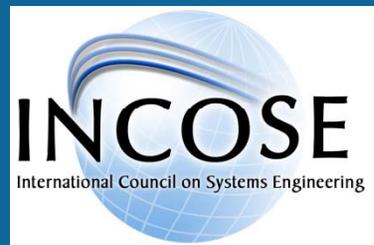


Lean Enablers for Systems Engineering

(Short) Version 1.0,
Systems Engineering Collaborators Information Exchange
May 4, 2010

Best Product Award 2010

Lean Systems Engineering Working Group



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

The INCOSE Lean SE Working Group

- Work started at the MIT Lean Advancement Initiative in 2004
- Moved to INCOSE in Jan. 2006 in ABQ, 30 participants in first meeting!
- March 2010: **147 names** and growing
- WG Co-Chairs (all volunteers, working in spare time)
 - Bo Oppenheim, LMU, Los Angeles
 - Deb Secor, Rockwell Collins, IA
- Initial activities
 - Completed INCOSE Web Page and Connect Site
 - Charter, Definitions, Reading list, Articles, Panels
- **Major effort: Development of Lean Enablers for Systems Engineering (LEfSE)**

- **Public site**
 - www.incose.org
 - Click on Working Groups
 - Click on Lean Systems Engineering
- **Products posted on the public site:**
 - 1.1 Presentation [Lean Enablers for Systems Engineering, Version 1.01, \(pdf, 0.764 MB\)](#)
 - 1.2 Articles:
 - LEfSE, [full-length paper, B.W.Oppenheim, E. Murman, D. Secor, Journal SE,](#)
 - LEfSE, [five-page summary, Cross Talk \(pdf, 0.798 MB\)](#)
 - LEfSE, [short summary, INCOSE INSIGHT, \(pdf, 0.524 MB\)](#)
 - 1.3 Chapter in the next edition of INCOSE SE Handbook
 - 1.4 [Lean SE Brochure \(pdf, 0.859 MB\) created in cooperation with INCOSE UK.](#)
 - 1.5 [LEfSE Quick Reference Guide \(8 pages, pdf, 0.268 MB\)](#)
 - 1.6 Book-long collection of one-page-per enabler forms. Each form lists the enabler, the value it promotes, the waste it prevents, explanations and examples, suggested implementation and related difficulty, suggested priority, examples and references (common project with France AFIS, due summer 2010)
 - 1.7 [Video with lecture by Bo Oppenheim to BAH \(1 hr 37 min total\), with slides intergrated](#)

Part 2.

Lean Fundamentals

Lean Thinking

- **Lean = The thinking based on Pursuit of Value with Minimum waste, with origins at Toyota**



Lean Thinking Captured into Six Lean Principles

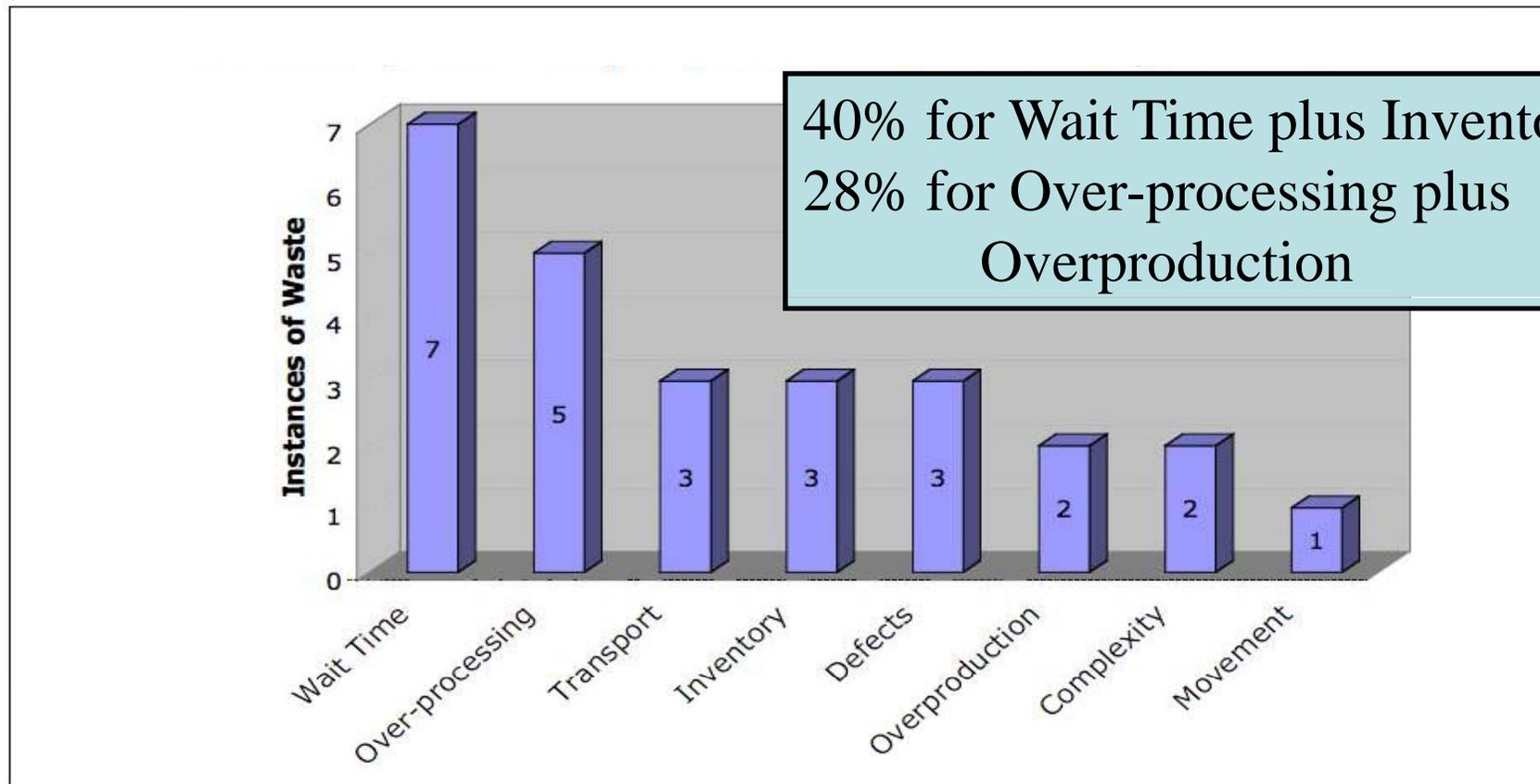
1. Customer defines value
2. Map the value stream: plan all end-to-end linked actions and processes necessary to realize value, streamlined, after eliminating waste
3. Make value flow continuously: without stopping, rework or backflow (valid iterations OK)
4. Let customers pull value: Customer's "pull/need" 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.

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



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.

Part 3.

Lean Systems Engineering

From Lean to Lean Systems Engineering

- **Lean** = organization of work 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.
- **Lean Systems Engineering** is the area of synergy of Lean and Systems Engineering

Value in Lean SE

Definition of Value in Lean SE:

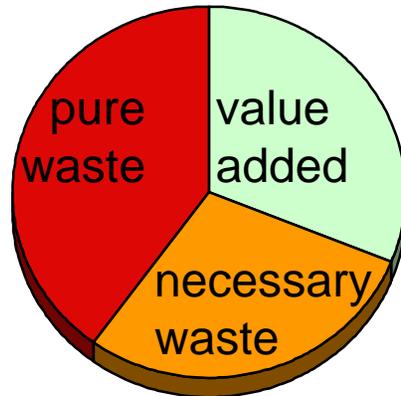
- **“Flawless mission assurance or product success delivered without waste, in the fastest possible time”**

- LSE WG web page

The Need

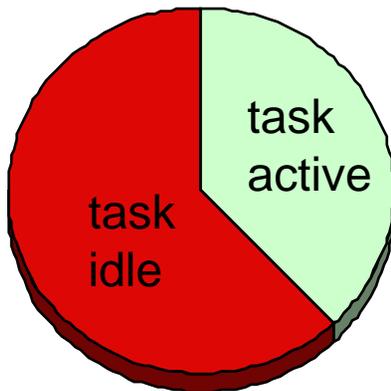
- **Recent studies of governmental programs by LAI, NASA and GAO indicated serious problems in Systems Engineering...**

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*)



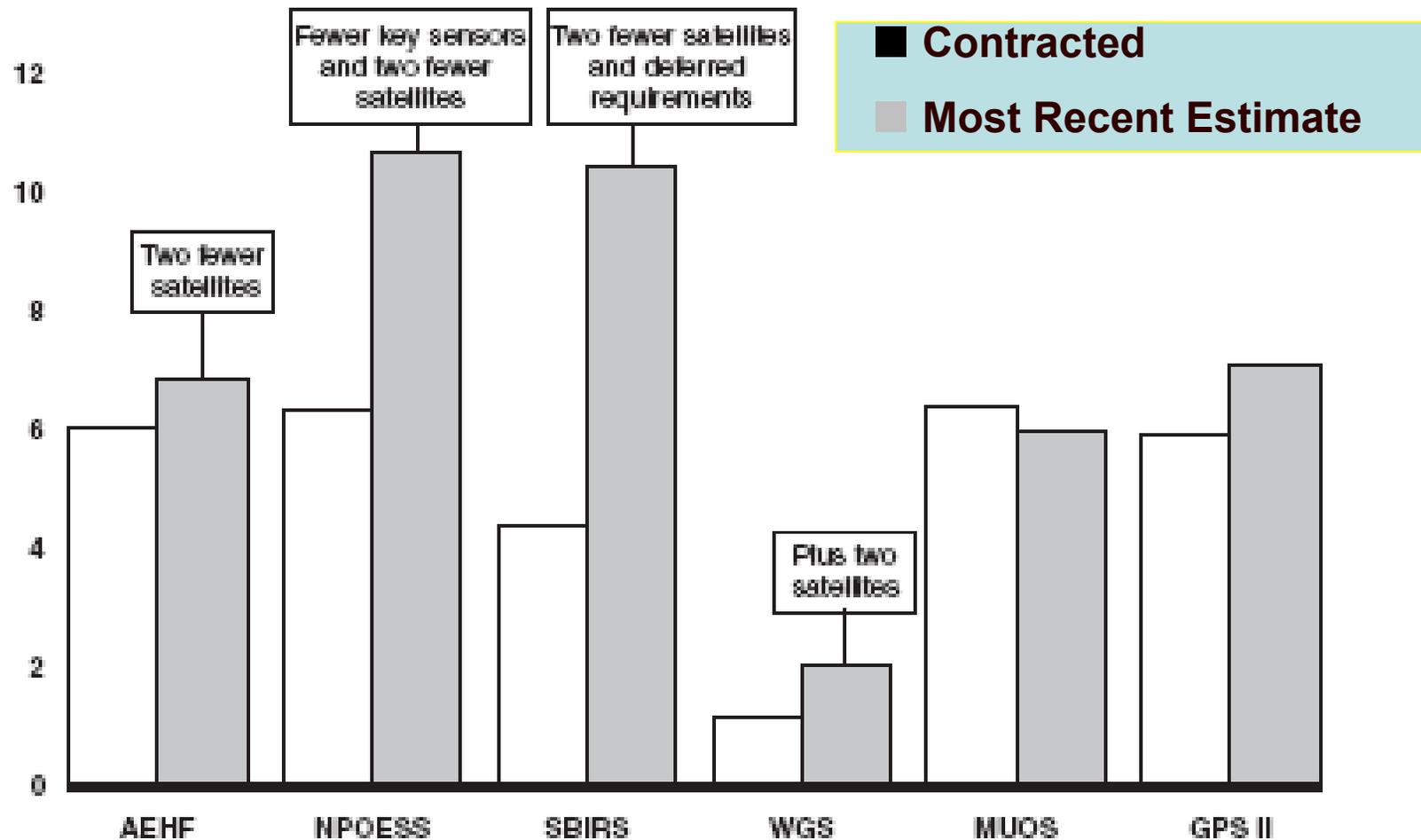
- **Time is wasted**

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

Need for Better SE: Cost Overruns

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

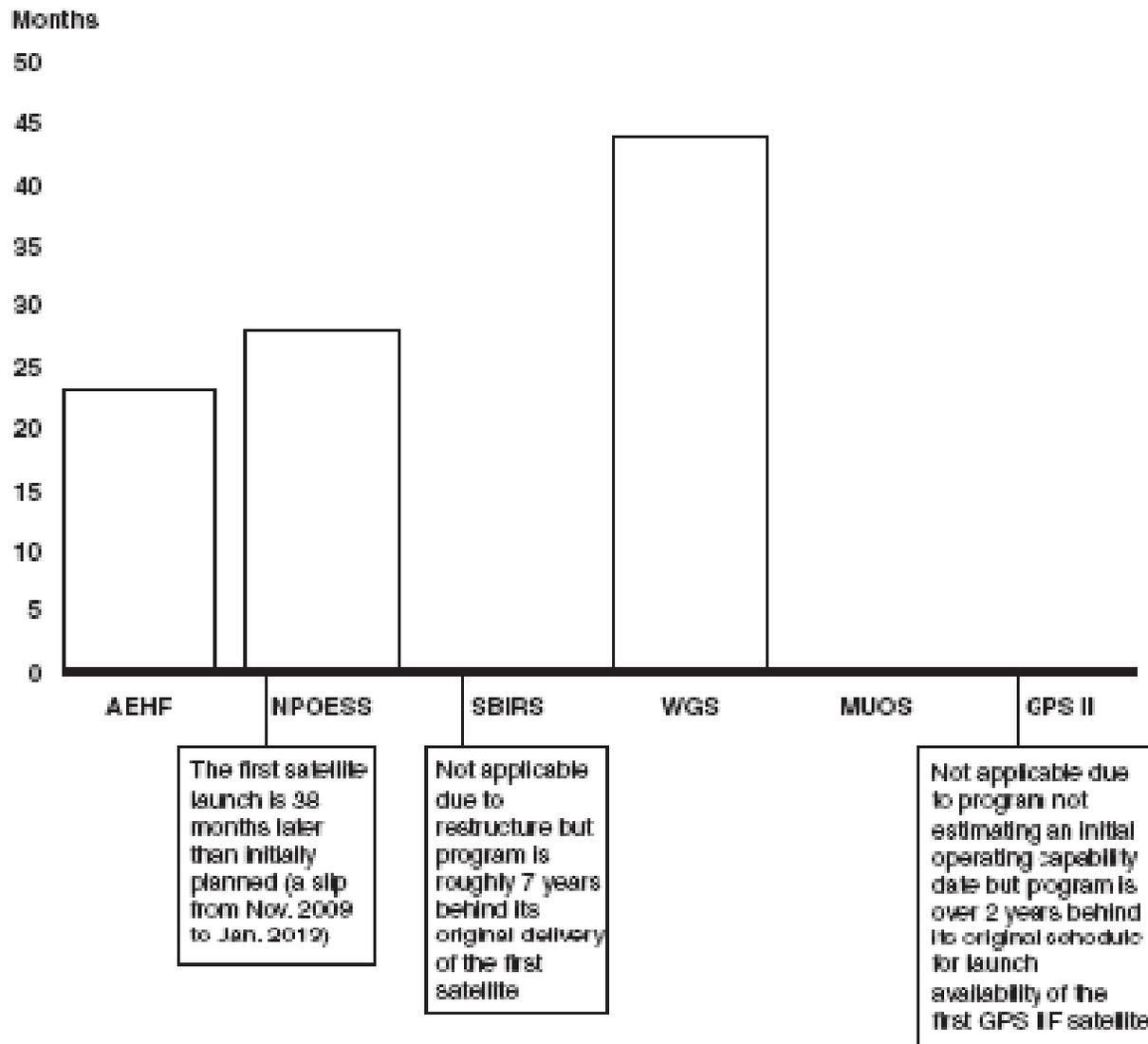
2008 dollars in billions



GAO: Space Acquisitions, 2008

Schedule Overruns

Figure 2: Additional Months Needed since Program Start



Source: GAO analysis of DOD data.

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 delayed
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 prime contractor data.

^aCost 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

- The traditional SE process is regarded as technically sound
- Amend the process with the wisdom of Lean Thinking
- The underlying philosophy:
 - Produce Lean Enablers: a checklist of do's and don'ts of SE for industry
 - Aim for “the asymptote of excellence in SE”
 - Do not be constrained by the present practices
 - Hard data difficult to develop, so use the “Tacit knowledge approach” (rely on collective wisdom of experts and practitioners)
 - Integrate Systems Engineering and relevant parts of Program and Enterprise Management
- Lean Enablers not intended as a regulation or mandatory procedure.
 - Intent: improve awareness of best practices among all stakeholders
- Do not repeat information already covered in the SE handbooks (INCOSE, 15288, NASA, DoD, company,...)

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**

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
 - Uzi Orion (ELOP) uzio@elop.co.il
 - Dave Ratzer (Rockwell Collins) dlatrater@rockwellcollins.com
 - 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**

Part 5

The Product:

Lean Enablers for Systems Engineering, Version 1.0

Lean Enablers for System Engineering

Principle	Enabler (number of sub enablers)
1 – Value	1.1 Follow all the practices for the requirements capture and development in the INCOSE Handbook. In addition: 1.2 Establish the Value of the End Product or System to the Customer (6) 1.3 Frequently involve the customer (4)
2 – Map the Value Stream (Plan the Program)	2.1 Plan the Program according to the INCOSE Handbook process. In addition: 2.2 Map the SE and PD Value Streams and eliminate No-Value Added elements (12) 2.3 Plan for frontloading the program (4) 2.4 Plan to develop only what needs developing (5) 2.5 Plan to prevent potential conflict with suppliers (4) 2.5 Plan leading indicators and metrics to manage the program (5)
3 – Flow	3.1 Execute the program according to the INCOSE Handbook process. In addition: 3.2 Clarify, derive, prioritize requirements early and often during execution (6) 3.3 Front load architectural design and implementation (5) 3.4 Systems Engineers to accept responsibility for coordination of PD activities (4) 3.5 Use efficient and effective communication and coordination (9) 3.6 Promote smooth SE flow (4) 3.7 Make program progress visible to all (4) 3.8 Use Lean tools (5)
4 – Pull	4.1 Tailor for a given program according to the INCOSE Handbook process. In addition: 4.2 Pull tasks and outputs based on need, and reject others as waste (9)
5 – Perfection	5.1 Pursue continuous improvement according to the INCOSE Handbook process. In addition: 5.2 Strive for excellence of SE processes (8) 5.3 Use Lessons Learned from past programs for future programs (5) 5.4 Develop perfect communication, coordination and collaboration policy across people and processes (8) 5.5 For every program use a Chief Engineer role to lead and integrate the program from start to finish (8) 5.6 Drive out waste through design standardization, process standardization, & skill-set standardization (3) 5.7 Promote all three complementary continuous improvement methods to draw best energy and creativity from all employees (3)
6 – Respect for People	6.1 Pursue people management according to the INCOSE Handbook process. In addition: 6.2 Build an organization based on respect for people (14) 6.3 Expect and support engineers to strive for technical excellence (4) 6.4 Nurture a learning environment (8) 6.5 Treat people as most valued assets, not as commodities

- 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 (“very important”), or 1 (“important”), 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 PD¹ planning. (U 0.17)**
Examples: Toyota, HondaJet, Citation X.
- 5. Use formal value stream mapping methods to identify and eliminate SE and PD¹ 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***

[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, 31 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 variability¹, 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)

[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 communication 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)

[\[1\]](#) "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)**

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 tailoring tasks and pulling them and their outputs based only on legitimate need and rejecting others as waste.
- The "legitimate" is always interpreted in the context of value: "flawless mission assurance".
- The Pull promotes proactive coordination of task scope and modalities between the output creator and the user prior to the task execution, 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)

Lean Principle 5: Perfection

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 than 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)

Lean Principle 5: Perfection

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)

^[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

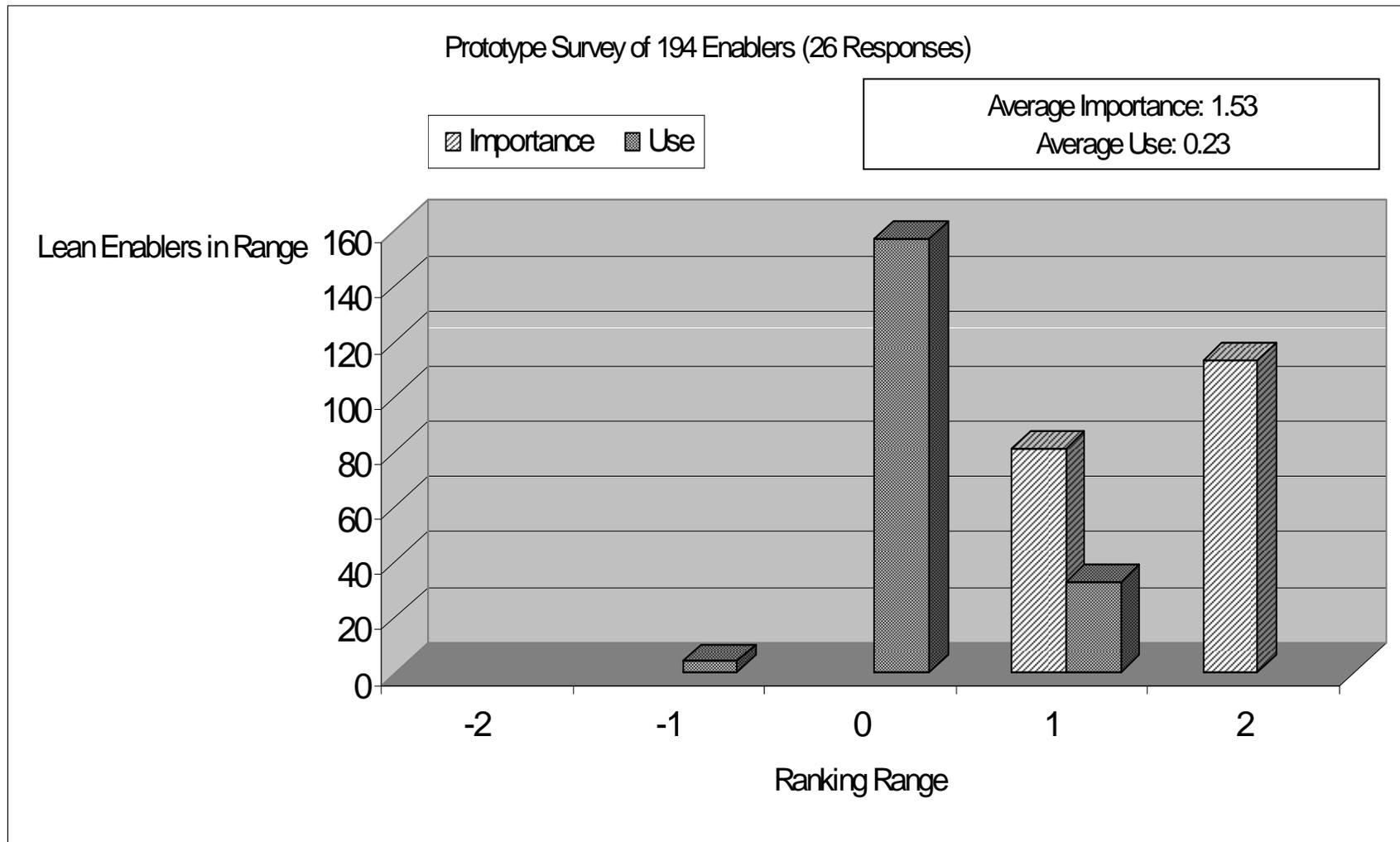
Part 6

“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

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 #
<p>Visionary Leadership - Role of organizational leadership in establishing a clear overarching purpose, deriving and articulating a compelling but credible vision to fulfill that purpose.</p>	<p>1.2.6, 1.3.1, 3.4, 5.5, 5.7, 6.2</p>
<p>Capability Maturity – Organization attainment of high levels of “Capability Maturity” to support and facilitate the undertaking of complex systems development</p>	<p>2.2, 2.3, 2.5, 3.3, 3.5, 3.6, 5.2, 5.3, 5.4, 5.6</p>
<p>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.</p>	<p>1.2, 1.3, 2.2.3, 2.6, 3.4, 3.6, 5.2</p>
<p>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".</p>	<p>2.5, 5.2, 5.3, 5.4, 5.6, 5.7, 6.3</p>
<p>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.</p>	<p>5.2, 6.2, 6.3</p>

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 #
<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • Hold program managers accountable for their choices. 	5.5
<ul style="list-style-type: none"> • Require program managers to stay with a project to its end. 	5.5
<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • Encourage program managers to share bad news, and encourage collaboration and communication. 	3.5, 3.7

Part 7.

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-IS 2010**
 - **INCOSE-wide webinar**
 - **EuCOSE-Stockholm, 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**
 - **DoD System Engineering Directorate (Collaborator's Information Exchange), May 2010**
- **Lean SE WG focus in INCOSE IW 2010 on implementation**
- **Change process**
 - **Version 1.0 is mature but not final: continuous growth of knowledge will require future changes**
 - **On-line process for changes implemented**

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**

Part 8.

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**
- **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 development benefited from academic depth, breadth, and rigor.**

Summary

- **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**
- **A formal process of continuous improvement and periodic releases has been setup as new knowledge and experience becomes available.**
- **LEfSE were endorsed by two surveys and by comparisons with the recent recommendations by NASA and GAO.**
 - **The surveys indicated high levels of the need for and low levels of the use of LEfSE in industry.**
 - **The comparisons indicated that LEfSE are consistent with the NASA and GAO recommendations, and are much more comprehensive and actionable.**