Lean applies to engineering

Lean engineering process eliminates waste, focuses on value creation, and improves cycle time

Efficient and standard process enables better engineering

Integrated Product and Process development (IPPD) and other tools are critical for lean enterprise
Lean Engineering Enables Faster and More Efficient Design

Forward Fuselage Development Total IPT Labor

Source: “Lean Engineering”, LAI Lean Academy™, V3, 2005
Source: “Lean Engineering ”, John Coyle (Boeing), LAI Executive Board Presentation, June 1, 2000

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Lecture #8: October 05, 2005

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Lean Engineering Improves Manufacturing

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

Comparison of Mfg. Labor (hrs) before and after Lean Engineering:

- **76% Slope**
- **83% Slope**

**Reduction in Work Content via Improved Design**

**48% Savings**

Source: “Lean Engineering”, LAI Lean Academy™, V3, 2005
Source: “Lean Engineering”, John Coyle (Boeing), LAI Executive Board Presentation, June 1, 2000

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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

Source: “Lean Engineering”, LAI Lean Academy™, V3, 2005
What is Product Development?

“The set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product”. Ulrich K. and Eppinger, S, Product Design and Development, McGraw-Hill, 1995

Source: Adapted from Aerojet General Corporation Briefing- “Value Stream Analysis Applied to the Product Development Process”
Creating the right products…
- Creating product architectures, families, and designs that increase value for all enterprise stakeholders.

With effective lifecycle & enterprise integration…
- Using lean engineering to create value throughout the product lifecycle and the enterprise.

Using efficient engineering processes.
- Applying lean thinking to eliminate wastes and improve cycle time and quality in engineering.


Framework based upon a decade of Lean Aerospace Initiative research and industry/government implementation
One Approach: Value in PD Emerges Through Uncertainty Reduction

Activities accumulate information, eliminate risk, use resources

Risk → Info → Process Outcome

Value Realized

A Framework for Reducing Uncertainty in PD

<table>
<thead>
<tr>
<th>Uncertainties</th>
<th>Risks/Opportunities</th>
<th>Mitigations/Exploitations</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lack of Knowledge</td>
<td>• Disaster</td>
<td>• Margins</td>
<td>• Reliability</td>
</tr>
<tr>
<td>• Lack of Definition</td>
<td>• Failure</td>
<td>• Redundancy</td>
<td>• Robustness</td>
</tr>
<tr>
<td>• Statistically Characterized Variables</td>
<td>• Degradation</td>
<td>• Design Choices</td>
<td>• Versatility</td>
</tr>
<tr>
<td>• Known Unknowns</td>
<td>• Cost/Schedule (+/-)</td>
<td>• Verification and Test</td>
<td>• Flexibility</td>
</tr>
<tr>
<td>• Unknown Unknowns</td>
<td>• Market shifts (+/-)</td>
<td>• Generality</td>
<td>• Evolvability</td>
</tr>
<tr>
<td></td>
<td>• Need shifts (+/-)</td>
<td>• Upgradeability</td>
<td>• Interoperability</td>
</tr>
<tr>
<td></td>
<td>• Extra Capacity</td>
<td>• Modularity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emergent Capabilities</td>
<td>• Tradespace Exploration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Portfolios&amp;Real Options</td>
<td></td>
</tr>
</tbody>
</table>

<Uncertainty> causes <Risk> handled by <Mitigation> resulting in <Outcome>

Source: HL McManus and Daniel Hastings, Presentation at INCOSE 2005 - Rochester NY, July 2005
Value Measurement

EVMS is commonly a common measure of “value” in PD

Typically generated from WBS at project launch

- Relationship to underlying processes varies
- Level of detail can make it difficult to get program-level perspective on state of work completed, in-process, waiting, or otherwise in play
Waste Drivers – The Causes of Waste

Main Categories of Waste Drivers

- Handing task over to colleague
- Waiting
- Handoffs
- Inventory
- Reinvention
- Poor knowledge reuse
- Large information buffers
- Engineers waiting for data

… and 6 other

… and 36 other

Source: Christof Bauch, Lean Product Development enabling display: Making waste transparent, TUM Thesis 2004

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Complete Framework for Causes of Waste in Product Development

- **Waiting**
  - Waiting for data, answers, specifications, test results, approvals, decisions, releases, review events, signs
  - Information is waiting for capacity available (human or machine)
  - Information is waiting for people
  - Waiting for capacity

- **Transport/Handoffs**
  - Handoffs
  - Stop and go tasks/Task switching
  - Ineffective Communication

- **Waiting for data, answers, specifications, test results, approvals, decisions, releases, review events, signs**
  - Information hunting
  - Remote locations

- **Excessive data traffic**
  - Excessive data storage

- **Lack of direct access**
  - Lack of system discipline

- **Unnecessary detail and accuracy**
  - Unnecessary detail and accuracy

- **Unnecessary features and processes**
  - Excessive features

- **Inappropriate use of competency**
  - Inappropriate use of competency

- **Excessive approvals**
  - Excessive approvals

- **Excessive transactions**
  - Excessive transactions

- **Overall testing equipment and prototypes**
  - Over-dissemination of information

- **Over-production**
  - Over-production

- **Reinvention**
  - Reinvention

- **Defective information**
  - Defective information

- **Poor design re-use**
  - Poor design re-use

- **Poor knowledge re-use**
  - Poor knowledge re-use

- **Unclear roles, responsibilities and rights**
  - Unclear roles, responsibilities and rights

- **Unclear goals and objectives**
  - Unclear goals and objectives

- **Insufficient readiness to cooperate**
  - Insufficient readiness to cooperate

- **Limited IT resources**
  - Limited IT resources

- **Over-production/Unsynchronized processes**
  - Over-production

- **Overload**
  - Overload

- **Exceeding capacity utilization**
  - Exceeding capacity utilization

- **Large batch sizes**
  - Large batch sizes

- **High system variability**
  - High system variability

- **Poor schedule discipline**
  - Poor schedule discipline

- **Poor testing and verification**
  - Poor testing and verification

- **Overproduction**
  - Overproduction

- **Unclear rules for cooperation**
  - Unclear rules for cooperation

- **Unclear goals and objectives**
  - Unclear goals and objectives

- **Poor design re-use**
  - Poor design re-use

- **Poor knowledge re-use**
  - Poor knowledge re-use

- **Poor design re-use**
  - Poor design re-use

- **Poor knowledge re-use**
  - Poor knowledge re-use

Source: Christof Bauch, Lean Product Development enabling display: Making waste transparent, TUM Thesis 2004
Tracking Waste in Programs Using Swim-Lane VSM

Source: Jin Kato, LAI Plenary presentation, March 2004
Making Processes Flow

- Value Stream Mapping and Analysis required for understanding
- Process mapping and Design Structure Matrix methods most powerful for process improvement
- Process mapping customized for PD developed
F-16 Lean Build-To-Package
Support Center PDVSM Results

849 BTP packages

<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>No. of Handoffs</td>
<td>75%</td>
</tr>
<tr>
<td>Travel Distance</td>
<td>90%</td>
</tr>
</tbody>
</table>

PDVSM Used For Spacecraft Mechanical Environmental Test

As-Is Process

To-Be Process

<table>
<thead>
<tr>
<th>Category</th>
<th>Before</th>
<th>After</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Cycle Time</td>
<td>14.7 Days</td>
<td>8.6 Days</td>
<td>41%</td>
</tr>
<tr>
<td>Labor</td>
<td>$1,687,908</td>
<td>$701,564</td>
<td>58%</td>
</tr>
<tr>
<td>Material</td>
<td>$554,304</td>
<td>$132,864</td>
<td>76%</td>
</tr>
<tr>
<td>Travel Distance</td>
<td>85,560 Feet</td>
<td>7,200 Feet</td>
<td>92%</td>
</tr>
</tbody>
</table>

Critical path system test cycle time reduced by 6 days

Source: Lockheed Martin Missiles and Space Systems
Additional Tools of Lean Engineering

- Integrated 3-D solids-based design
- Design for manufacturing and assembly (DFMA)
- Common parts / specifications / design reuse
- Dimensional management
- Variability reduction
- Production simulation

Source: “Lean Engineering”, LAI Lean Academy™, V3, 2005
Design for Manufacturing & Assembly
Reduced F/A-18E/F Parts Count

Forward Fuselage and Equipment
- C/D Parts: 5,907
- E/F Parts: 3,296

Center/Aft Fuselage, Vertical Tails and Systems
- C/D Parts: 5,500
- E/F Parts: 2,847

Wings and Horizontal Tails
- C/D Parts: 1,774
- E/F Parts: 1,033

Total*
- C/D Parts: 14,104
- E/F Parts: 8,099

*Includes joining parts

E/F 25% larger and 42% fewer parts than C/D
Multi-use Parts/Design Reuse

- Fewer part numbers (so more of each) reduces part cost
- Same multi-use part reduces assembly variation
- Same symmetrical part reduces identification errors
Key Characteristics: Critical few product features that significantly affect the quality, performance, or cost of the product

System KCs

Subassembly KCs

Feature KCs

Critical parameters that cannot withstand variation – thus causing a loss (rework, scrap, repair, or failure) in fabrication / production.

Source: Anna C. Thornton, Variation Risk Management, John Wiley & Sons, Inc. 2004
Lean manufacturing requires robust designs and capable processes!

**Variability Reduction**

**Dimensional Management in Product Development**
- Coordinated datums and tools
- Geometric dimensioning and tolerancing
- Process capability data
- 3-D statistical modeling

**Statistical Process Control in Manufacturing**
- Key processes
- Control charting
- Process improvement
- Feedback to design

*Key Characteristics*
- Focus on the significant few

Source: "Lean Engineering", LAI Lean Academy™, V3, 2005
Integrated Product Team

**FUNCTIONAL REPS**

- Program Mgmt
- Engineering
- Manufacturing
- Logistics
- Test & Eval
- Contracting
- Suppliers
- User

(All APPROPRIATE Areas)

Source: “Lean Engineering”, LAI Lean Academy™, V3, 2005

- Build successful programs
- Identify and resolve issues
- Make sound, timely decisions

Team Leader

Working together to:

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RTCE Structure Based on ICE

**Evolution of a Revolution**

ICE: “Integrated Concurrent Engineering”

Developed initially at JPL’s Product Design Center in 1994
Further enabled by creation of ICEMaker© software at Caltech

Not talking about the design, but actually doing the work together!

All design information is passed through a central server - each designer has access to the latest data and sees changes instantly

Source: David Stagney, presentation at LAI Plenary Conference, March 2003
Tremendous Success in the First 9 months!

- Completed at least 20 new product proposals this year
- Trimmed 33% lead time from their standard process
- Created new designs in as little as 4 hours – compared to up to 4 weeks previously
  - Distinct Competitive Advantage in time-sensitive situations
- Higher quality designs are being produced
  - More detail, earlier in process
    - Sharing over 7000 design variables in real time
- Objective decisions
- Focus on System Design - no sub-optimization
- Efficient Process and Motivated Team

Source: David Stagney, presentation at LAI Plenary Conference, March 2003
Emerging Vision of Lean PD

PD process/state awareness and transparency
Value-driven lean management metrics
Flow and pull of Information and decisions
Value stream mapping, improvement activities and processes on a continuous basis

Built on foundation of stable, consistently executed processes that are understood, assessed, and continuously improved by their users
Early decisions are critical - Disciplined lean systems engineering process is essential!

“Fuzzy Front End” Challenges

- Understanding what the customer values
- Deciding which product to pursue from amongst many opportunities
- Selecting the right product concept

Military: Software Development Value Stream(s)

OFP Value Stream

- Documentation (Technical Orders)
- Government Certification
- Support Equipment Software Changes
- Multiple Aircraft Sensor Software Changes
- Multiple Weapons Software Changes

Delivered Product

Best Practices

Identification
- Small multidisciplinary teams
- Adequate funding
- Multiple requirements ID methods used
- Independent assessment of solution

Screening
- Senior level decision
- Active portfolio management
- Strategic plan and resource constraints guide prioritization

Concept
- Requirements given as variables within desired range
- Team remains intact throughout process
- Data driven tradeoff analysis - use of prototypes

Business Case
- Clear, concise product concept, architecture and concept of employment
- Based upon:
  - Product lifecycle strategy
  - Fit with product portfolio
  - Returns to organization

Closure of Technical AND Business Case is Mandatory

Company A’s Front End Process

Front-End Process Flow

Requirements
Identification

Initial
Screening

Concept
Development

Business Case
Development / Final Screen

- Market & Business Need, New Ideas, Technology Developments
- Program Initiation Request
- Commercial Research
- Technical Research Feasibility Phase
- Business Plan

Screening Committee

Product Proposal List

Operational List

Senior Committee

Product Launch List

List maintained by Program Management for the committees

Performance of Company A’s Front End Process

Single high-level Screening Committee (~7 members, VP level)
  Oversees both R&D and planning processes across company
  Approves Program Initiation Requests (PIRs) and commits company funding ($300M-$1B authority—for reference: 1999 annual sales $2.7B)

Work in process (annual):
  ~100 concept solutions considered
  ~10 become PIRs; 10-20 continue further investigation at lower priority
  1-4 PIRs approved for development at final screening stage

Cross-functional front end teams (2-9 people) remain intact until products transition into production
  Conducts both initial studies and more rigorous concept evaluations

Process cycle times:
  Identification: Screening Committee meets every 6-8 weeks
  Concept evaluation: 90-180 days
  New product cycle time: 2-4 years
Enterprise Information Systems for PD

Scope of enterprise-focused PD encompasses multiple stakeholders, stages of the product lifecycle

PDM Systems in Context

PDM is currently largely focused on engineering
One part of a larger IT infrastructure
Many “home grown” applications driven by engineering

Enterprise IT infrastructure handles broader set of functions

Current Issues with PDM Use

PDM remains focused on the design stage

Suppliers moving up the food chain: Need for product data management capability

Change management and data migration are the biggest challenges/pitfalls

Lean principles and practices should be used when implementing PDM capability

PDM enables Lean Enterprise Transformation opportunity to address enterprise value stream

Cross-Platform Commonality Yields Significant PD Benefits in the Auto Industry

Result of concurrent technology transfer and multi-project management

Data based on 6-year MIT IMVP study of 17 auto manufacturers, 103 new programs

Many Opportunities to Benefit from Commonality in Aerospace Systems Over System Lifecycle

- Shared development costs
- Higher productivity
- Higher reliability
- Reduced complexity in supply
- Greater interoperability
- Reduced downtime
- Fewer maintenance hours
- Reduced DMS
- Increased operator competency
- Reduced documentation

Design reuse

- Reduced rework
- Reduced cycle time
- Reduced spares inventory
- Reduced training time
- Reduced training competency
- Reduced inventory
- Reduced tooling

Process reuse

- Reduced testing
- Reduced complexity in supply
- Reduced inventory
- Reduced support equipment

Economies of scale

- Reduced rework
- Reduced cycle time
- Reduced spares inventory
- Reduced training time
- Reduced training competency
- Reduced inventory
- Reduced tooling

Rqmts PD Production Operations

Lower risk

- Reduced time for source selection
- Faster solutions to problems
- Reduced testing
- Economies of scale
- Reduced inventory
- Reduced support equipment
- Reduced documentation

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Source: Matt Nuffort and Eric Rebentisch, LAI Plenary Conference Presentation, April 2001

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Commercial Airline:

Main engine starter is common across 747-400, 767, and 767-300ER

26 airports service these aircraft (11 common)

Airline only has to stock 14 spares, as opposed to 25 if they were not common

Military Helicopters:

85% commonality between UH-1Y and AH-1Z reduces the detachment maintenance personnel requirement from between 4 and 14 people (3 to 12%)

Source: “Managing Subsytems Commonality”, Matt Nuffort and Eric Rebentisch, LAI Presentation, Apr 10, 2001
### Organizational Data

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Implementing PLE (years)</td>
<td>10+</td>
<td>4</td>
<td>2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10</td>
</tr>
<tr>
<td>Market Share (%)</td>
<td>75&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94&lt;sup&gt;c&lt;/sup&gt;</td>
<td>60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>55</td>
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<tr>
<td>Overall Size (no. of people)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5500</td>
<td>2000</td>
<td>1300</td>
<td>5000</td>
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<tr>
<td>Number of Platforms</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Number of Derivatives</td>
<td>12</td>
<td>9&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0</td>
<td>24</td>
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<tr>
<td>PLE Ratio (Derivatives/Platforms)</td>
<td>2.4</td>
<td>1.5</td>
<td>0</td>
<td>3</td>
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<tr>
<td>PLE Cycle Time Ratio (Derivative Cycle Time/Platform Cycle Time)</td>
<td>0.25</td>
<td>0.5</td>
<td>0.35&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0.24</td>
</tr>
</tbody>
</table>

**Firms A and D have relatively more mature PLE capabilities**

**Long history of using the strategy**

**Greater number of derivatives per platform**

**Shorter product cycle times through derivatives**

Conclusions

Lean has demonstrated significant product development-related performance improvements in

Engineering processes
Program outcomes
Company-level performance
Multi-stakeholder enterprise and system lifecycle

Basics of value stream mapping, waste elimination, focus on value, and continuous improvement can be applied in a straightforward way

PD increases focus on information management and decision-making processes across multiple boundaries/stakeholders

Tools to reduce variation, uncertainty, novelty/exceptions, and programmatic disruptions (beginning at the front end of PD through production) enable increased focus on value creation for customer
Resources

LAI web site (lean.mit.edu)

Product lifecycle knowledge area

Presentations:
  Product Development/Product Lifecycle meetings
  LAI Plenary conference breakouts
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Allen Haggerty - MIT, Boeing (ret.)
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Edward Thoms - Boeing, IDS
Stan Weiss - Stanford, Lockheed Martin (ret.)
Venkat Allada - U MO Rolla