Learning Objectives

At the end of this module, you will be able to:

• Explain how lean principles and practices apply to engineering
• Explain the importance of customer value and the “front end” of engineering
• Describe tools for lean engineering
• Describe how lean engineering enables lean in the enterprise, throughout the product lifecycle
• Apply lean engineering techniques to redesign a simulated airplane
2 Key Take Aways

1. Lean thinking applies to the engineering process

2. Engineering plays a critical role in creating value in a lean enterprise
Applying Lean Fundamentals to Engineering

<table>
<thead>
<tr>
<th>Lean Thinking Steps</th>
<th>Manufacturing</th>
<th>Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Visible at each step</td>
<td>Harder to see</td>
</tr>
<tr>
<td></td>
<td>Goal is defined</td>
<td>Goal is emergent</td>
</tr>
<tr>
<td>Value Stream</td>
<td>Parts and materials flows</td>
<td>Information and knowledge flows</td>
</tr>
<tr>
<td>Flow</td>
<td>Iterations are waste</td>
<td>Planned iterations OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Must be efficient</td>
</tr>
<tr>
<td>Pull</td>
<td>Driven by takt time</td>
<td>Driven by enterprise needs</td>
</tr>
<tr>
<td>Perfection</td>
<td>Process repeatable without errors</td>
<td>Process enables enterprise improvement</td>
</tr>
</tbody>
</table>


Information flows in the Engineering Value Stream
## Eight Engineering Wastes

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Over-production</td>
<td>Analysis, reports, tests not needed</td>
</tr>
<tr>
<td>2. Inventory</td>
<td>Unfinished analysis, reports, tests</td>
</tr>
<tr>
<td>3. Transportation</td>
<td>Handoffs, complex validations</td>
</tr>
<tr>
<td>4. Unnecessary Movement</td>
<td>“Stop &amp; Go” tasks. Working on too many projects at one time.</td>
</tr>
<tr>
<td>5. Waiting</td>
<td>Waiting for decisions or waiting for input.</td>
</tr>
<tr>
<td>6. Defective Outputs</td>
<td>Rework due to wrong requirements or input. Errors causing the effort to be redone to correct the problem.</td>
</tr>
<tr>
<td>8. Unused employee creativity</td>
<td>Not engaging engineers in process improvements for engineering</td>
</tr>
</tbody>
</table>

Using Efficient Engineering Processes:
Applying lean thinking to eliminate wastes and improve cycle time and quality in engineering

- **Effort is wasted**
  - 40% of PD effort “pure waste”, 29% “necessary waste” *(workshop opinion survey)*
  - 30% of PD charged time “setup and waiting” *(aero and auto industry survey)*

- **Time is wasted**
  - 62% of tasks idle at any given time *(detailed member company study)*
  - 50-90% task idle time found in Kaizen-type events

VSM Applied to Product Development

- Same basic techniques apply
- Flows are knowledge and information flows rather than physical products
- Process steps may overlap or involve planned iterations
- Value added steps add or transform knowledge, or reduce uncertainty (role of analysis steps)
- Quantifies key parameters for each activity (cycle time, cost, quality defects, inventory, etc.)
- Provides systematic method to improve a process by eliminating waste
PDVSM Used For F16 Build-to-Package Process

Process Before Lean

Process After Lean

Single Piece flow, concurrent engineering, co-location

Courtesy of Lockheed Martin Corporation. Used with permission.

Source: Lockheed Martin Corporation
F-16 Lean Build-To-Package Support Center Results

- **Scope:** *Class II, ECP supplemental, production improvements, and make-it-work changes initiated by production requests*
- **Target improvement:** *Reduce average cycle-time by 50%*
- **Operational:** 1999
- **Future applications:** *Pursuing concept installation in other areas*

849 BTP packages from 7/7/99 to 1/17/00

<table>
<thead>
<tr>
<th>Category</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle-Time</td>
<td>75%</td>
</tr>
<tr>
<td>Process Steps</td>
<td>40%</td>
</tr>
<tr>
<td>Number of Handoffs</td>
<td>75%</td>
</tr>
<tr>
<td>Travel Distance</td>
<td>90%</td>
</tr>
</tbody>
</table>

Courtesy of Lockheed Martin Corporation. Used with permission.

Source: Lockheed Martin Corporation
2 Key Take Aways

1. Lean thinking applies to the engineering process

2. Engineering plays a critical role in creating value in a lean enterprise
Focus on the Front End Where Critical Decisions Are Made

% of Lifecycle “Budget”

Lifecycle Phase

Lean Thinking Needs to Start With Engineering

Customer Defines Product Value

Product Value is a function of the product
- Features and attributes to satisfy a customer need
- Quality or lack of defects
- Availability relative to when it is needed, and
- Price and/or cost of ownership to the customer

80% of a product’s cost is determined by the engineering design:

- Number of parts / tolerances
- Assembly technique (fasteners, EB welding, co-cure)
- Processes (heat treat, shot peen, etc.)
- Tooling approach (matched metal dies, injection molding, etc.)
- Materials (titanium, aluminum, composites, etc.)
- Avionics / software
- Design complexity
- Design re-use

Engineers must make the right choices, early in the process, to insure customer satisfaction and low lifecycle costs.
Supplier Participation Critical

Typically, 60-80% of Value Added by Suppliers

Value Specified → Customer → Value Delivered

Product Development → Value Created → Production

Producible Design Meeting Value Expectations

Early Involvement

Suppliers as Partners
Integrated Product and Process Development - IPPD

- Preferred approach to develop producible design meeting value expectations
- Utilizes:
  - Systems Engineering: Translates customer needs and requirements into product architecture and set of specifications
  - Integrated Product Teams (IPTs): Incorporates knowledge about all lifecycle phases
  - Modern Engineering tools: Enable lean processes
  - Training: Assures human resources are ready

Capable people, processes and tools are required
Tools of Lean Engineering

- Integrated digital tools reduce wastes of handoffs and waiting, and increase quality
  - Mechanical (3-D solids based design)
  - VLSIC (Very Large Scale Integrated Circuit) toolsets
  - Software development environments/Model-Based Engineering
- Production simulation (and software equivalents)
- Common parts / specifications / design reuse
- Design for manufacturing and assembly (DFMA)
- Dimensional/configuration/interface management
- Variability reduction
- Product Lifecycle Management (PLM) software

All of these tools enabled by people working together in Integrated Product Teams (IPTs)
Integrated Digital Tools from Concept to Hardware

Common data base replaces disconnected legacy tools, paper, mock-ups

Courtesy of Boeing. Used with permission.
Common Parts, Design Reuse

8X Multi-Use
LH & RH Mirror

3X Multi-Use
LH & RH Mirror

2X Multi-Use
LH & RH Same

Slat Spar

Slat Spar Splices

Slat Spar Stiffener

Made Symmetrical
LH & RH Same

Made Mirror Image
LH & RH Pair Same

Slat Spar Splices

Reduces part cost and increases quality

Courtesy of Boeing. Used with permission.

Source: Ned Newman, The Boeing Company (C-17)
Part Count Reduction: DFMA

• Why reduce part count?
  • Reduce recurring & non-recurring cost
  • Reduce design, manufacturing, assembly, testing and inspection work
  • Reduce inventory
  • Reduce maintenance spares

• Sometimes requires “performance” trades, but not always – and cost and schedule savings are typically significant
Redesign the airplane! Rules:

- Satisfy customer
  - Moldline (outside shape) must remain exactly the same
  - Landing gear must be (and only landing gear can be) brown
  - In-service quality must improve
  - Increase delivery quantities
- Reduce manufacturing costs
  - Part count ($5/part)
  - Fewer parts = more capacity
- Incorporate suppliers
  - Innovations
  - Reduced part diversity (?)

Present your design to your facilitator
Demonstrate it satisfies all criteria

Photo by Hugh McManus
Lean Engineering in Practice

Now let’s look at some real-world examples of lean engineering benefits…

Courtesy of Boeing. Used with Permission.

Courtesy of Ray Leopold. Used with permission.
Lean Engineering Enables Faster and More Efficient Design

Forward Fuselage Development Total IPT Labor

Months from End of Conceptual Design Phase

Source: “Lean Engineering”, John Coyle (Boeing), LAI Executive Board Presentation, June 1, 2000
F-18 E/F is 25% larger but has 42% fewer parts than C/D

<table>
<thead>
<tr>
<th>Section</th>
<th>C/D Parts</th>
<th>E/F Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Fuselage and Equipment</td>
<td>5,907</td>
<td>3,296</td>
</tr>
<tr>
<td>Center/Aft Fuselage, Vertical Tails and Systems</td>
<td>5,500</td>
<td>2,847</td>
</tr>
<tr>
<td>Wings and Horizontal Tails</td>
<td>1,774</td>
<td>1,033</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14,104</strong></td>
<td><strong>8,099</strong></td>
</tr>
</tbody>
</table>

*Includes joining parts

Source: The Boeing Company

Courtesy of Boeing. Used with permission.
Lean Engineering Enables Faster Delivery Times

Iridium Manufacturing

- Cycle time of 25 days vs. industry standard of 12-18 months
- Dock-to-Dock rate of 4.3 Days

Iridium Deployment

- 72 Satellites in 12 Months, 12 Days
- 14 Satellites on 3 Launch Vehicles, from 3 Countries, in 13 Days
- 22 Successful Consecutive Launches

Source: Ray Leopold, MIT Minta Martin Lecture, May 2004

Courtesy of Ray Leopold. Used with permission.
Lean Engineering Reduces Manufacturing Labor

Additional Reduction in T1 via Virtual Mfg. of Approx. 9 Units

Before Lean Engineering
After Lean Engineering

Reduction in Work Content via Improved Design

Source: “Lean Engineering”, John Coyle (Boeing), LAI Executive Board Presentation, June 1, 2000

Courtesy of Boeing. Used with permission.
**Lean Engineering Wrap Up**

**Lean Engineering**
- Focus on Customer Value
- IPPD and IPTs
- Integrated Digital Design Tools
- Production Simulation
- DFMA
- Design Reuse & Commonality
- Variability Reduction

**Lean Manufacturing**
- High Performance Work Org
- Advance Technology Assembly
- Cycle Time Reduction
- Variability Reduction/SPC
- Value Stream Mapping
- Kaizen Events
- Operator Verification

**Lean Supply Chain**
- Supplier Base Reduction
- Certified Suppliers
- Suppliers as Partners
- Electronic Commerce/CITIS
- IPT Participation

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Adapted from: “Lean Engineering”, John Coyle (Boeing), LAI Executive Board Presentation, June 1, 2000

Courtesy of Boeing. Used with permission.
Reading List

Clausing, D., Total Quality Development, ASME Press, New York, 1994


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Contributors
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