Applications of Lean Ideas to the Aerospace Industry
Professor Deborah Nightingale, MIT
Lean Thinking Strategies and Applications
June 25, 2004
Outline

• Lean Aerospace Initiative origin and mission
• Functional lean successes
• Successes through interaction between functions
• Success through enterprise integration and value creation
• Total enterprise integration of all stakeholders
• Enterprise transformation insights
Lean Aerospace Initiative (LAI)
1993 Genesis of the Lean Aerospace Initiative

US Air Force asked:

*Can the concepts, principles and practices of the Toyota Production System be applied to the military aircraft industry?*

Yes!
# Historical Industrial Paradigms

<table>
<thead>
<tr>
<th>Year</th>
<th>Paradigm</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1885</td>
<td>Craft Production</td>
<td>Machine then harden, Fit on assembly, Customization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Highly skilled workforce, Low production rates, High cost</td>
</tr>
<tr>
<td>1913</td>
<td>Mass Production</td>
<td>Parts inter-changeability, Moving production line, Production engineering, “Workers don’t like to think”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unskilled labor, High production rates, Low cost, Persistent quality problems, Inflexible models</td>
</tr>
<tr>
<td>1955-1990</td>
<td>Toyota Production System</td>
<td>Worker as problem solver, Worker as process owner enabled by: Training, Upstream quality, Minimal inventory, Just-in-time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eliminate waste, Responsive to change, Low cost, Improving productivity, High quality product, Greater value for stakeholders</td>
</tr>
<tr>
<td>1993-...</td>
<td>Lean Enterprise</td>
<td>“Lean” applied to all functions in enterprise value stream, Optimization of value delivered to all stakeholders and enterprises in value chain, Low cost, Improving productivity, High quality product, Greater value for stakeholders</td>
</tr>
</tbody>
</table>

**“Lean” is elimination of waste and efficient creation of enterprise value**
Lean Aerospace Initiative

Consortium

➢ Airframe, engine, avionics, missile and space companies
➢ Air Force agencies and System Program Offices (C-17, F-22)
➢ NASA, Army, Navy
➢ Pentagon—OSD, AF Secretariat
➢ International Association of Machinists
➢ Massachusetts Institute of Technology
### LAI Consortium

... a venue for collaboration on Aerospace challenges

<table>
<thead>
<tr>
<th>Avionics/Missiles</th>
<th>Space</th>
</tr>
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<tbody>
<tr>
<td>BAE SYSTEMS North America</td>
<td>Aerojet-General Corp.</td>
</tr>
<tr>
<td>Raytheon Co.</td>
<td>Northrop Grumman Space Technology</td>
</tr>
<tr>
<td>Raytheon RMS, NCS, SAS</td>
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<tr>
<td>Rockwell Collins, Inc.</td>
<td></td>
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<tr>
<td>Textron Systems Corp</td>
<td></td>
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<tr>
<td>Lockheed Martin Systems Integration Group</td>
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<td>L3 Com</td>
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<table>
<thead>
<tr>
<th>Airframe</th>
<th>MIT</th>
<th>Other Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boeing Integrated Defense Systems</td>
<td>Center for Technology, Policy, and Industrial Development</td>
<td>IAM</td>
</tr>
<tr>
<td>Boeing Commercial Airplanes</td>
<td>School of Engineering:</td>
<td>AIA</td>
</tr>
<tr>
<td>Boeing Phantom Works</td>
<td>Aerospace</td>
<td>DAU</td>
</tr>
<tr>
<td>Lockheed Martin Aeronautics Company</td>
<td>Mechanical</td>
<td>IDA</td>
</tr>
<tr>
<td>Northrop Grumman Integrated Systems</td>
<td>Sloan School of Management</td>
<td></td>
</tr>
<tr>
<td>Sikorsky</td>
<td></td>
<td></td>
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<tr>
<td>Bell Helicopter</td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Propulsion/Systems</th>
<th>US Air Force</th>
<th>Other Government</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolls Royce (N.A.)</td>
<td>SAF/AQ</td>
<td>DCMA</td>
</tr>
<tr>
<td>Pratt &amp; Whitney</td>
<td>Aeronautical Systems Center</td>
<td>NASA</td>
</tr>
<tr>
<td>Hamilton Sundstrand</td>
<td>Air Force Research Laboratory</td>
<td>NAVAIR</td>
</tr>
<tr>
<td>Curtiss-Wright Flight Systems</td>
<td>(Materials and Manufacturing Directorate)</td>
<td>AMCOM</td>
</tr>
<tr>
<td>Harris Government Comm.</td>
<td>Space and Missile Center</td>
<td>OUSD(AT&amp;L)</td>
</tr>
<tr>
<td>United Defense Ground Systems Div.</td>
<td>Electronic Systems Center</td>
<td></td>
</tr>
<tr>
<td>Aerospace Testing Alliance</td>
<td></td>
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</tr>
</tbody>
</table>

| SPOs: F-22, C-17 | |

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LAI Mission and Goals

**LAI Mission:** Research, develop and promulgate knowledge, principles, practices and tools to enable and accelerate the envisioned transformation of the greater US aerospace enterprise through people and processes.

1. Support the on-going lean transformation of industry
2. Enable lean value-creating supplier base
3. Support lean transformation of the government
4. Educate and train stakeholders in value-creating lean principles and practices
5. Improve effectiveness of organizations and all the employees across the total enterprise
6. Support member lean implementation efforts by sustaining tools and knowledge base and by sponsoring outreach events
LAI Has Expanded to a Total Enterprise Focus

Functional Lean Successes
- Manufacturing
- Product Dev.
- Supplier Network

“Islands” of Success

Successes Through Interaction Between Functions
Lean Applied to Enabling Processes
- HR
- IT, etc.

Transition from Waste Minimization to Value Creation
Success Through Enterprise Integration

Success Through Total Enterprise Integration of All Stakeholders
- Industry
- Government
- Suppliers
- Employees
Functional Lean Successes

- Manufacturing
- Product Dev.
- Supplier Network

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Lean Works Everywhere

- **Export licensing:**
  - 56 steps to 21 steps
  - 52 handoffs to 5 handoffs
  - Cycle time from 60 days to 30 days
  - 50% 1st pass yield to >90% 1st pass yield

- **Payroll:**
  - Reduced non-value added steps by 50%
  - 15 forms to 1 form
  - Reduced signatures/approvals by 25%

- **Recruiting:**
  - Cycle time from 14 days to 48 hours
  - 50% reduction of paper resumes

- **Proposal:**
  - Cycle time from 30.6 days to 7 days

- **Program support:**
  - $3M savings

- **Interface management:**
  - Proposal, contract, billing, and collection steps
  - Generated $21M additional cash

- **Engineering order release:**
  - Cycle time from 76 to 4 days
  - Total queue time from 56 days to 60 minutes

- **Process definition:**
  - Work package completion cycle from 4 months to 3 wks

- **Financial reporting:**
  - 13 weeks to 3 weeks
Lean Engineering
Case Studies
Lean Engineering Requires a Process

- “Invention is 1% inspiration and 99% perspiration” - TA Edison

- Engineering processes often poorly defined, loosely followed  
  *(LAI Case Studies)*

- 40% of design effort “pure waste” 29% “necessary waste”  
  *(LAI Workshop Survey)*

- 30% of design charged time “setup and waiting”  
  *(Aero and Auto Industry Survey)*

[Diagram showing the distribution of value added, necessary waste, pure waste, and other categories.]
<table>
<thead>
<tr>
<th></th>
<th>Manufacturing</th>
<th>Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Define Value</strong></td>
<td>Visible at each step, defined goal</td>
<td>Harder to see, emergent goals</td>
</tr>
<tr>
<td><strong>Identify Value Stream</strong></td>
<td>Parts and material</td>
<td>Information &amp; knowledge</td>
</tr>
<tr>
<td><strong>Make process flow</strong></td>
<td>Iterations are waste</td>
<td>Iterations often beneficial</td>
</tr>
<tr>
<td><strong>Customer pull</strong></td>
<td>Driven by Takt time</td>
<td>Driven by needs of enterprise</td>
</tr>
<tr>
<td><strong>Perfection</strong></td>
<td>Process repeatable without errors</td>
<td>Process enables innovation and cuts cycle time</td>
</tr>
</tbody>
</table>
# The Seven Info-Wastes

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Over-production</td>
<td>Creation of unnecessary data and information; Information over-dissemination; Pushing, not pulling, data</td>
</tr>
<tr>
<td>2. Inventory</td>
<td>Lack of control; Too much in information; Complicated retrieval; Outdated, obsolete information</td>
</tr>
<tr>
<td>3. Transportation</td>
<td>Information incompatibility; Software incompatibility; Communications failure; Security issues</td>
</tr>
<tr>
<td>4. Unnecessary Movement</td>
<td>Lack of direct access; Reformatting</td>
</tr>
<tr>
<td>5. Waiting</td>
<td>Late delivery of information; Delivery too early (leads to rework)</td>
</tr>
<tr>
<td>6. Defective Products</td>
<td>Haste; Lack of reviews, tests, verifications; Need for information or knowledge, data delivered</td>
</tr>
<tr>
<td>7. Processing</td>
<td>Unnecessary serial production; Excessive/custom formatting; Too many iterations</td>
</tr>
</tbody>
</table>

Source: Lean Aerospace Initiative
Engineering Requires the Seamless Flow of Information and Knowledge

- Information can be an IT problem - solutions exist, but are not easy
- Knowledge is a people problem - requires communication - this is hard!

Program Phase

Communication Key to Flow and Pull

- Flow cannot be achieved until engineering processes move and communicate without errors or waiting

- 62% of tasks idle at any given time (detailed member company study)

- 50-90% task idle time found in Kaizen-type events (case studies)
Co-Location Improves Integration

Scope: Class II, ECP Supplemental, Production Improvements, and Make-It-Work Changes Initiated by Production Requests

Value stream simplified, made sequential/concurrent
Single-piece flow implemented in co-located “Engineering cell”
Priority access to resources

<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>

Source: Hugh McManus, Product Development Focus Team LAI
Case Results for Engineering Release Process

- Value stream mapped and bottlenecks found
- Process rearranged for sequential flow
- Waiting and delays removed
- Reduced Cycle time by 73%
- Reduced Rework of Released Engr. from 66% to <3%
- Reduced Number of Signatures 63%
Successes Through Interaction Between Functions

- Functional Lean Successes
  - Manufacturing
  - Product Dev.
  - Supplier Network

- "Islands" of Success

- Lean Applied to Enabling Processes
  - HR
  - IT, etc.

- Transition from Waste Minimization to Value Creation
- Success Through Enterprise Integration

- Success Through Total Enterprise Integration of All Stakeholders
  - Industry
  - Government
  - Suppliers
  - Employees
Supplier Network Case Studies
F/A-22 Raptor Supplier Network Illustrates Central Challenge

F/A-22 is supported by an extensive multi-tiered supplier network

Supplier Content as % of Contract Value

- LM Aero: 60%
- Boeing: 61%
- Pratt & Whitney: 70%

It is estimated that 60% of supplier costs are also procured.
That puts 36% of the F/A-22 Program cost in sub-tier suppliers.

Lean Supply Chain Management Differs Sharply from Conventional Practices

<table>
<thead>
<tr>
<th>ILLUSTRATIVE CHARACTERISTICS</th>
<th>CONVENTIONAL MODEL</th>
<th>LEAN MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number &amp; structure</td>
<td>Many; vertical</td>
<td>Fewer; clustered</td>
</tr>
<tr>
<td>Procurement personnel</td>
<td>Large</td>
<td>Limited</td>
</tr>
<tr>
<td>Outsourcing</td>
<td>Cost-based</td>
<td>Strategic</td>
</tr>
<tr>
<td>Nature of interactions</td>
<td>Adversarial; zero-sum</td>
<td>Cooperative; positive-sum</td>
</tr>
<tr>
<td>Relationship focus</td>
<td>Transaction-focused</td>
<td>Mutually-beneficial</td>
</tr>
<tr>
<td>Selection criteria</td>
<td>Lowest price</td>
<td>Performance</td>
</tr>
<tr>
<td>Contract length</td>
<td>Short-term</td>
<td>Long-term</td>
</tr>
<tr>
<td>Pricing practices</td>
<td>Competitive bids</td>
<td>Target costing</td>
</tr>
<tr>
<td>Price changes</td>
<td>Upward</td>
<td>Downward</td>
</tr>
<tr>
<td>Quality</td>
<td>Inspection-intensive</td>
<td>Designed-in</td>
</tr>
<tr>
<td>Delivery</td>
<td>Large quantities</td>
<td>Smaller quantities (JIT)</td>
</tr>
<tr>
<td>Inventory buffers</td>
<td>Large</td>
<td>Minimized; eliminated</td>
</tr>
<tr>
<td>Communication</td>
<td>Limited; task-related</td>
<td>Extensive; multi-level</td>
</tr>
<tr>
<td>Information flow</td>
<td>Directive; one-way</td>
<td>Collaborative; two-way</td>
</tr>
<tr>
<td>Role in development</td>
<td>Limited; build-to-print</td>
<td>Substantial</td>
</tr>
</tbody>
</table>
Boeing 737 “Next Generation”-- Synchronized Work Flow throughout the Enterprise Value stream to Support Moving Line

BEFORE
- Reliable & delivered on time, but at what cost?
- Quality emphasis; push system; point solutions
- Imperative (1996): Increase production from 10 to 28 planes per month to keep up with jump in demand & meet delivery commitments -- never before done

AFTER
- Focus on pull, not push
- Quality ➔ Process Kaizen ➔ System Kaizen
- Value stream focus; Nine step lean process
- Breakthrough process redesign
- Entire system synchronized to support moving line
Another Example: Engine Parts Casting
Supplier Worked with Customer Company to
Achieve Synchronized Flow
Case Study Shows Significant Performance Improvements through Supplier Partnerships

Case study: Major producer of complex airframe structures

REDUCED CYCLE TIME
(Main Product Order-to-Shipment, months)

IMPROVED SUPPLIER DELIVERY
(Dock-to-Stock, w/o prior inspection)

REDUCED SUPPLIER DEFECTS
(Defects found at factory floor)
Supplier Partnerships Driven by Strategic Corporate Thrust to Develop Integrated Supplier Networks

<table>
<thead>
<tr>
<th>KEY PRACTICES</th>
<th>BEFORE</th>
<th>AFTER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reduced and streamlined supplier base</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Number of direct production suppliers</td>
<td>542</td>
<td>162</td>
</tr>
<tr>
<td><strong>Improved procurement efficiency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Procurement personnel as % of total employment (%)</td>
<td>4.9</td>
<td>1.9</td>
</tr>
<tr>
<td>• Subcontracting cycle time (days)</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td><strong>Improved supplier quality and schedule</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Procurement (dollars) from certified suppliers (%)</td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>• Supplier on-time performance (% of all shipments)</td>
<td>76.4*</td>
<td>83.0</td>
</tr>
<tr>
<td><strong>Established strategic supplier partnerships</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Procurement dollars under long-term agreements(%)</td>
<td>0</td>
<td>95</td>
</tr>
<tr>
<td>• “Best value” subcontracts as % all awards</td>
<td>50.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Refers to 1991
Early supplier integration into design delivers best value to the customer

- Early and major supplier role in designing complex products with integral system architecture in a collaborative design process -- IPTs; joint configuration control
- Up-front integration of product development, manufacturing processes and supplier networks
- Delegation of progressively greater responsibility for designing, testing and producing more and more complex parts/components
- Leveraging a wealth of in-depth supplier-based technical knowledge and innovative capacity
- Value analysis and target costing to achieve substantial cost reductions
- Product lifecycle commitment & incentivized contracting
Evolution of Early Supplier Integration in Aerospace

“Old” Approach

Prime

Key Suppliers

Subtiers

Arm’s length; interfaces totally defined and controlled

“Current” Lean

Prime

Key Suppliers

Subtiers

Collaborative; but constrained by prior workshare arrangements

“Emerging” Lean

Prime

Key Suppliers

Subtiers

Virtual Team w/o boundaries

Collaborative and seamlessly integrated, enabling architectural innovation

ARCHITECTURAL INNOVATION: Major modification of how components in a system/product are linked together

- Significant improvement in system/product architecture through changes in form/structure, functional interfaces or system configuration
- Knowledge integration over the supplier network (value stream perspective; prime-key suppliers-subtiers; tapping supplier technology base)
Fostering Innovation across Supplier Networks Ensures Continuous Delivery of Value to all Stakeholders

• **Research:** Case studies on F-22 Raptor avionics subsystems -- what incentives, practices & tools foster innovation across suppliers?

• **Major finding:** Innovation by suppliers is hampered by many factors. This seriously undermines weapon system affordability.
  
  • Excessive performance and testing requirements that do not add value
  • One-way communication flows; concern for secrecy; “keyhole” visibility by suppliers into product system architecture
  • Little incentive to invest in process improvements due to program uncertainty; limited internal supplier resources
  • Yearly contract renegotiations wasteful & impede longer-term solutions

• **Recommendations:**
  • Use multiyear incentive contracting & sharing of cost savings
  • Improve communications with suppliers; share technology roadmaps
  • Make shared investments in selected opportunity areas to reduce costs
  • Provide government funding for technology transfer to subtiers
Case Study on Electronic Integration of Supplier Networks

**Challenge:** Electronic integration of supplier networks for technical data exchange as well as for synchronization of business processes

- Important success factors include:
  - **Clear business vision & strategy**
  - **Early stakeholder participation** (e.g., top management support; internal process owners; suppliers; joint configuration control)
  - **Migration/integration of specific functionality** benefits of legacy systems into evolving new IT/IS infrastructure
  - **Great care and thought in scaling-up** experimental IT/IS projects into **fully-functional operational systems**

- Electronic integration of suppliers requires a process of positive reinforcement -- greater mutual information exchange helps build increased trust, which in turn enables a closer collaborative relationship and longer-term strategic partnership
Lean Effect on Aerospace (LEAP) Case Studies
Purpose and Approach

• **Purpose:** Conduct an exploratory study to respond to an LAI Executive Board request:
  • What has been the impact of lean on the US aerospace industry?
  • To what degree have lean principles diffused through the industry?

• **Approach:**
  • **Survey:** Broad overview -- both impact & diffusion
  • **Focused case studies:** Selected cases of lean transformation; diverse set of programs & products; site visits & structured interviews; common method

Assess accomplishments
Identify key enablers and future challenges
Case Studies

Boeing 737 Fuselage
Atlas
F-16

Phalanx
AMRAAM
Commercial Aviation Electronics

737 Fuselage
Boeing Commercial Airplane Group, Wichita, KS
1996-2001

Results:

- 25% decrease in unit cost
- 50% decrease in labor hours/unit (1998-2000)
- Reduced flow time by 21% (from “classic” to “Next Generation” models)

1996 Imperative:

- Keep up with jump in demand – from 10 to 28 planes/mo.

Challenge:

- Reliability & on-time delivered, but at what cost?
- Need to reduce flow time.

- Quality ⇄ Process Kaizen ⇄ System Kaizen
- Value stream focus – Nine step lean process
- Breakthrough process redesign
- Senior leadership commitment
- Worker education – Knowledge at all levels
- Lean maturity assessment
- Supply chain partnerships
F-16 Falcon

Lockheed Martin Aeronautics Company, Ft. Worth, TX
1992 - 2001

Results:
- Constant price with decreasing production rates (180/yr to 24/yr) and significantly improved capability
- Continuous customer-focused improvements

1992 Turning Point:
- Quality problems; cost-overruns
- Pressure from Air Force customer for change
- Need to reduce number & cost of non-conformances

Emphasis on cost and quality; focus on customer & metrics
- Identifying & pursuing core competencies
- Consolidated materiel
- Formal IPT teaming structure
- Wider lean implementation
- Improved engineering response time

Corporate lean focus – top-down commitment to improve entire enterprise


Improvement
Commercial Aviation Electronics
Rockwell Collins - Melbourne, FL 2000-2002

Results:
1st test yield improved by as much as 50%
37% increase in labor productivity

Turning Point:
98% responsiveness & customer acceptance no longer good enough

Challenge:
Improve cycle time & cost beyond what current processes could deliver; respond to competitive pressures

• Value stream mapping – Enterprise-wide
• Creation of single-piece flow in product work cells
• Work cells for simple products, then for more complex products – learning feedback
• Committed leadership & worker solidarity
• Closely-linked relationships with suppliers

Aggressive learning process in lean implementation leading to significant productivity improvements
<table>
<thead>
<tr>
<th>Results:</th>
<th>Integration of repair and upgrade with new system delivery</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>50% reduction in cycle time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Turning Point: 1996</th>
<th>Production &amp; profitability problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge:</td>
<td>Make program more than marginally profitable complex product; difficult to produce; high % of parts produced internally; long lead times</td>
</tr>
</tbody>
</table>

**1996-'98:** Overcame initial hurdles; built on Agile basics
- Phalanx adopts Hughes Agile program; Raytheon acquires Hughes
- Navy privatizes depot; production moves from Tucson to Louisville

**1999-'02:** Integration of program enterprise
- Combined new production & sustainment at the same site
- Fusion of Agile/Six-Sigma/Lean principles
- Cultural transformation – trust-based relationships

Expanding Raytheon Six Sigma throughout the enterprise (to customers and sustainment infrastructure)
AMRAAM

Raytheon Missile Systems (RMS), Tucson, AZ
1992-2001

Results: “...cut cost of a missile from $1 million to $250,000 in 7 years, doubled deliveries in 12 months, improved reliability to three times what RMS contracted for.”*

Integration of production and sustainment

1996

Turning Point: Tough competition between Hughes & Raytheon; need to eliminate waste & create capability to quickly react to changing environment

- Collocated development, production, repair & upgrade operations
- Six Sigma/Lean
- Enterprise-wide transformation focus; empowered workers; extensive training
- Parts count reduction; closely-linked relationships with suppliers
- Trust-based relationship with customer

Six Sigma/Lean tools institutionalized enterprise-wide

Source: * Miller, W. Industry Week Best Plant Award (1999)

web.mit.edu/lean
Results: Production cycle time reduced by 50% (from 48 mo. to 24)
Booster of Atlas III has 11,000 fewer parts than booster of Atlas IIAS

1995
Turning point: Customer demand to reduce cycle time (48 to 24 mo.)

Challenge: Double production capacity without doubling the facility
Reduce cycle time & cost while maintaining mission success

- Emphasis on cycle time reduction
- LM-21 Initiative; Kaizen events; value relationships with suppliers
- Committed & engaged leadership
- Reorganization around value streams
- Significantly reduced parts count
- Engaging workforce in self-reinforcing learning process
- Continued efforts to evolve high-performance supplier network
- Pulling LAI tools/knowledge
Synthesis

- Strong evidence of successful lean transformation in aerospace -- acceleration of progress since 1997
- Significant progress made on factory floor but also noticeable diffusion of lean beyond the factory floor
- Based on survey, diffusion of lean to supplier base seriously lagging
- Case studies show that common achievements embrace quality improvements, cycle time reduction, improved customer satisfaction and COST REDUCTION – significant benefits of lean even across enterprise boundaries
- Case studies underscore importance of enterprise-wide systemic change initiatives & committed top-down leadership
- Customer engagement in change process as a key stakeholder shown to accelerate change process
- Lean and Six Sigma – two mutually complementary change initiatives – merging across the industry into a unified enabler for systemic change
Future Challenges

- Wide recognition of need to continue expanding achievements beyond the factory floor -- engineering, human resources, finance, IT/IS

- Need for greater integration across functional groups & organizational interfaces throughout the program value stream (e.g., with customers, supplier networks)

- Challenge of greater integration within multi-program enterprises along multiple value streams (e.g., design commonality, process standardization)
Success Through Enterprise Integration and Value Creation

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Successes Through Enterprise Integration

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- Suppliers
- Employees
Lean Journey: From the Factory Floor to the Total Enterprise

“A lean enterprise is an integrated entity that efficiently creates value for its multiple stakeholders by employing lean principles and practices."

– Lean Enterprise Value, Murman et al.
Lean Enterprise Value Principles

• Create lean value by doing the right job and doing the job right
• Deliver value only after identifying stakeholder value and constructing robust value propositions
• Fully realize lean value only by adopting an enterprise perspective
• Address interdependencies across enterprise levels to increase lean value
• People, not just processes, effectuate lean value
Enterprise Stakeholders

- Customer Acquirers
- End Users Consumers
- Shareholders
- Partners
- Corporation
- Suppliers
- Society
- Unions

Enterprise

Employees
Creating Value

Delivering what stakeholders want and need.

For example:

- Timely, quality products at a reasonable price to customers
- Competitive returns on investments to shareholders
- Rewarding work environment, stable jobs for workforce
- Early and informed involvement of suppliers
- Environmental and civic responsibility to the public
Value Creation Framework

Value Identification → Value Proposition → Value Delivery
Taking Stock -
JDAM Lean Enterprise
From the Beginning...

- Acquisition Reform Pilot Program
- Minimum Requirements
  - Performance Related - Few Specs, CDRLs
- Waivers from Most FARs Allowed Commercial Suppliers to Join the Team
- Strong Integrated Product Team with Boeing, SPO and Suppliers
Lean Goes in First

- Supplier Team Helped Refine Partitioning of Design (Traded Work Share for Team Benefit)
- Big Picture Look at Kitting
  - Batteries Shipped to Actuator Supplier
  - Containers Shipped to Strake Supplier

Total System Design (Product and Process) Supports Lean
New Start on Factory Design

- EMD Hardware Produced in Batch & Queue Factory
- “Just-in-Time” Learning Used To Set Up New Factory

<table>
<thead>
<tr>
<th>Performance Characteristic</th>
<th>“Business-As-Usual” Forecast</th>
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<tr>
<td>Cycle Time</td>
<td>Hrs 48</td>
</tr>
<tr>
<td>Touch Labor</td>
<td>Min 300</td>
</tr>
<tr>
<td>Floorspace</td>
<td>Ft² 60,000</td>
</tr>
<tr>
<td>People Travel</td>
<td>Ft 1600</td>
</tr>
<tr>
<td>(to/from dock)</td>
<td></td>
</tr>
<tr>
<td>Two-Man Ops</td>
<td>Min 36</td>
</tr>
<tr>
<td>Inventory Turns</td>
<td>- 3</td>
</tr>
<tr>
<td>Safety &amp; Health</td>
<td>- Heavy Lifts</td>
</tr>
</tbody>
</table>

Dismal Forecasts Prior to New Production System

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Boeing Factory Today*

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<tbody>
<tr>
<td>Cycle Time</td>
<td>Hrs 19 (48)</td>
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<tr>
<td>Touch Labor</td>
<td>Min 200 (300)</td>
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<tr>
<td>Floorspace</td>
<td>Ft² 14K (60K)</td>
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<tr>
<td>People Travel</td>
<td>Ft 0 (1600)</td>
</tr>
<tr>
<td>Two-Man Ops</td>
<td>Min 0 (36)</td>
</tr>
<tr>
<td>Inventory Turns</td>
<td>- 10 (3)</td>
</tr>
<tr>
<td>Safety &amp; Health</td>
<td>- Lift Assists!</td>
</tr>
</tbody>
</table>

Huge Improvements from Business-As-Usual!!!

* Until Next Accelerated Improvement Workshop
Accelerated Improvement Workshop Tackled Challenge of Meeting Production Rates

• 40% Increased Throughput
• Removing Work Content & Balancing Line

August Workshop Results

### August Workshop Results

- **Aug 00**
- **Nov 00**
- **Jan 01**

**Daily Rates**

- **Kosovo Surge**

**Work Content**

- 2Q98
- 4Q98
- 2Q99
- 4Q99
- 2Q00
- 4Q00

**POST ASSY**

**ACP**

**P/N FIN**

- 2Q98
- 4Q98
- 2Q99
- 4Q99
- 2Q00
- 4Q00
Improving Downstream

- Mantech Provided Contract Support to Drive Lean Through the Value Stream
- Small and Medium Enterprise Initiative (SMEI)
  - Six JDAM Suppliers Participate in 4-Year Program
  - Training, Action Plans, Metrics
- Pilot Supplier Development Tools
- Incentive for Commercial Suppliers to Take a Risk on DoD Contract
- “Success” Means Supplier Owns the Vision
JDAM Lean Lessons Learned

- Lean is a Long Term Commitment
  - Cannot Let Job Rotations Weaken the Drive
- We Will Never Be Lean Enough
- Lean Gains Importance as Complexity Increases
- Lean is Not a Launch and Leave Tool
  - With a Lean Factory, Scrap Can be Created at Alarming Rates if Suppliers Lose Their Edge or Process Control Moves to the Back Burner
- Lean is not for the Feint of Heart
  - Trust and Relationships Matter
Traditional Value Chain

Material Flow

Suppliers → Raw Material Sourcing → Production → Distribution → Markets

Information Flow
JDAM
Raw Materials to Detonation
“What is the Value Stream beyond the Factory?”

Market
- Target/Mission Planning
- Breakout/Build-up

Distribution
- Transportation/Storage
- DD250

Production
- OEM/Prime

Sourcing
- Subcontractors

Suppliers
- Raw Materials

Value Stream?
Who is the Customer(s)?
What Does Each Customer Value?
Are Support Operations Efficient

Barrier

Value Chain Analyzed & Lean Techniques
Flowed Down To Subs (Waste Removed & Cost Reduced)
Establish A Lean JDAM Enterprise

- Detonation
- Target/Mission Planning
- Breakout/Build-up
- Transportation/Storage
- DD250
- OEM/Prime
- Subcontractors
- Raw Materials

Continuous Improvement

- ID Value Stream/Customers
- Maintain Alignment Across Organizations
- Est. Performance Metrics to Gage Improvements
- Eliminate Non-Value Tasks
- ID Value to All Customers
- Eliminate Casual Interactions
- Pursuit of Excellence
Total Enterprise Integration of All Stakeholders

Functional Lean Successes
- Manufacturing
- Product Dev.
- Supplier Network

“Islands” of Success

Successes Through Interaction Between Functions
- Lean Applied to Enabling Processes
  - HR
  - IT, etc.

Success Through Enterprise Integration

Transition from Waste Minimization to Value Creation

Success Through Total Enterprise Integration of All Stakeholders
- Industry
- Government
- Suppliers
- Employees

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Air Force Lean Now Initiative Established in Collaboration with LAI

- **What:** Lean Transformation of Air Force Material Command
- **Why:** Provide On Time, Effects Based Capability to the War Fighter
- **Who:** Lean Aerospace Initiative Consortium Members Teamed with AFMC within the LAI venue
LAI Has Provided Lean Now Deployment Venue

- AFMC Leadership

- Industry Members Provided Strong Support
  - Many Members Provide Near “Full time” SMEs at no cost

- Lean Now Workshop Developed by LAI Industry Members, MIT and Air Force Team … The Best of the Best!

- One Week Facilitator Course Developed…LAI Industry Members, MIT, Air Force…The Best of the Best!

- LAI Developed Tools Deployed
  - LESAT, GLESAT, PDVSMA, LEV Simulation Game, Enterprise TTL
  - MIT Process to develop feedback of tools and methods

Supporting LAI Members
- Boeing, Lockheed Martin, MIT, Northrop Grumman, Pratt and Whitney, Raytheon, Rockwell Collins, Rolls-Royce, Textron
Prototype Focus…the Interfaces

CTF (F/A-22)
LAI SME
F/A-22 SPO
MIT LAI
LM Aero
Boeing
Discipline Experts

Alpha Contracting
(Global Hawk)
Northrop-Grumman
Raytheon
MIT LAI
Global Hawk SPO

Contract Closeout (F-16)
LAI SME
MIT/LAI
F-16 SPO
DCMA, DCAA, DFAS
LM Aero

Turbine Engine Test (AEDC)
LAI SME
MIT/LAI
AEDC, AFMC, ASC, AFRL, ALC, AFFTC, NAVAIR, GE, RR and P&W

ITSP (ESC)
LAI SME
Discipline Experts

Procurement Request
(Ogden ALC)
MIT LAI
Discipline Experts
Local Results and Behavior Change…
New Capabilities and Skills,

CTF OFP Load (F/A-22)
• Selected improvements within processes:
  • Software Install Time Reduced from 97 hours to 46 hours
    • Validated on the F/A-22
  • 50-95% Span Time Reduction
  • 56% reduction in non-value added steps
  • 91% reduction in part traveled distance
• Implemented web based spares ordering system
• Process improvements:
  • Parts purging within CTF compound
  • Dedicated parts research
• CTF deploying lean (VSM, Kaizens, Internal Coaches, etc…)

Alpha Contracting (Global Hawk)
• 37% Initial cycle time reduction for Alpha Contracting
• Created Enterprise Level Tier I and Production Tier II VSM’s
• Project Plans Ongoing (10 Major Events Completed):
  • ISS $2M savings per ship set / $49M life cycle savings
  • AICS/GICS $33.8M life cycle savings
  • 38% Production delivery cycle time reduction per BL-10
  • Additional $5M Est. Savings for Producibility Initiatives
Lean Deployments Have Matured To Large Enterprise Deployments

AEDC Groundbreaking Initiative:

- Total Enterprise Approach - Not Program Specific
- Numerous Organizational Interfaces
  - Government-industry
  - Tri-service: Army, Navy, And Air Force
  - Cross Functional: S&T, Ground Test, Flight Test, Program Office, Depot Maintenance, Logistics, OEM Design And Manufacture
- Embedded Contractor (ATA) In AEDC Daily Operations
  - Recently Joined LAI as Full Member
Enabling Capabilities of Lean Enterprise Transformation

Wave 1 Lean Now Projects Complete

Wave 2 Prototypes Begin

52+ Events/Projects for F/A-22, GH, F-16 Hosts

Lean Now Facilitators Course Developed

Deploying Lean (VSM, Kaizens, Internal Coaches, etc…)

Enterprise Engagement

Enterprise Transformation 2004

2002 Prototypes

2004 Prototypes

AEDC Turbine Engine Test

OO-ALC Procurement Request

OO-ALC

Transition to Lean roadmap

Deployment Roadmap

EVSMA

Strategic Objectives

Current/Future State

Contract Closeout

Contracting

GH

GH ISS

ICS

Load

OFP

CTF

CTF

2002 2004

Alpha

GH

GH ISS

ICS

Lean Now Workshop Developed

GH

OFP

Load

Contract Closeout

Deployment

Lean Now

Enterprise Leadership Team

Executive Leadership Team

Transition to Lean roadmap

Strategy

Engagements

Begin

10 Lean Workshops/Facilitator Training

 strategic

 engagements

 begin

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Enterprise Assessment & Implementation Insights
Integrated Enterprise

Customer

Product Support

Finance, H/R, Legal, etc...

Supplier Network

Manufacturing Operations

Product Development
Process Architecture
View of Lean Enterprise

Life Cycle Processes

Enabling Infrastructure Processes

Enterprise Leadership Processes

Source: Lean Aerospace Initiative, MIT © 2001
Enterprise Process Architecture

Life Cycle Processes
- Business Acquisition and Program Management
- Requirements Definition
- Product/Process Development
- Supply Chain Management
- Production
- Distribution and Support

Enabling Infrastructure Processes
- Finance
- Information Technology
- Human Resources
- Quality Assurance
- Facilities and Services
- Environment, Health, and Safety

Enterprise Leadership Processes
- Strategic Planning
- Business Models
- Managing Business Growth
- Strategic Partnering
- Organizational Structure and Integration
- Transformation Management
What Is LESAT?

- A tool for self-assessing the present state of “leanness” of an enterprise and its readiness to change
- Comprised of:
  - Capability maturity model for enterprise leadership, life cycle and enabling processes
  - Supporting materials: (Facilitator’s Guide, Glossary, etc.)

Source: Lean Aerospace Initiative, MIT © 2001
LESAT Structure is Consistent with Enterprise Architecture

Section I  Section II  Section III

Life Cycle Processes  Lean  Life  Enabling
Enabling Infrastructure Processes  Transformation  Cycle  Infrastructure
Enterprise Leadership Processes  / Leadership  Processes  Processes

Source: Lean Aerospace Initiative, MIT © 2001

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LESAT as a Leading Indicator of Improved Enterprise Value Delivery

State of Enterprise Leanness
(LESAT - Leading Indicators)

Enterprise Performance Measures
(Lagging Indicators)

Life Cycle Processes
(LESAT Sec II)

Enabling Infrastructure Processes
(LESAT Sec III)

Enterprise Leadership Processes
(LESAT Section I)

Customer focus of Sec II creates

Reduced waste in Sec II & III cuts costs and creates

Lean in Sec I, II & III creates a more involved and empowered workforce

Customer Value

Financial Value

Employee Value

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Leading Indicator Relations in Lean Enterprise Transformation

- **Enterprise Leadership Processes** (Drive Lean Change)
  - **Enabling Infrastructure Processes** (Support LCP’s)
  - **Life Cycle Processes** (Revenue Generation)

Leads, Enables

Enables

Leads, Enables
Findings: Leadership Drives Transformation of Life Cycle Processes

Source: Cory Hallam, 2003

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Findings: Leadership Drives Transformation of Enabling Processes

$y = 0.7458x + 0.7466$
$R^2 = 0.6438$

Source: Cory Hallam, 2003
Findings: Strong Infrastructure Enables Lifecycle Transformation

\[
y = 1.0779x - 0.2044 \\
R^2 = 0.6699
\]

Source: Cory Hallam, 2003
Main Empirical Findings

- Industry is in its lean enterprise infancy
- There are significant correlations in the lean maturity of enterprise processes
- Leadership commitment is critical to lean enterprise transformation
- Infrastructure processes such as IT and HR are critical lean enterprise enablers
- Management information feedback is present in high lean maturity enterprises
“The soft stuff is the hard stuff"

- Chris Cool, VP, Lean Enterprise
  Northrop Grumman, ISS Sector
Enterprise Transformation Insights

• Transformation is continuous and takes years, not months
• Senior executive leadership, commitment, and involvement are critical success factors in enterprise transformation
• Biggest challenge is institutionalizing lean and sustaining the change
• Enterprises must be viewed as a holistic system

Enterprise leader **must** lead a change initiative of this magnitude -- cannot be delegated!
“The notion that you can drive lean from the bottom up is ‘pure bunk’.”

-Mike Rother
Becoming Lean, 1998
Enterprise Leadership

• Major undertaking to transform enterprise from mass-production orientation to one based on Lean
• Comprehensive change initiative - touches every person and process in the organization
• Enterprise Leader must lead a change initiative of this magnitude
• Success depends upon the personal involvement, understanding, and leadership of enterprise leader
• CANNOT BE DELEGATED
Implications for Industry

• Establish senior leadership commitment to begin transformation
• Improve maturity in leadership/transformation practices
• Create formal information feedback mechanisms to
  • prioritize strategically important lean improvement efforts
  • build on lean capabilities
  • build leadership support for continued lean change/operations
The Journey to a Lean Total Integrated Enterprise is Extremely Challenging
Questions