16.885J/ESD.35J
Aircraft Systems Engineering

Lean Systems Engineering II

November 18, 2003

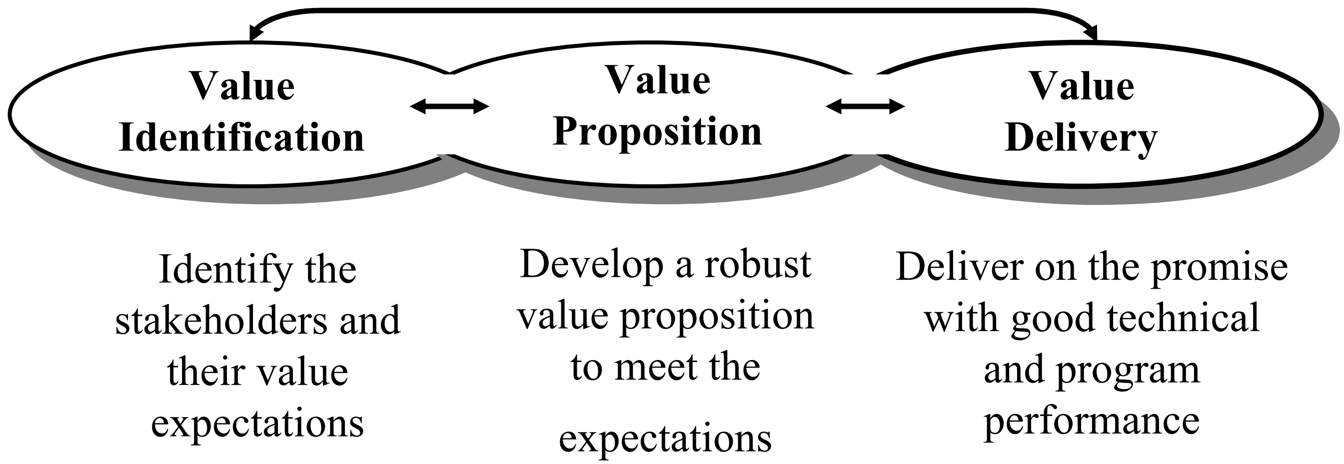
Prof. Earll Murman

Systems Engineering and Lean Thinking

- ***Systems Engineering*** grew out of the space industry in response to the need to deliver technically complex systems that worked flawlessly upon first use
  - SE has emphasized technical performance and risk management of complex systems.
- ***Lean Thinking*** grew out of the Japanese automobile industry in response to the need to deliver quality products with minimum use of resources.
  - Lean has emphasized waste minimization and flexibility in the production of high quality affordable products with short development and production lead times.
- Both processes evolved over time with the ***common goal of delivering product or system lifecycle value to the customer.***

Lean Systems Engineering

Value Phases

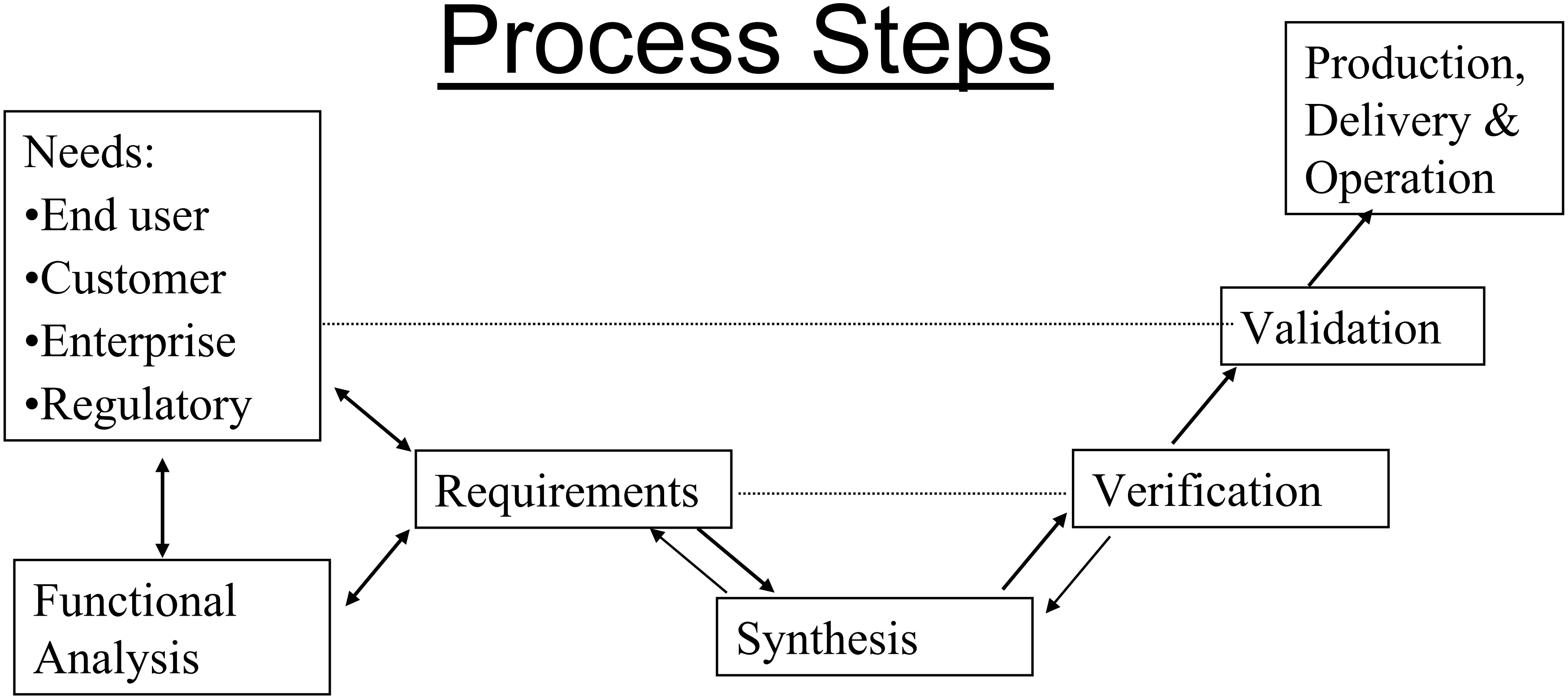


- Lean Systems Engineering (LeanSE) ***applies the fundamentals of lean thinking to systems engineering*** with the objective of delivering best lifecycle value for complex systems and products.
- An example of lean thinking applied to systems engineering is the use of IPPD and IPTs - see Lean Systems Engineering I lecture.
- Understanding and delivering ***value*** is the key concept to LeanSE
- A broad definition of *value is how various stakeholders find particular worth, utility, benefit, or reward in exchange for their respective contributions to the enterprise.*

Today's Topics

- Recap of system engineering fundamentals
- Revisit fundamentals of lean thinking
  - Value principles, the guide to applying lean thinking
  - Lean Enterprise Model (LEM), a reference for identifying evidence of lean thinking applied to an enterprise
- Comparison of F/A-18E/F practices to the LEM
  - An example of looking for evidence of LeanSE
- Examples of LeanSE extracted from various Lean Aerospace Initiative research projects

Simplified Systems Engineering Process Steps



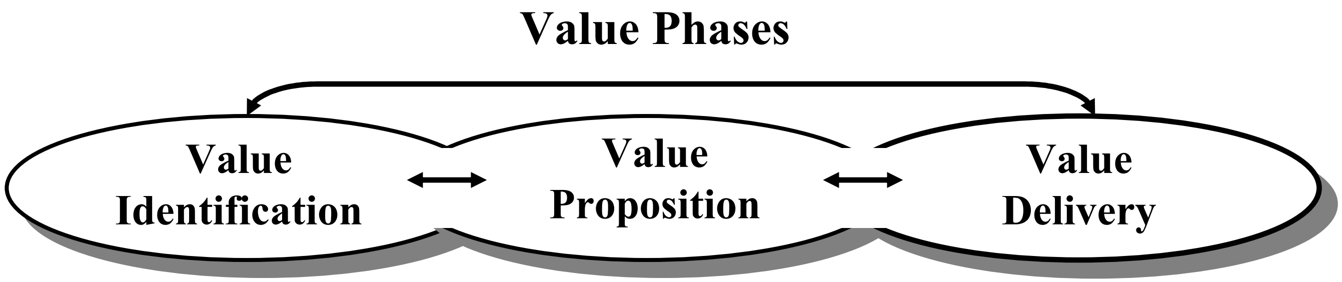
Systems engineering process is applied recursively at multiple levels: system, subsystem, component.

Source: Adapted f rom Jackson, S. *Systems Engineering for Commercial Aircraft*

Other Systems Engineering Elements

- Allocation of functions and “budgets” to subsystems
- Interface management and control
- IPPD
- Trade studies
- Decision gates or milestones
  - SRR, SDR, PDR, CDR,…
- Risk management
- Lifecycle perspective

Fundamentals For Developing a Lean Process



- Specify value: Value is defined by customer in terms of specific products & services
- Identify the value stream: Map out all end-to-end linked actions, processes and functions necessary for transforming inputs to outputs to identify and eliminate waste (Value Stream Map or VSM)
- Make value flow continuously: Having eliminated waste, make remaining value-creating steps “flow”
- Let customers pull value: Customer’s “pull” cascades all the way back to the lowest level supplier, enabling just-in-time production
- Pursue perfection: Pursue continuous process of improvement striving for perfection

Source: James Womack and Daniel T. Jones, *Lean Thinking* (New York: Simon & Schuster, 1996).

Value - Slack's definition

A more specific definition of value useful for system development is given by Slack:

"Value is a measure of worth of a specific product or service by a customer, and is a function of (1) the product's usefulness in satisfying a customer need, (2) the relative importance of the need being satisfied, (3) the availability of the product relative to when it is needed and (4) the cost of ownership to the customer."

(1) and (2) relate to *Performance (or quality)*

(3) relates to *Schedule*

(4) relates to *Cost/Price*

Achieving Performance, Schedule, and Cost objectives with acceptable risk is the generic challenge in developing products and systems.

Source: Slack, R, "The application of Lean Principles to the Military Aerospace Product Development Process" MIT SM Thesis, Dec 1998

Examples of Value Metrics

Performance

- Vehicle performance (range-payload, speed, maneuver parameters)
- Ilities (Quality, reliability, maintainability, upgradability)
- System compatibility (ATC, airport infrastructure, mission management)
- Environmental (Noise, emissions, total environmental impact)

Cost

- Development costs
- Production costs, nonrecurring and recurring
- Operation costs
- Upgrade or conversion costs
- Disposal costs

Schedule

- Acquisition response time, or lead time
  - Recognition time
  - Initiation time
  - Product development cycle time
- Order to ship time
  - Lead time
  - Production cycle time
- In-service turn around time

Value provides a multidimensional framework

Value: A Symbolic Representation

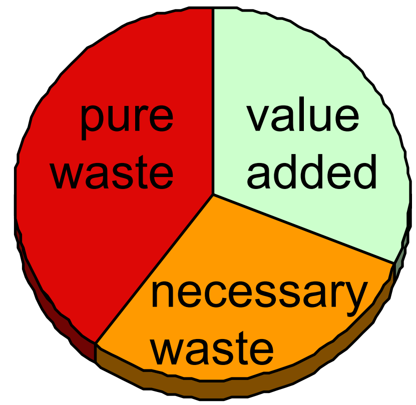
$$Value = \frac{f_p(performance)}{f_c(\cos t) \bullet f_t(time)}$$

- Similar to definition developed by value engineers, value = function/cost
- Value defined by the customer for each system or product
- Comprised of specific performance, cost, schedule metrics with weightings representing customer utility functions and normalizations for consistency

Source: Murman, E.M., Walton, M., and Rebentisch, E. "Challenges in the Better, Faster, Cheaper Era of Aeronautical Design, Engineering and Manufacturing", The Aeronautical Journal, Oct 2000, pp 481-489

Waste Happens In Product Development

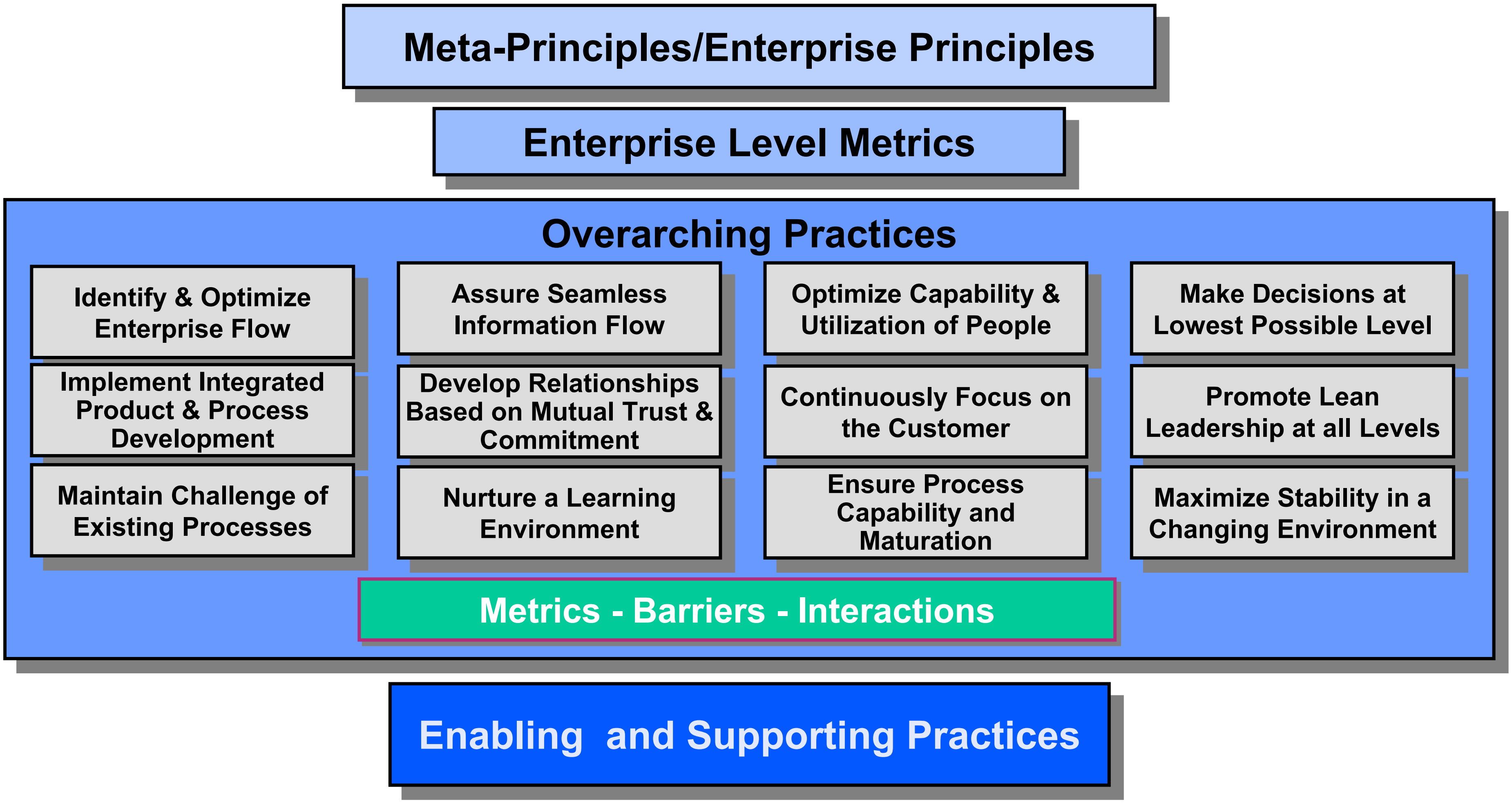
- Effort is wasted
  - 40% of PD effort "pure waste", 29% "necessary waste" ***(LAI PD workshop opinion survey)***
  - 30% of PD charged time "setup and waiting" ***(aero and auto industry survey)***
- *Time* is wasted
  - 62% of *tasks* idle at any given time ***(LAI detailed member company study)***
  - 50-90% task idle time found in Kaizen-type events



Cycle time and downstream costs are the keys

Source: "Seeing and Improving the Product Development Value Stream", Hugh McManus LAI Executive Board Presentation, June 1, 2000

Lean Enterprise Model Overview



LEM provides a baseline reference for benchmarking lean enterprises

Source: web.mit.edu/lean

Example - Analysis of the F/A-18E/F

- Lean Aerospace Initiative case study in Summer 2000
  - Study team: Alexis Stanke (lead), Lt. Col. Rob Dare, Prof. Murman
  - Documented in Stanke's LAI Presentation 22 Sep 00 and SM Thesis
- Concentration on Product Development and Acquisition
  - Data collection included interfaces with suppliers, production, logistics, product and business support, and program management
  - Secondary sources included production
- Over 80 people from 3 organizations interviewed
  - NAVAIR - Navy Program Office
  - Boeing, St. Louis - Prime Contractor
  - Northrop Grumman, El Segundo - Principal Sub-Contractor
- Attended program meetings
- Collected program documentation
- Lived the program culture during the site visits

F/A-18E/F Super Hornet The Most Capable and Survivable Carrier-Based Combat Aircraft

Super Hornet Requirements

- 25% greater *payload*
- 3 times greater ordnance *bringback*
- 40% increase in unrefueled *range*
- 5 times more *survivable*
- Designed for future *growth*

- **Replace the A-6, F-14 and earlier model Hornets**
- **Reduced support costs**
- **Strike fighter for multi-mission effectiveness**

Air Superiority	**Fighter Escort**	**Reconnaissance**	**Aerial Refueling**	**Close Air Support**	**Air Defense Suppression**	**Day/Night Precision Strike**	**All Weather Attack**

Highly capable across the full mission spectrum

Enterprise Principles

- Right Thing at the Right Place, the Right Time, and in the Right Quantity
  - Weapon system which meets and exceeds 1) technical requirements, 2) cost, and 3) schedule goals
    - F/A-18E/F changed the perspective that achieving 2 out of 3 was good enough
  - Program goals set at the contract award in 1992 were met
  - Philosophy that the “airplane is the boss” when trades are made
- Effective Relationships within the Value Stream
  - Establish and maintain program credibility
  - Hornet Industry Team
  - Culture change within the organizations involved with the 18 Aircraft Agreement

Source: “Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model”, Alexis Stanke, LAI Product Development Workshop, September 22, 2000

Enterprise Principles cont.

- Continuous Improvement
  - Numerous program management practices introduced
    - Created strategies and practices that can be institutionalized and adhered to
  - Program trades were made with a long-term view of the path ahead instead of looking for short-term rewards
  - Early success of the program set high expectations for future phases
- Optimal First Delivered Unit Quality
  - OPEVAL report released in Feb. 00 with a rating of "operationally effective and suitable"
  - Sea Worthiness trial performance

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

1: Identify and Optimize Enterprise Flow

"Optimize the flow of products and services, either affecting or within the process, from concept design through point of use."

- Collocation of product and people
- Alignment of organizational structure to the product work breakdown structure
- Common CAD modeling software used across the enterprise
- Low Rate Expandable Tooling (LRET) minimized number of jigs and movements
- Work content in production areas is reorganized to prevent bottlenecks

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

2: Assure Seamless Information Flow

"Provide processes for seamless and timely transfer of and access to pertinent information."

- Open and honest communication
  - Ask for help needed
- Internet technology and company web sites enable sharing data and information within the enterprise
  - Access to data is timely and efficient
  - Databases are linked throughout the value chain
- Metrics shared weekly throughout the enterprise
- "Drop Dead" philosophy
  - Documenting your job so that someone could come in the next day and pick it up where you left off

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

3: Optimize Capability and Utilization of People

"Assure properly trained people are available when needed."

- Using an 18 month production gap as an opportunity for career and skill development programs
- IPT structure broadened functional responsibilities to facilitate the development of a flexible workforce
- Choose the best person to solve the problem, regardless of which part of the enterprise they are from

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

4: Make Decisions at Lowest Possible Level

"Design the organizational structure and management systems to accelerate and enhance decision making at the point of knowledge, application, and need."

- Organization chart was aligned with the product work breakdown structure to establish multi-disciplinary teams
- Joint Configuration Change Board (JCCB) is an example of how responsibility for decisions is shared throughout the value chain and how well-defined processes expedite this decision process
- People are empowered to make decisions through the flow down of requirements and metrics creating Responsibility, Authority, and Accountability (RAA)

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

5: Implement Integrated Product and Process Development

"Create products through an integrated team effort of people and organizations which are knowledgeable of and responsible for all phases of the product's life cycle from concept definition through development, production, deployment, operations and support, and final disposal."

- Systems engineering practices were used in product design
- Requirements were established and flowed down to the responsible teams (RAA)
- Risk management process is structured and shared throughout the enterprise
- Design for manufacturing and assembly led to 42% reduction of part count over C/D
  - Low Rate Expandable Tooling (LRET) design and Variation Simulation Analysis (VSA)

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

5: Implement Integrated Product and Process Development - Continued

"Create products through an integrated team effort of people and organizations which are knowledgeable of and responsible for all phases of the product's life cycle from concept definition through development, production, deployment, operations and support, and final disposal."

- The capability for growth and adaptability was designed in and continues to improve through the Enhanced Forward Fuselage (EFF) redesign
- Many stakeholders were involved in pre-contract planning
- Earned Value tracking of cost and schedule metrics incorporated through the "perform to plan" philosophy

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

6: Develop Relationships Based on Mutual Trust and Commitment

"Establish stable and on-going cooperative relationships within the extended enterprise, encompassing both customers and suppliers."

- Program leadership emphasis on maintaining credibility
- Leadership brings people together and facilitates working together by preventing strong personalities from taking over
- Labor-management partnerships are established through High Performance Work Organizations (HPWO) where issues can be worked by a team regardless of affiliation
- Many functions were involved in the program definition process early and given an equal voice to establish common objectives and cooperative relationships

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

7: Continuously Focus on the Customer

"Proactively understand and respond to the needs of the internal and external customers."

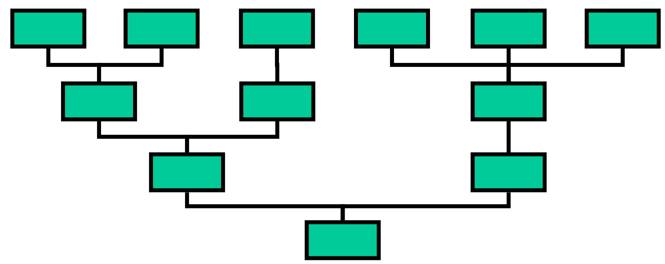
- Award fee periods each had unique criteria which were understood at the beginning of each period to optimize the flexibility of the contract to changing requirements
- Enterprise stakeholders worked effectively to resolve issues found during test - Integrated Test Team
  - Wing drop issue and solution
- Contractors supported customer's requirements definition process
- Organizational counterparts throughout the enterprise with active working relationships

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

8: Promote Lean Leadership at All Levels

"Align and involve all stakeholders to achieve the enterprise's lean vision."

- Leadership alignment across enterprise
- Management support mentality - turn the organization chart upside down



- Program management training
  - Boeing Program Management Best Practices
  - Integrated command media to describe IPT processes
- Activities to implement lean practices in the production areas

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

9: Maintain Challenges of Existing Processes

"Ensure a culture and systems that use quantitative measurement and analysis to continuously improve processes."

- Cost Reduction Initiative (CRI) structure is a way to generate, evaluate, and implement improvements
- Risk management process includes mitigation plans to fix problems systematically using root cause analysis
- Jointly established targets for continuous improvement are included on the 2030 roadmap, generated by the Hornet Roadmap Team using a structured QFD process
- Management pushed to evaluate the alternative no growth (in cost or weight) solution in terms of risk

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

10: Nurture a Learning Environment

"Provide for the development and growth of both organizations' and individuals' support of attaining lean enterprise goals."

- Lessons learned databases are used to capture, communicate, and apply experience generated learning
  - Over 900 lessons learned from the A/B and C/D models were incorporated in the E/F version
- Some benchmarking was done early in the program
- Knowledge is utilized throughout the enterprise regardless of where it originates

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

11: Ensure Process Capability and Maturity

"Establish and maintain processes capable of consistently designing and producing the key characteristics of the product or service."

- Common databases, tools, and practices have been defined throughout the value chain
- Enhanced Forward Fuselage (EFF) project is a large scale example of exploiting process maturation for cost benefit
- Process capability and maturity leveraged with other programs

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

12: Maximize Stability in a Changing Environment

"Establish strategies to maintain program stability in a changing customer driven environment."

- Program was never rebaselined
- Multi-year contract signed June 2000
- "Perform to Plan" philosophy led directly to the notable schedule performance of the program
- Maintained stable workforce capability over an 18 month production gap
- Program was structured to absorb changes with minimal impact by using a Block upgrade strategy
- State of the art technology was properly judged, facilitating programming high risk developments off critical paths

Source: "Best Lifecycle Value, the F/A-18E/F, and the Lean Enterprise Model", Alexis Stanke, LAI Product Development Workshop, September 22, 2000

Summary of F/A-18E/F Case Study

- High correlation between F/A-18E/F observed practices and the LEM Overarching and Enabling Practices
  - Additional enabling practices observed
- F/A-18E/F used a disciplined systems engineering process including establishing and managing requirements, IPPD, trade studies, risk management, earned value, and more.
- F/A-18E/F achieved or exceeded all program goals

Observation:

The F/A-18E/F program illustrates the application of Lean Systems Engineering.

Examples of Lean Systems Engineering

- Extracted from various Lean Aerospace Initiative research projects
- Covering various phases of the lifecycle
  - Requirements generation and flowdown
  - Design synthesis
  - Production
  - Flight testing
- Cited references on LAI Website web.mit.edu/lean

Question: What are the LEM principles and practices evident in the following examples?

Best Practices in User Needs/Requirements Generation - Motivation

- Multiple projects are always competing for limited resources in large organizations
- High percentage of product lifecycle cost is determined in “front end” activities
- Prior research showed significant program cost growth due to requirements problems
- Strong link between budget instability and poorly performing front end process
- Significant performance improvements in commercial firms in recent years attributed improving front end processes

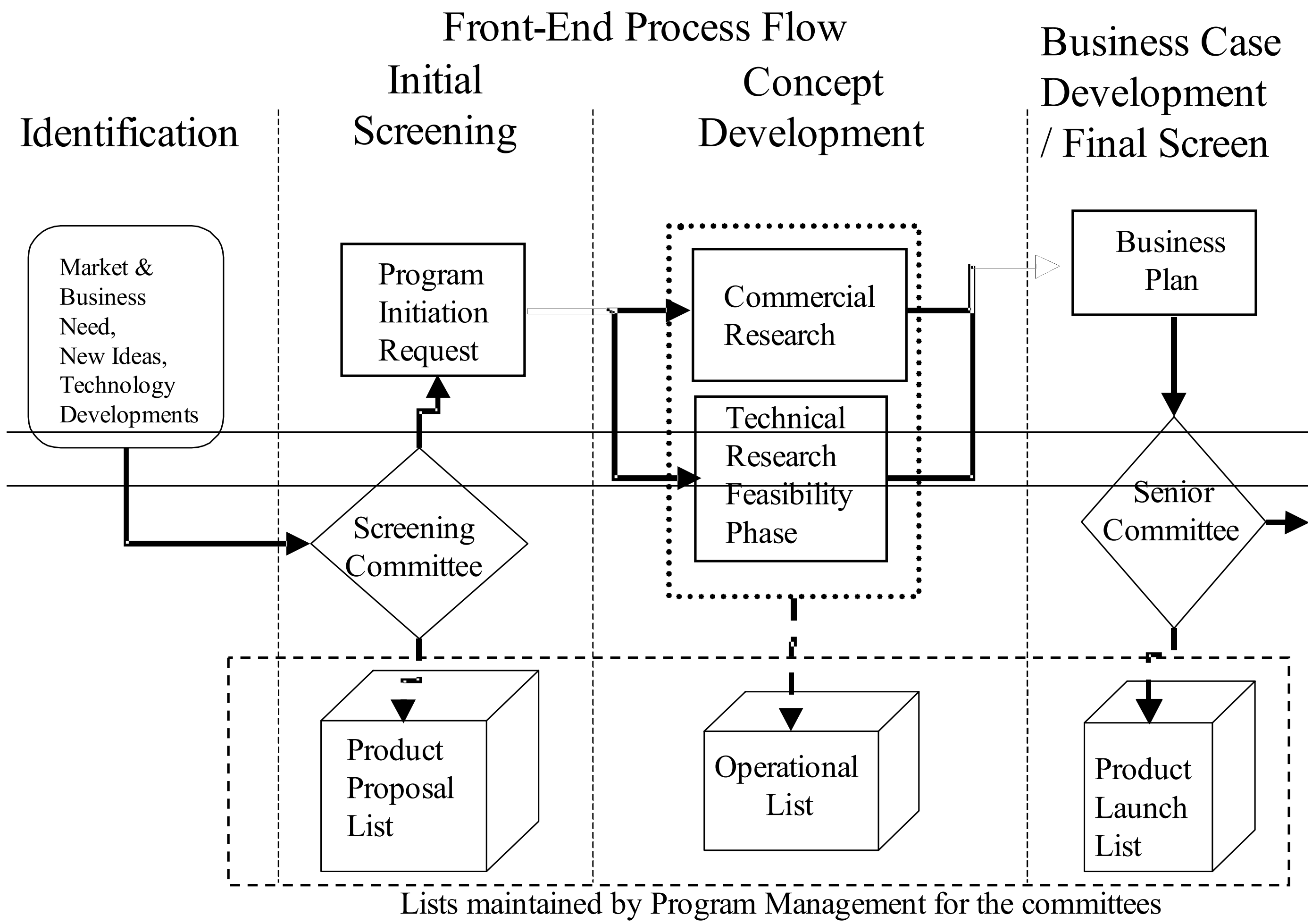
Source: “Best Practices in User Needs/Requirements Generation”, Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

Research Activity Summary

- Data collection part of Headquarters Air Force (HAF) 2002 reengineering team effort
- Multiple methods used for data collection
  - 321 Interviews (~ 300 Military Specific)
  - Benchmarking survey developed to collect process characteristics data
- 17 case studies total
  - 9 military organizations
    - 5 Military Services (one foreign)
      - All AF MAJCOMs, 1 ALC, 3 Centers, ANG, AFRES
      - Army TRADOC, Navy N-80, 81, 88, Marines
      - French 'Acquisition Service'
    - 4 Joint Commands (USJFCOM, USSOCOM, USSPACECOM, NORAD)
    - Several other military organizations provided background information
  - 8 commercial organizations
    - **2 aerospace airframe**
    - **2 airlines**
    - **2 chemical/materials**
    - **2 computer/software**

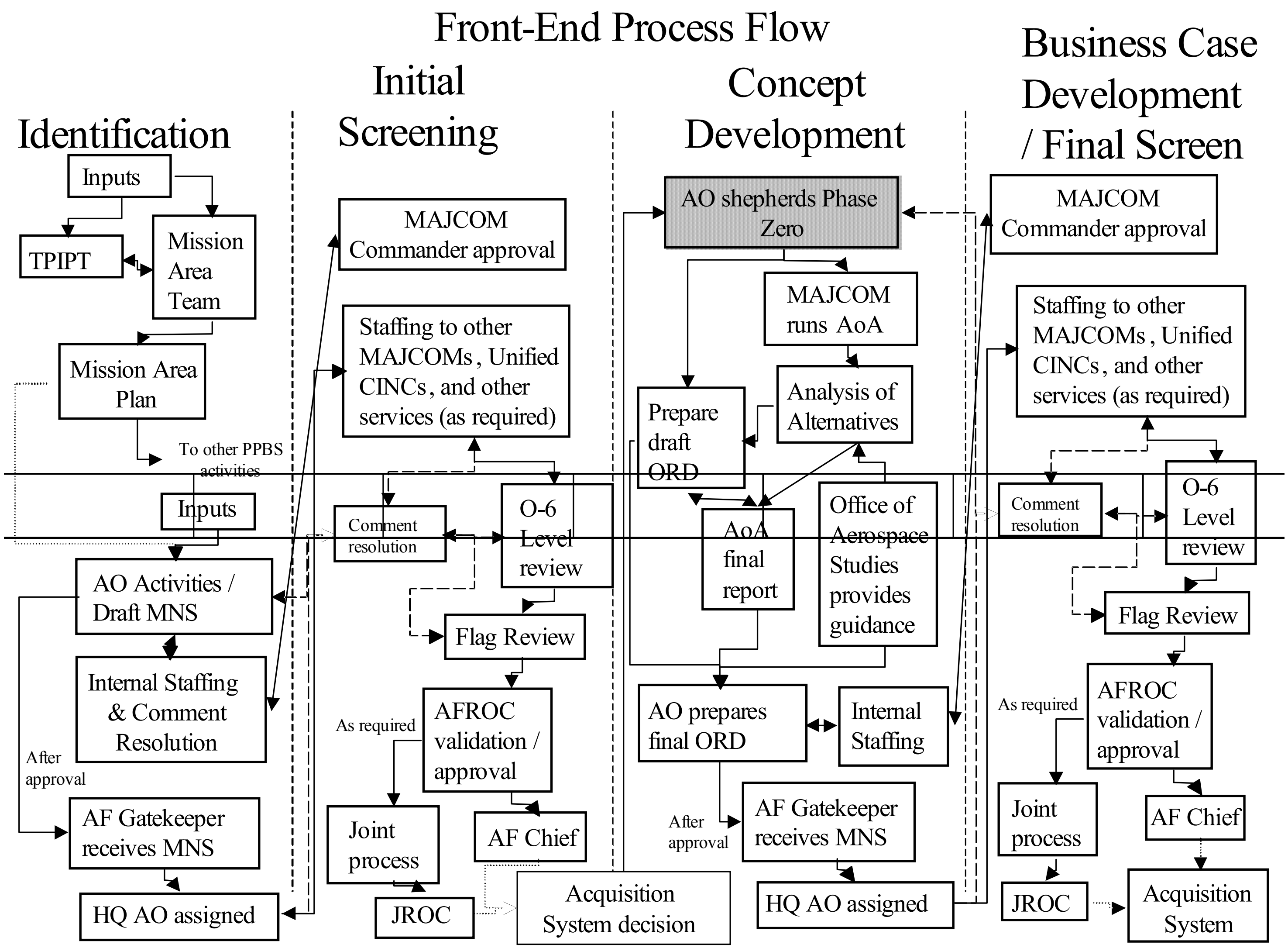
Source: "Best Practices in User Needs/Requirements Generation", Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

Company A's Front End Process



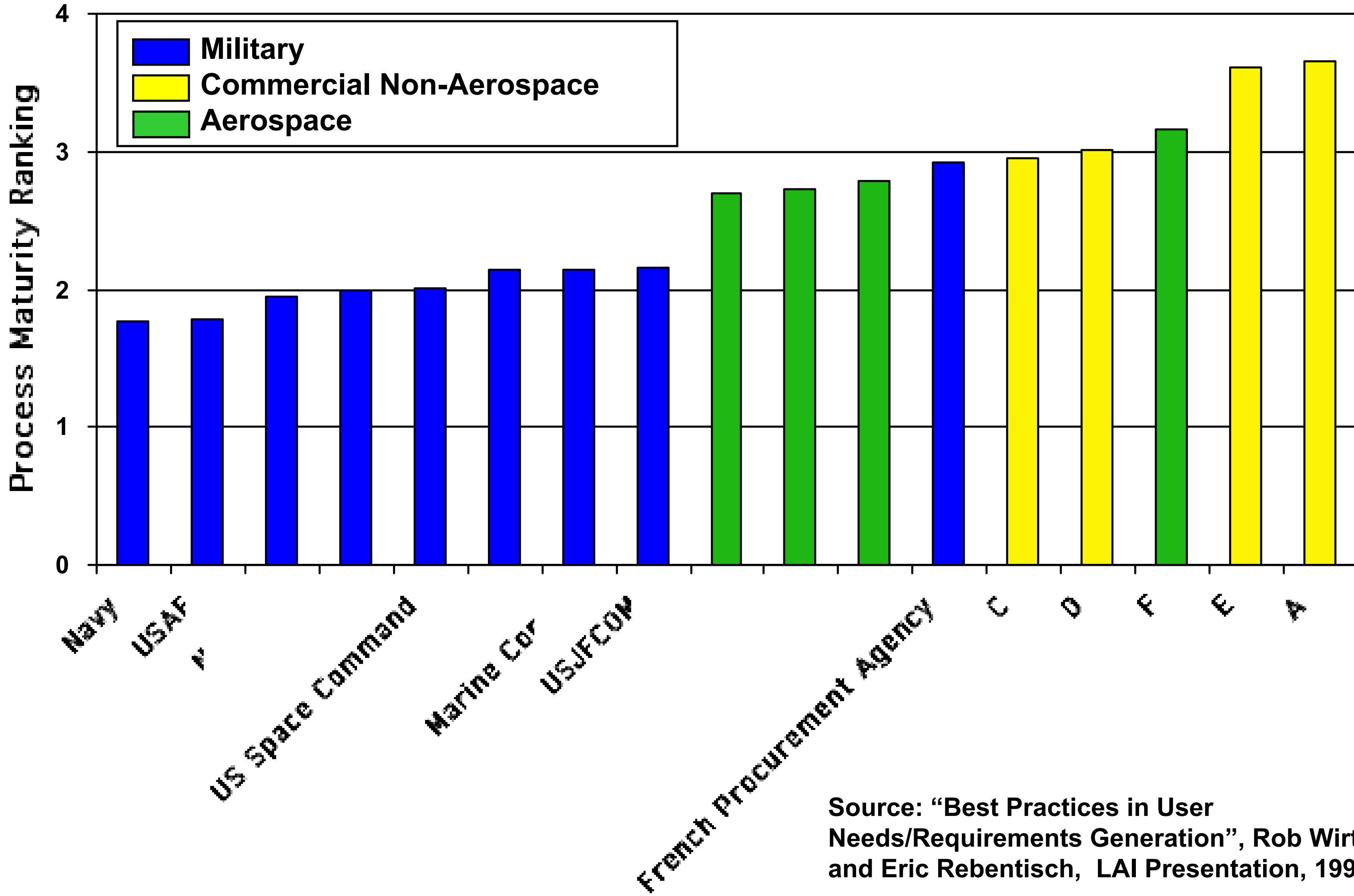
Source: "Best Practices in User Needs/Requirements Generation", Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

USAF Front End Process



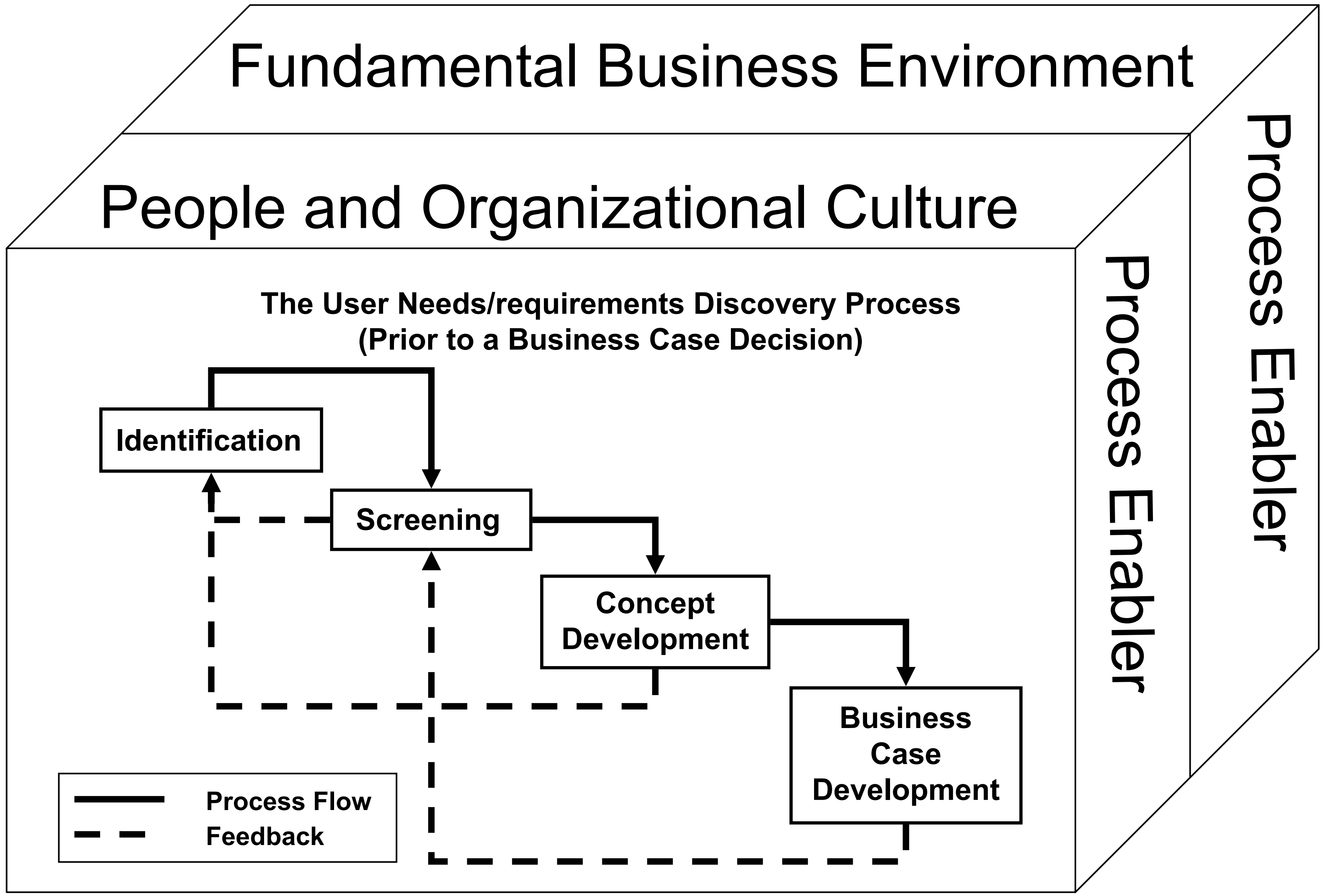
Source: "Best Practices in User Needs/Requirements Generation", Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

Overall Requirements Process Maturity



Source: "Best Practices in User Needs/Requirements Generation", Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

Overall Framework View



Source: "Best Practices in User Needs/Requirements Generation", Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

Case Observations: Key Front End Process Elements

- Requirements
  - Use of multiple structured methods (QFD, DSM, etc.)
- Screening
  - Front-end done within one organization that has total control of resources
  - Pre-negotiated exit criteria for potential solutions
- Concept Development
  - Appropriate uses of prototypes/simulation
  - All product features are given priorities to help in tradeoff analysis
- Business Case Development
  - Concept approval also commits resources of company to project

Source: "Best Practices in User Needs/Requirements Generation", Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

Case Observations (cont.): Key Enablers

- Organizational
  - Cross-functional
  - Teams are prevalent
  - ‘Core’ team members and job stability
  - Senior leadership engaged and makes critical screening decisions
- Business Foundation
  - Common database and integrated IT tools
  - Emphasis on portfolio management

Source: “Best Practices in User Needs/Requirements Generation”, Rob Wirthin and Eric Rebentisch, LAI Presentation, 1999

Improving the Software Upgrade Value Stream - Study Overview

- 2 year study responding to LAI consortium desire for software and requirements research
- Comprehensive look at government and industry practices for deriving software requirements from system requirements
- “Successful” software programs studied to glean candidate best practices
- Lean Enterprise Model used as a guide
- Value stream view adopted
- Seven major research findings
- Recommended framework for improvement

Source: “Improving the Software Upgrade Value Stream”, Brian Ippolito and Earll Murman, LAI Executive Board Presentation, June 1, 2000

Study Scope

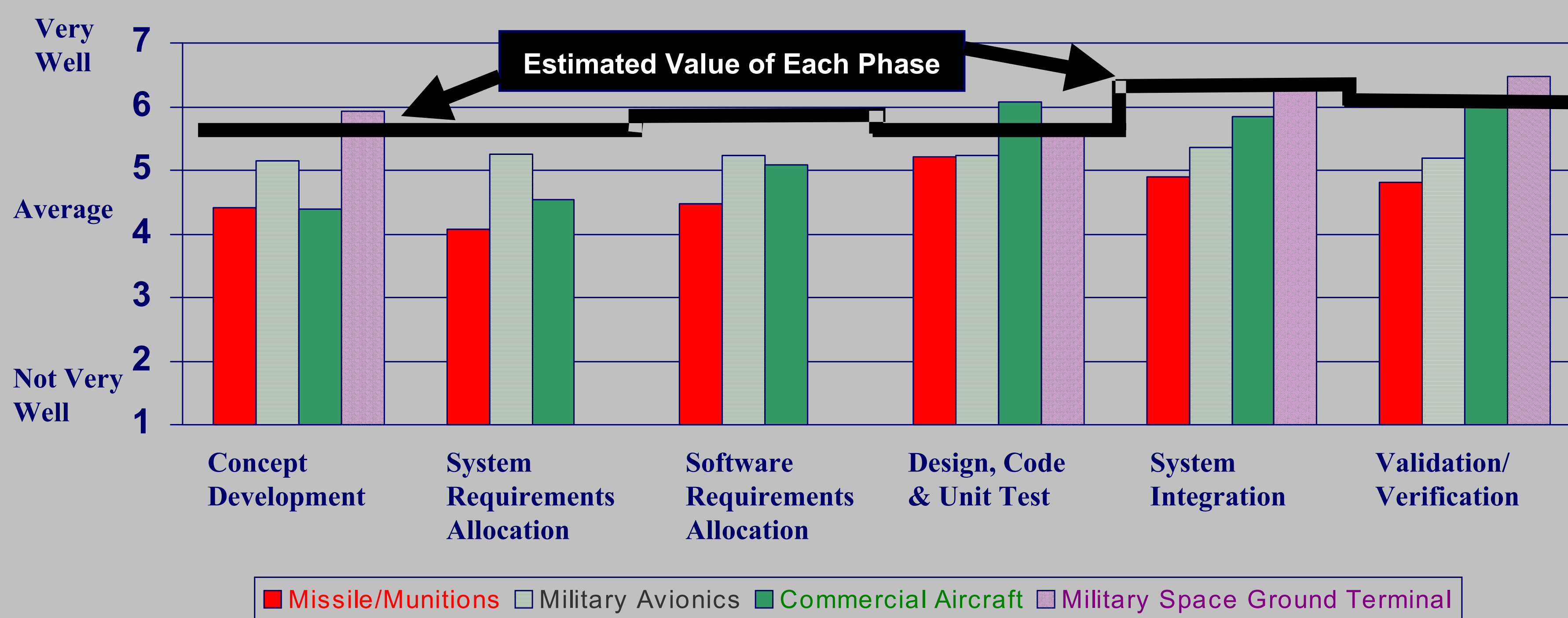
- 10 mission critical software upgrade programs studied
- Four application domains
  - Military avionics, military space ground terminal, commercial aircraft, missile/munitions
- 128 surveys collected from program and process leadership (program managers, chief engineers, end users, software and systems leads...)
- 3 detailed case studies with 45 interviews
  - Military Avionics, Commercial Auto-pilot, Military Space Ground Terminal
- Extensive review of data with LAI consortium, study participants, professional community

Source: "Improving the Software Upgrade Value Stream", Brian Ippolito and Earll Murman, LAI Executive Board Presentation, June 1, 2000

Software Development Processes

Value: "Estimate the value that each of the following contribute to developing software in a timely, cost effective approach to meet the users needs."

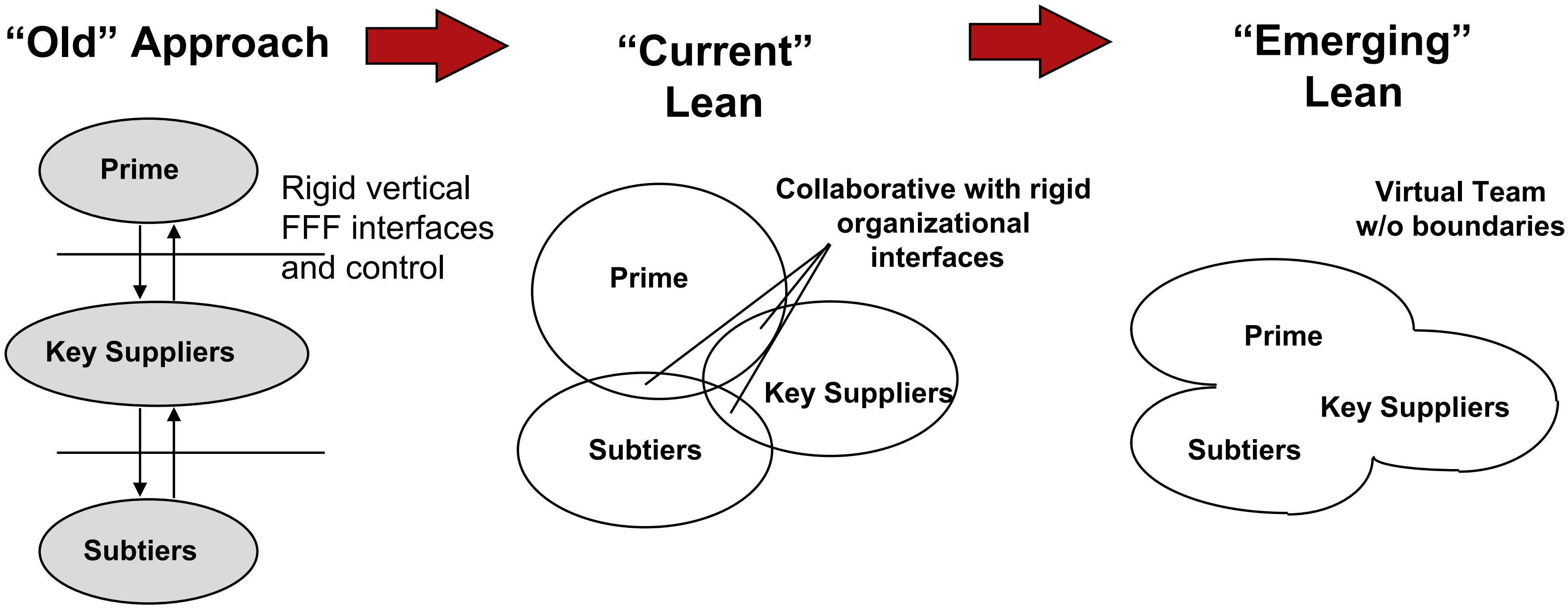
Effective "How well do you think your program executed the following phases of software development."



Although all phases of the software development process are deemed to add value, they are not accomplished with the same level of effectiveness.

Source: "Improving the Software Upgrade Value Stream", Brian Ippolito and Earll Murman, LAI Executive Board Presentation, June 1, 2000

Early Supplier Integration into Design and Development: Case Studies



Arm's length; interfaces totally defined and controlled

Collaborative; but constrained by prior workshare arrangements

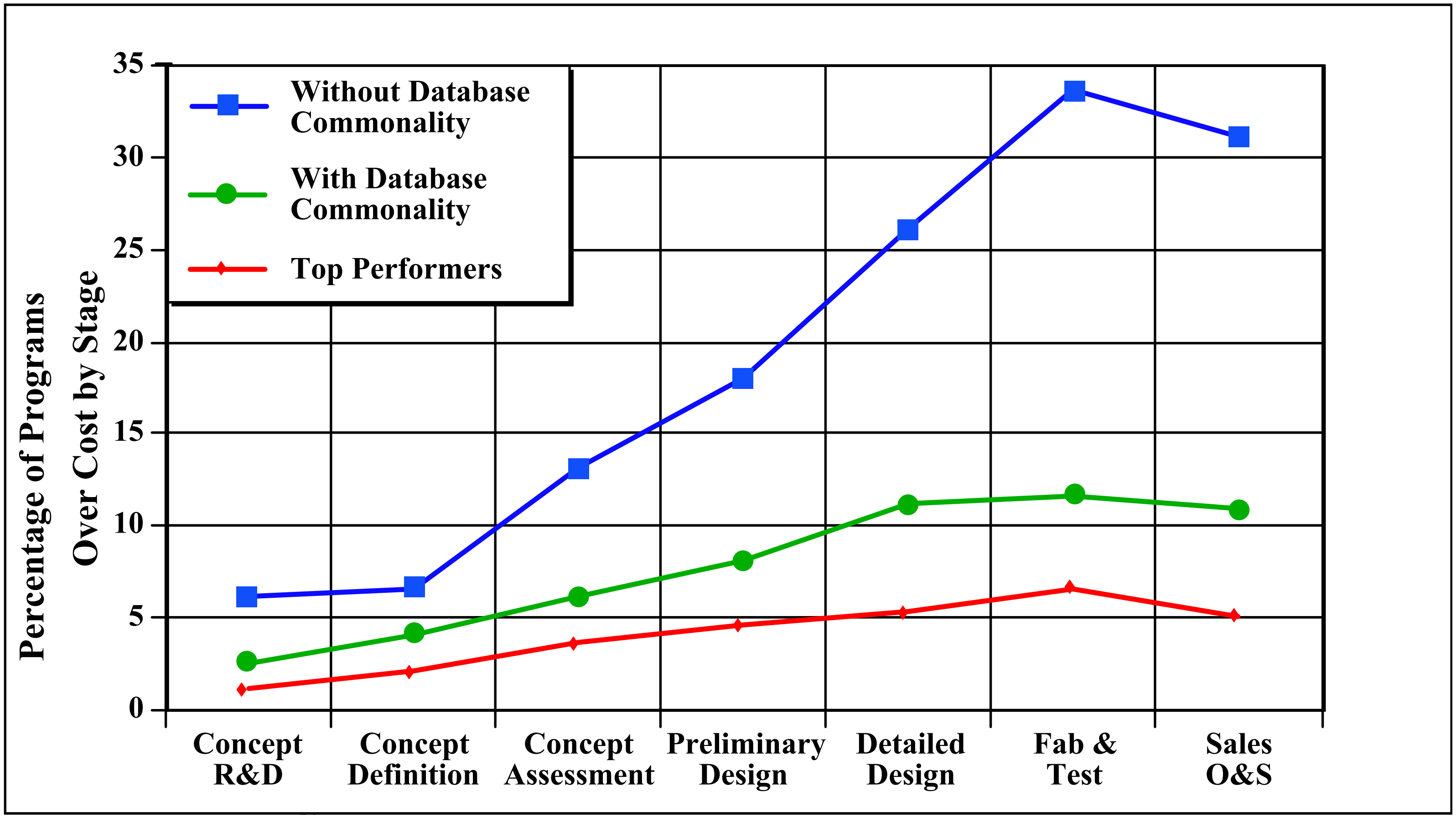
Collaborative and seamlessly integrated, enabling architectural innovation

FINDING: "Virtual" teaming across multiple tiers of the supply chain early in design process fostered innovation in product architecture (major changes in product form/structure, functional interfaces, system configuration), resulting in

- **40-60% cost avoidance**
- **25% reduction in cycle time**
- **Significant quality improvement**

Source: Bozdogan and Deyst, LAI Study

Database Commonality

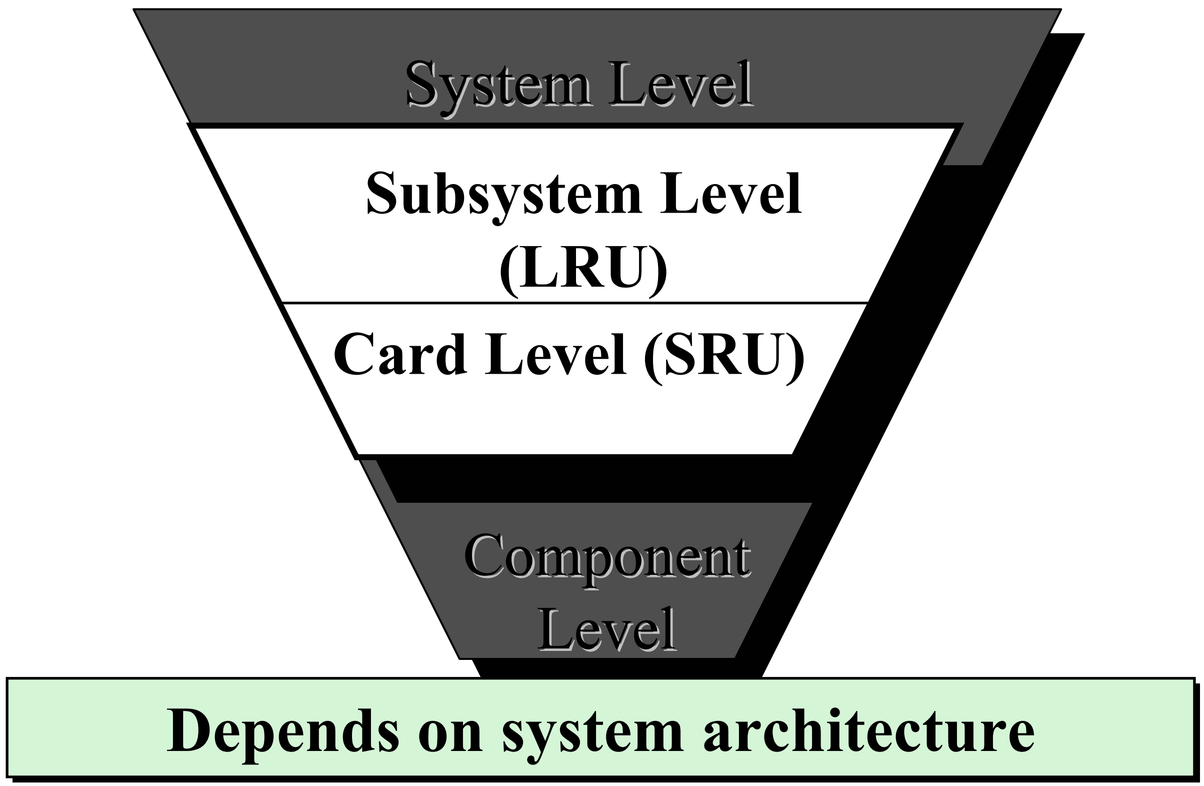


Interoperability and/or commonality of design, manufacturability, cost and other databases significantly reduces likelihood of cost and schedule overruns in product development

Source: MIT Product Development Survey (1993-94)

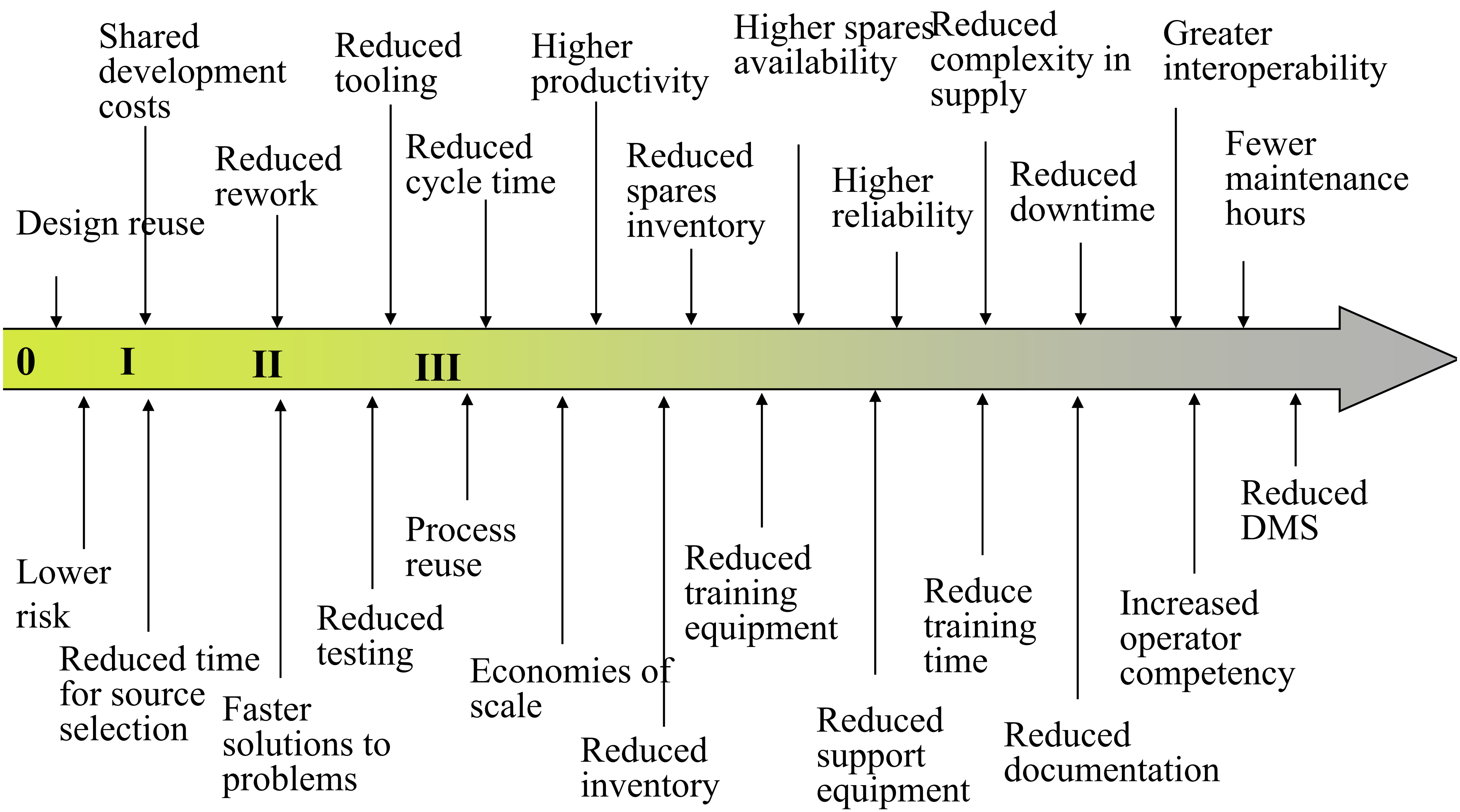
What Level of Commonality Across Project Lines Makes Most Sense

- Commonality generally makes the most sense at the subsystem (LRU) level



Source: "Managing Subsytems Commonality", Matt Nuffort and Eric Rebentisch, LAI Presentation, Apr 10, 2001

Benefits of Subsystems Commonality: Timeline



Source: "Managing Subsytems Commonality", Matt Nufort and Eric Rebentisch, LAI Presentation, Apr 10, 2001

Conclusions Of Nuffort - Rebentisch

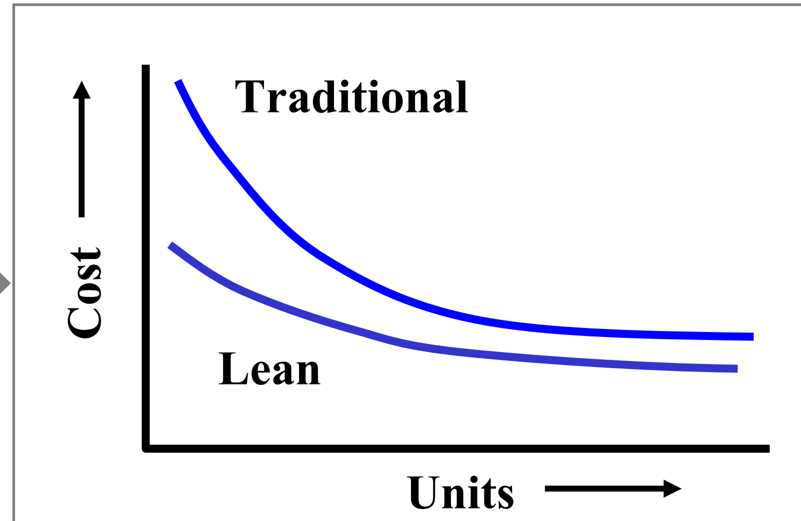
- 21 programs studied, 84 interviews
- Data very sparse. Lots of “judgement” applied
- Subsystem commonality reduces subsystem ownership cost
  - 15-40 Percent savings in acquisition cost of subsystem*
  - 20-45 Percent savings in annual O&S costs*

* cost structure dependent

Lean Enterprise Thrusts

Lean Engineering

- **DMAPS**
  - **Parametric 3D Solids**
  - **Dimensional Management**
  - **Virtual Manufacturing**
  - **Model Based Definition (Int/Ext)**
- **DFMA**
  - **Enables Lean Mfg.**
  - **Enables Lean SM&P**



Lean Manufacturing

- **Throughput Studies**
- **Variability Reduction/SPC**
- **HPWOs**
- **AIWs**
- **Advanced Technology Assembly**
- **Operator Verification**

Lean Supplier Management

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

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

Lean Engineering Is Enabled by Advanced Tools and Processes

Parametric Solids

Integrated Product Teams

Early Supplier Involvement

Model Based Definition Release Packages

Integrated Data Packages

Reduced Inspection/ Smart Inspection

Product/Tools Validated by Simulation

Design for Process Capability

Virtual Design Reviews/ Collaboration

Common Product Data Storage

Standard Parts

Design for Manufacturing and Assembly

Application of New Technology

Advanced Technology Assembly

3-D Product Structure (BOM)

Design Linkage to Financials

Value Stream Analysis

Dimensional Management/ Key Characteristics

Design for Affordability

A&M Standard Tools

Design for Flow

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

Precision Assembly

Process understanding key to precision improvement

- Drive to 6 sigma processes
- Precision assembly
  - Parts define location
  - Reduced assembly tooling
  - Remove trim and shim from assembly

Old Paradigm	**New Paradigm**
Tooling defines part location	**Parts themselves define location**

Source: J.P. Koonmen, "Implementing Precision Assembly Techniques in The Commercial Aircraft Industry" MIT SM Thesis, 1994, and Hoppes (1995). Also See Lean Enterprise Value, pp 127-130

Toolless Assembly Case Study Benefits

Category	Old Paradigm	New Paradigm
Hard tools	28	0
Soft tools	2/part #	1/part #
Major assembly steps	10	5
Assembly hrs	100%	47%
Process capability	$C_{pk}<1$ (3.0σ)	$C_{pk}>1.5$ (4.5σ)
Number of shims	18	0
Quality (nonconformances/part)	.3 (> 1000)	.7 (<20) *

* Early results with improving trend

Source: J.P. Koonmen, "Implementing Precision Assembly Techniques in The Commercial Aircraft Industry" MIT SM Thesis, 1994, and Hoppes (1995). Also See Lean Enterprise Value, pp 127-130

Enablers of Precision Assembly

- Design
  - parts, assembly, assembly sequence, tooling, ...
- Precision fabrication
  - contour and features
- Common, CAD definition
- Measurement technology
- Lean production system

Source: J.P. Koonmen, "Implementing Precision Assembly Techniques in The Commercial Aircraft Industry" MIT SM Thesis, 1994, and Hoppes (1995). Also See Lean Enterprise Value, pp 127-130

F-16 Lean Build-To-Package Support Center

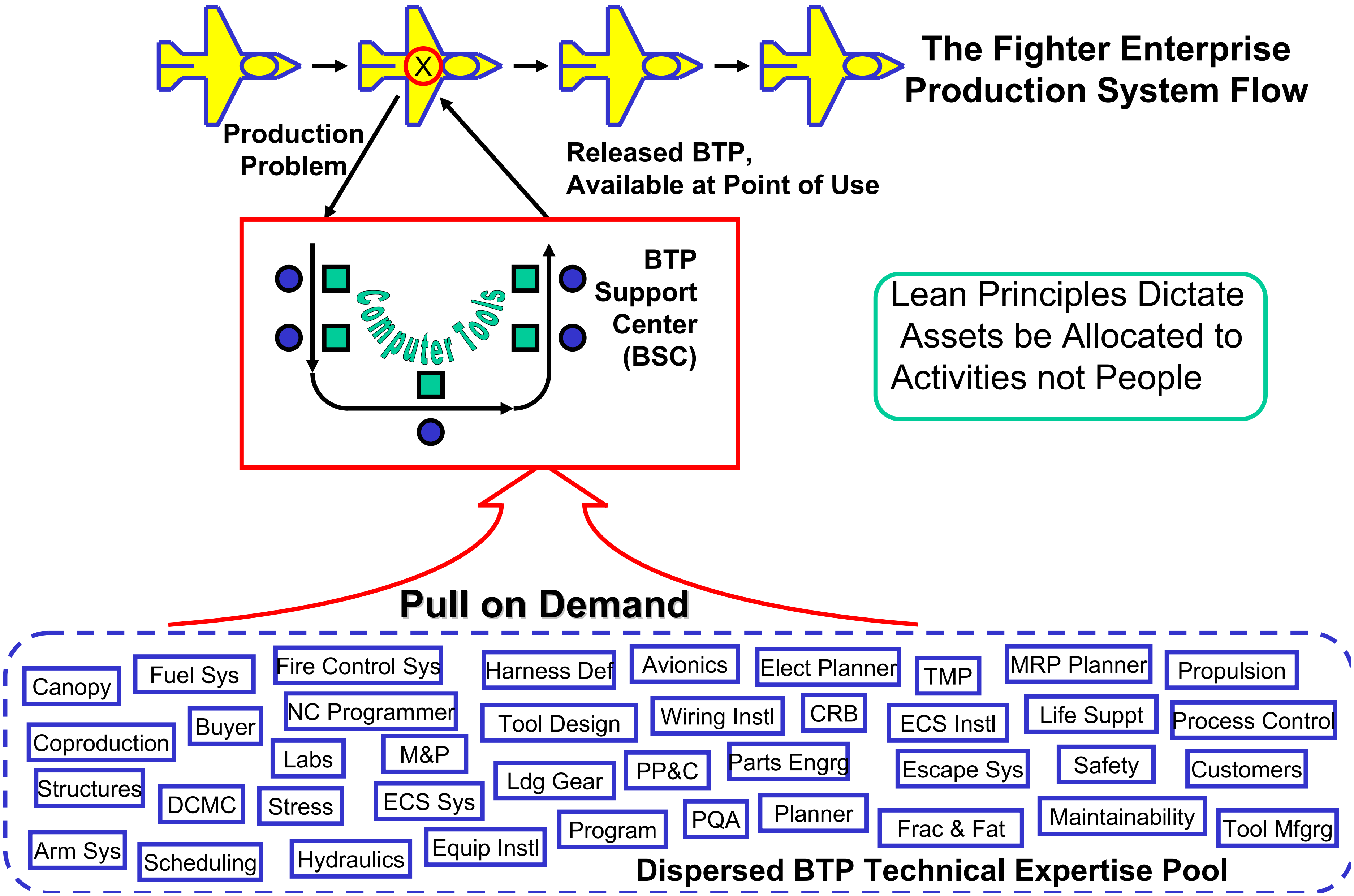
Source: "Seeing and Improving the Product Development Value Stream", Hugh McManus LAI Executive Board Presentation, June 1, 2000

- 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

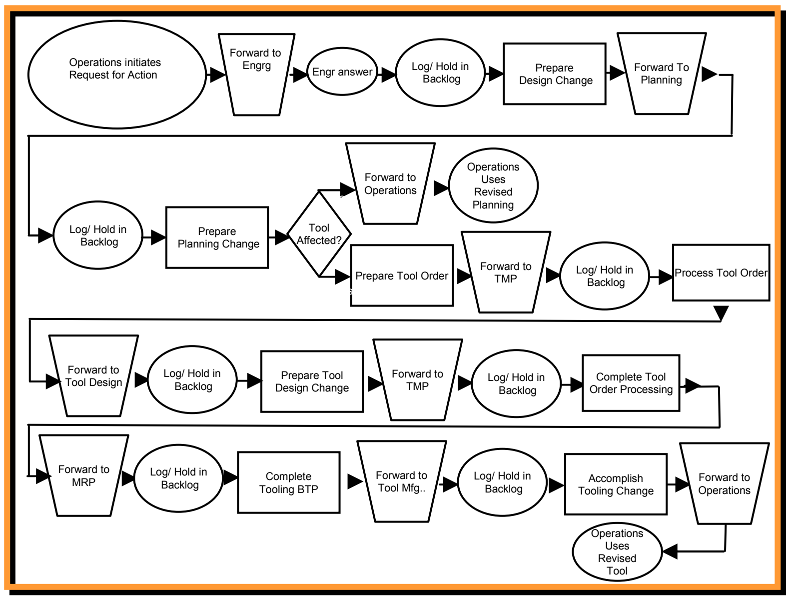
Category	% Reduction
Cycle-Time	75%
Process Steps	40%
Number of Handoffs	75%
Travel Distance	90%

Build-To-Package Support Operational Concept

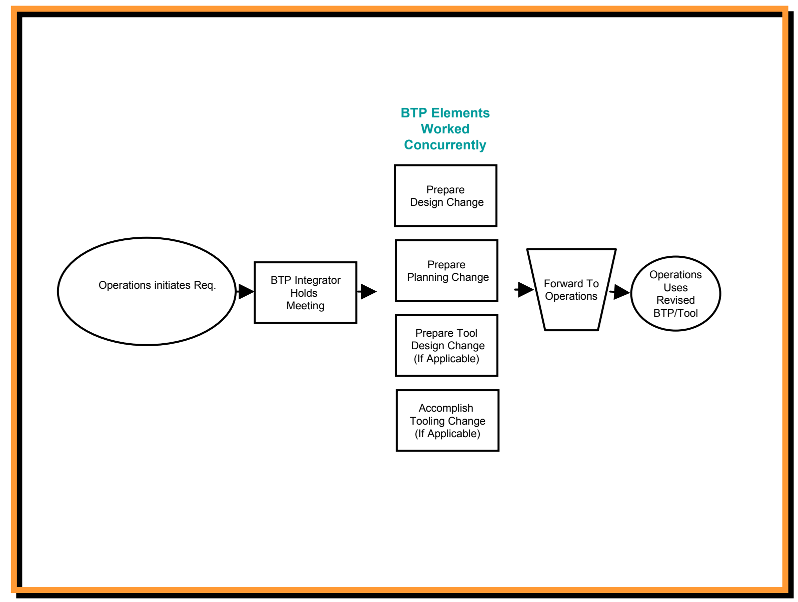


Results From F16 Forward Fuselage BTPSC

Process Before Lean



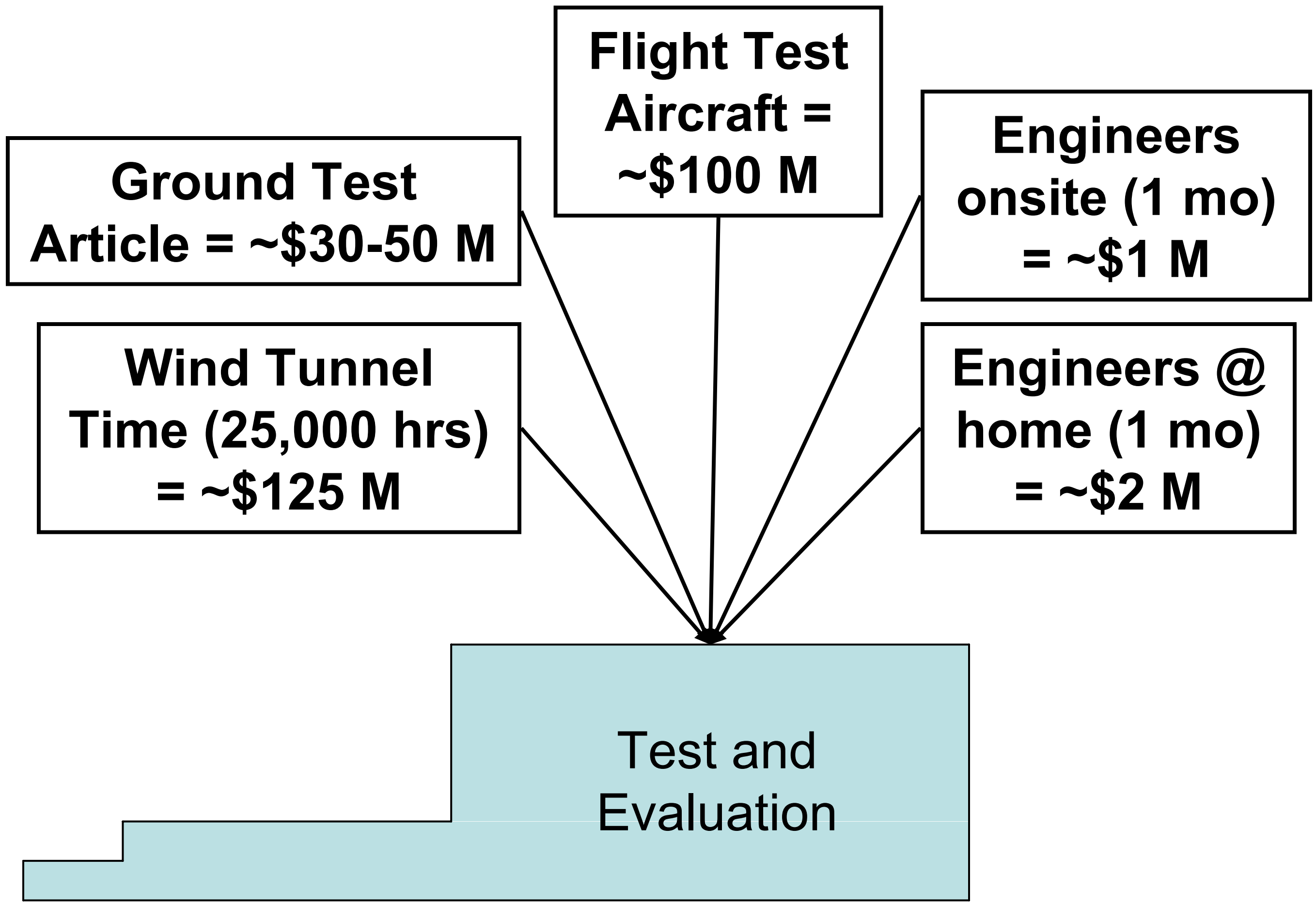
Process After Lean



Single Piece flow, concurrent engineering, co-location

Source: "Seeing and Improving the Product Development Value Stream", Hugh McManus LAI Executive Board Presentation, June 1, 2000

Key Cost Drivers for Aircraft Test and Evaluation



- **Approximate cost: $1 Million per day**

Source: "Opportunities for Lean Thinking in Aircraft Flight Test and Evaluation ", Carmen Carreras and Earll Murman, Society of Flight Test Engineers, June 2002

Case Study Findings

- Very little process data is being collected
- Upstream activities have a major impact on efficiency of flight testing
  - Late arrival of flight test article
- Lean practices are applicable to flight testing
  - Approval of test plans are at too high a level
- Intersecting value streams (e.g. shared service like telemetry and a particular flight test program) can produce waste
  - Resource conflicts, untimely services

Opportunities exist for applying lean thinking to flight testing.

Source: "Opportunities for Lean Thinking in Aircraft Flight Test and Evaluation ", Carmen Carreras and Earll Murman, Society of Flight Test Engineers, June 2002

Summary

- Lean Thinking applied to Systems Engineering (aka Lean Systems Engineering) indicates benefits
  - Evidence of LeanSE programs
  - Evidence of LeanSE throughout the product lifecycle
- Plenty of opportunities for further LeanSE
- A focus on value creation is the key to implementing LeanSE

Look for evidence of Lean System Engineering in your case studies using the Lean Enterprise Model and Simplified Systems Engineering Model

Statistical Process Control

- SPC is “The application of statistical techniques to understand and analyze variation in a system”
- SPC is the heart of modern quality systems
- It relies on
  - Continual measurement of process variables; e.g. hole diameters, stock thickness, temperature control,…
  - Using simple statistical analysis to analyze and display data
  - Stabilizing all process to assure process capability
  - Keeping design tolerances within known process capability
  - Training of the entire workforce on SPC techniques
- The “ultimate goal” of SPC is to achieve processes that have 6σ capability which translates into “fewer than 3.4 defects per million” (TI SPC Guidelines).