Lean Product Development

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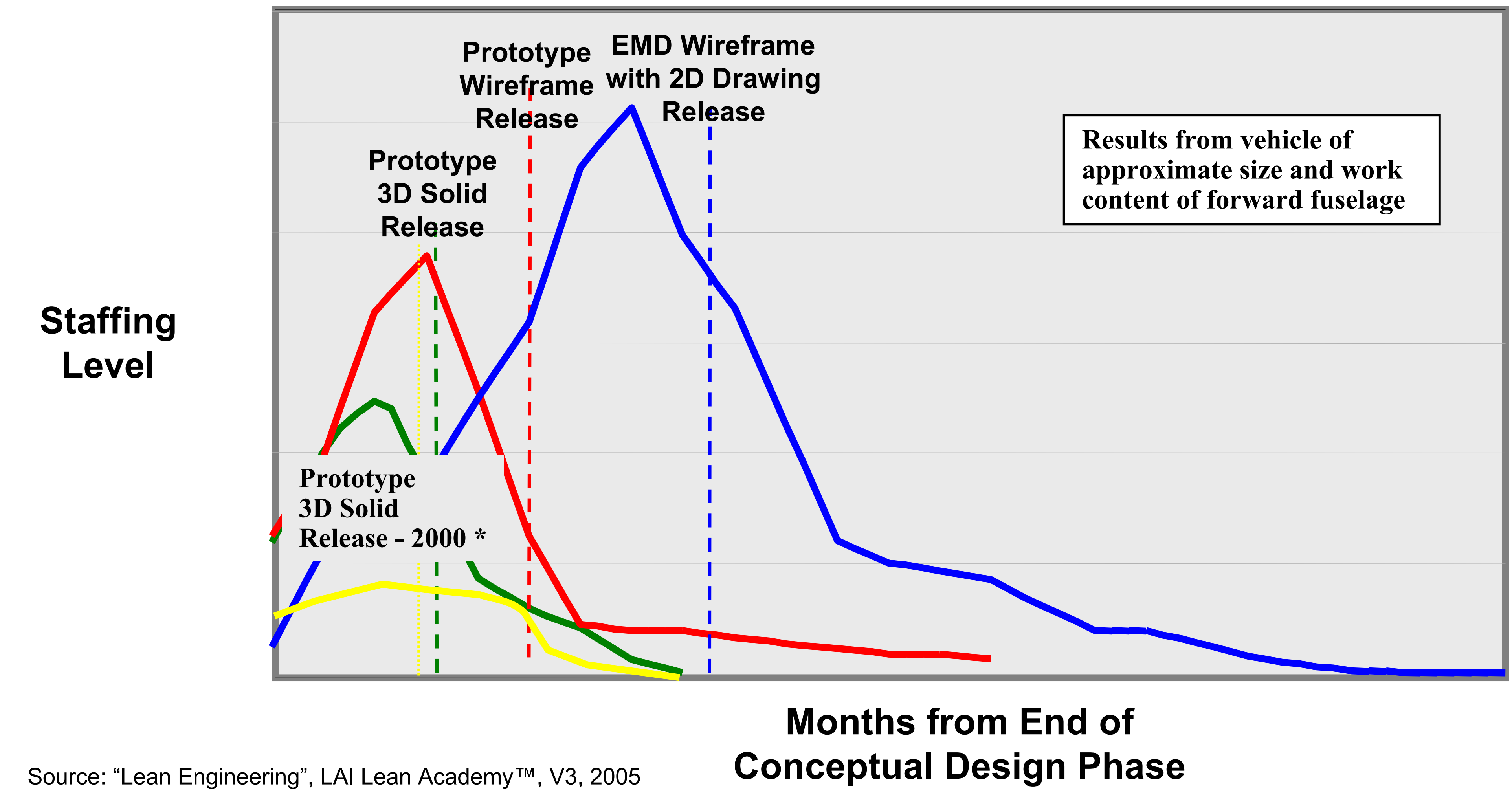
October 5, 2005

Lean Engineering Learning Points

- 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

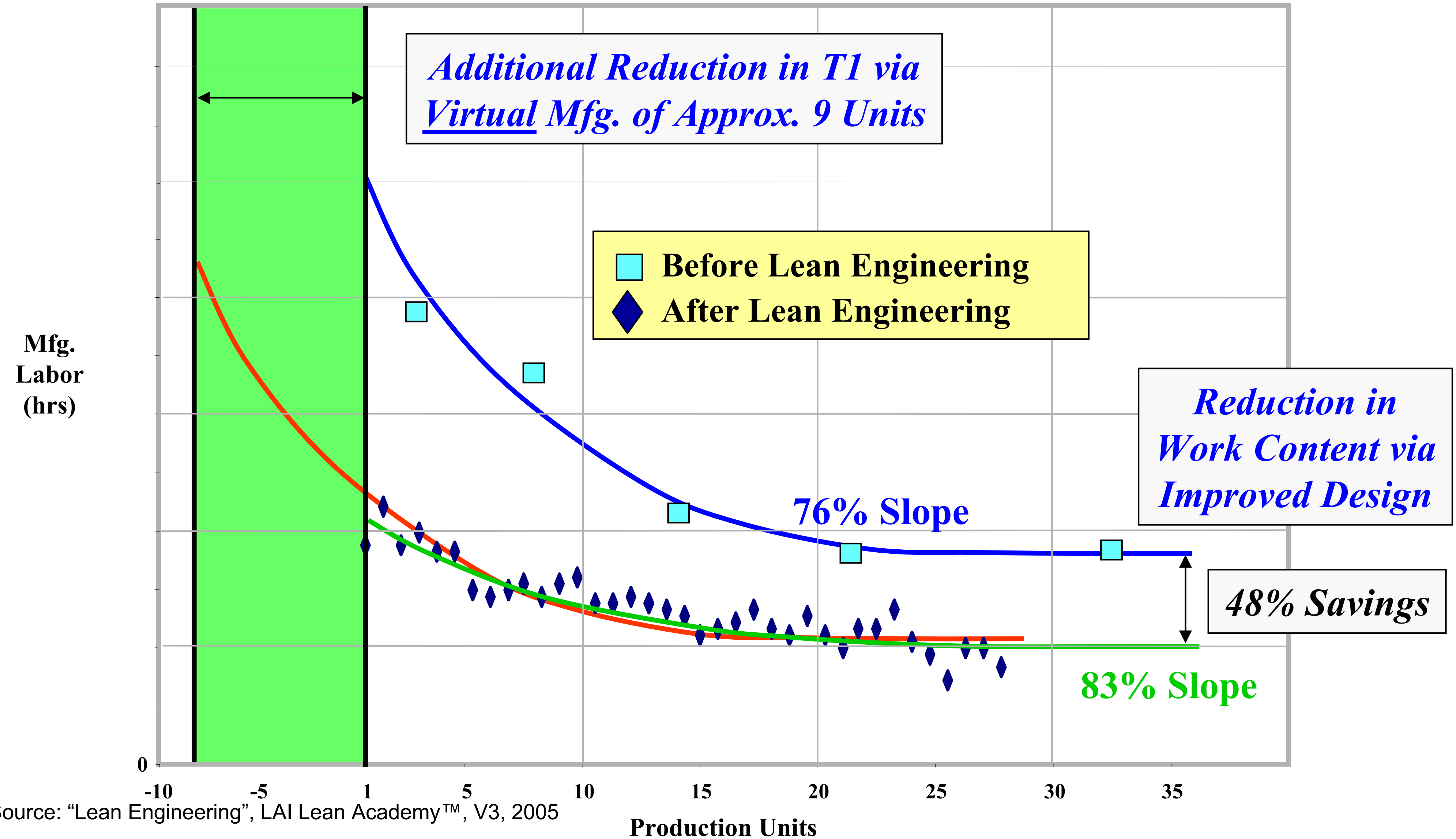
Forward Fuselage Development Total IPT Labor



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

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

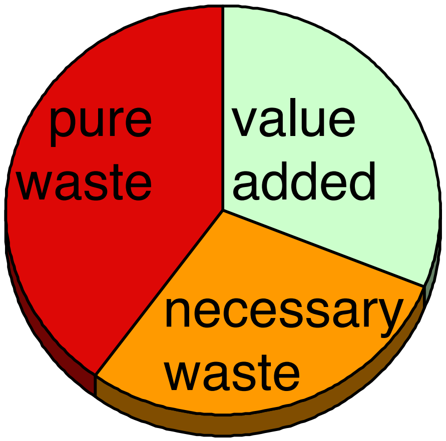
Lean Engineering Improves Manufacturing



Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

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

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)*

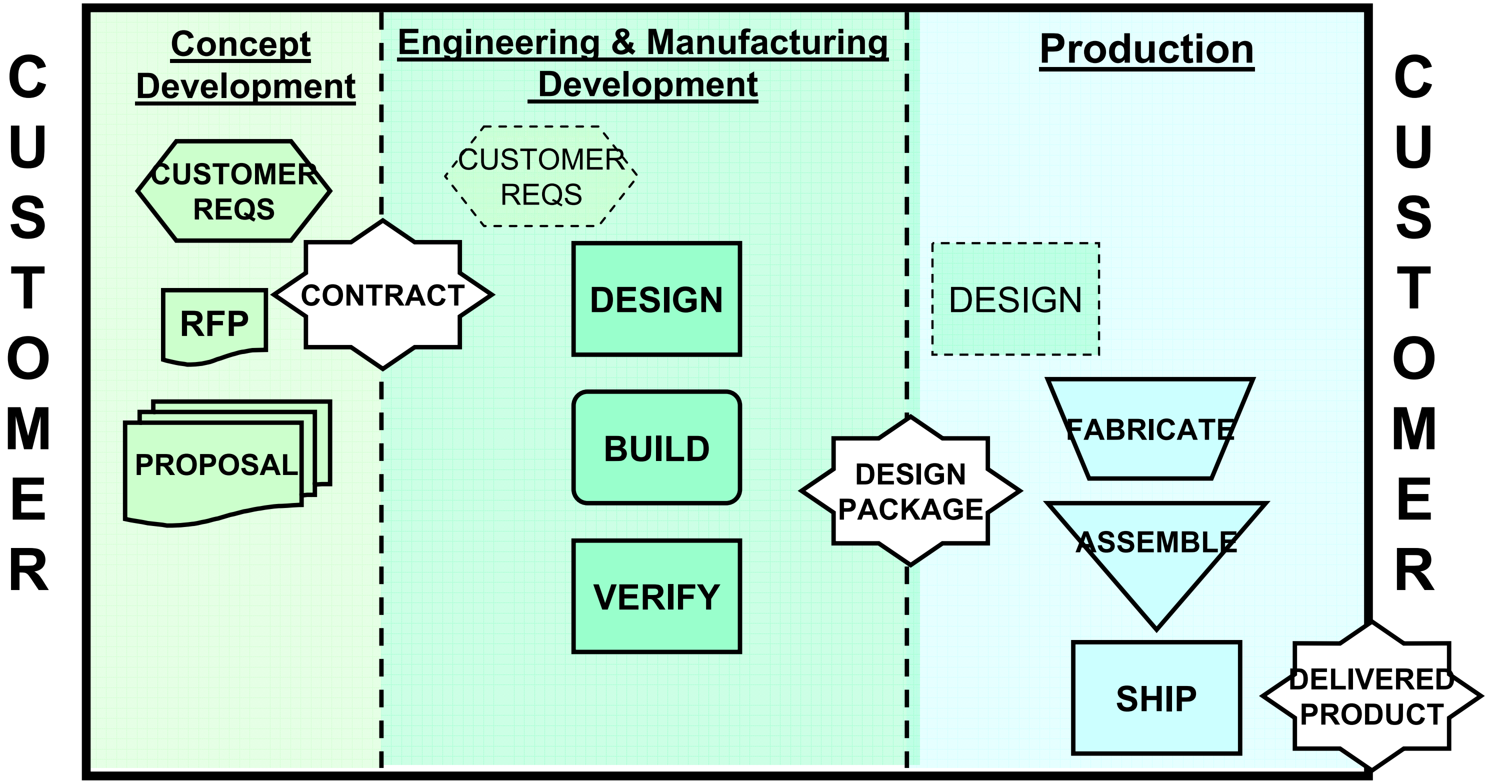
50-90% task idle time found in Kaizen-type events

Source: McManus, H.L. "Product Development Value Stream Mapping Manual", LAI Release Beta, April 2004

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"

Lean Engineering: Doing the Right Thing Right

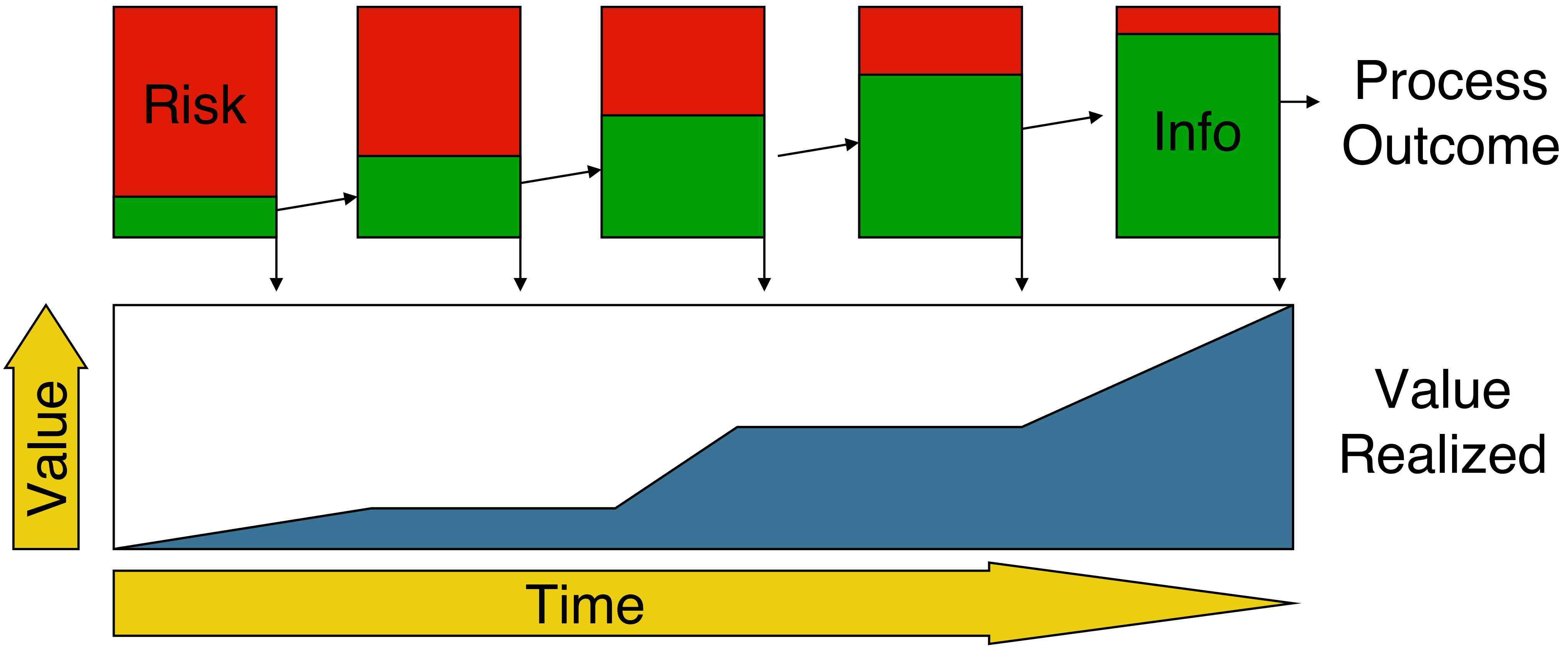
- **Creating the right products…**
  - Creating product architectures, families, and designs that increase value for all enterprise stakeholders.
- **With effective lifecycle & enterprise integration…**
  - Using lean engineering to create value throughout the product lifecycle and the enterprise.
- **Using efficient engineering processes.**
  - Applying lean thinking to eliminate wastes and improve cycle time and quality in engineering.

Source: McManus, H.L. "Product Development Value Stream Mapping Manual", LAI Release Beta, April 2004

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



Adapted From Chase, "Value Creation in the Product Development Process", 2001.

A Framework for Reducing Uncertainty in PD

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

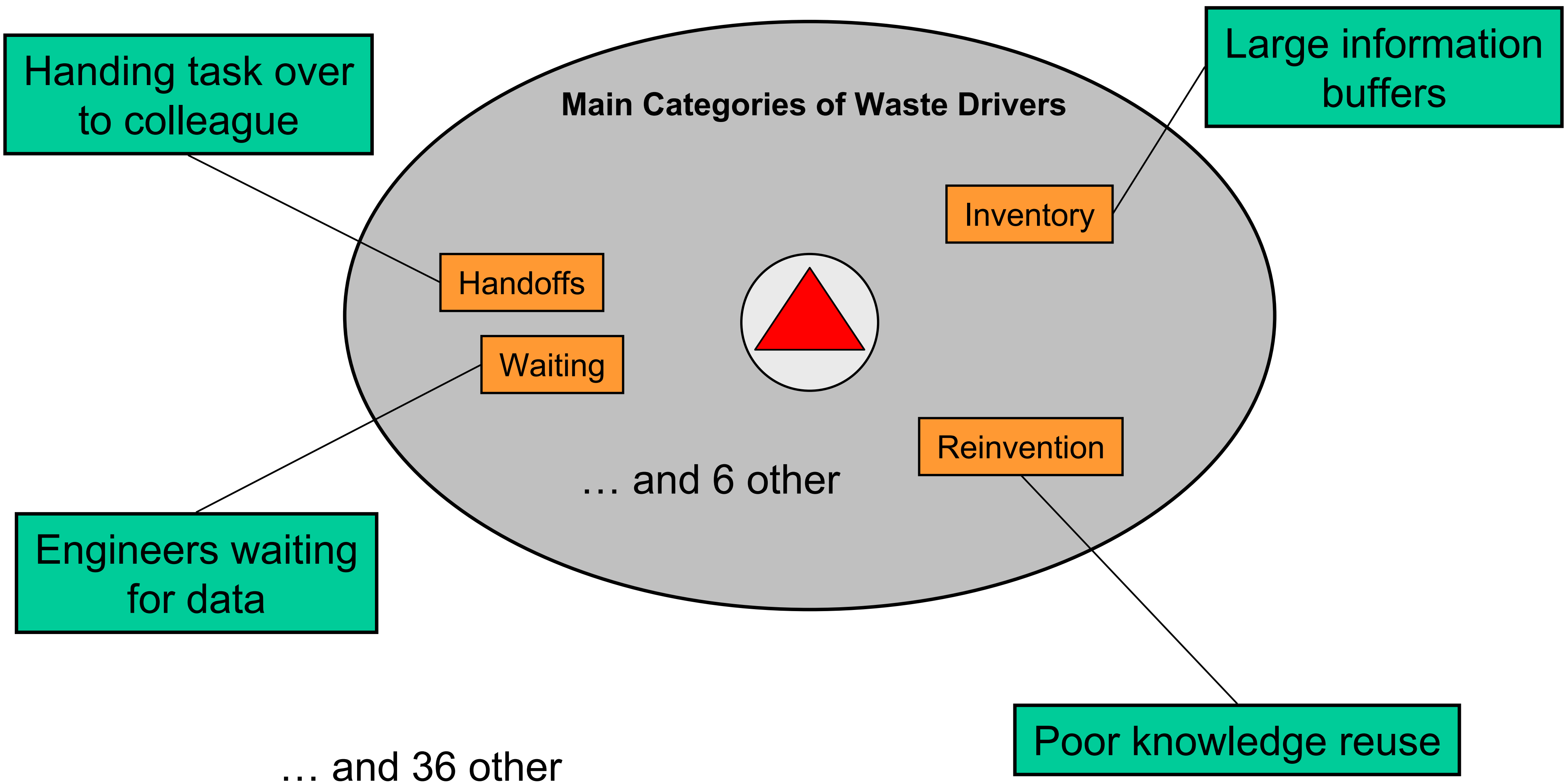
<Uncertainty> causes <Risk> handled by <Mitigation> resulting in <Outcome>

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

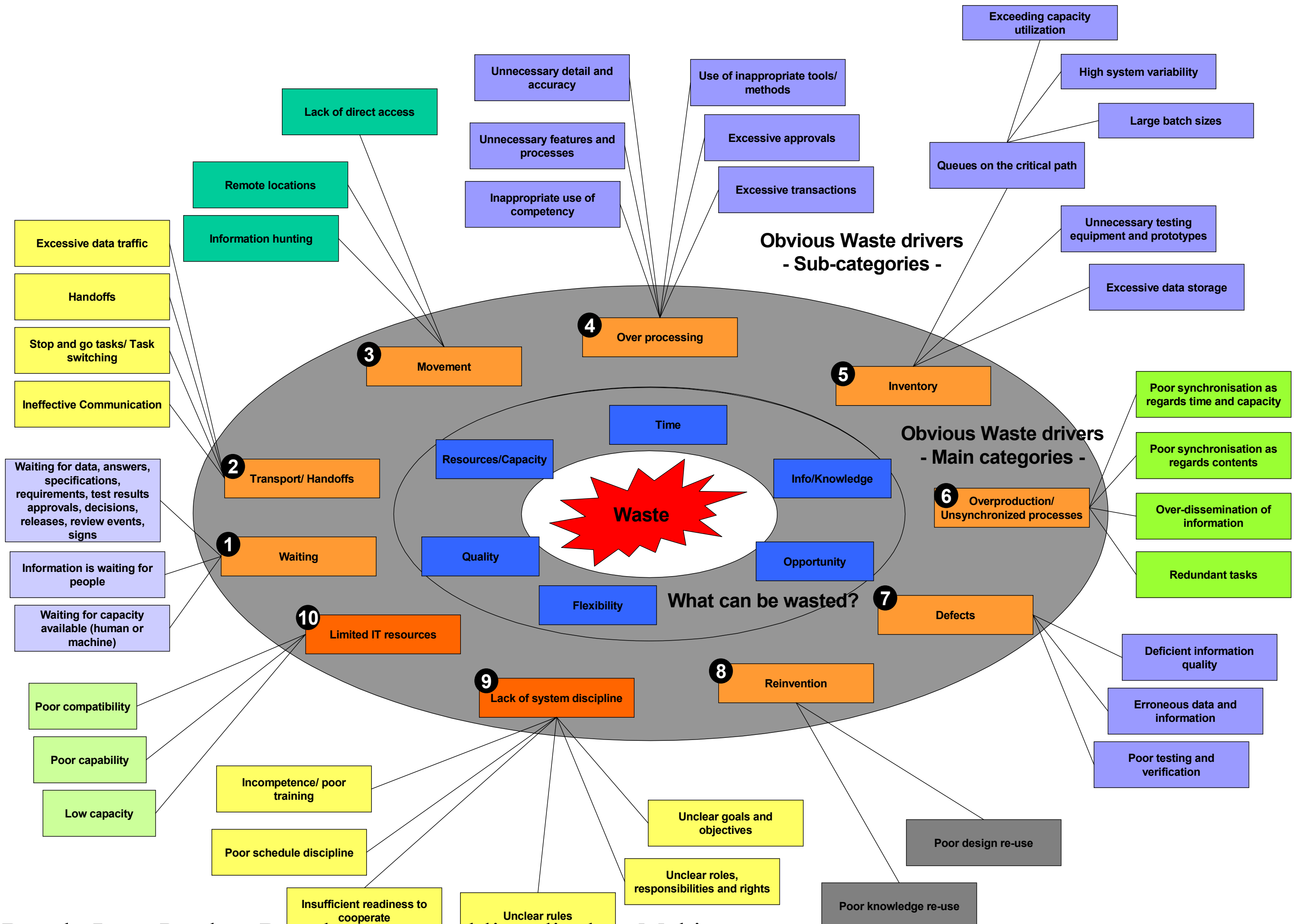
Waste Drivers – The Causes of Waste



… and 36 other

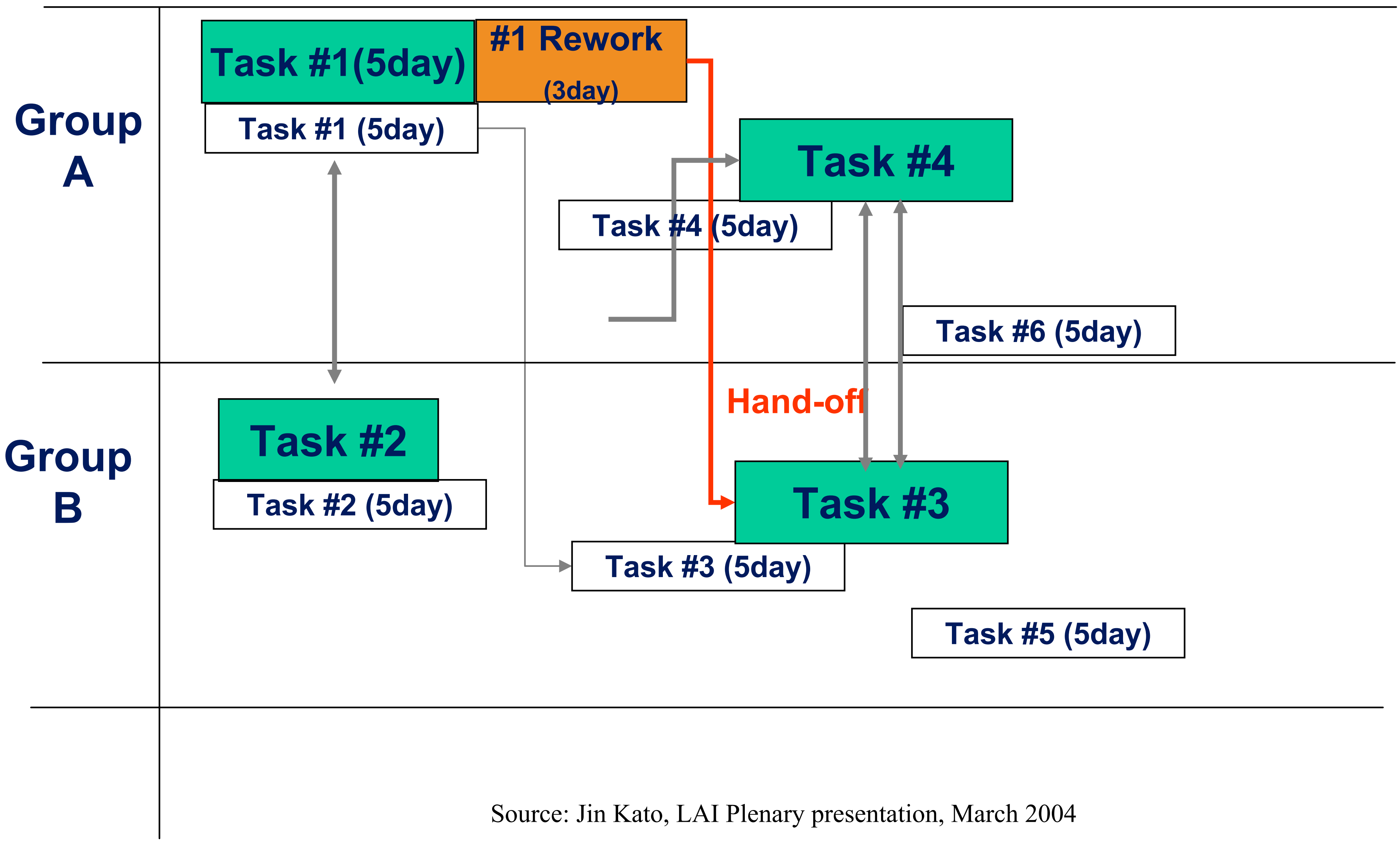
Source: Christof Bauch, Lean Product Development enabling display: Making waste transparent, TUM Thesis 2004

Complete Framework for Causes of Waste in Product Development



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

Tracking Waste in Programs Using Swim-Lane VSM

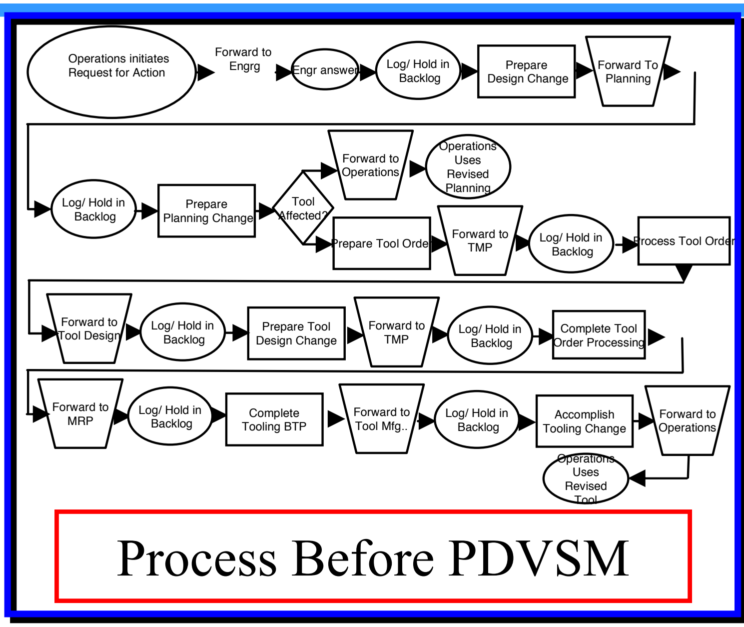


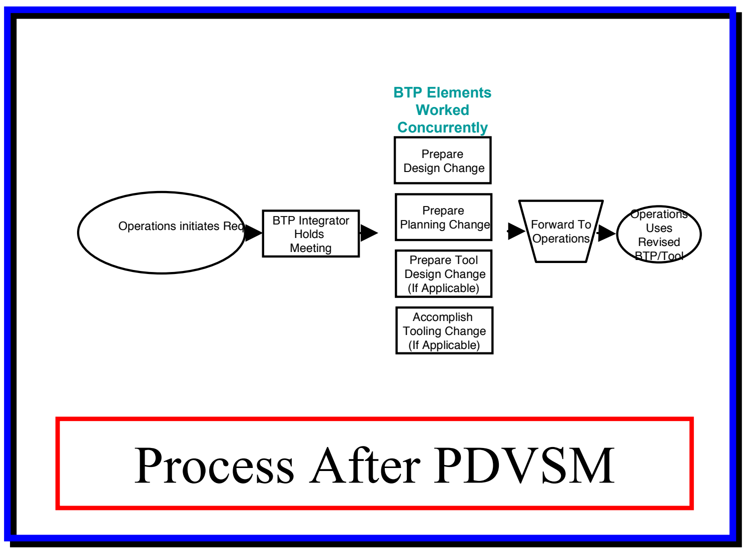
Source: Jin Kato, LAI Plenary presentation, March 2004

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





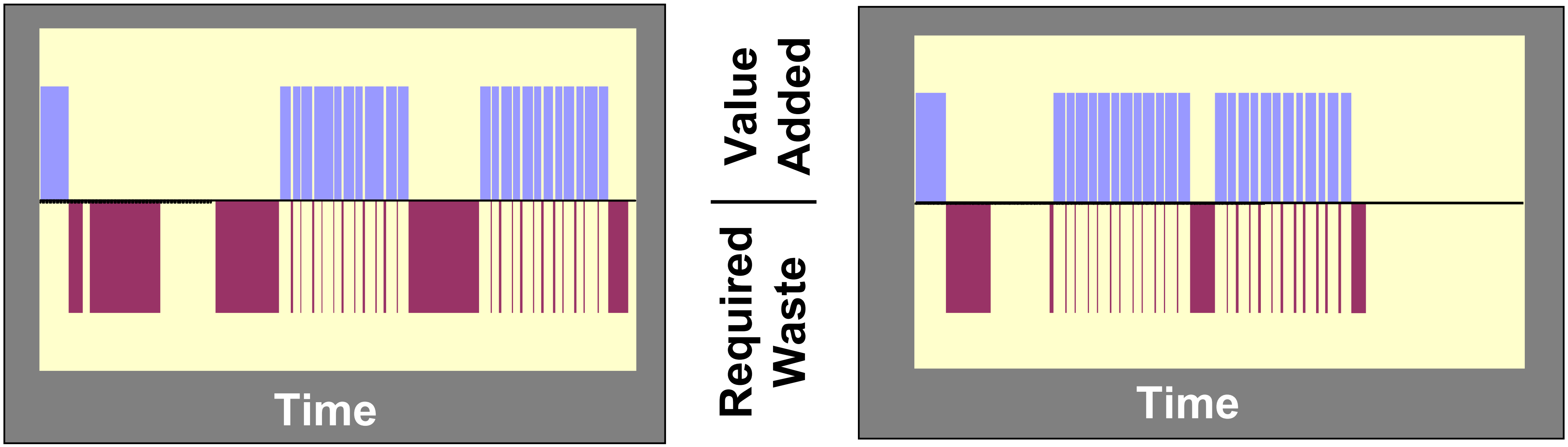
849 BTP packages

Category	Reduction
Cycle-Time	75%
Process Steps	40%
No. of Handoffs	75%
Travel Distance	90%

Source: "F-16 Build-T- Package Support Center Process", Gary Goodman, Lockheed Martin Tactical Aircraft Systems LAI Product Development Team Presentation, Jan 2000

PDVSM Used For Spacecraft Mechanical Environmental Test

As-Is Process | **To-Be Process**



Category	Before	After	Reduction
Test Cycle Time	14.7 Days	8.6 Days	41%
Labor	$1,687,908	$701,564	58%
Material	$554,304	$132,864	76%
Travel Distance	85,560 Feet	7,200 Feet	92%

Critical path system test cycle time reduced by 6 days

Source:Lockheed Martin Missiles and Space Systems

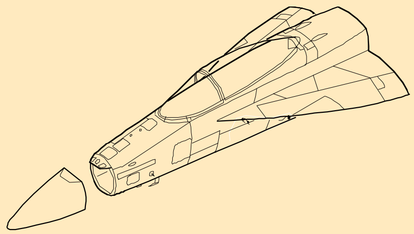
Additional Tools of Lean Engineering

- 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



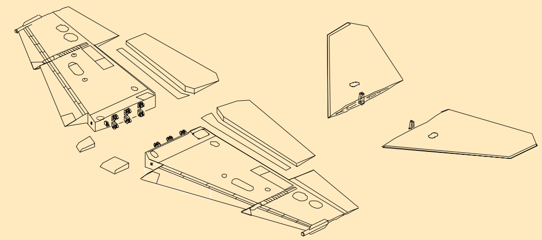
C/D Parts
5,907

E/F Parts
3,296

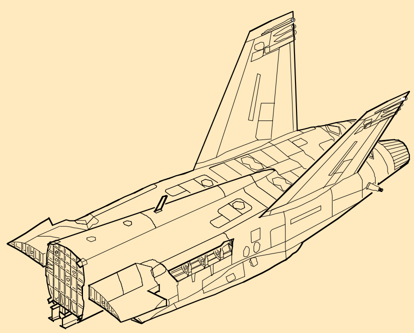
Wings and Horizontal Tails

C/D Parts
1,774

E/F Parts
1,033

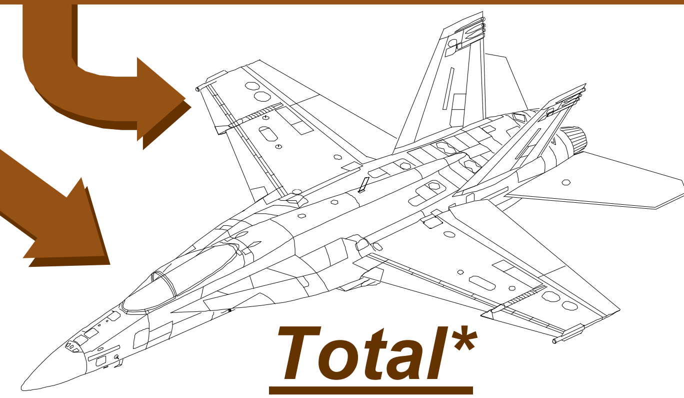


Center/Aft Fuselage, Vertical Tails and Systems



C/D Parts
5,500

E/F Parts
2,847



*Total**

C/D Parts	E/F Parts
14,104	8,099

*Includes joining parts

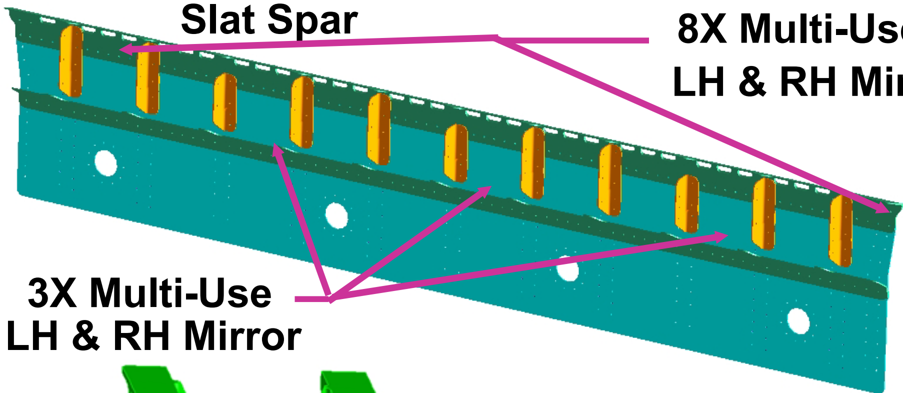
NAVAIR Approved for Public Release: SP168.04

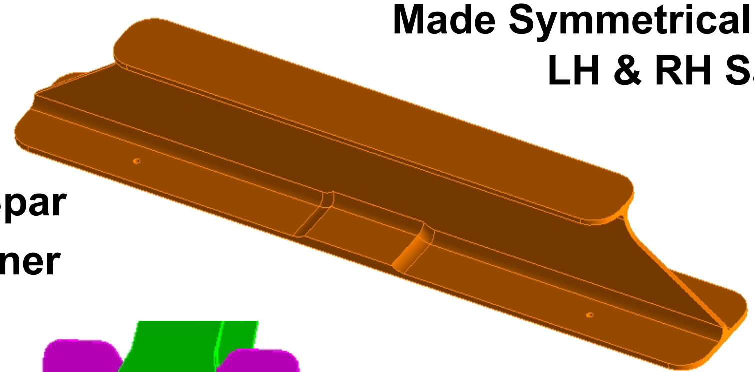
E/F 25% larger and 42% fewer parts than C/D

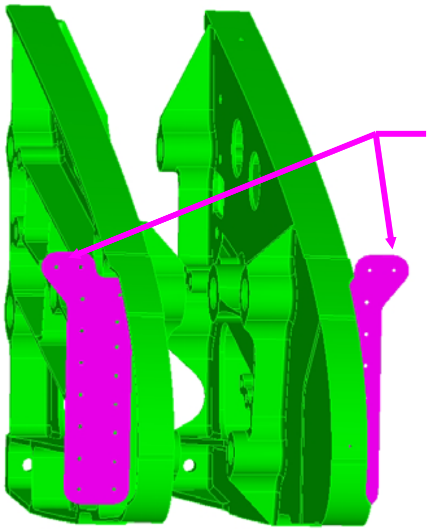
CC84740117.ppt

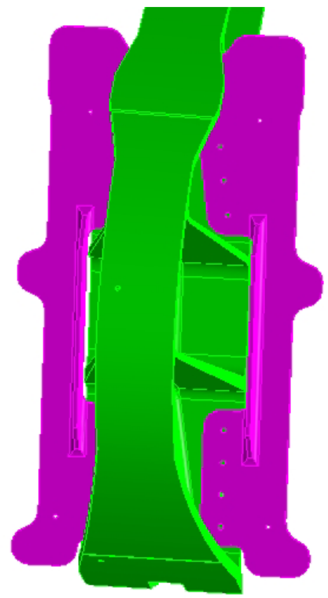
Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

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

Dimensional Management Enabled by Key Characteristics

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

Variability Reduction

Dimensional Management in Product Development

- **Coordinated datums and tools**
- **Geometric dimensioning and tolerancing**
- **Process capability data**
- **3-D statistical modeling**

Key Characteristics

- **Focus on the significant few**

Statistical Process Control in Manufacturing

- **Key processes**
- **Control charting**
- **Process improvement**
- **Feedback to design**

Lean manufacturing requires robust designs and capable processes!

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)

Team Leader

Working together to:

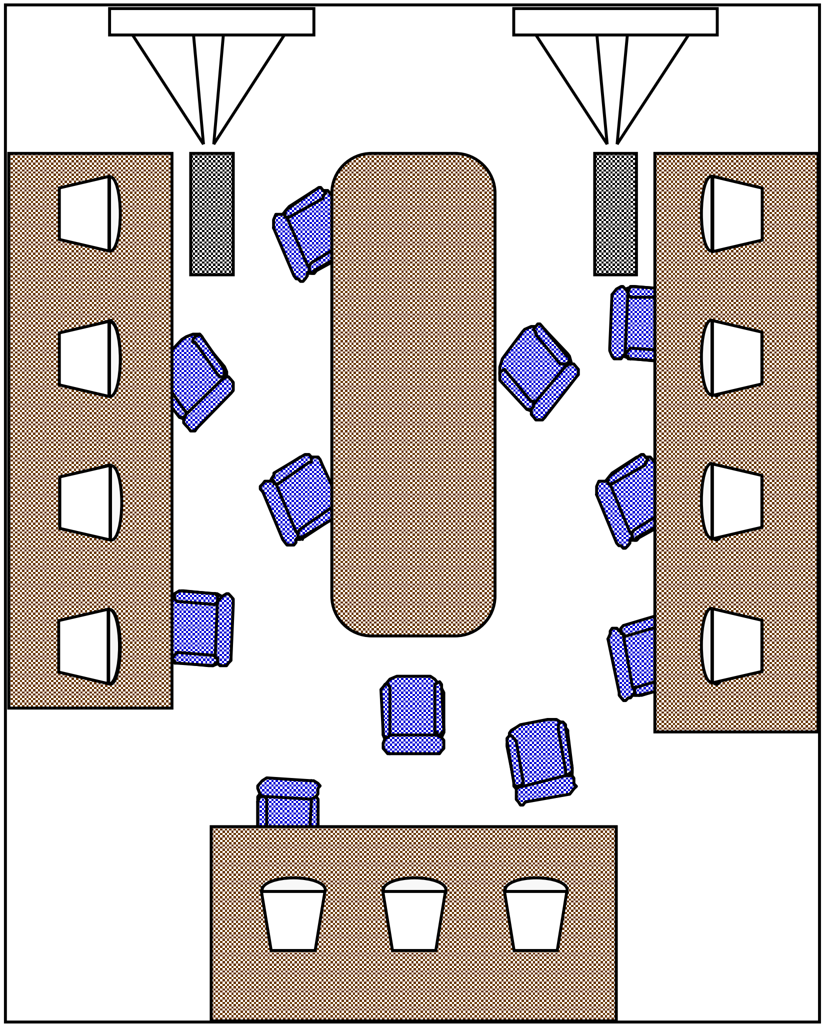
- Build successful programs
- Identify and resolve issues
- Make sound, timely decisions

Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

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

RTCE Team Context

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

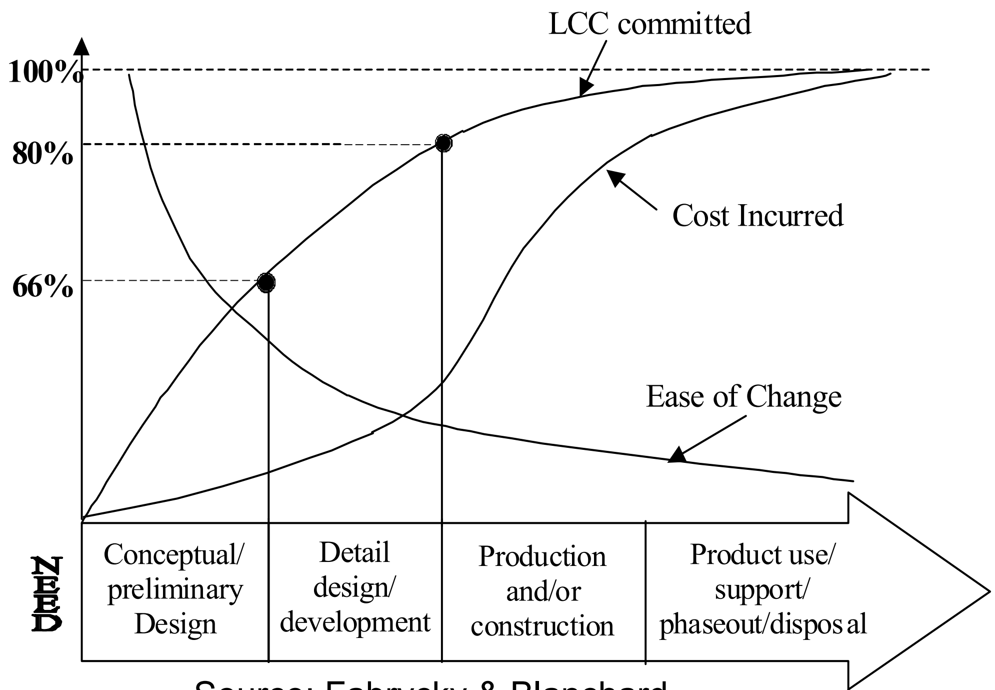
Value-driven lean management metrics

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

Creating the Right Products: Creating product architectures, families, and designs that increase value for all enterprise stakeholders.



Source: Fabrycky & Blanchard

"Fuzzy Front End" Challenges

Understanding what the customer values

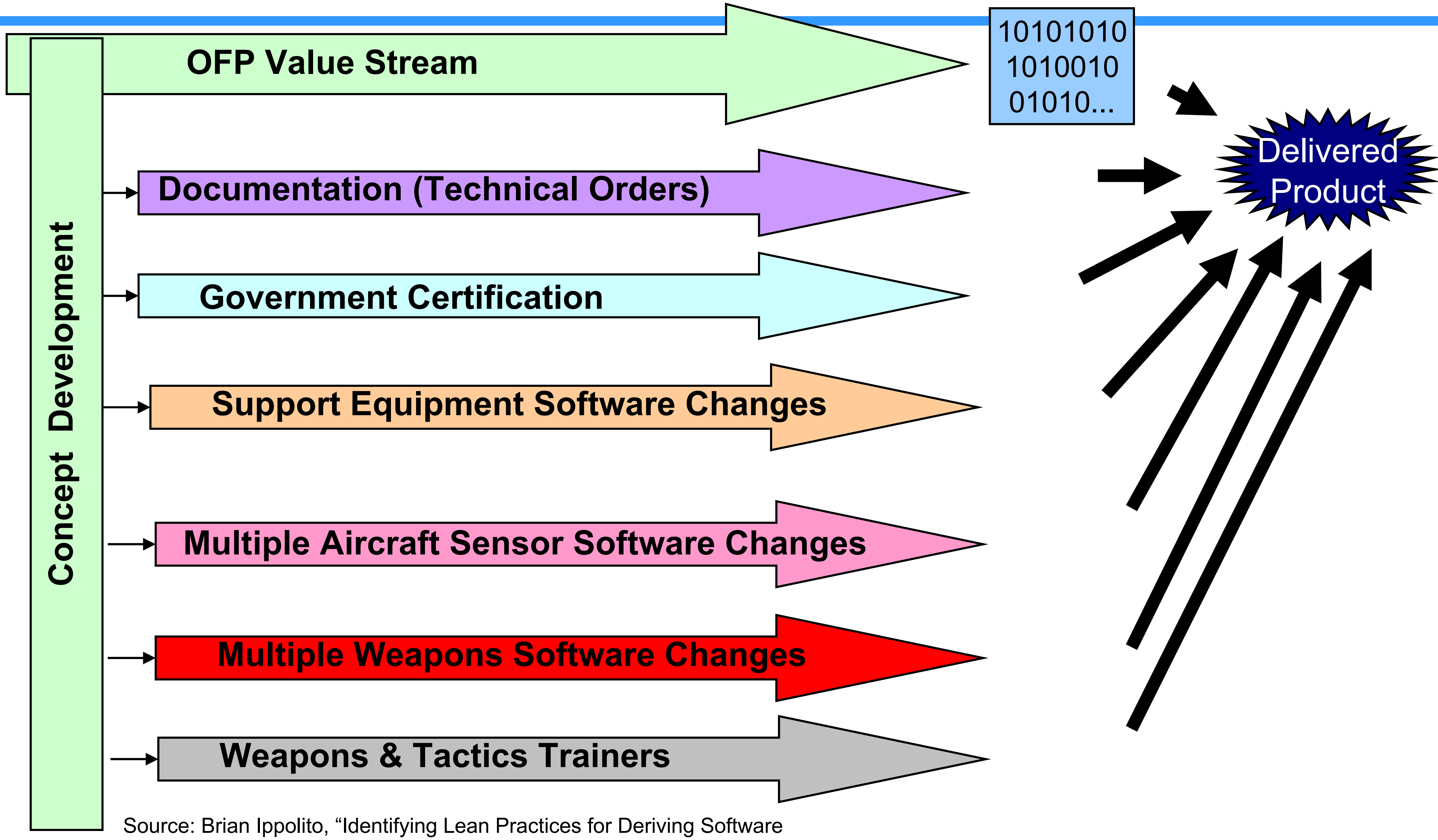
Deciding which product to pursue from amongst many opportunities

Selecting the right product concept

Early decisions are critical - Disciplined lean systems engineering process is essential!

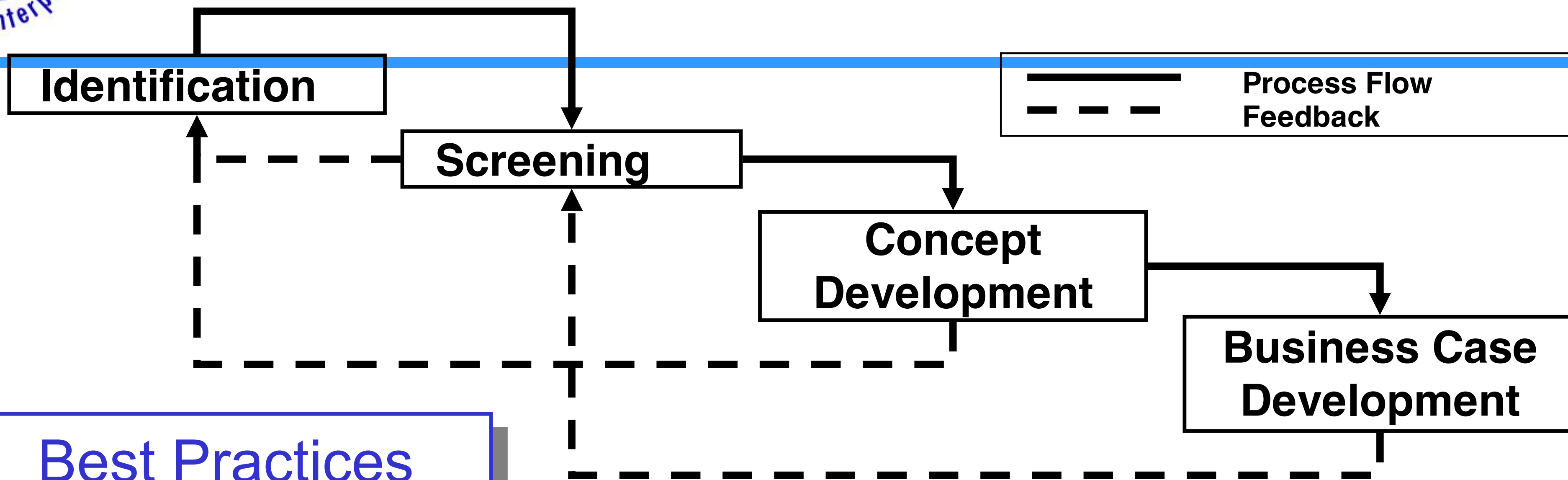
Source: McManus, H.L., Allen Haggerty, Earll M. Murman, "Lean Engineering: Doing the Right Thing Right", presentation at 1st International Conference on Innovation and Integration in Aerospace Sciences, August 5, 2005

Military: Software Development Value Stream(s)



Source: Brian Ippolito, "Identifying Lean Practices for Deriving Software Requirements", MIT Master's Thesis, February 2000

Framework For Effective Front-End Process



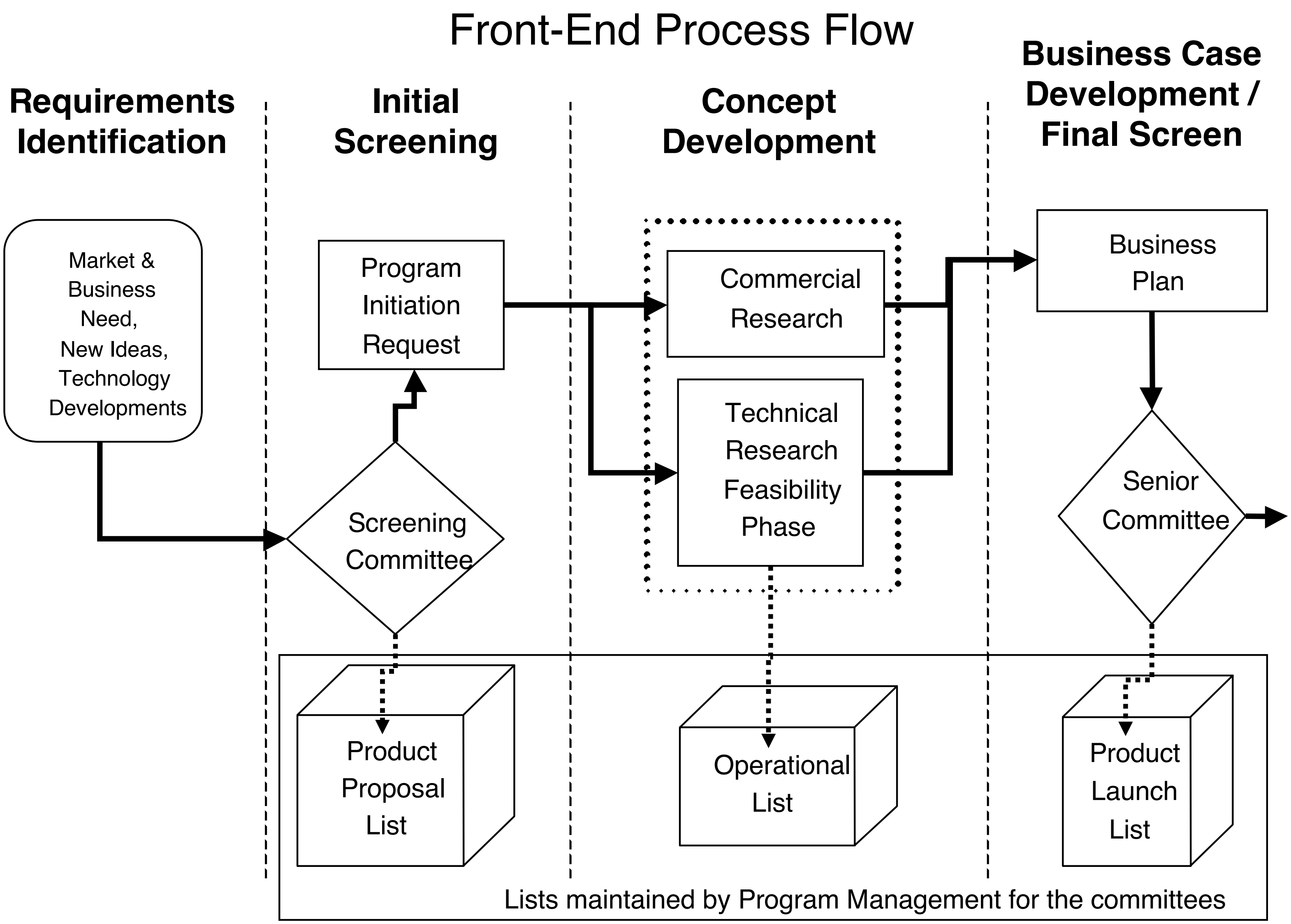
Best Practices

Identification	Screening	Concept	Business Case
Small multidisciplinary teams Adequate funding Multiple requirements ID methods used Independent assessment of solution	Senior level decision Active portfolio management Strategic plan and resource constraints guide prioritization	Requirements given as variables within desired range Team remains intact throughout process Data driven tradeoff analysis - use of prototypes	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

Source: J. R. Withlin, "Best Practices in User Needs/Requirements Generation", MS Thesis, MIT 1994

Company A's Front End Process



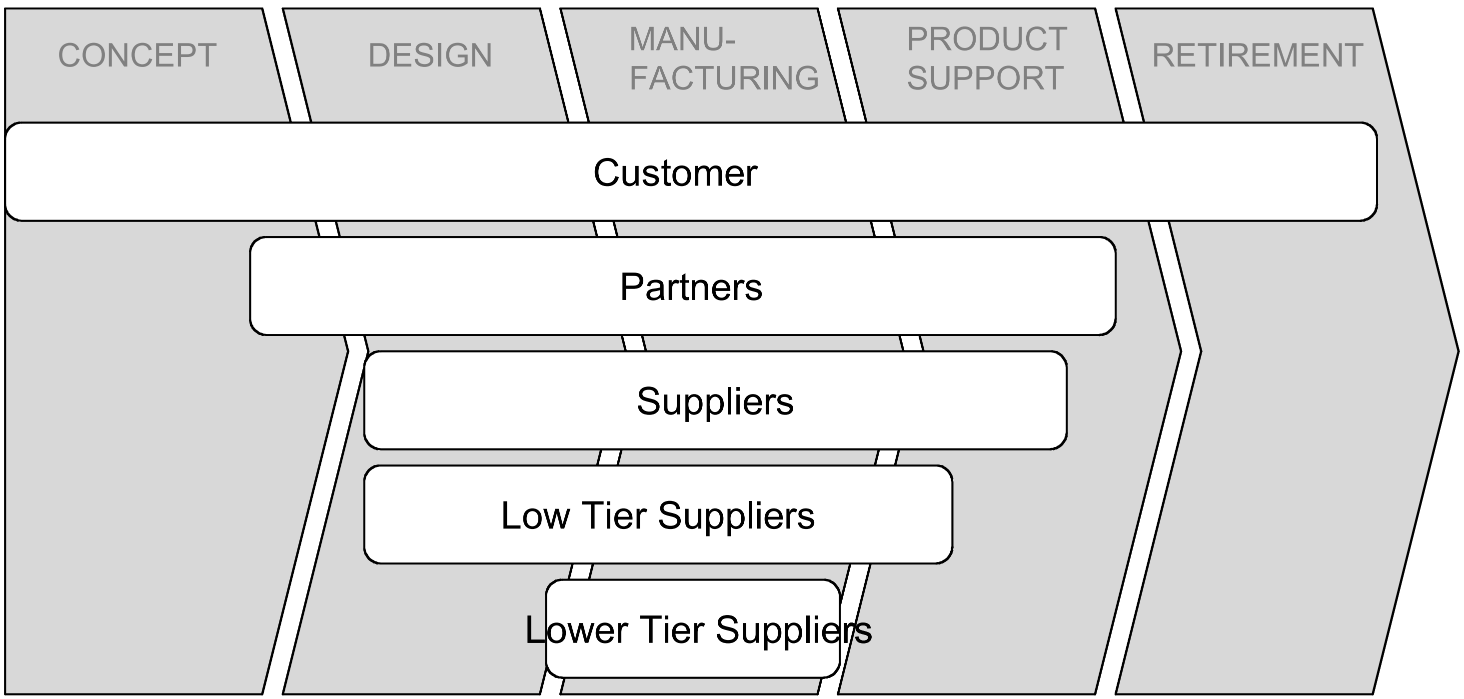
Source: J. R. Withlin, "Best Practices in User Needs/Requirements Generation", MS Thesis, MIT 1994

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

Source: J. R. Withlin, “Best Practices in User Needs/Requirements Generation”, MS Thesis, MIT 1994

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



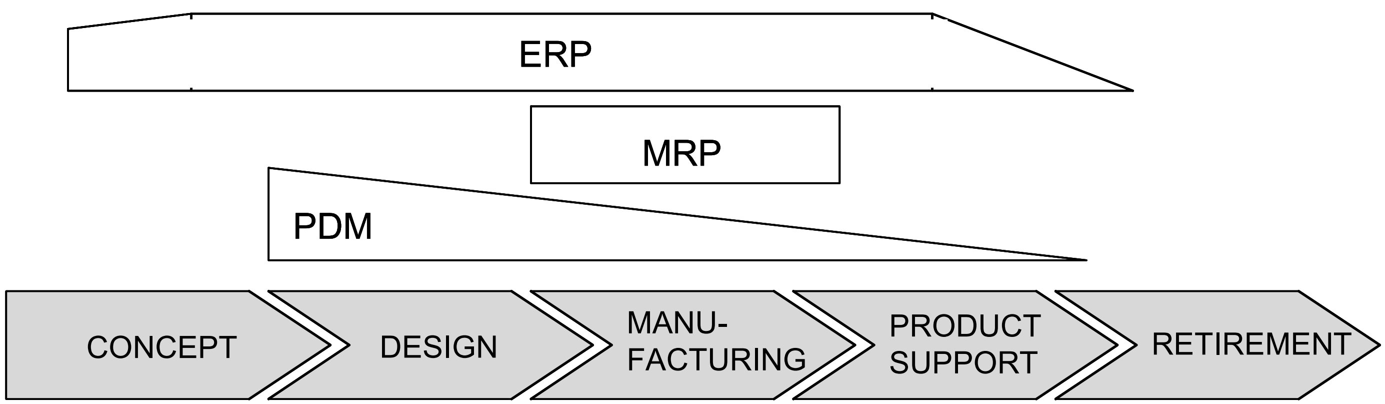
Source: Erisa Hines, Lifecycle Perspectives on Product Data Management, MIT Master's thesis, August 2005

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



Source: Erisa Hines, Lifecycle Perspectives on Product Data Management, MIT Master's thesis, August 2005

Current Issues with PDM Use

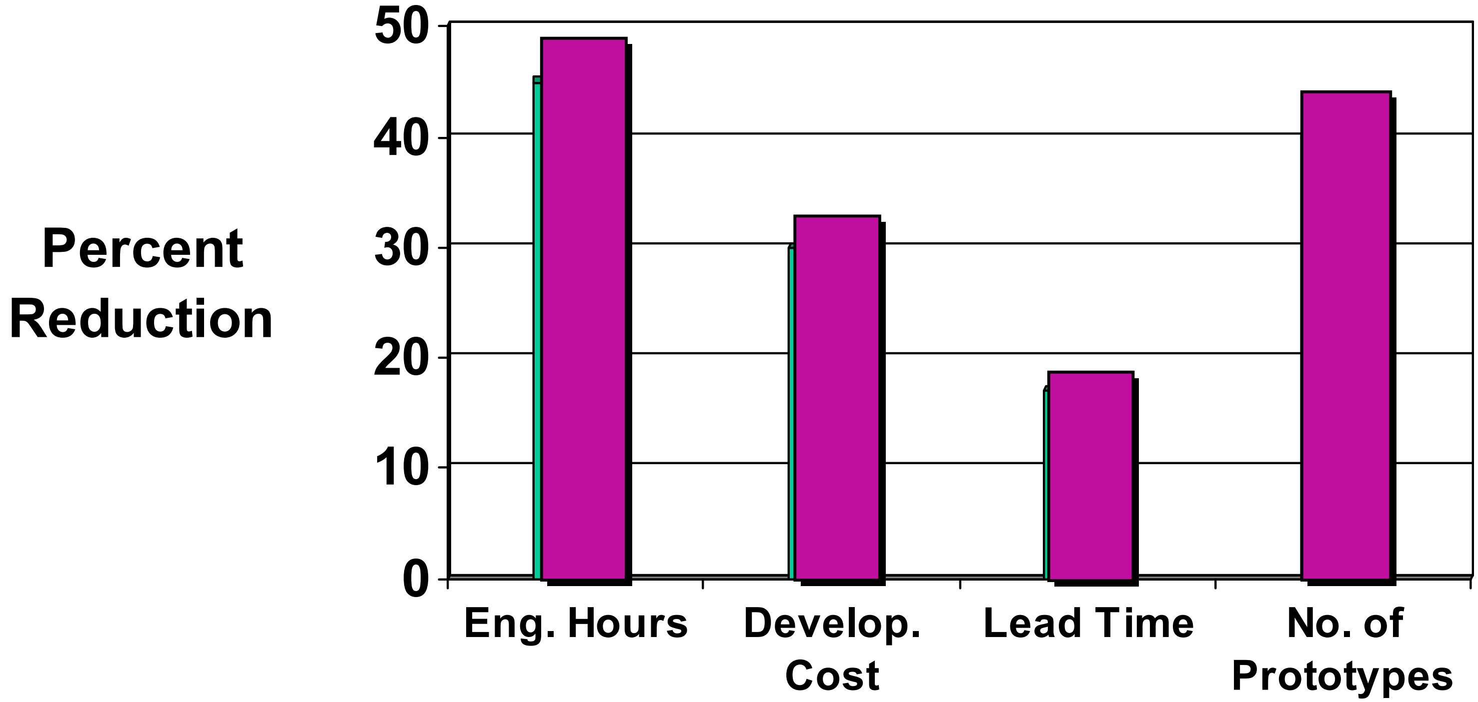
- PDM remains focused on the design stage
- Suppliers moving up the food chain: Need for product data management capability
- Change management and data migration are the biggest challenges/pitfalls
- Lean principles and practices should be used when implementing PDM capability
- PDM enables Lean Enterprise Transformation
  - opportunity to address enterprise value stream

Source: Erisa Hines, Lifecycle Perspectives on Product Data Management, MIT Master's thesis, August 2005

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

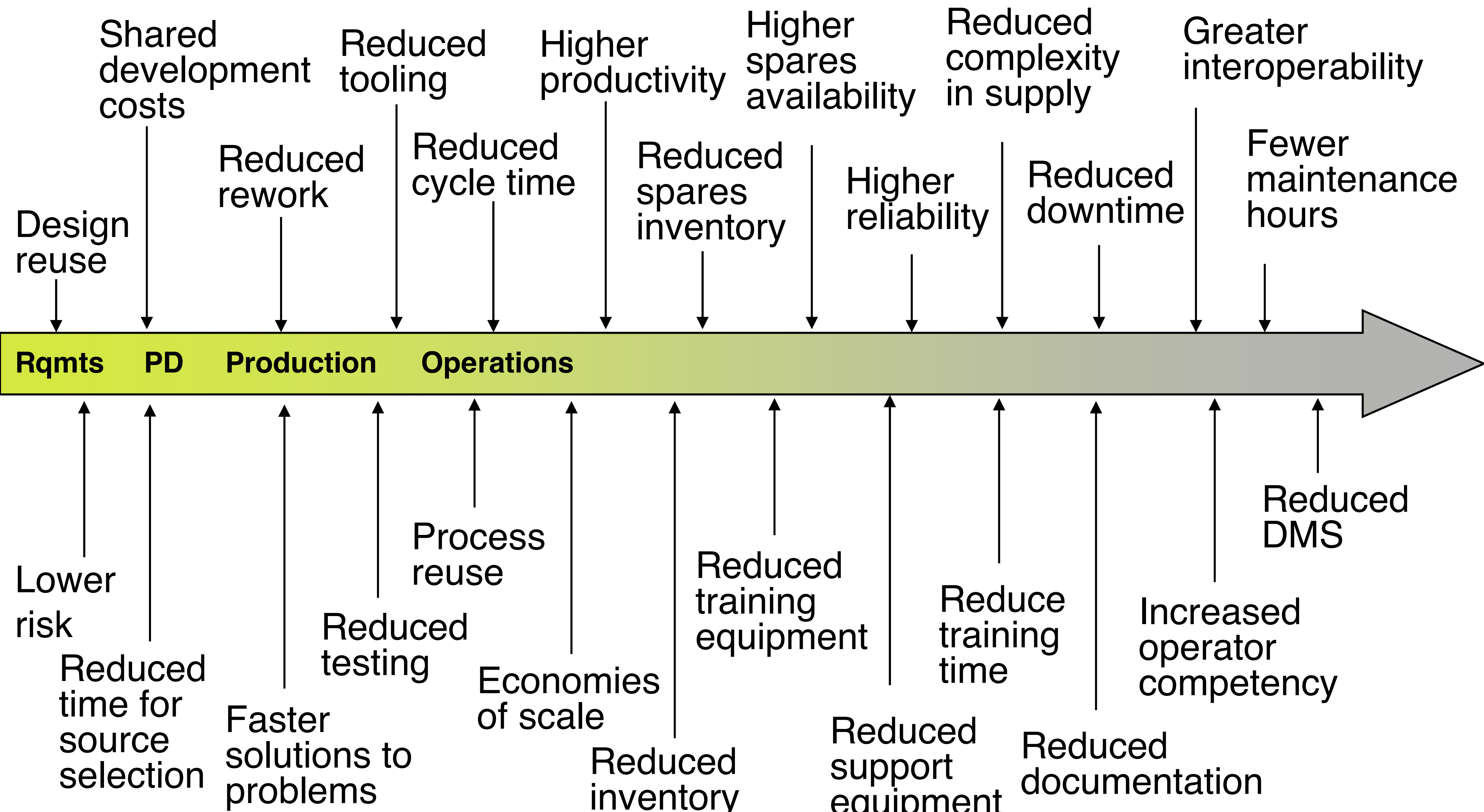
Result of concurrent technology transfer and multi-project management

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



Cusumano and Nobeoka, "Thinking Beyond Lean," 1998.

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



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

Subsystem Commonality Across Product Lines Reduces Design, Operations & Support Costs

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

Increased PD Performance Using Product Line Discipline

Organizational Data	A	B	C	D
Time Implementing PLE (years)	10+	4	2[a]	10
Market Share (%)	75[b]	94[c]	60[b]	55
Overall Size (no. of people)[d]	5500	2000	1300	5000
Number of Platforms	5	6	1	8
Number of Derivatives	12	9[e]	0	24
PLE Ratio (Derivatives/Platforms)	2.4	1.5	0	3
PLE Cycle Time Ratio (Derivative Cycle Time/Platform Cycle Time)	0.25	0.5	0.35[f]	0.24

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**

Source: Michelle Beckert, Organizational Characteristics for Successful Product Line Engineering, MIT Master's thesis, June 2000

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

Acknowledgements

Allen Haggerty - MIT, Boeing (ret.)

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Bo Oppenheim - Loyola Marymount

Alexis Stanke - MIT

Edward Thoms - Boeing, IDS

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