Lean Enablers for Systems Engineering

Bohdan "Bo" W. Oppenheim

Abstract

Lean Thinking is the paradigm that enabled Toyota to rise to the best and largest auto company in the world. The paradigm includes not only Lean manufacturing but also extraordinary effective Product Development and Systems Engineering, as well as a culture based on Respect for People.

Systems Engineering is regarded as a technically sound process but often burdened with waste and inefficiencies. Lean Systems Engineering is a new body of knowledge applying the wisdom of Lean Thinking to Systems Engineering. Systems Engineering and Lean have overlaps and differences, but both represent processes that evolved over time with the common goal of delivering product or system lifecycle value to the customer. Lean Systems Engineering represents synergy of the two, leading to superior systems engineering process.

Most emphatically, Lean Systems Engineering is not a re-packaged FBC or Acquisition Reform". Lean Systems Engineering does not mean "less Systems Engineering"; it means more and better Systems Engineering, with better preparations, planning, front-loading, training, and more common sense, leading to better program execution.

Lean Enablers for Systems Engineering is a product designed by 14 experts from industry, academia, and U.S. and foreign governments, supported by 115+ strong Lean Systems Engineering Working Group of INCOSE. Lean Enablers are formulated as 194 "do's" and "don'ts" of Systems Engineering practice focused on Mission Assurance/Product Success and elimination of waste.

The workshop will cover three parts:

1. Description of the development process of Lean Enablers for SE
2. Presentation of 194 Lean Enablers organized into six Lean Principles: Value, Value Stream Mapping, Flow, Pull, Perfection, and People.
3. "Validation" of the Lean Enablers by surveys, and by benchmarking with recent studies by NASA and U.S. Government Accounting Office.
4. Early feedback from past tutorials and implementation

Biography

Bohdan "Bo" W. OPPENHEIM is the founder and Co-Chair of the Lean Systems Engineering Working Group of INCOSE, and leader of the development effort of Lean Enablers for Systems Engineering. He is a Professor of Mechanical and Systems Engineering and Graduate Director of Mechanical Engineering at LMU in Los Angeles, California. He serves as the local Coordinator of the Educational Network of the Lean Advancement Initiative consortium at MIT. He is on the Steering Committee of the Lean Education Academic Network. For seven years he served as a Director of the U.S. Department of Energy Industrial Assessment Center assessing 125 U.S. industrial plants for lean productivity. He consulted Boeing, Northrop Grumman, Raytheon, Airbus, EADS, Telekomunikacja Polska, and 50 other firms on Lean, Systems Engineering and Quality. He has $2.5 million in externally funded grants on his credit. He teaches graduate courses on Lean Systems Engineering, Lean Manufacturing, Lean Product Development, Lean Final Engineering, Lean Office, Lean Supply Chain, and Quality. He authored 25 journal papers.

He was born in Warsaw, Poland.

His engineering degrees include Ph.D. from Southampton, U.K. in Systems Dynamics; Engineer's Degree from MIT in Ocean Systems; MS from Stevens Institute of Technology; and B.S. (equiv.) from Warsaw Technical University in Aeronautics. His professional experience spans space, naval, mechanical, software, and manufacturing industries.

Lean Enablers for Systems Engineering

Version 1.0, Released February 1, 2009

INCOSE Best Product Award 2010

Lean Systems Engineering Working Group

REVISIONS LOG

VER.	DATE	CHANGES	WHO
1.0	Feb.1,09	Formal release at INCOSE IW in San Francisco	WG
1.01	April 1, 09	Added slides 2, 45, 48,55, 62, 64, 72	Bo Oppenheim
1.02	July 2, 2009	Corrected typo on slide 44	Bo Oppenheim
1.03	Feb.6, 2010	Updated slides 1, 8, 89 and corrected typo on slides 5, 37	Bo Oppenheim

Introductions

1. History: from LAI to INCOSE
2. Lean Fundamentals
3. Lean Systems Engineering
4. Development of Lean Enablers for Systems Engineering
5. The Product: Lean Enablers for Systems Engineering
6. “Validation”
7. Future Work
8. Summary

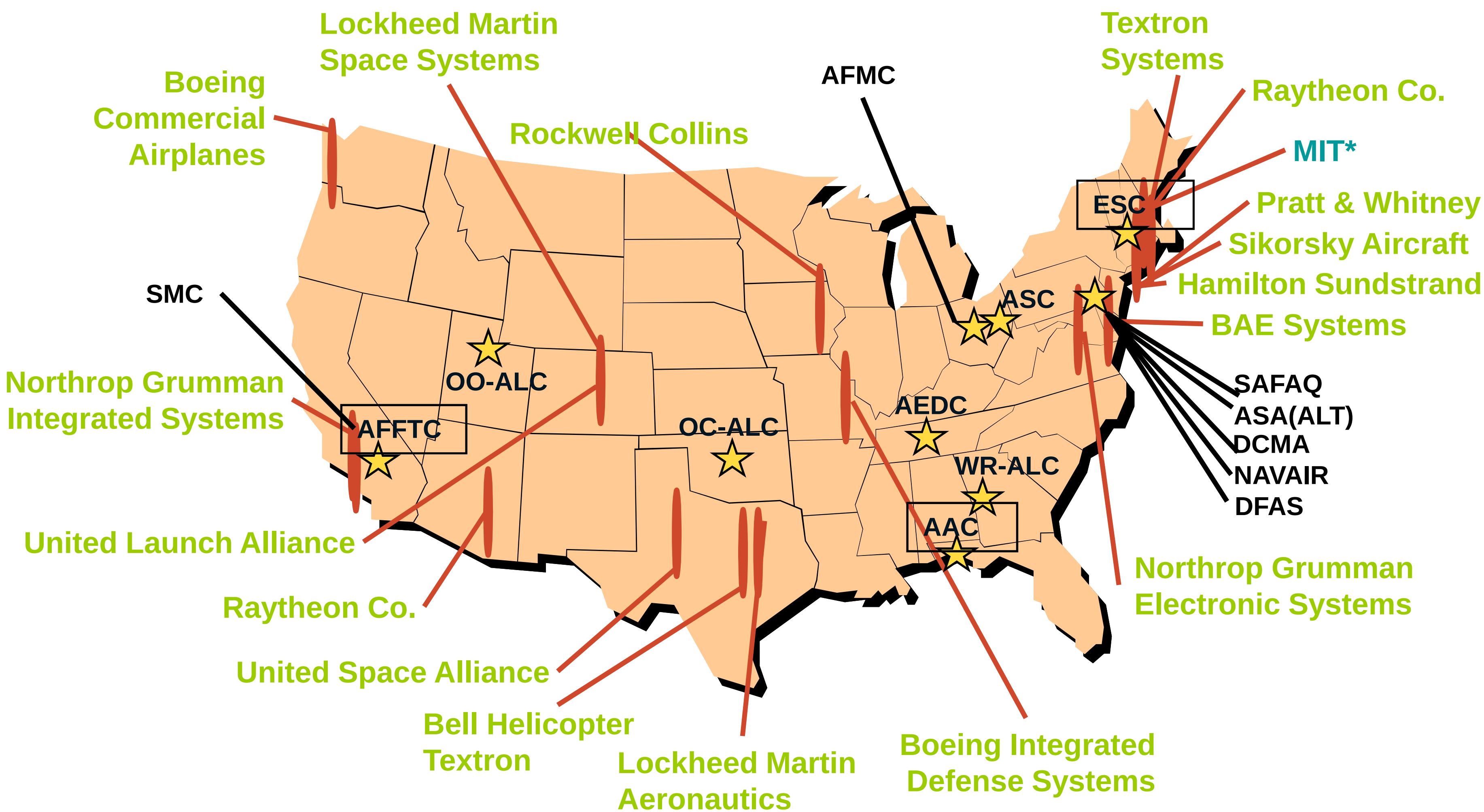
Part 1. History:
From LAI to INCOSE

Origins at the MIT LAI

- 1993 Lean Aircraft Initiative consortium started at MIT
- 1993-present major research by the LAI community in various areas of Lean
- 1998 LAI changes name to Lean Aerospace Initiative
- 2003: LAI invited other universities to join the LAI Educational Network, some active in Lean research
- 2004 – Lean SE working group was formed within the EdNet, migrated to INCOSE in 2006
- 2007 – LAI renamed to Lean Advancement Initiative (//lean.mit.edu)

LAI Membership 2008

U.S.Military

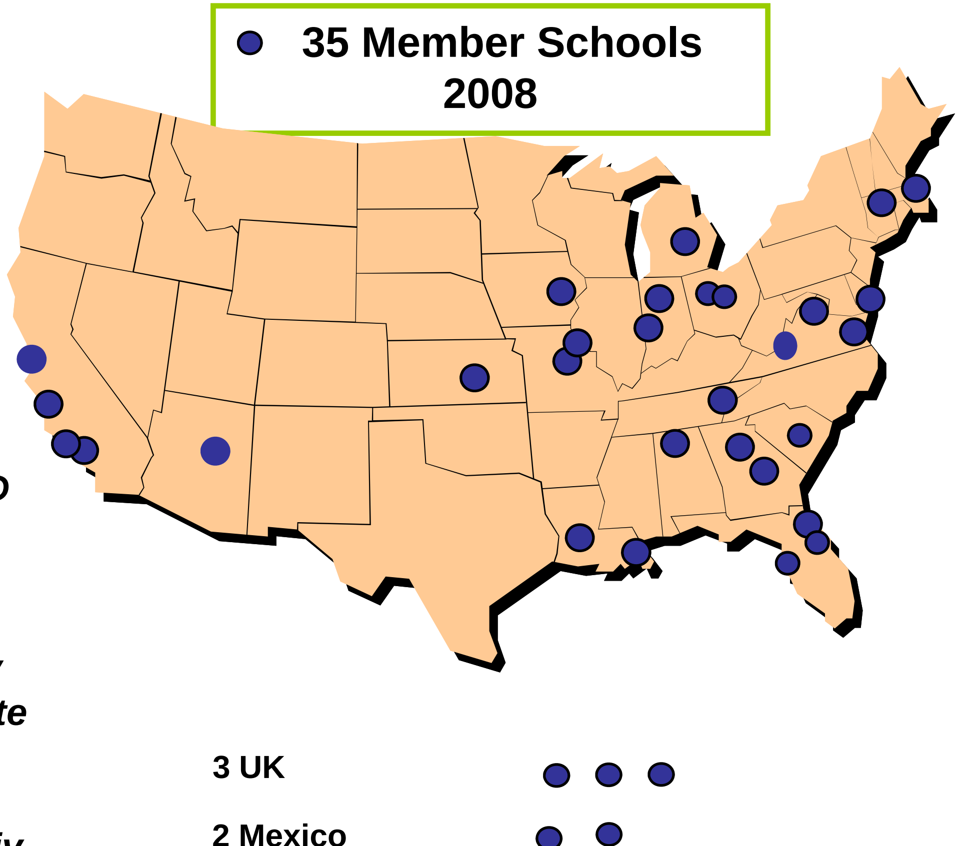


LAI Lean Academy™

http://lean.mit.edu

LAI Educational Network “EdNet”, 2008

AFIT
AZ State U
Cal Poly SLO
Cranfield (UK)
DAU
Embry-Riddle
Georgia Tech
Indiana State Univ
Jacksonville Univ
Loyola College, MD
Loyola Marymount
Macon State Col
MIT
Old Dominion Univ
North Carolina State
Purdue Univ
St. Louis Univ, MO
San Jose State Univ



Tecnológico de Monterrey (MX)
Universidad Popular Autónoma del Estado de Puebla (MX)
U of AL, Huntsville
U of Iowa
U of Michigan
U MO Rolla
USC
U of Bath (UK)
U of South Florida
U of Tenn, Knoxville
U of New Orleans
U of Louisiana, Lafayette
University of VA
U of Warwick (UK)
Wichita State Univ
Wright State Univ
WPI

The INCOSE Lean SE Working Group

- Initiated in Jan. 2006 in ABQ, 30 participants in first meeting!
- -in order to draw on the collective wisdom of INCOSE members
- June 2006: 60 participants in Orlando
- February 2010: 140+ names and growing
- WG Core Team (all volunteers, working in spare time)

  Co-chairs identified with asterisk:
  - Dave Cleotelis*, Raytheon, FL (2006-08)
  - Charles Garland*, AFIT
  - Ray Jorgensen*, Rockwell Collins, IA
  - Earll Murman, MIT, ret.; WG Core Team Member Emeritus
  - Bo Oppenheim*, LMU, Los Angeles
  - Deb Secor*, Rockwell Collins, IA
- Webmasters: Ray Jorgensen (CONNECT), Bo Oppenheim (Public site)

Past Work of the WG

- Organized eight meetings (I/2006, VI/2006, I/2007, VI/2007, I/2008, VI/2008, I/2009,VI/2009)

- Initial activities
  - Completed INCOSE Web Page and Connect Site
  - Charter (next slide), Definitions, Reading list, Articles (see web)
  - Panels and Presentations

- **Major effort: Development of Lean Enablers for Systems Engineering (LEfSE)**

Web access

- **Public site**
  - **www.incose.org**
  - **Click on Working Groups**
  - **Click on Lean Systems Engineering**

- **INCOSE CONNECT (members only)**
  - **www.incose.org**
  - **Click CONNECT**
  - **Click on Lean Systems Engineering WG**

Lean SE WG Charter

It is our goal to strengthen the practice of Systems Engineering (SE) by exploring and capturing the synergy between traditional SE and Lean. To do this, we will apply the wisdom of Lean Thinking into SE practices integrating people, processes, and tools for the most effective delivery of value to program stakeholders; formulate the Body of Knowledge of Lean SE; develop supplements to the INCOSE SE Handbook (and other such manuals) with Lean Enablers for SE; and develop and disseminate training materials and publications on Lean SE within the INCOSE community, industry, and academia.

(Changed to reflect the current project on 11-15-08)

Part 2.
Lean Fundamentals

Lean Thinking

- Lean = The thinking credited for the extraordinary success of Toyota: monotonic rise to the best, most profitable and biggest auto company in the world
- Adopted and emulated by thousands of companies worldwide
- Based on Pursuit of Value with Minimum waste

TOYOTA

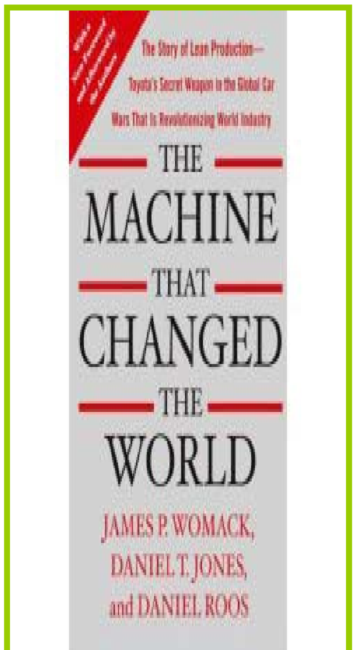
Lean Thinking Captured into Six Lean Principles

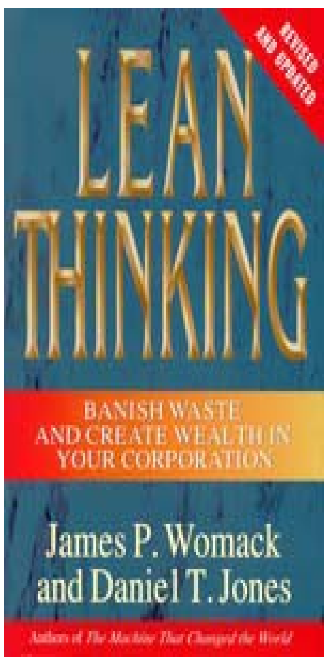
1. Customer defines value
2. Map the value stream: plan all end-to-end linked actions and processes necessary to realize value, streamlined, after eliminating waste
3. Make value flow continuously: without stopping, rework or backflow (valid iterations OK)
4. Let customers pull value: Customer's "pull/need" defines all tasks and their timing
5. Pursue perfection: all imperfections become visible, which is motivating to the continuous process of improvement
6. Respect people

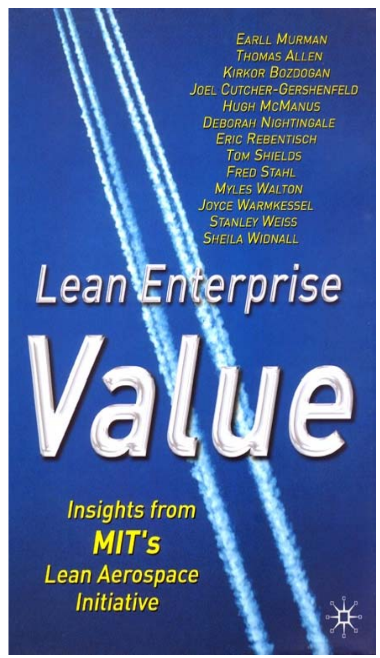
Discussed in detail later in the context of SE.

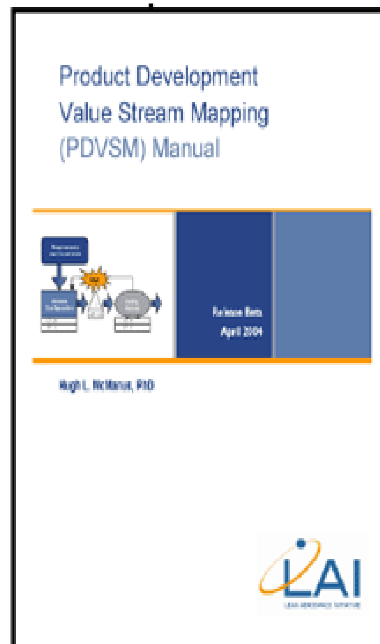
Selected Lean Milestones

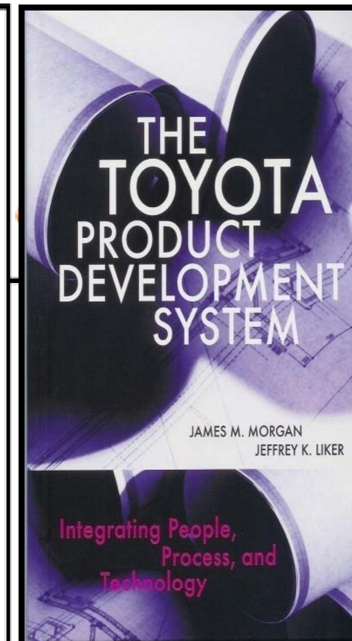
1990	1996	2002	2004	2007











Maturity of Various Areas of Lean

We know this:

- Lean applies to any quantity of products: from one-off (like PD) to large volumes (like cars or aircraft)
- Lean applies to all areas of work!

ENTERPRISE AREA	Maturity
Lean Manufacturing	Very mature
Lean Enterprise	Mature
Lean Supply Network	Mature
Lean Office (we all work in an office environment)	Mature
Lean (Final) Engineering	Mature
Lean Product Development	Less Mature, fast growing
Lean Systems Engineering	Until now, least mature; challenge for our INCOSE LSE WG

Lean = Pursue Value with Minimum Waste

Define Value Added

Value Added

- The external customer is willing to pay for "Value"
- Transforms information or material
- Provides specified performance right the first time

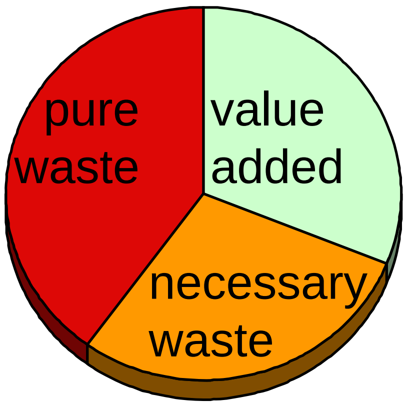
Non-Value Added – Necessary

- No value is created but which cannot be eliminated based on current technology or thinking
- Required (regulatory, company mandate, legal)

Non-Value Added - Waste

- Consumes resources but creates no value in the eyes of the customer
- If you can't get rid of the activity, it's non-value added but necessary

Huge Waste Exists 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)*

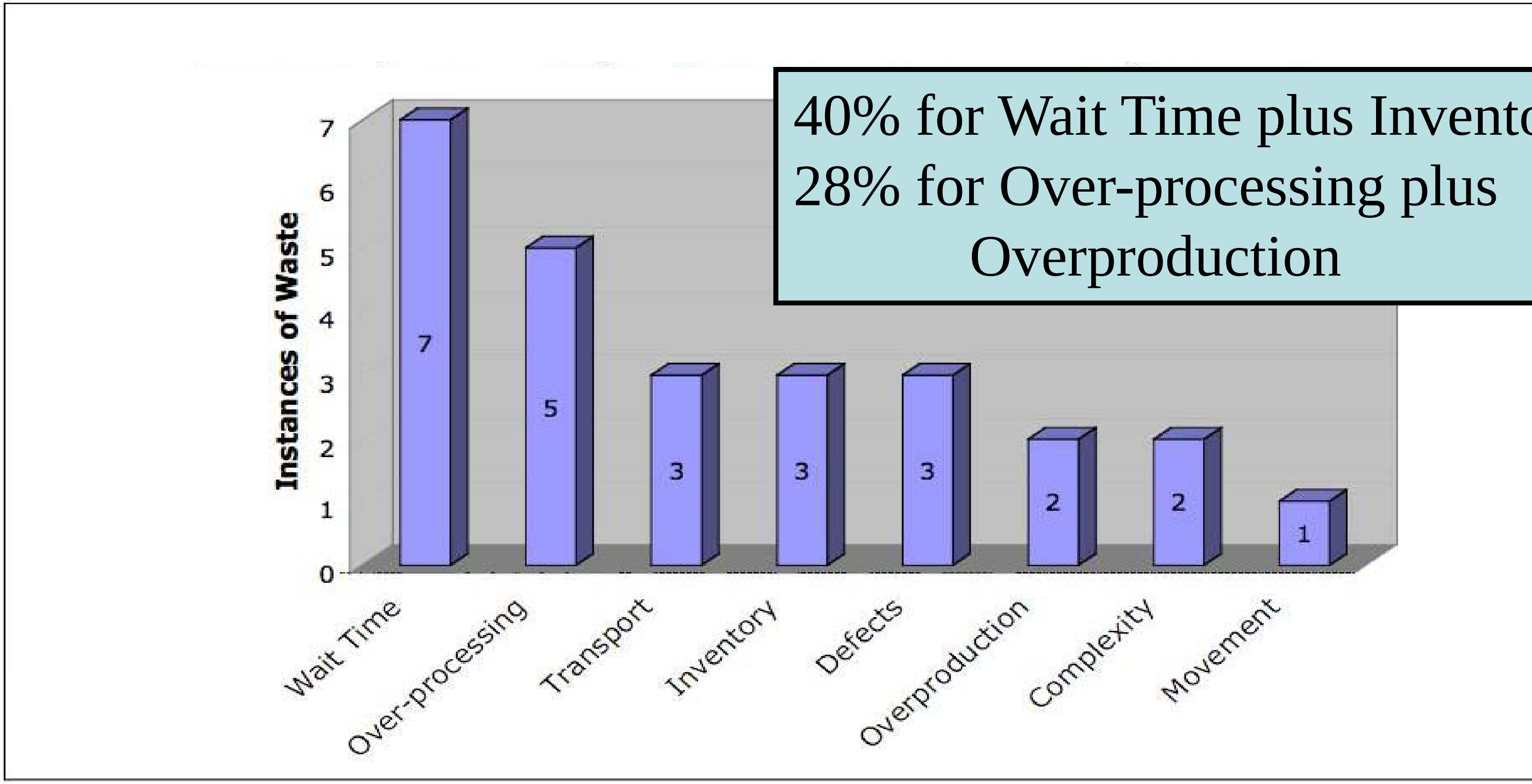
- ***Time* is wasted**
  - **62% of *tasks* idle at any given time** *(detailed member company study)*
  - **50-90% task idle time found in Kaizen-type events**

Source: McManus, H.L. “Product Development Value Stream Mapping Manual”, … I Releas… April 2004

Ohno’s Categorization of Waste into Seven Types

1. Over-production	Creating too much material or information
2. Inventory	Having more material or information than you need
3. Transportation	Moving material or information
4. Unnecessary Movement	Moving people to access or process material or information
5. Waiting	Waiting for material or information, or material or information waiting to be processed
6. Defective Outputs	Errors or mistakes causing the effort to be redone to correct the problem
7. Over-processing	Processing more than necessary to produce the desired output

Measurement of Info Waste for 25 Organizations



40% for Wait Time plus Inventory
28% for Over-processing plus Overproduction

Slack, Robert A., "Application of Lean Principles to the Military Aerospace Product Development Process," Masters thesis in Engineering and Management, Massachusetts Institute of Technology, December 1998.

Examples and Descriptions of PD Waste Categories

Adopted for PD

WASTE	EXAMPLES/DESCRIPTION
1. Overproduction	• Creating unnecessary information • Performing work which is not needed • Creating documents that nobody requested • Pushing data rather than pulling data • Over dissemination = sending information to too many people (just think of email copies) • Too much detail, administrative overhead • Sending a volume when a single number was requested • Reinventing the wheel • Needlessly repetitive development • Some meetings • Ignored expertise • Discarded knowledge (layoffs!) to be rediscovered • Measuring waste in some Six Sigma projects

Adopted by Oppenheim, with elements from LAI EdNet

Examples and Descriptions of PD Waste Categories

WASTE	EXAMPLES/DESCRIPTION
2. Transportation	• Inefficient transmittal of information • Communication failure: lost data, wrong format, information incompatibility • Transportation for approvals • Multiple sources or destinations • Security slowing the transportation • Disjointed facilities and/or political "made in 50 states"
3. Waiting (30% of design charged time; 63% of all tasks idle at any given time)	• Waiting for data, test result, information, decision, signature... • Late delivery, wrong delivery • Poor planning, scheduling, precedence, and coordination • Disorganization, reorganization

Examples and Descriptions of PD Waste Categories

WASTE	DESCRIPTION
4. Over Processing	• Working more than necessary to produce the outcome • Point design used too early, causing massive iterations • Starting with small margins and complex models • Unnecessary serial effort • Uncontrolled iterations (too many tasks iterated) • Work on a wrong release (information churning) • Data conversions • Answering wrong questions • Many of contractual obligations (e.g., 2D drawings) • Unclear or unstable requirements • Complex software monuments (using PRO ENGINEER or NASTRAN where a spreadsheet would do)

Examples and Descriptions of PD Waste Categories

WASTE	DESCRIPTION
5. Inventory	• Keeping more information than needed • Poor configuration management and complicated retrieval • Poor 5 S's in factory or office • Lacking central release
6. Unnecessary movement	• People having to move to gain or access information • Manual intervention to compensate for the lack of process • Information pushed to wrong sources • Hand-offs
7. Defects	• Insufficient quality of information • The killer "re's": Rewrite, Redo, Reprogram, Recalibrate, Rerun, Recertify, Reschedule, Recheck, Recondition, Reship, Restock, Retest, Re-inspect, Return, Re-measure, Reorder, Rework... • Incomplete, ambiguous or inaccurate information

Part 3.

Lean Systems Engineering

From Lean to Lean Systems Engineering

- **Lean = organization of work within a company and between all cooperating companies which is based on the elimination of waste from all activities**

  – Jim Womack

- **Lean Systems Engineering is the application of lean six sigma principles, practices and tools to systems engineering in order to enhance the delivery of value to the system's stakeholders**

  – LSE WG INCOSE page.

Synergy of Lean and Systems Engineering

- Systems Engineering grew out of the space industry
  - To help deliver flawless complex systems
  - SE focus: technical performance and risk management

- Lean grew out of Toyota
  - To help deliver quality products at minimum cost
  - Lean focus: waste minimization, short schedules, low cost, flexibility, quality

- Common goal: Deliver system lifecycle value to the customer

- Lean Systems Engineering is the area of synergy of Lean and Systems Engineering
  - Goal: Deliver best lifecycle value for technically complex systems with minimum resources.

Adopted from Murman, 2006

Example program demonstrating that Lean and SE are synergistic

F/A-18 E/F

- Ten other aerospace successes using Lean thinking are listed in [Murman, 2008] on WG web site

Value in Lean SE

Definition of Value in Lean SE:

- **"Flawless mission assurance or product success delivered without waste, in the fastest possible time"**

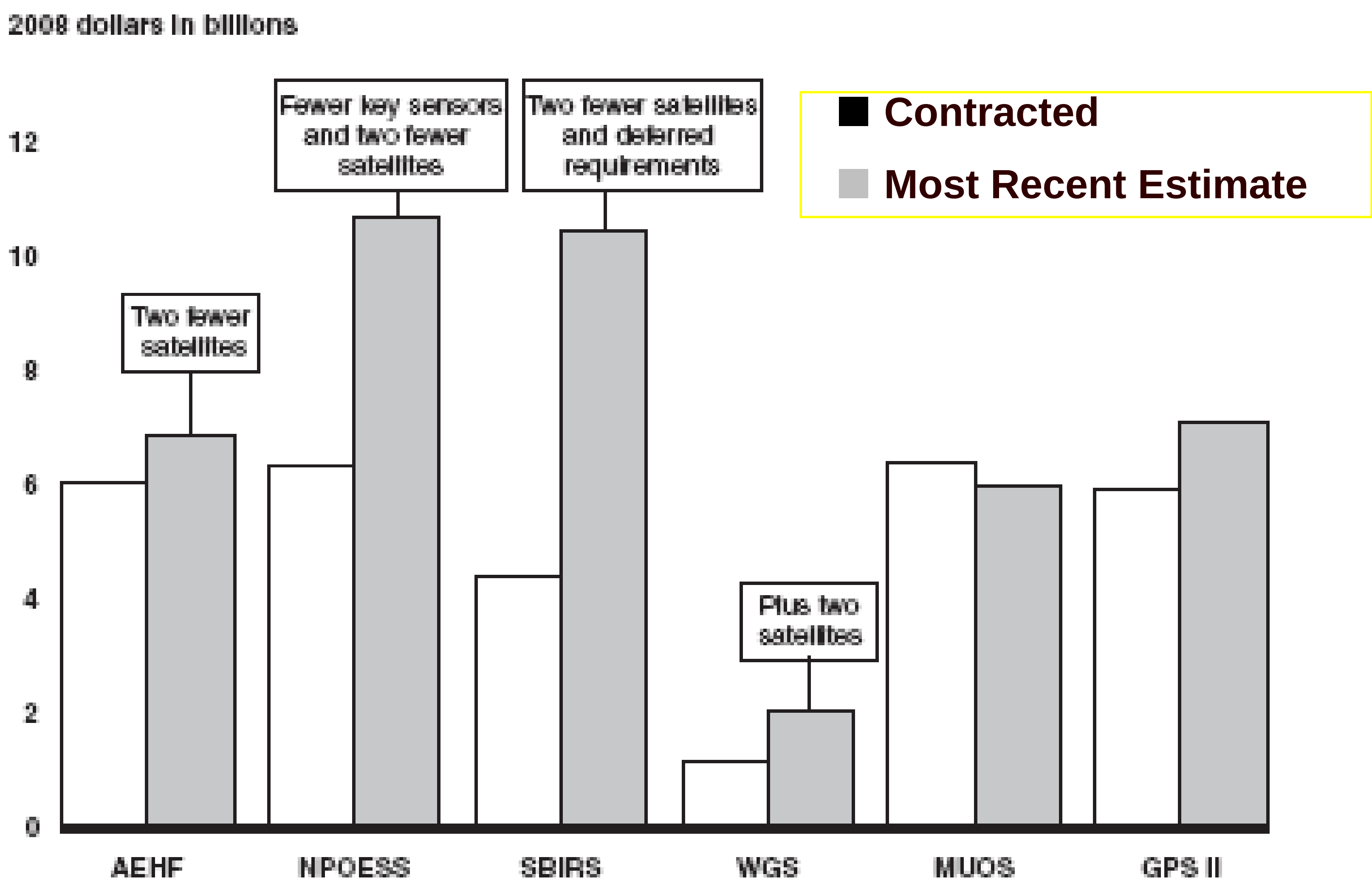
  - LSE WG web page

The Need

- Recent studies of governmental programs by NASA and GAO indicated serious problems in Systems Engineering...

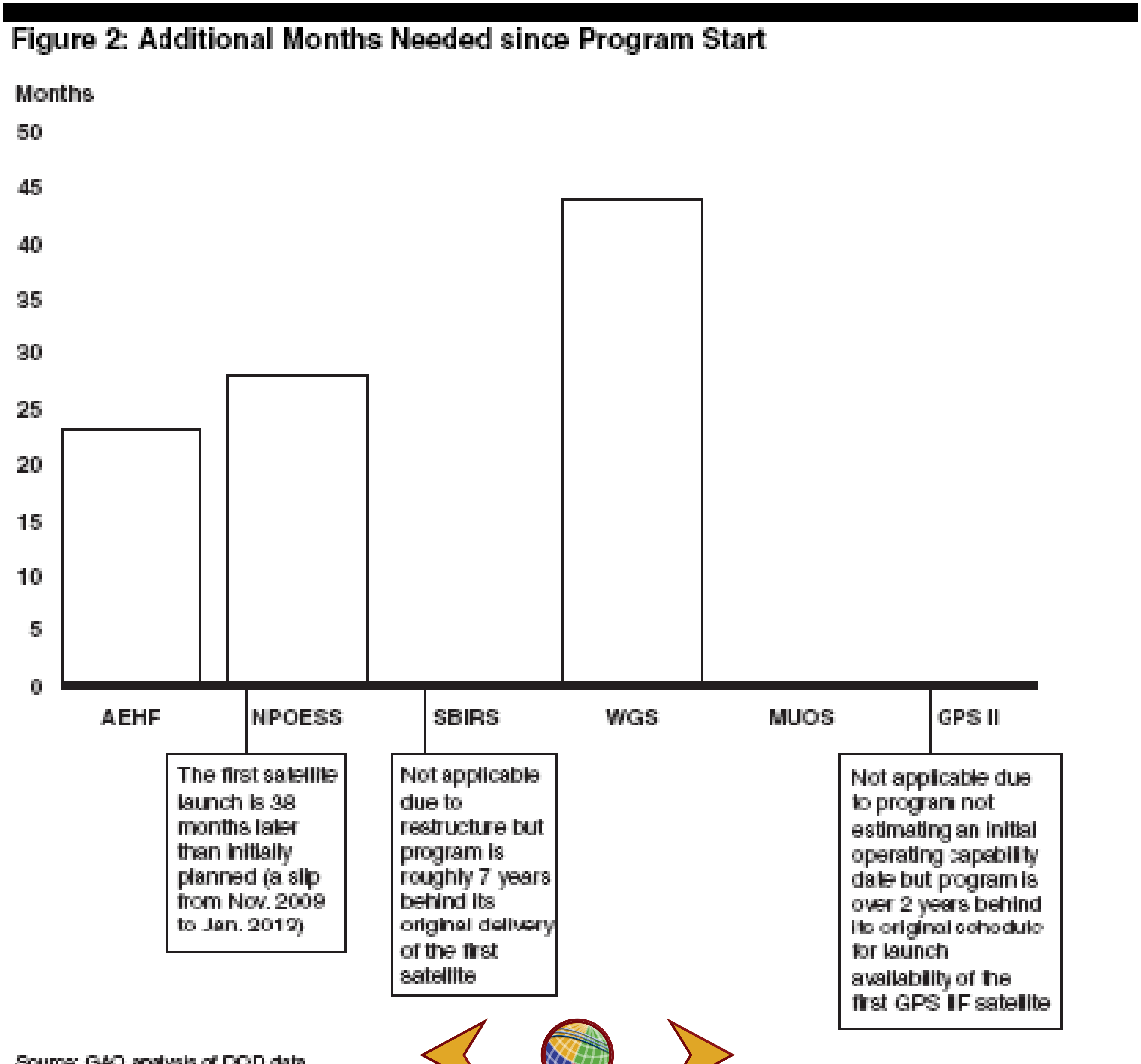
Need for Better SE: Cost Overruns

Figure 1: Differences in Total Program Costs from Program Start and Most Recent Estimates



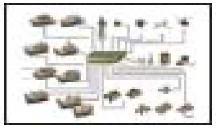
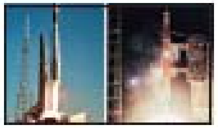
GAO: Space Acquisitions, 2008

Schedule Overruns



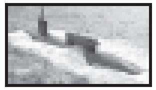
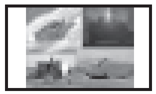
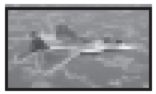
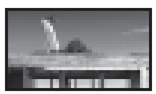
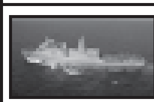
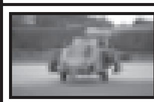
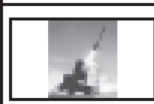
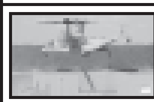
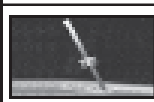
Overruns Cause Reduced Buying Power

Table 4: Examples of Reduced Buying Power (constant 2007 dollars)

Program		Initial estimate	Initial quantity	Latest estimate	Latest quantity	Percentage of unit cost increase
Joint Strike Fighter		$196.5 billion	2,866 aircraft	$223.3 billion	2,458 aircraft	32.3
Future Combat Systems		$85.5 billion	15 systems	$131.7 billion	15 systems	54.1
V-22 Joint Services Advanced Vertical Lift Aircraft		$36.9 billion	913 aircraft	$50.0 billion	458 aircraft	170.2
Evolved Expendable Launch Vehicle		$16.0 billion	181 vehicles	$28.6 billion	138 vehicles	134.7
Space Based Infrared System High		$4.2 billion	5 satellites	$10.4 billion	3 satellites	311.6
Expeditionary Fighting Vehicle		$8.4 billion	1,025 vehicles	$11.3 billion	1,025 vehicles	33.7

Source: GA[illegible]nalysis of D[illegible] Images [illegible]d in their respective order: JSF Program Office; Program Manager, Future Combat System[illegible]; V-22 Joi[illegible] Office; (Left[illegible]5 ILS/Lockheed Martin, (right) © 2003 The Boeing Company; Lockheed Martin Space Sys[illegible] Company; [illegible] Dynamics [illegible]d Systems.

Weapon System Quality Problems and Impact

System		Source of quality problem			Impact of quality problem	
		Systems engineering	Manufacturing	Supplier quality	Cost (dollars in millions)	Schedule
Advanced SEAL Delivery System[a]		✓		✓	$87	Program halted
Advanced Threat Infrared Countermeasure/ Common Missile Warning System		✓	✓		$117	5-year delay
Expeditionary Fighting Vehicle		✓			$750	4-year extension to system development
F-22A		✓	✓	✓	$400	No schedule impact to program
Global Hawk[a]		✓		✓	$239	4-month production slip for sensor suite
Joint Air-to-Surface Standoff Missile			✓	✓	$39	Program deferred
LPD 17 Amphibious Transport Dock[a]		✓	✓	✓	$846	3-year delay
MH-60s Fleet Combat Support Helicopter			✓		No cost impact to program	6-month production slip
Patriot Advanced Capability-3		✓	✓	✓	$26	6-month delay
V-22 Joint Services Advanced Vertical Lift Aircraft		✓			$165	Flight operations halted for 17-months
Wideband Global SATCOM			✓	✓	$10	18-month delay for initial operating capability

Source: GAO analysis of DOD and contractor data.

[a]Cost and schedule figures are not solely attributable to quality problems.

Part 4.

Development of Lean Enablers for SE (LEfSE)

Overall Strategy for the Lean Enablers

- Challenge to apply the wisdom of Lean Thinking to SE practices
- The underlying philosophy:
  - Produce Lean Enablers: a checklist of do's and don'ts of SE
  - Aim for "the asymptote of excellence in SE"
  - Make SE as Value driven and as Waste free as possible
  - Hard data difficult to develop, so use the "Tacit knowledge approach" (rely on collective wisdom of experts and practitioners)
- Lean Enablers not intended as a regulation or mandatory procedure.
  - Intent: improve awareness of best practices among all stakeholders
  - If a particular program or organization falls short of one or more of the Lean Enablers, this is not a reason yet to reject or resist the Enablers.
- LE for SE should not repeat information already covered in the SE handbook, e.g. requirements management, risk management, IPTs, etc. – which are considered sound, but lacking Lean Thinking

Credits for the Work on LEfSE

- **Concept-through-Beta Team (Oct 07- Jan 08)**
  - Earll Murman*, MIT, Core Team Co-lead
  - Col. Jim Horejsi, SMC
  - Mike Schavietello, Boeing
  - Jim Zehmer, Toyota
  - Larry Earnest, NGIS
  - Deb Secor, Rockwell Collins
  - Ray Jorgensen, Rockwell Collins
  - Bo Oppenheim*, LMU, Core Team Co-lead

    * Prepared Alpha and Beta versions
- **Beta survey (29 respondents)**
- **Prototype Team (Jan. 28 – June 19)**
  - Larry Earnest (Northrop Grumman-IS) larry.earnest@ngc.com
  - Roy Jorgensen (Rockwell Collins) rwjorgen@rockwellcollins.com
  - Ron Lyells (Honeywell ABQ) ron.lyells@honeywell.com
  - Bo Oppenheim** (LMU) boppenheim@lmu.edu
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  - Deb Secor (Rockwell Collins) dasecor@rockwellcollins.com
  - Hillary G. Sillitto (UK MoD Abbey Wood) hillary.sillitto@incose.org
  - Stan Weiss (Stanford Univ.) siweiss@stanford.edu
  - Avigdor Zonnenshain avigdorz@rafael.co.il

    ** Coordinating Editor of the Prototype
- **Prototype survey (26 respondents at large)**
- **Lean SE Working Group (100+ members) reviewing**
- **Co-Chairs released Version 1.0**

Development of LEfSE

- **The Development Followed the Established Process**
  - **Concept (Oct. 2007)**
  - **Alpha**
  - **Beta (including survey)**
  - **Prototype (including survey)**
  - **Version 1.0 released (Feb.1, 2009)**
  - **Online Change Process for future changes**

Development Phases of LEfSE

DEVELOPMENT PHASE	ACTIVITIES	OUTCOME	TEAM AND NUMBER OF EXPERTS
Conceptual Design	•Brainstorming meeting to identify best SE/PM practices (other than those in SE Handbooks) based on Lean Thinking.	Captured 16 pages of ideas.	Beta Team (8 individuals)
Alpha	•Massive iterations of enabler drafts. Attempt to edit into callout boxes in INCOSE SE Handbook Input-Process-Output charts. - - Found impractical and changed the format to standard text, listed under eight Lean headings. •Added relevant enablers from LPD literature.	Alpha enablers	•Murman and Oppenheim
Beta	•Editing iterations. •Designed Beta survey asking to rank enablers' Importance and Use •Beta version reviewed by LSE WG.	•160 Beta enablers. •29 surveys returned w/comments	Beta Team edited. •Beta Survey returned by 19 SEs from MAAC and 10 from INCOSE •40 members of LSE WG reviewed Beta.
Prototype	•Enablers regrouped into Six Lean Principles. •Rounds of negotiations and editing. •Prototype survey of Importance and Use •Comparisons with NASA and GAO studies. •Decision to release online.	194 Prototype enablers organized into six Lean principles.	•Prototype Team (10 individuals) •Prototype survey returned by 26 SEs at large.
Version 1.0	•All Prototype enablers passed the survey Importance filter. •Cosmetic edits. •Set up for formal online changes.	V.1.0 (194 enablers listed under six Lean Principles) released online.	•LSE WG Co-Chairs
Future Continuous Improvement Process and Dissemination	•Anyone can submit change request; WG members to add arguments for and against; bi-annual voting by WG and new releases •Dissemination of LEfSE to academia, industry, government.	•Formal on-line change request process, designed for voting by WG •Training charts.	•100+ members of LSE WG

LEfSE Format

- 15 months in development
- The LEfSE organized into the Six Lean Principles (5 classical ones plus “Respect for People”)
- Released online for efficient access and configuration management
- Framed in a broad enough way to fit as a supplement to any SE manual, such as INCOSE, DoD, NASA, company handbooks or manuals.

Intended Audience for LEfSE

- To paraphrase Samantha Brown, INCOSE President Elect: "*There is a Valley of Death between Academia and Industry*". Our WG attempts to bridge the Valley.
- LEfSE formulated for Industry SE practitioners
- But the development strongly benefited from academic depth, breadth, and rigor.
- Focused on providing affordable, timely solutions to increasingly complex challenges
- Improving response time from the identification of need to the release of the system
- Integrating Systems Engineering and relevant parts of Program and Enterprise Management
- All stakeholders - from Enterprise, Program and SE Managers - to entry-level engineers should be familiar with LEfSE.

Articles on LEfSE

- *Lean Enablers for Systems Engineering* by Bohdan W. Oppenheim, Earll M. Murman, Deb Secor prepared for J. SE (40 pages)
  - Preprint soon available on INCOSE Lean SE website
- *Lean Enablers for Systems Engineering* by Bohdan W. Oppenheim, CrossTalk Defense Journal, July-August 2009 (5 pages)
  - Available on INCOSE Lean SE website
- *Lean Enablers for Systems Engineering* by Bohdan W. Oppenheim, INSIGHT (INCOSE newsletter) (3 pages)
  - Available on INCOSE Lean SE website

Part 5
The Product:
Lean Enablers for Systems Engineering, Version 1.0

Notes

A. Symbols (U 1.5) etc. at each enabler denote the average Use Rankings from the Prototype Survey, using the following scale

-2 = strongly disagree

-1 = disagree

0 = neutral

1 = agree

2 = strongly agree

- that the given enabler is used in industry, according to my lifetime experience

B. The survey also asked about the Importance of the given enabler to the Program success. All average Importance values are at 2 or 1, so not listed.

C. The example programs or companies are taken from public-domain references and are not meant to be exclusive.

Summary of Lean Principle 1: Value

- **The initial phase of every program should capture:**
  - **A comprehensive, unambiguous, and detailed understanding of Value to the customer**
  - **Not only the traditional requirements, but also the needs, context, and interpretations**

- **Many programs tend to rush through this phase without a robust process**
- **Ending in incomplete or incorrect requirements that burden the subsequent program with waste.**

- **The enablers promote the development of a robust and effective process**
  - **of capturing the complete customer value proposition**
  - **disseminating it among the program team**
  - **training and aligning the team towards this goal**
  - **involving the customer and other relevant stakeholders in the process**
  - **and doing it with sufficient breadth and depth to avoid later waste.**

Two striking observations from the Use values:

- Enabler 1.2.1.c **The Lean culture of "right the first time" is not widespread (Use = 0.09)**
- Enabler 1.2.6 **The understanding of customer culture among program employees is poor, (Use = -0.52)**

Lean Principle 1: Value

1. **Follow all practices for the requirements capture and development in the INCOSE Handbook. In addition: (U 0.29)**

2. **Establish the Value of the End Product or System to the Customer. (U 0.60)**

   Examples: Toyota, Rockwell Collins, B-777, F/A-18E/F, Citation X, HondaJet

   1. **Define value as the outcome of an activity that satisfies at least three conditions: (U 0.36)**
      a. **The external customer is willing to pay for “Value.” (U 0.65)**
      b. **Transforms information or material or reduces uncertainty. (U 0.57)**
      c. **Provides specified performance right the first time. (U 0.09)**
   2. **Define value-added in terms of value to the customer and his needs. (U 0.50)**
   3. **Develop a robust process to capture, develop, and disseminate customer value with extreme clarity. (U 0.00)**
   4. **Develop an agile process to anticipate, accommodate and communicate changing customer requirements. (U 0.28)**
   5. **Do not ignore potential conflicts with other stakeholder values, and seek consensus. (U 0.28)**
   6. **Explain customer culture to Program employees, i.e. the value system, approach, attitude, expectations, and issues. (U -0.52)**

Lean Principle 1: Value

3. Frequently Involve the Customer. (U 0.92)

Examples: Toyota, Citation X, B-777, Iridium

1. **Everyone involved in the program must have a customer-first spirit. (U 0.56)** *Example: Toyota*
2. **Establish frequent and effective interaction with internal and external customers. (U 0.56)**
3. **Pursue an architecture that captures customer requirements clearly and can be adaptive to changes. (U 0.36)**
4. **Establish a plan that delineates the artifacts and interactions that provide the best means for drawing out customer requirements. (U 0.39)**

Summary of Lean Principle 2: Map the VS (Plan the Program)

- **Poor planning is the notorious reason for wasteful programs.**
- **Therefore, the Second or "Value Stream" Principle promotes excellence of program preparations, and excellence of the planning, including:**
  - **Comprehensive checklist for planning of all end-to-end linked streamlined processes necessary to realize value without waste.**
  - **Integration of the planning of SE, PM and other relevant enterprise activities to avoid the frequent waste that occurs at the functional interfaces.**
  - **The benefits of old-fashioned co-location**
  - **The use of most experienced individuals early: during the critical planning and conceptual phases**
  - **Planning for maximum frontloading.**
  - **Planning of the coordination and communication means**
  - **Preventing subsequent conflicts,**
  - **Planning effective metrics**
  - **Tailoring and planning of task precedence and content for smooth flow**

Note:

- **2.2.6) Programs do poor job scrutinizing every step to ensure it adds value, and planning nothing because "it has always been done", Use = -0.54.**
- **2.4) Programs tend to reinvent the wheel rather than reuse proven solutions (U 0.13)**

Lean Principle 2: Map the Value Stream (Plan the Program)

1. Plan the Program according to the INCOSE Handbook Process. In addition: (U 0.23)

Lean Principle 2: Map the Value Stream (Plan the Program)

2. Map the SE and PD Value Streams and Eliminate Non-Value Added Elements. (U -0.40)

Examples: Toyota, Rockwell Collins

1. **Develop and execute clear communication plan that covers entire value stream and stakeholders. (U -0.29)** *Examples: Toyota,, F/A-18E/F*
2. **Have cross functional stakeholders work together to build the agreed value stream. (U -0.04)** ***Examples: F/A-18E/F, B-777***
3. **Create a plan where both Systems Engineering and other Product Development activities are appropriately integrated. (U 0.30)**

   Example: F/A-18E/F, Iridium
4. **Maximize co-location opportunities for SE and PD[1] planning. (U 0.17)**

   Examples: Toyota, HondaJet, Citation X.
5. **Use formal value stream mapping methods to identify and eliminate SE and PD[1] waste, and to tailor and scale tasks. (U -0.67)** *Example: Rockwell Collins.*
6. **Scrutinize every step to ensure it adds value, and plan nothing because "it has always been done“. (U -0.54)** *Example: Iridium*

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[1] SE is a part of PD. In this paragraph, the PD should be understood as denoting all PD activities other than SE, including design, development, manufacturing, integration, testing etc.)

Lean Principle 2: Map the Value Stream (Plan the Program)

2. Map the SE and PD Value Streams and Eliminate Non-Value Added Elements. (U -0.40) - cont.

7. **Carefully plan for precedence of both SE and PD tasks (which task to feed what other tasks with what data and when), understanding task dependencies and parent-child relationships. (U 0.42)**
8. **Maximize concurrency of SE and other PD Tasks. (U 0.42)**
9. **Synchronize work flow activities using scheduling across functions, and even more detailed scheduling within functions. (U 0.65)**

   Example: Toyota
10. **For every action, define who is responsible, approving, supporting, and informing ("RASI"), using a standard and effective tool, paying attention to precedence of tasks. (U 0.39)**
11. **Plan for level workflow and with precision to enable schedule adherence and drive out arrival time variation. (U -0.30)** ***Example: Toyota***
12. **Plan below full capacity to enable flow of work without accumulation of variability[1], and permit scheduling flexibility in work loading, i.e., have appropriate contingencies and schedule buffers. (U -0.26)**
13. **Plan to use visual methods wherever possible to communicate schedules, workloads, changes to customer requirements, etc. (U 0.22)**

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[1] Queuing theory proves that the flow approaching 100% of capacity always slows down asymptotically due to the accumulation of variability, even in the absence of any bottlenecks (e.g., automobile traffic)

Lean Principle 2: Map the Value Stream (Plan the Program)

3. Plan for Front-Loading the Program. (U 0.33)

Examples: Toyota, Rockwell Collins

1. **Plan to utilize cross-functional teams made up of the most experienced and compatible people at the start of the project to look at a broad range of solution sets. (U 0.36)**
2. **Explore trade space and margins fully before focusing on a point design and too small margins. (U 0.36)**
3. **Anticipate and plan to resolve as many downstream issues and risks as early as possible to prevent downstream problems. (U 0.40)** *Examples: F/A-18 E/F, B-777*
4. **Plan early for consistent robustness and "first time right" under "normal" circumstances instead of hero-behavior in later "crisis" situations. (U 0.12)**

Lean Principle 2: Map the Value Stream (Plan the Program)

4. Plan to Develop Only What Needs Developing (U - 0.13)

Examples: Iridium, Honda Jet, F-117A

1. **Promote reuse and sharing of program assets: Utilize platforms, standards, busses, and modules of knowledge, hardware and software. (U 0.32)**
2. **Insist that a module proposed for use is robust before using it. (U 0.20)** *Example: Toyota*
3. **Remove show-stopping research/unproven technology from critical path, staff with experts, and include it in the Risk Mitigation Plan. (U 0.24)** *Example: HondaJet*
4. **Defer unproven technology to future technology development efforts, or future systems. (U 0.04)**
5. **Maximize opportunities for future upgrades, (e.g., reserve some volume, mass, electric power, computer power, and connector pins), even if the contract calls for only one item. (U 0.40)** *Examples: Iridium, F/A-18E/F, B-777*

Lean Principle 2: Map the Value Stream (Plan the Program)

5. **Plan to Prevent Potential Conflicts with Suppliers. (U 0.40)**

   Examples: Toyota, Iridium, JDAM, F/A18-E/F, Citation X

   1. Select suppliers who are technically and culturally compatible. (U 0.46)
   2. Strive to develop seamless partnership between suppliers and the product development team. (U 0.21)
   3. Plan to include and manage the major suppliers as a part of your team. (U 0.42)
   4. Have the suppliers brief the design team on current and future capabilities during conceptual formation of the project. (U 0.13)

6. **Plan Leading Indicators and Metrics to Manage the Program. (U 0.25)**

   1. Use leading indicators to enable action before waste occurs. (U -0.04)
   2. Focus metrics around customer value, not profits. (U -0.33)

      Example: Wiremold
   3. Use only few simple and easy to understand metrics and share them frequently throughout the enterprise. (U 0.16)

      Example: Wiremold
   4. Use metrics structured to motivate the right behavior. (U 0.00)

      Example: Wiremold
   5. Use only those metrics that meet a stated need or objective. (U 0.04)

      Example: Wiremold.

Summary of Lean Principle 3: Flow

- **In complex programs, opportunities for the progress to stop are overwhelming, and it takes careful preparation, planning and coordination effort to overcome them.**
- **The Third, or "Flow" Principle enables the work to flow smoothly and continuously without the waste of stopping and waiting, rework, or backflow.**
- **The Flow Principle contains a comprehensive checklist of the practices enabling the flow, including:**
  - **frequent clarification of requirements**
  - **frontloading the design and implementation**
  - **making progress visible to all**
  - **using the most effective communications and coordination practices**
  - **and effective tools.**
- **The Enablers elevate the SE Responsibility, Authority and Accountability for coordination of all technical activities and for the overall technical program success.**
- **It is a sad commentary on the traditional programs that so many enablers with common sense have earned the a low Use value.**

Lean Principle 3: Flow

1. **Execute the Program according to the INCOSE Handbook Process. In addition: (U 0.17)**

2. **Clarify, Derive, Prioritize Requirements Early and Often During Execution. (U 0.08)**

   Examples: Toyota, HondaJet, Citation X, Rockwell Collins, Iridium

   1. **Since formal written requirements are rarely enough, allow for follow up verbal clarification of context and need, without allowing requirements creep. (U 0.36)**
   2. **Create effective channels for clarification of requirements (possibly involve customer participation in development IPTs). (U 0.56)**
   3. **Listen for and capture unspoken customer requirements. (U 0.20)**
   4. **Use architectural methods and modeling for system representations (3D integrated CAE toolset, mockups, prototypes, models, simulations, and software design tools) that allow interactions with customers as the best means of drawing out customer requirements. (U 0.72)**
   5. **"Fail early - fail often" through rapid learning techniques (prototyping, tests, digital preassembly, spiral development, models, and simulation). (U 0.04)**
   6. **Identify a small number of goals and objectives that articulate what the program is set up to do, how it will do it, and what the success criteria will be to align stakeholders - and repeat these goals and objectives consistently and often. (U 0.28)**

Lean Principle 3: Flow

3. **Front Load Architectural Design and Implementation. (U 0.44)**

   Example: Toyota, Rockwell Collins

   1. **Explore multiple concepts, architectures and designs early. (U 0.44)**
   2. **Explore constraints and perform real trades before converging on a point design. (U 0.46)**
   3. **Use a clear architectural description of the agreed solution to plan a coherent program, engineering and commercial structures. (U 0.44)**
   4. **All other things being equal, select the simplest solution. (U 0.12) [1]**
   5. **Invite suppliers to make a serious contribution to SE, design and development as program trusted partner. (U 0.24)**

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[1] "Any fool can make anything complex but it takes a genius and courage to create a simple solution" - Albert Einstein

Lean Principle 3: Flow

4. Systems Engineers to accept Responsibility for coordination of PD Activities. (U 0.11)
    1. Promote maximum seamless teaming of SE and other PD engineers. (U 0.36)
    2. SE to regard all other engineers as their partners and internal customers, and vice-versa. (U 0.12)
    3. Maintain team continuity between phases to maximize experiential learning. (U 0.04)
    4. Plan for maximum continuity of Systems Engineering staff during the Program. (U 0.20)

Lean Principle 3: Flow

5. Use Efficient and Effective Communication and Coordination. (U 0.22) *Examples: Toyota, F/A-18E/F. B-777, Southwest Airlines, HondaJet*

1. Capture and absorb lessons learned from almost all programs: "never enough coordination and communication." (U -0.52)
2. Maximize coordination of effort and flow (one of the main responsibilities of Lean SE). (U 0.24)
3. Maintain counterparts with active working relationships throughout the enterprise to facilitate efficient communication and coordination among different parts of the enterprise, and with suppliers. (U 0.50)
4. Use frequent, timely, open and honest communication. (U 0.48)
5. Promote direct informal communications immediately as needed. (U 0.76)
6. Use concise one-page electronic forms (e.g., Toyota's A3 form) rather than verbose unstructured memos to communicate, and keep detailed working data as backup. (U -0.28)
7. Report cross-functional issues to be resolved on concise standard one-page forms to Chief's office in real time for his/her prompt resolution. (U -0.33)
8. Communicate all expectations to suppliers with crystal clarity, including the context and need, and all procedures and expectations for acceptance tests, and ensure the requirements are stable. (U 0.35)
9. Trust engineers to communicate with suppliers' engineers directly for efficient clarification, within a framework of rules, (but watch for high risk items which must be handled at the top level). (U 0.36)

Lean Principle 3: Flow

6. Promote Smooth SE Flow. (U 0.38)

Examples: Toyota, FA-18 E/F, Citation X, Rockwell Collins

1. Use formal frequent comprehensive integrative events in addition to programmatic reviews. (U 0.00)
   a. Question everything with multiple “whys.” (U -0.04)
   b. Align process flow to decision flow. (U 0.16)
   c. Resolve all issues as they occur in frequent integrative events. (U -0.08)
   d. Discuss tradeoffs and options. (U 0.72)
2. Be willing to challenge the customer's assumptions on technical and meritocratic grounds, and to maximize program stability, relying on technical expertise. (U 0.48)
3. Minimize handoffs to avoid rework. (U -0.04)
4. Optimize human resources when allocating VA and RNVA tasks. (U 0.08) [1]
   a. Use engineers to do VA engineering. (U 0.36)
   b. When engineers are not absolutely required, use non-engineers to do RNVA (administration, project management, costing, metrics, program, etc.). (U 0.08)
5. Ensure the use of the same measurement standards and data base commonality. (U 0.13)
6. Ensure that both data deliverers and receivers understand the mutual needs and expectations. (U 0.36)

[1] VA = value added, RNVA = Required non value added

7. Make Program Progress Visible to All. (U 0.18)

Examples: Toyota, HondaJet, Citation X, F/A-18E/F

1. **Make work progress visible and easy to understand to all, including external customer. (U 0.36)**
2. **Utilize Visual Controls in public spaces for best visibility (avoid computer screens). (U 0.08)**
3. **Develop a system making imperfections and delays visible to all. (U 0.16)**
4. **Use traffic light system (green, yellow, red) to report task status visually (good, warning, critical) and make certain problems are not concealed. (U 0.80)**

8. Use Lean Tools. (U 0.25)

Example: Toyota, Rockwell Collins

1. **Use Lean tools to promote the flow of information and minimize handoffs: small batch size of information, small takt times, wide communication bandwidth, standardization, work cells, training. (U -0.12)**
2. **Use minimum number of tools and make common wherever possible. (U -0.04)**
3. **Minimize the number of the software revision updates and centrally control the update releases to prevent information churning. (U 0.36)**
4. **Adapt the technology to fit the people and process. (U 0.17)**
5. **Avoid excessively complex "monument" tools. (U -0.04)**

Summary of Lean Principle 4: Pull

- **The "Pull" Principle is a powerful guard against the waste of:**
  - **unneeded tasks**
  - **over-processed tasks**
  - **task rework (not to be confused with legitimately needed and optimized iteration loops)**
  - **and the tasks which are not needed but are left over from previous programs or company habits.**

- **The Pull promotes the culture of <u>tailoring tasks and pulling them and their outputs</u> based only on legitimate need and <u>rejecting others as waste</u>.**

- **The "legitimate" is always interpreted in the context of value: "<u>flawless mission assurance</u>".**

- **The Pull promotes <u>proactive coordination of task scope and modalities between the output creator and the user prior to the task execution</u>, for all transactions, to eliminate the waste of misunderstanding, defects, rework and waiting.**

- **Again, the Use values indicate a poor implementation of these common-sense practices.**

Lean Principle 4: Pull

1. **Tailor for a given program according to the INCOSE Handbook Process. In addition: (U 0.00)**

2. **Pull Tasks and Outputs Based on Need, and Reject Others as Waste. (U -0.22)** *Example: Toyota, Rockwell Collins*
    1. Let information needs pull the necessary work activities. (U -0.04)
    2. Promote the culture in which engineers pull knowledge as they need it and limit the supply of information to only genuine users. (U -0.04)
    3. Understand the Value Stream Flow. (U -0.32)
    4. Train the team to recognize who the internal customer (Receiver) is for every task as well as the supplier (Giver) to each task- use a SIPOC (supplier, inputs, process, outputs, customer) model to better understand the value stream. (U -0.04)
    5. Stay connected to the internal customer during the task execution. (U 0.32)
    6. Avoid rework by coordinating task requirements with internal customer for every non-routine task. (U 0.08)
    7. Promote effective real time direct communication between each Giver and Receiver in the value flow. (U 0.24)
    8. Develop Giver-Receiver relationships based on mutual trust and respect. (U 0.36)
    9. When pulling work, use customer value to separate value added from waste. (U 0.00)

Summary of Lean Principle 5: Perfection

- The fifth or "Perfection" Principle strives for excellence and continuous improvement of the SE process and related Enterprise Management
- The enablers promote:
  - Making all imperfections visible to all - which is motivating to the immediate improvement
  - Comprehensive capture and use of lessons learned from past programs.
  - Driving out waste through design standardization, process standardization, and skill-set standardization
  - Employing all three complementary CI methods: sugg., Kaizen, 6 Sigma
- Excellent communication, coordination and collaboration to enable CI
- The Principle elevates the role of Chief SE to lead and integrate the program from start to finish (see enabler 5.5)

- Note: Enabler 5.2.2, "Promote excellence under 'normal' circumstances instead of hero-behavior in 'crisis' situations" - earned only the (U = -0.40)
- This confirms the anecdotal perception that traditional programs are perpetually in the crisis management mode.

Lean Principle 5: Perfection

1. **Pursue Continuous Improvement according to the INCOSE Handbook Process. In addition: (U 0.20)**

2. **Strive for Excellence of SE Processes. (U 0.44)** ***Example: Iridium***

   1. **Do not ignore the basics of Quality: (U 0.84)**
      a. **Build in robust quality at each step of the process, and resolve and do not pass along problems. (U 0.17) *Example: Toyota***
      b. **Strive for perfection in each process step without introducing waste. (U -0.16)**
      c. **Do not rely on final inspection; error proof wherever possible. (U 0.08)**
      d. **If final inspection is required by contract, perfect upstream processes pursuing 100% inspection pass rate. (U 0.28)**
      e. **Move final inspectors upstream to take the role of quality mentors. (U 0.08)**
      f. **Apply basic PDCA method (plan, do, check, act) to problem solving. (U 0.48)**
      g. **Adopt and promote a culture of stopping and permanently fixing a problem as soon as it becomes apparent. (U -0.08)**
   2. **Promote excellence under "normal" circumstances instead of hero-behavior in "crisis" situations. (U -0.40) *Example: Iridium***
   3. **Use and communicate failures as opportunities for learning emphasizing process and not people problems. (U 0.04) *Example: Toyota***
   4. **Treat any imperfection as opportunity for immediate improvement and lesson to be learned, and practice frequent reviews of lessons learned. (U -0.20)**

2. Strive for Excellence of SE Processes. (U 0.44) -cont.

5. Maintain a consistent disciplined approach to engineering. (U 0.52) Example: Toyota, F/A-18E/F
6. Promote the idea that the system should incorporate continuous improvement in the organizational culture, but also... (U 0.42)
7. ...balance the need for excellence with avoidance of overproduction waste (pursue refinement to the point of assuring Value and "first time right", and prevent overprocessing waste). (U 0.25)
8. Use a balanced matrix/project organizational approach avoiding extremes: territorial functional organizations with isolated technical specialists, and all-powerful IPTs separated from functional expertise and standardization. (U 0.21) *Examples: Toyota, F/A-18E/F*

Lean Principle 5: Perfection

3. Use Lessons Learned from Past Programs for Future Programs. (U 0.11)

Examples: Toyota, F/A-18E/F

1. **Maximize opportunities to make each next program better then the last. (U 0.13)**
2. **Create mechanisms to capture, communicate, and apply experience-generated learning and checklists. (U 0.17)**
3. **Insist on workforce training of root cause and appropriate corrective action. (U 0.04)**
4. **Identify best practices through benchmarking and professional literature. (U 0.26)**
5. **Share metrics of supplier performance back to them so they can improve. (U 0.39)**

4. Develop Perfect Communication, Coordination and Collaboration Policy across People and Processes. (U 0.11)

Example: Toyota, Southwest Airlines

1. Develop a plan and train the entire program team in communications and coordination methods at the program beginning. (U 0.13)
2. Include communication competence among the desired skills during hiring. (U 0.29)
3. Promote good coordination and communications skills with training and mentoring. (U 0.33)
4. Publish instructions for e-mail distributions and electronic communications. (U -0.04)
5. Publish instructions for artifact content and data storage: central capture versus local storage, and for paper versus electronic, balancing between excessive bureaucracy and the need for traceability. (U 0.33)
6. Publish a directory of the entire program team and provide training to new hires on how to locate the needed nodes of knowledge. (U 0.38)
7. Ensure timely and efficient access to centralized data. (U 0.58)
8. Develop an effective body of knowledge that is historical, searchable, shared by team, and knowledge management strategy to enable the sharing of data and information within the enterprise. (U 0.13)

Lean Principle 5: Perfection

5. **For Every Program Use a Chief Engineer Role[1] to Lead and Integrate Development from Start to Finish. (U 0.00)**

Examples: Toyota, HondaJet, Iridium, Citation X

1. **The Chief Engineer role to be Responsible, with Authority and Accountability for the program technical success. (U 0.48)**
2. **Have the Chief Engineer role lead both the product and people integration. (U 0.04)**
3. **Have the Chief Engineer role lead through personal influence, technical know how, and authority over product development decisions. (U 0.17)**
4. **Groom an exceptional Chief Engineer role with the skills to lead the development, the people, and assure program success. (U 0.04)**
5. **If Program Manager and Chief Engineer are two separate individuals (required by contract or organizational practice), co-locate both to enable constant close coordination. (U 0.29)**

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[1] A frequent practice in recent U.S. governmental programs is to have two program managers: the "Program Manager" responsible for the program business success, and "Chief Systems Engineer" responsible for Systems Engineering. Numerous functional engineers are responsible for various technical areas. In some programs this causes split responsibilities, authorities and accountabilities, often with imperfect results. In contrast, many U.S. and overseas commercial programs use only one person fully responsible for the entire program success (both technical and business). The person is called by various names, e.g. Chief Engineer (very successful Toyota model, see Morgan and Liker's *Toyota Product Development System),* Product Manager, Product Engineer, or similar. Early U.S. aerospace programs also used extremely successful single-person "Chief Engineer" role (e.g., early Jack Northrop, Howard Hughes, Kelly Johnson of the Skunk Works, early NASA space programs, and others). Murman (*Lean Aerospace Engineering*, AIAA 092407, 2007) discusses some more recent successful programs with a single top manager in the dual technical and business leadership role. Since this document is intended for INCOSE Handbook, dealing with the scope of Systems Engineering rather than entire program management, the editors have addressed only the technical role of the Chief Engineer, saying nothing whether that person should also be the overall manager of the program, or share the management with a separate business manager person. However, nothing in this document should be taken as promoting the dual-head model. The dual-head model is not required under the U.S. government acquisition policies, and is not promoted in the INCOSE Handbook version 3.1.

Lean Principle 5: Perfection

6. **Drive out Waste through Design Standardization, Process Standardization, and Skill-Set Standardization. (U 0.56)**

Example: Toyota

1. **Promote design standardization with engineering checklists, standard architecture, modularization, busses, and platforms. (U 0.57)**
2. **Promote process standardization in development, management, and manufacturing. (U 0.67)**
3. **Promote standardized skill sets with careful training and mentoring, rotations, strategic assignments, and assessments of competencies. (U -0.05)**

Lean Principle 5: Perfection

7. **Promote All Three Complementary Continuous Improvement Methods to Draw Best Energy and Creativity from All Employees. (U 0.63)**

Example: Toyota

1. **Utilize and reward bottom up suggestions for solving employee-level problems. (U 0.17)**
2. **Use quick response small Kaizen teams comprised of problem stakeholders for local problems and development of standards. (U 0.13)**
3. **Use the formal large Six Sigma teams for the problems which cannot be addressed by the bottom-up and Kaizen improvement systems, and do not let the Six Sigma program destroy those systems. (U 0.13)**

Summary of Lean Principle 6: Respect for People

- **The Sixth or "People" Principle promotes the best human relations at work based on respect for people:**
  - **Trust**
  - **Honesty**
  - **Respect**
  - **Empowerment**
  - **Teamwork**
  - **Stability**
  - **Motivation**
  - **Drive for excellence**
  - **and healthy hiring and promotion policies.**

- **It calls for a vision which draws and inspires the best people**

- **It promotes a learning environment.**

- **Interestingly, this Principle appears to have earned the highest average Use rankings of all principles.**

Lean Principle 6: Respect for People

1. **Pursue People Management according to the INCOSE Handbook Process. In addition: (U 0.36)**

2. **Build an Organization Based on Respect for People. (U 1.00)**

   Examples: Toyota, Southwest Airlines, Iridium

   1. **Create a vision which draws and inspires the best people. (U 0.58)**

      Examples: Iridium, HondaJet
   2. **Invest in people selection and development to promote enterprise and program excellence. (U 0.46)**
   3. **Promote excellent human relations: trust, respect, empowerment, teamwork, stability, motivation, drive for excellence. (U 0.71)**
   4. **Read applicant's resume carefully for both technical and non-technical skills, and do not allow mindless computer scanning for keywords. (U 0.50)**
   5. **Promote direct human communication. (U 0.63)**
   6. **Promote and honor technical meritocracy. (U 0.83)**
   7. **Reward based upon team performance, and include teaming ability among the criteria for hiring and promotion. (U 0.25)**

Lean Principle 6: Respect for People

2. Build an Organization Based on Respect for People – cont. (U 0.36)

8. **Use flow down of Responsibility, Authority and Accountability (RAA) to make decisions at lowest appropriate level. (U 0.09)**

   Example: F/A-18E/F

9. **Eliminate fear and promote conflict resolution at the lowest level. (U 0.29)**
10. **Keep management decisions crystal clear but also promote and reward the bottom-up culture of continuous improvement and human creativity and entrepreneurship. (U 0.04)**
11. **Do not manage from cubicle; go to the spot and see for yourself. (U 0.17)**

    Examples: Citation X, HondaJet

12. **Within program policy and within their area of work, empower people to accept responsibility by promoting the motto "ask for forgiveness rather than ask for permission." (U 0.28)**
13. **Build a culture of mutual support (there is no shame in asking for help). (U 0.36)**
14. **Prefer physical team co-location to the virtual co-location. (U 0.44)**

    Examples: Honda Jet, Toyota, Citation X

Lean Principle 6: Respect for People

3. Expect and Support Engineers to Strive for Technical Excellence. (U 0.60)

Examples: Toyota, Rockwell Collins

1. **Establish and support Communities of Practice. (U 0.67)**
2. **Invest in Workforce Development. (U 0.83)**
3. **Assure tailored lean training for all employees. (U 0.21)**
4. **Give leaders at all levels in-depth lean training. (U 0.13)**

Lean Principle 6: Respect for People

4. **Nurture a Learning Environment. (U 0.00)**

   Examples: Toyota, Southwest Airlines

   1. **Perpetuate technical excellence through mentoring, training, continuing education, and other means. (U 0.82)**
   2. **Promote and reward continuous learning through education and experiential learning. (U 0.36)**
   3. **Provide knowledge experts as resources and for mentoring. (U 0.45)**
   4. **Pursue the most powerful competitive weapon: the ability to learn rapidly and continuously improve. (U 0.55)**
   5. **Value people for the skills they contribute to the program with mutual respect and appreciation. (U 0.45)**
   6. **Capture learning to stabilize the program when people change. (U 0.09)**
   7. **Develop Standards paying attention to human factors, including reading and perception abilities. (U -0.18)**
   8. **Immediately organize a quick training in any new standard. (U -0.27)**

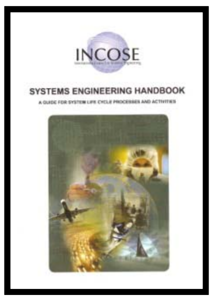
5. **Treat People as Most Valued Assets, not as Commodities. (U 0.70)**

   Examples: Toyota, HondaJet Southwest Airlines

Lean Enabler Map to INCOSE Systems Engineering Handbook

LEAN ENABLERS

+



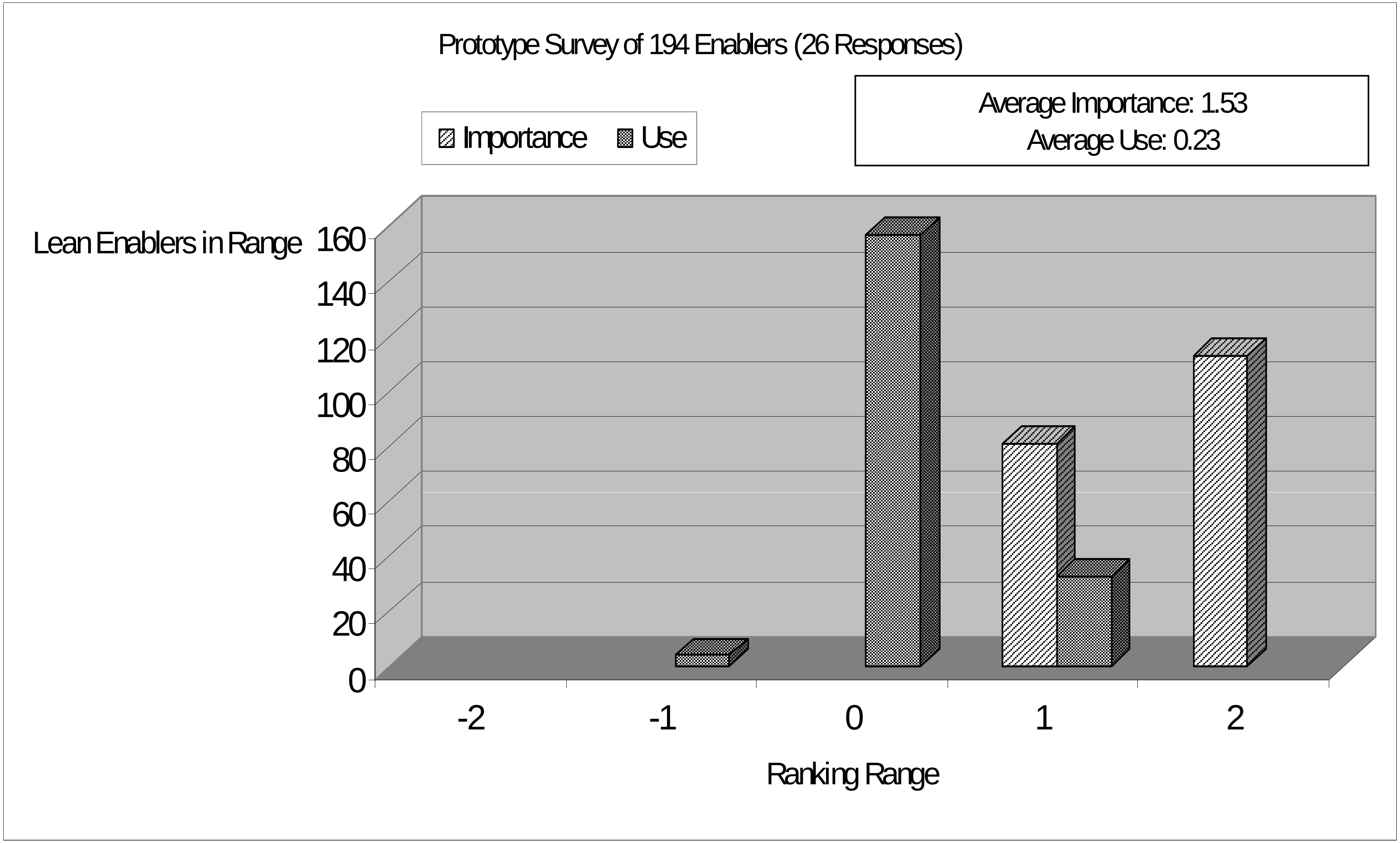
Handbook Table of Contents	Lean Enablers
2.6 Value of Systems Engineering	Definition - Lean SE
3.4 Development Stage Approaches	1.0
4.2 Stakeholder Requirements & Definition	2.2
4.5 Implementation Process	3.6
5.2 Project Planning Process	2.6, 5.5
5.3 Project Assessment	3.7
5.4 Project Control	3.8
5.5 Decision Making	5.5
6.4 System Life Cycle Management	5.6
6.5 Resource Management	2.5
6.8 Supply process	2.5
7.2 Requirements Management	1.3, 3.2
8.2 Architectural Design	3.3, 5.6
8.7 Quality Management	5.2, 5.6 5.7
8.8 Resource Management	3.5, 5.6
9.1 Design for…..	Design for Lean
Appendices	
F. Acquisition and Supply	2.5
G.3 Continuous Process Improvement	4.2, 5.2, 5.3, 5.7
H.2 IPPD	3.5
I.2 Concept of Operations	2.3, 2.4
I.6 Requirements and Design Loops	3.2
K1 Define, Refine Alternatives	3.3
M2 Enabler to S.E. Practice	6.2, 6.4, 6.5, 4.2
M3 Technical & Management Process	6.3, 5.4

Part 6
"Validation"

“Validation”

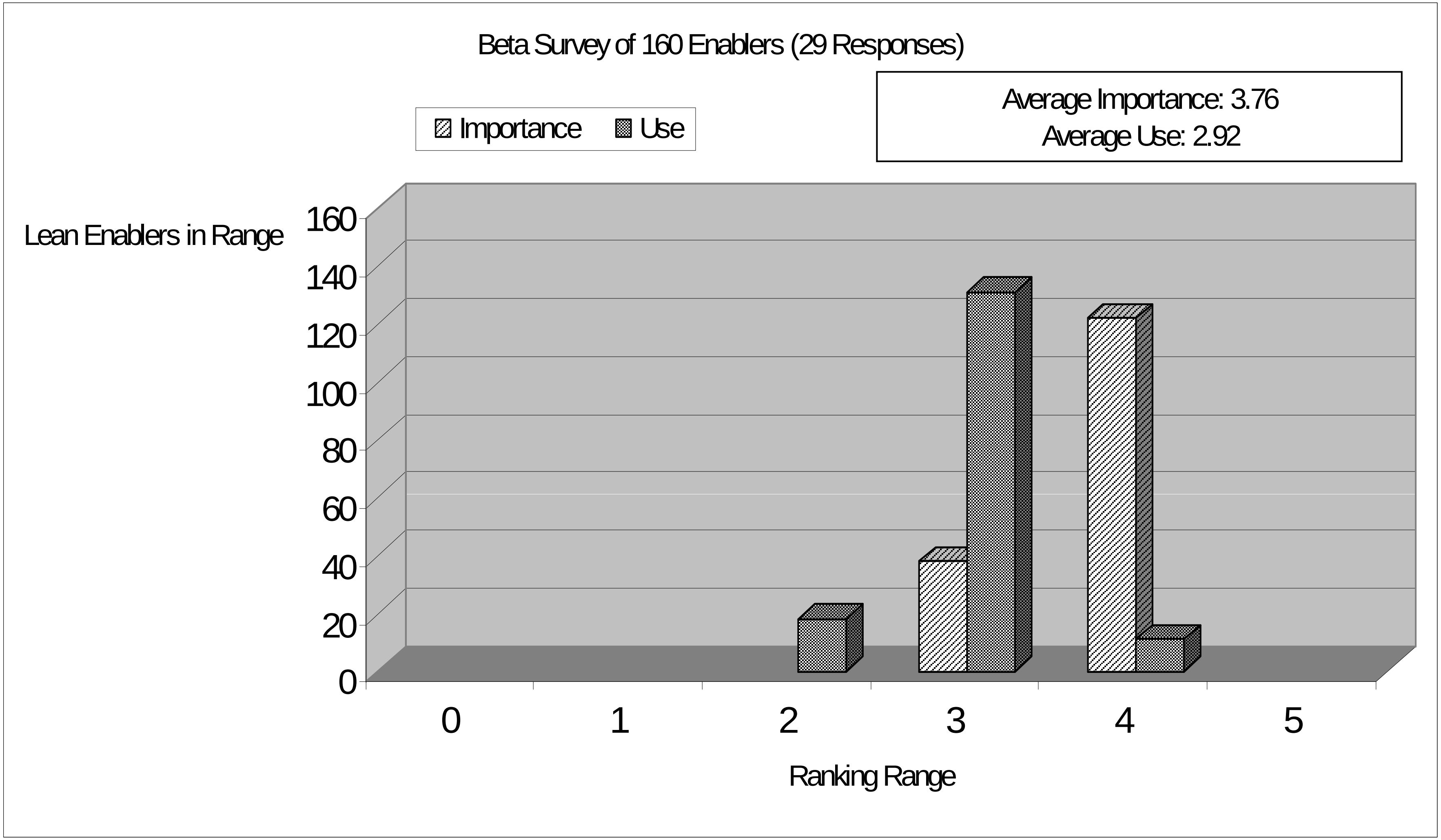
- **Ideally, LEfSE should be validated by comparing the program performance**
  - **between traditional programs and those following the LEfSE**
  - **e.g., the value delivered, stakeholder satisfaction, and program cost and schedule**
- **This, of course, is not practical:**
  - **Many governmental programs take years, some 20+ yrs**
  - **Implementing all LEfSE would be a challenge to most programs**
- **Instead, a quick reaction from the SE practitioners was needed. So, surveys and benchmarking were used.**

Prototype Survey



All 194 enablers passed the Importance test

Beta Survey


Beta Survey of 160 Enablers (29 Responses)
Importance
Use
Average Importance: 3.76
Average Use: 2.92
Lean Enablers in Range
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
Ranking Range

Prototype Survey Results

- **High ranking of Importance**
- **Much lower ranking of the Use**
- **Conclusions:**
  - **Importance confirmed = We are on the right track**
  - **Use is low = Significant opportunity to improve SE practices**
  - **Prototype has crisper results than Beta**

Additional Check: NASA Benchmarking Report

- Gratifying to notice that separate from our work, a study by NASA released in October of 2007, achieved results consistent with Lean Enablers, but not nearly as comprehensive
- For this study NASA benchmarked the practices of best aerospace companies in an attempt to capture the key enabling factors and best practices that lead to their success.
- Some of these companies include:
  - Raytheon Missile Systems
  - Boeing Satellite Development Center
  - Boeing Commercial Aircraft Division
  - Lockheed Missile & Fire Control
  - ARMY Aviation & Missile Research and Development & Engineering Center

NASA Pilot Benchmarking Initiative: Exploring Design Excellence Leading to Improved Safety and Reliability, October 2007

NASA's "Key Enablers for Systems Engineering"

NASA "Key Enablers of Successful Programs"	LSfSE Enabler #
Visionary Leadership - Role of organizational leadership in establishing a clear overarching purpose, deriving and articulating a compelling but credible vision to fulfill that purpose.	1.2.6, 1.3.1, 3.4, 5.5, 5.7, 6.2
Capability Maturity – Organization attainment of high levels of "Capability Maturity" to support and facilitate the undertaking of complex systems development	2.2, 2.3, 2.5, 3.3, 3.5, 3.6, 5.2, 5.3, 5.4, 5.6
Systems Engineering Culture – A pervasive mental state and bias for Systems Engineering methods applied to problem solving across the development lifecycle and at all levels of enterprise processes.	1.2, 1.3, 2.2.3, 2.6, 3.4, 3.6, 5.2
Design Robustness Mindset – High levels of focus on system safety and reliability driven by a bias toward achieving robustness, supported by the cultural attitude of "Failure is not an Option".	2.5, 5.2, 5.3, 5.4, 5.6, 5.7, 6.3
Accountability Structure - Effective decision making accomplished through clearly defined structures of assigned responsibility and accountability for decisions at appropriate levels and phases of system development.	5.2, 6.2, 6.3

NASA's "Best Practices for Systems Engineering"

NASA "Best Practices"	LEfSE Enabler #
Leading with Vision: Sharing the Vision, Providing Goals, Direction & Visible Commitment	1.2.3, 1.2.6, 1.3.1, 3.2.6, 3.5.2, 5.5, 6.2.1, 6.2.10, 6.2.11
Focusing on Requirements: Mission Success Driven Requirements & Validation Process	1.2, 1.3, 3.2
Achieving Robust Systems: By Rigorous Analysis, Robustness of Design, HALT/HASS testing	1.2.3, 1.2.4, 2.2.3, 2.3.4, 2.4.2, 2.4.3, 3.2.5, 5.2.1a
Models & Simulation: Model-based Systems Engineering with "seamless" models, validated with Experts	1.3.3, 2.3.2, 3.2.4, 3.2.5
Visible Metrics: Effective measures, visible supporting data for better decisions at each organizational level	2.6, 3.7
Systems Management: Managing for Value & Excellence throughout the Life-cycle	1.2, 1.3, 2.2, 2.3, 2.4, 4.2, 5.2, 5.5
Building Culture: Based on Foundation "Systems" Principles, Continuous improvement	5.2, 5.6, 5.7, 6.2, 6.3

Additional Check: GAO Report

- **Also gratifying that a summary of best practices for recent commercial space programs by GAO in 2007, made similar recommendations consistent with Lean Enablers, but again not nearly as comprehensive**

Additional Validation: GAO Report

GAO Commercial Best Practices during Program Development	Lean Enabler #
• Use quantifiable data and demonstrable knowledge to make go/no-go decisions, covering critical facets of the program such as cost, schedule, technology readiness, design readiness, production readiness, and relationships with suppliers.	2.5, 2.6, 3.2, 3.3–3.7
• Do not allow development to proceed until certain thresholds are met—for example, a high proportion of engineering drawings completed or production processes under statistical control.	2.6.4, 5.2
• Empower program managers to make decisions on the direction of the program and to resolve problems and implement solutions.	1.2.5, 2.5, 3.5.7, 5.5, 6.2.8
• Hold program managers accountable for their choices.	5.5
• Require program managers to stay with a project to its end.	5.5
• Hold suppliers accountable to deliver high-quality parts for their product through such activities as regular supplier audits and performance evaluations of quality and delivery, among other things.	2.5
• Encourage program managers to share bad news, and encourage collaboration and communication.	3.5, 3.7

Part 7.
Future Work

Future Work

- **Dissemination and Gathering Experiences**
  - Version 1.0 being disseminated
  - Broad dissemination ongoing: in local INCOSE Chapters, company and academic workshops, and conferences (using this presentation)
  - Workshops delivered or scheduled:
    - Loyola Marymount University (4)
    - INCOSE-Cedar Rapids (Oct. 2007)
    - INCOSE-Israel (2), March 3, 2009
    - INCOSE-Los Angeles, March 21, 2009
    - INCOSE-France (2), May 26, 2009
    - INCOSE-Seattle
    - INCOSE-University College London
    - INCOSE-Singapore
    - INCOSE-IW 2010
    - The Aerospace Corporation
    - Booz Allen Hamilton, Los Angeles
    - MIT LAI Knowledge Exchange Event
    - Stevens Institute of Technology
    - Naval Postgraduate School, Monterrey, CA
    - Lean Software Conference, Atlanta, GA
- **Change process**
  - Version 1.0 is mature but not final: continuous growth of knowledge will require future changes
  - On-line process has been implemented for making changes (next slides)

Change Process

- At any time any INCOSE member can propose:
  - A new enabler
  - An edit or deletion of an existing enabler
  - Using on-line form (next slide)
  - Recommended: the submitter should be a SE professional and understand Lean Thinking.
- Once the form is activated, other WG members can enter their arguments for or against the change
- Bi-annually, an email reminder will be sent to the LSE WG asking members to vote online on the active proposals
- Majority vote will accept/reject the proposal for the next release of the LEfSE.

Online LEfSE Change Proposal Form

Change Request Form for "Lean Enablers for Systems Engineering" **(one change per form)**	
Instructions: **Initiator:** Please fill out rows A-E **Reactions to the proposal**: Please write in either row F or G	
A.	**Enabler number (existing number if you are proposing a replacement or deletion, new number if an addition)**:
B.	**Proposed new text for the enabler, or deletion**:
C.	**Justification for the proposed change by the Change Requestor**:
D.	**Requestor:** first and last name, affiliation, email, work phone and cell phone
E.	**Date**:
F.	[For use by WG members] Please write argument(s) in support of the proposal and enter your name, email and phone.
G.	For use by WG members] Please write argument(s) opposing the proposal and enter your name, email and phone.
H.	Results of Voting by the LSE Working Group: Yes: Nay:

Future Work

- As many program engineers and managers as possible at every level should be trained in the LEfSE because this should lead to better programs
- Request to the Lean SE WG members:
  - Please promote LEfSE in your organizations
  - Please help arrange workshops in your company, your INCOSE Chapter, or a university eager to learn
  - Gather experiences with LEfSE and provide feedback
- The Lean SE Working Group is ready for next challenges – all ideas are welcomed

Part 8. Summary

Summary

- The established SE process is regarded as sound technically, but suffering from inefficiencies
- Lean Enablers for Systems Engineering (LEfSE) have been developed to supplement the SE process with the wisdom of Lean Thinking
- The LEfSE are formulated as 194 "do's and don'ts“ and organized into six Lean Principles, published online www.INCOSE.org
- LEfSE were endorsed by two surveys and by comparisons with the recent recommendations by NASA and GAO.
- Lean SE does not mean “less SE”. It means “more and better and more frontloaded SE, better integrated with the Enterprise”
- The Value is defined as flawless mission or product assurance with minimum waste, in the shortest possible time, while satisfying the stakeholders.
- LEfSE have been formulated for industry Systems Engineers and broader PD community
- The LEfSE are not intended to become a mandatory practice. Instead, they should be used as a checklist of good practices in enterprises, programs, and at every level of work

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