffness at brake pivots: Total mass
- Total mass: Lateral stiffness at brake pivots
- Lateral stiffness at brake pivots: Steertube length
- Steertube length: Wheel sizes
- Wheel sizes: Maximum tire width
- Maximum tire width: Time to assemble to frame
- Time to assemble to frame: Fender compatibility
- Fender compatibility: In-stills pride
- In-stills pride: Time in spray chamber w/o water entry
- Time in spray chamber w/o water entry: Cycles in mud chamber w/o contamination
- Cycles in mud chamber w/o contamination: Time to disassemble/assemble for maintenance
- Time to disassemble/assemble for maintenance: Special tools required to degrade rubber parts
- Special tools required to degrade rubber parts: UV test duration to degrade rubber parts
- UV test duration to degrade rubber parts: Monster cycles to failure
- Monster cycles to failure: Japan Industrial Standards test
- Japan Industrial Standards test: Bending strength (frontal loading)
## Benchmark on Customer Needs

<table>
<thead>
<tr>
<th></th>
<th>NEED</th>
<th>Imp</th>
<th>ST Tritrack</th>
<th>Maniray 2</th>
<th>Rox Tahx Quadra</th>
<th>Rox Tahx Ti 21</th>
<th>Tonka Pro</th>
<th>Gunhill Head Shox</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The suspension reduces vibration to the hands.</td>
<td>3</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>The suspension allows easy traversal of slow, difficult terrain.</td>
<td>2</td>
<td>•</td>
<td>••</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>The suspension enables high speed descents on bumpy trails.</td>
<td>5</td>
<td>•</td>
<td>••</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>The suspension allows sensitivity adjustment.</td>
<td>3</td>
<td>•</td>
<td>••</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>The suspension preserves the steering characteristics of the bike.</td>
<td>4</td>
<td>••</td>
<td>••••</td>
<td>••••••</td>
<td>••••••</td>
<td>••••••</td>
<td>•••••••</td>
</tr>
<tr>
<td>6</td>
<td>The suspension remains rigid during hard cornering.</td>
<td>4</td>
<td>•</td>
<td>••</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>The suspension is lightweight.</td>
<td>4</td>
<td>•</td>
<td>••</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>The suspension provides stiff mounting points for the brakes.</td>
<td>2</td>
<td>•</td>
<td>••</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>The suspension fits a wide variety of bikes, wheels, and tires.</td>
<td>5</td>
<td>••••••</td>
<td>••••••</td>
<td>••••••</td>
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## Assign Marginal and Ideal Values

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<th>Ideal Value</th>
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<td>dB</td>
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<td>subj</td>
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Concept Development Process

Mission Statement

- Identify Customer Needs
- Establish Target Specifications
- Generate Product Concepts
- Select Product Concept(s)
- Test Product Concept(s)
- Set Final Specifications
- Plan Downstream Development

Target Specs
Based on customer needs and benchmarking

Final Specs
Based on selected concept, feasibility, models, testing, and trade-offs

Perform Economic Analysis
Benchmark Competitive Products
Build and Test Models and Prototypes
Perceptual Mapping Exercise

Chocolate

KitKat

Nestlé Crunch

Hershey’s w/ Almonds

Hershey’s Milk Chocolate

Opportunity?
Specification Trade-offs

Trade-off Curves for Three Concepts

- Rox Tahx Ti 21
- Maniray 2
- Gunhill Head Shox
- ST Tritrack
- Rox Tahx Quadra
- Tonka Pro

Score on Monster (Gs)

Estimated Manufacturing Cost ($)

Marginal values

Ideal values
## Set Final Specifications

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<th>METRIC</th>
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Quality Function Deployment
(House of Quality)

- relative importance
- customer needs
- target and final specs
- technical correlations
- engineering metrics
- benchmarking on needs
- relationships between customer needs and engineering metrics