Advanced Lean Management of Engineering Programs

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http://cse.lmu.edu/programs/Systems_Engineering/faculty/oppenheim.htm

LOYOLA MARYMOUNT UNIVERSITY, Los Angeles, since 1981

- Professor of Systems Engineering (and Mechanical Engineering, 1983-2010)
- Graduate Director of Mechanical Engineering, 1995-2010
- Director, US Department of Energy Industrial Assessment Center, 2000-2007
- Founder and Co-Chair, Lean Systems Engineering Working Group, INCOSE (www.incose.org)
- Coordinator, Lean Aerospace Initiative Educational Network (MIT based)
- On Steering Committee of INCOSE/PMI/MIT LAI Lean Project Management
- On Steering Committee of Lean Education Academic Network

EDUCATION

- PhD, 1980, U. of Southampton U.K., in System Dynamics
- Naval Architect, 1974, MIT
- M.S, 1972, Stevens Institute of Technology, Ocean Systems
- B.S. (equiv.), 1970, Warsaw University of Technology, Mech. Eng. Energetics, Aeronautics (MEiL)

INDUSTRIAL EXPERIENCE

- 121 industrial plants assessed for Lean/Productivity/Quality
- Author (with S. Rubin) of POGO simulator for U.S. liquid rockets used by NASA
- Lectured and consulted on lean, productivity, quality, systems engineering in 17 countries

  Including at Northrop-Grumman (1985-1990, 2008), The Aerospace Corporation (1990-1994), Boeing (2002-2004), Airbus (2006), France Telecom (2008-09), Global Marine Development (1974-77), 100 other firms and governmental institutions

HONORS: Fulbright (2011), Shingo Award (2011), Shingo Award (2013), INCOSE Best Product (2009), LACES Best Teacher (2004), S. Ruth INCOSE Award

Course Content

1. Lean Fundamentals (Manufacturing)
2. The Basics of Lean Product Development
3. Systems Engineering Fundamentals (and Polish Needs)
4. What Happened to Traditional Systems Engineering?
5. Vastly Better PD & Systems Engineering at SpaceX
6. Lean Product Development Flow (LPDF)
7. Lean Final (Parts) Engineering
8. Lean Enablers for Managing Engineering Programs
9. Lean Office

(1) Two days; other topics one per day

Part I: Lean Fundamentals (Manufacturing)

What is Lean? (as in "not fat", "slim", "dieted")

- Lean = organization of work within a company and between all cooperating companies which is focused on the delivery of value with minimum waste
- Waste is everywhere, more than anyone before Lean could imagine: 60-70 % of charged time in best companies, 90-99+ % in bad ones.

This our productivity reserve!

Lean Thinking

“It is so simple…we are looking at the time from order to delivery and payment by the customer ...and we trying to shorten that time by elimination o waste"

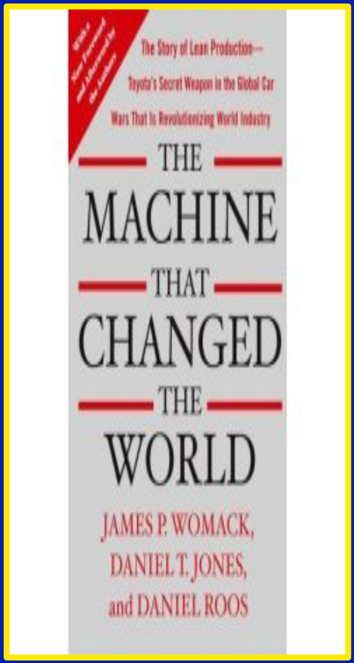
– *Taiichi Ohno, "father" of Lean in Toyocie*

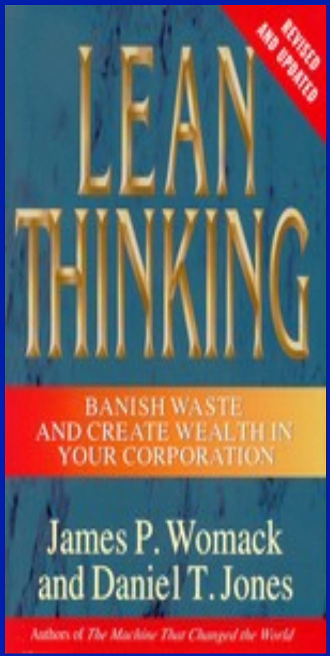
Basic Reading in Lean Thinking

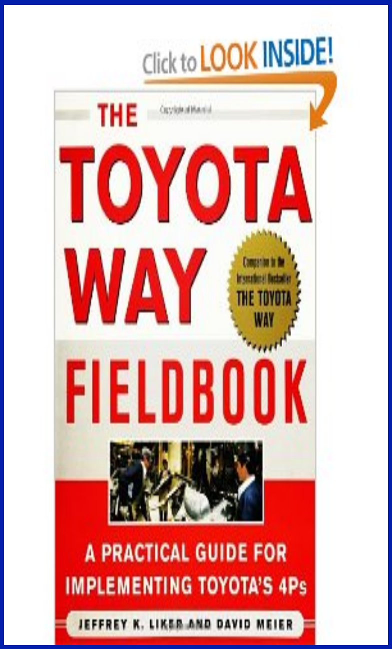
1990

1996

2004







Value, Waste and Lean Principles

- Three concepts are critical to the understanding of Lean:
  - Value
  - Waste ("muda" in Japanese)
  - The process of creating Value with no Waste

Lean should not lead to layoffs and firings.

Value

- Value is whatever the customer orders and is willing to pay for.
- Only the customer is the judge of value.

Waste Elimination = Fundamental Lean Concept

- **Waste:** Anything other than the minimum amount of equipment, materials, parts, space and worker's time, which are absolutely essential to add value to the product or service

NORTHROP GRUMMAN

Northrop-Grumman

Ohno’s Seven Types of Waste (plus one)

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
8. Talent	Wasting human talent, creativity, enthusiasm

Value versus Waste

- Value Added (VA)
  - Transforms or shapes material or information or reduces risk
  - And the customer would be willing to pay for it if asked
  - And it's done right the first time
- Required Non-Value Added (RNVA)
  - Required (regulatory, company mandate, legal)
  - The task creates no value but it cannot be eliminated based on current technology or thinking
- Non-Value Added = Pure waste (often between the VA)
  - Consumes resources but creates no value in the eyes of the customer

Six Lean Principles

1. Specify **value**: Value is defined by customer in terms of specific products. Capture the sense of value perfectly.
2. Identify the **value stream**: Map out all end-to-end linked actions, processes and functions necessary for transforming raw materials into products, while eliminating waste
3. Make value **flow** continuously: Make the remaining linked value-creating steps "flow" per common takt time, without backflow, stoppages
4. Let customers **pull** value: Customer's "pull" cascades all the way back to the lowest level supplier, enabling the super-efficient just-in-time production
5. Pursue **perfection**: Make imperfections visible, eliminate each once and for all, pursue continuous process of improvement striving for perfection
6. **Respect People**

LAI Lean Academy™, Oppenheim+Murman+Secor

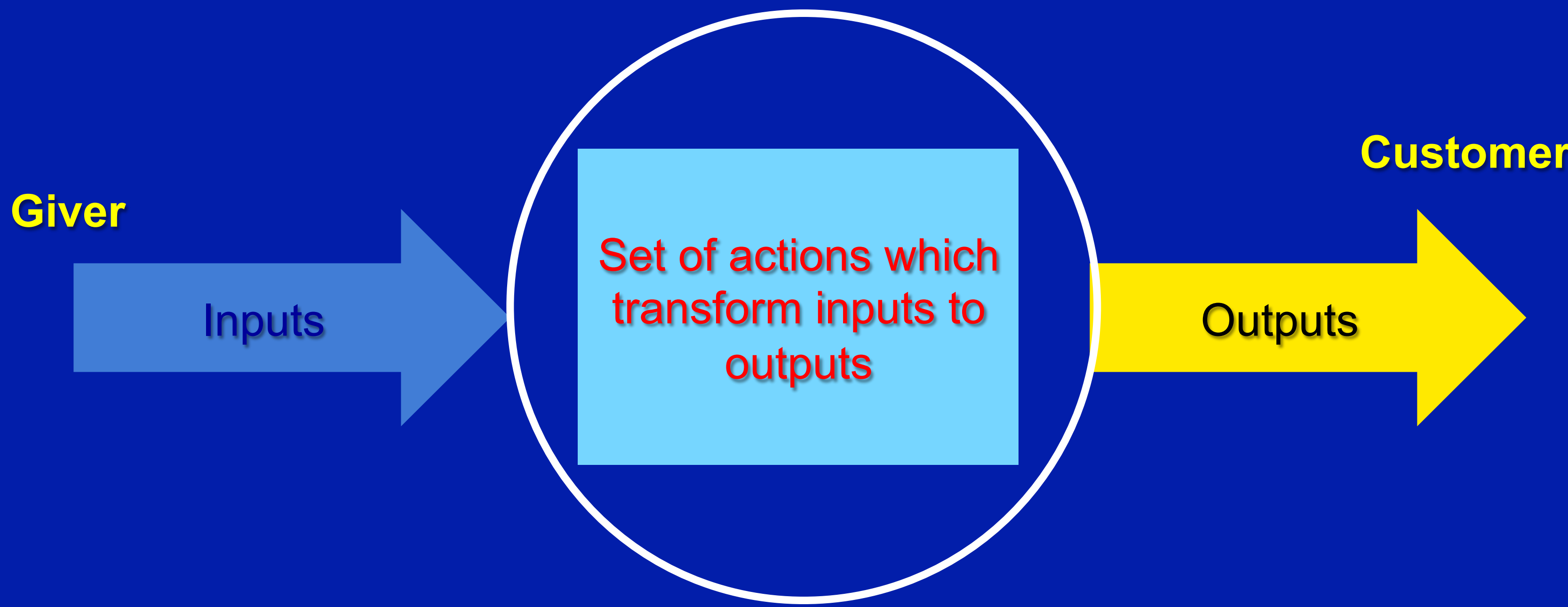
Principle 2: Value Stream
What Moves in a Value Stream?

In manufacturing or construction… material flows

In design & services…information flows

In health services…patients flow

Principle 2: Value Stream
What is a Process?

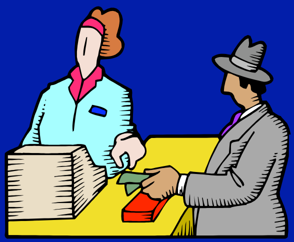


Process: A series of actions, changes, or functions bringing about a result

Ref: http://www.dictionary.com, Jan. 8, 2003

Principle 2: Value Stream
Identify the Customer

- What happens to the outputs of a process?



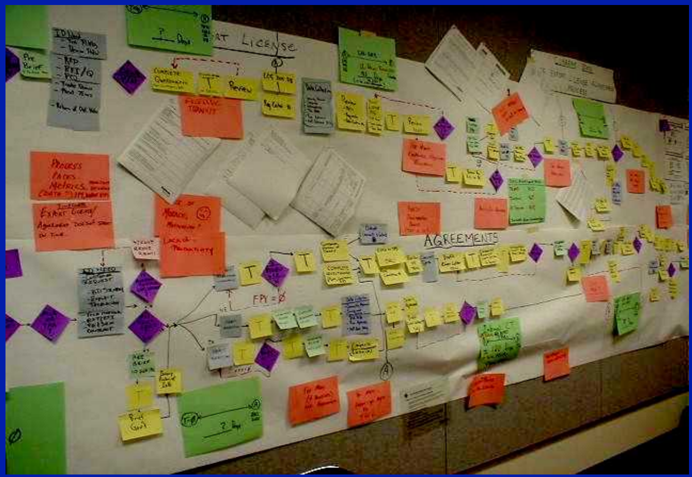
They go to a CUSTOMER!

- **External customers - are outside an organization, money is typically exchanged with external customers**
  - **End users are customers who pay for an operational or consumable product or service**

- **Internal customers - are inside an organization, money is typically not exchanged directly with internal customers**

Principle 2: Value Stream Mapping
Basic Steps to VSM

1. Define the boundaries
2. Define the value
3. "Walk" the process
   – Identify tasks and flows of material and information between them
4. Gather data
   – Identify resources for each task and flow
5. Create the "Current State" map
6. Analyze current conditions
   – Identify value added and waste
   – Reconfigure process to eliminate waste and maximize value
7. Visualize "Ideal State"
8. Create the "Future State" map
9. Develop action plans and tracking



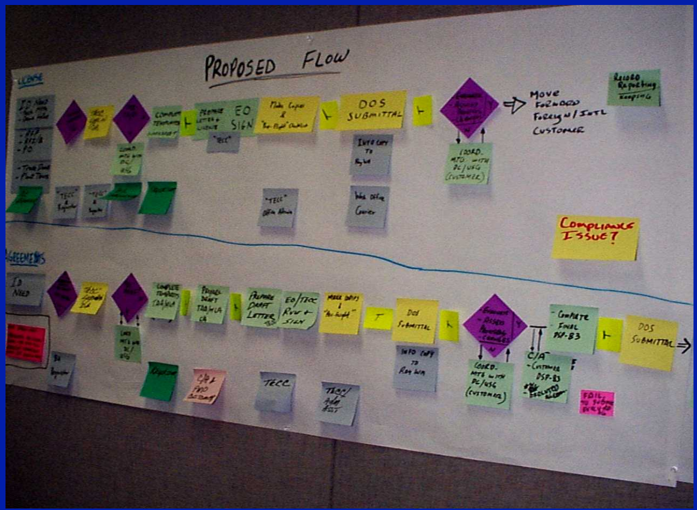
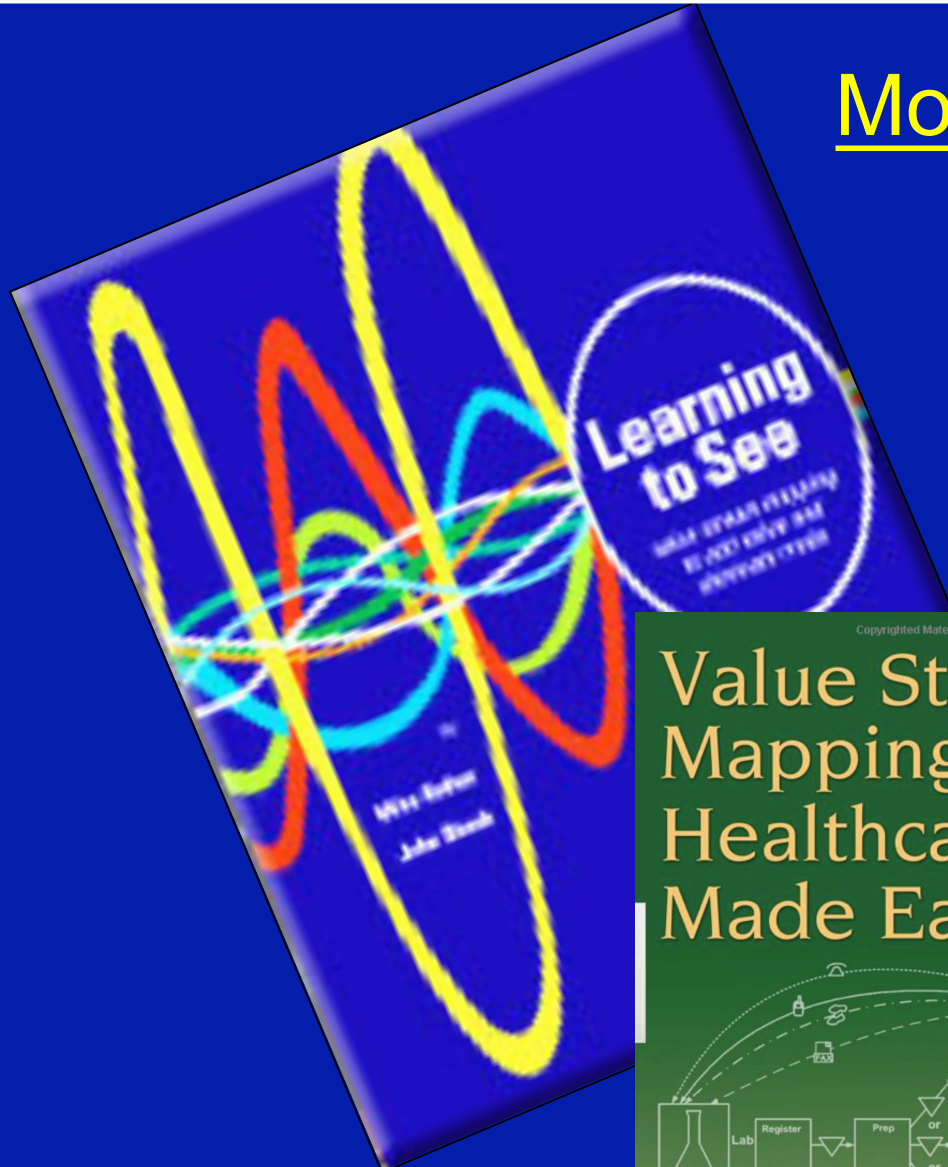
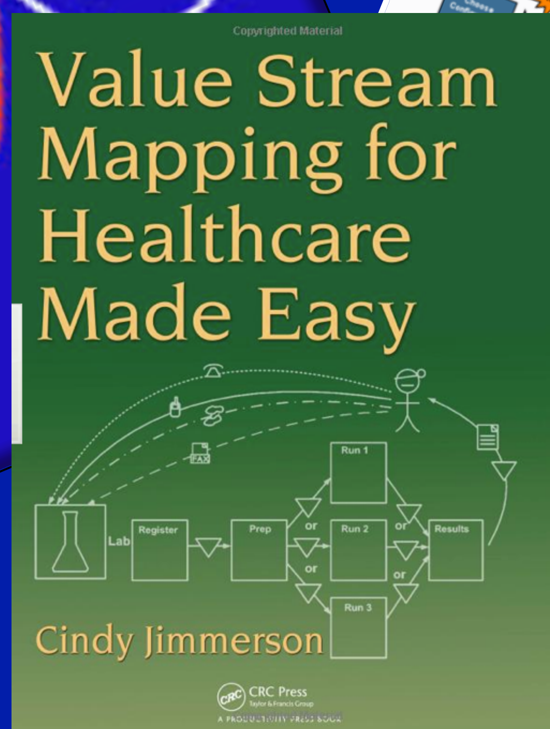


Photo source: Raytheon
LAI Lean Academy™

More Information on VSM

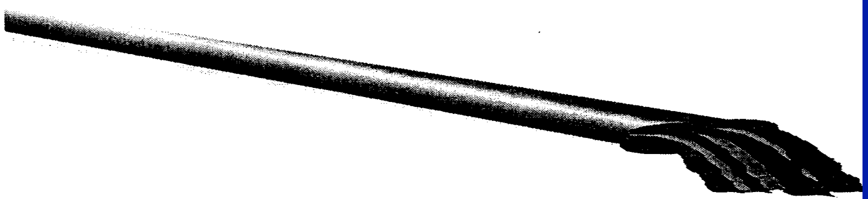




Principle 3: Flow

- **Definition:** The product, information or service flows predictably in single pieces without batching along the value stream without stoppages, interruptions, or backflows.

Traditional - waiting, delays, idle time - waste



Lean - moving and producing at a predictable rate

Northrop-Grumman

Principle 3: Flow

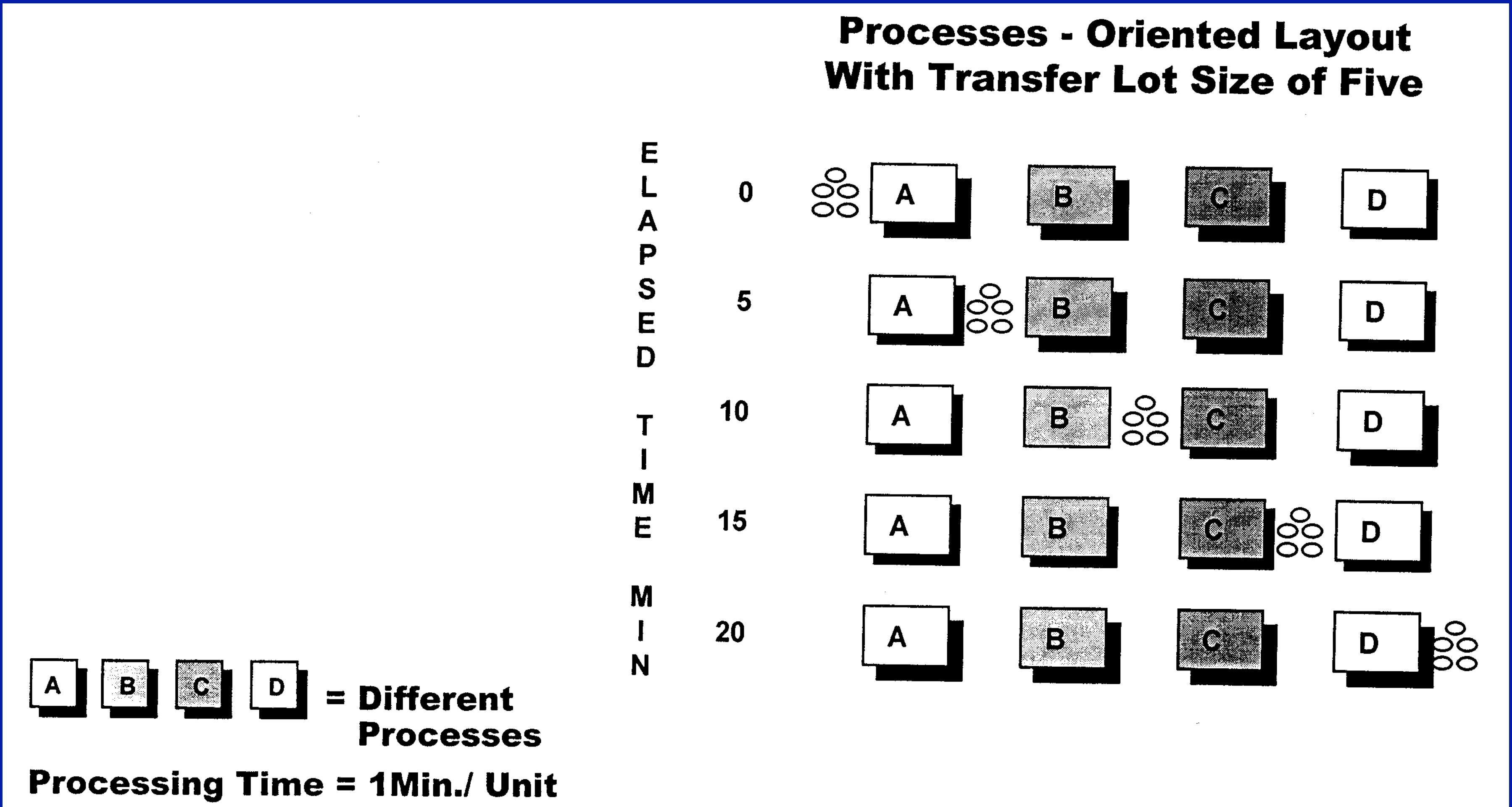
Flow = predictable and robust sequence of value-adding activities performed exactly when needed and only on the items needed, with no waiting or rework or inventories.

- Activities can always be performed much more efficiently and accurately when the product is worked on continuously from raw material to finished good
- Traditional culture: stovepipes, functional villages, batch and queue, huge inventories, huge waiting.

JIT/TPS Tools

Single-Piece Flow Shortens Delivery Time.

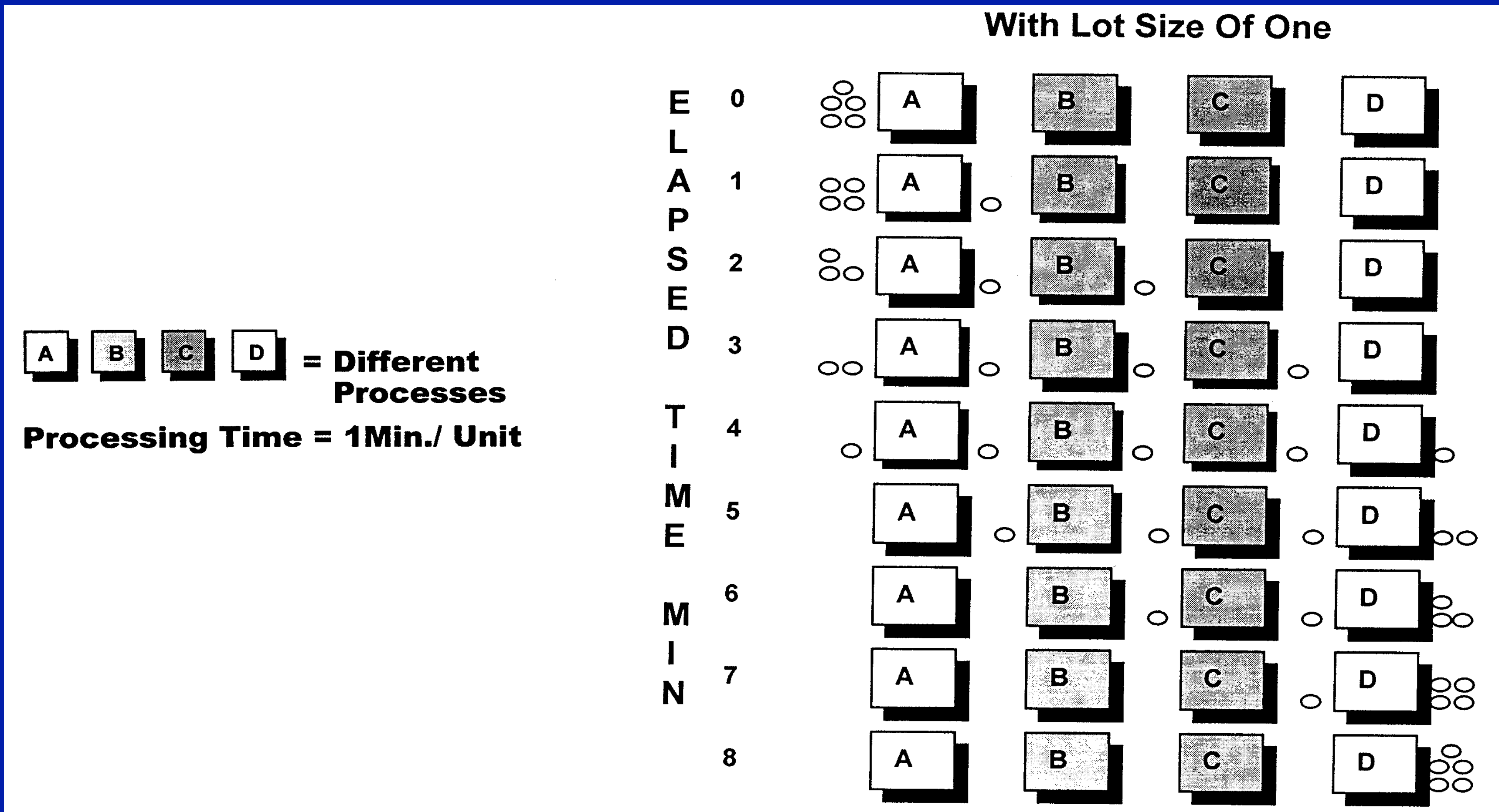
First look at the batch size of five



Northrop-Grumman

JIT/TPS Tools

Now, look at single piece flow



Northrop-Grumman

JIT/TPS Tools

Single-Piece Flow Benefits

	Batch Size = 5	Single Piece Flow
Time to finish the batch	20	8
Time to first piece out	16	4
% time machines are idle	64	16 (75% cut)
Infrastructure energy savings ~ time	None	60%

Principle 4: Pull

- Push system – each activity delivers its output when it is done
  - Results in build up of batches with lots of inventory; defective goods pile up. Inventories go obsolete, occupy space, costs.
- Pull system – each activity delivers its output just as the next activity needs its input ("just-in-time")
  - Triggered by the customer (external & internal)
  - Results in smooth flow with no batches or voids
  - Minimizes inventory and rework due to defects
- Inherently, there is very little waste in a pull system

Principle 5: Perfection

Something extraordinary begins to happen after Principles 1-4 have been implemented:

- The flow visualization makes the slightest imperfections visible and aggravating to all
- The Flow gives people a sense of urgency to deal with all imperfections
- There is no end to the process of reducing effort, time, space, cost and mistakes

Make all imperfections visible, then swarm them to eliminate once and for all, and eliminate fear to enable making imperfections visible

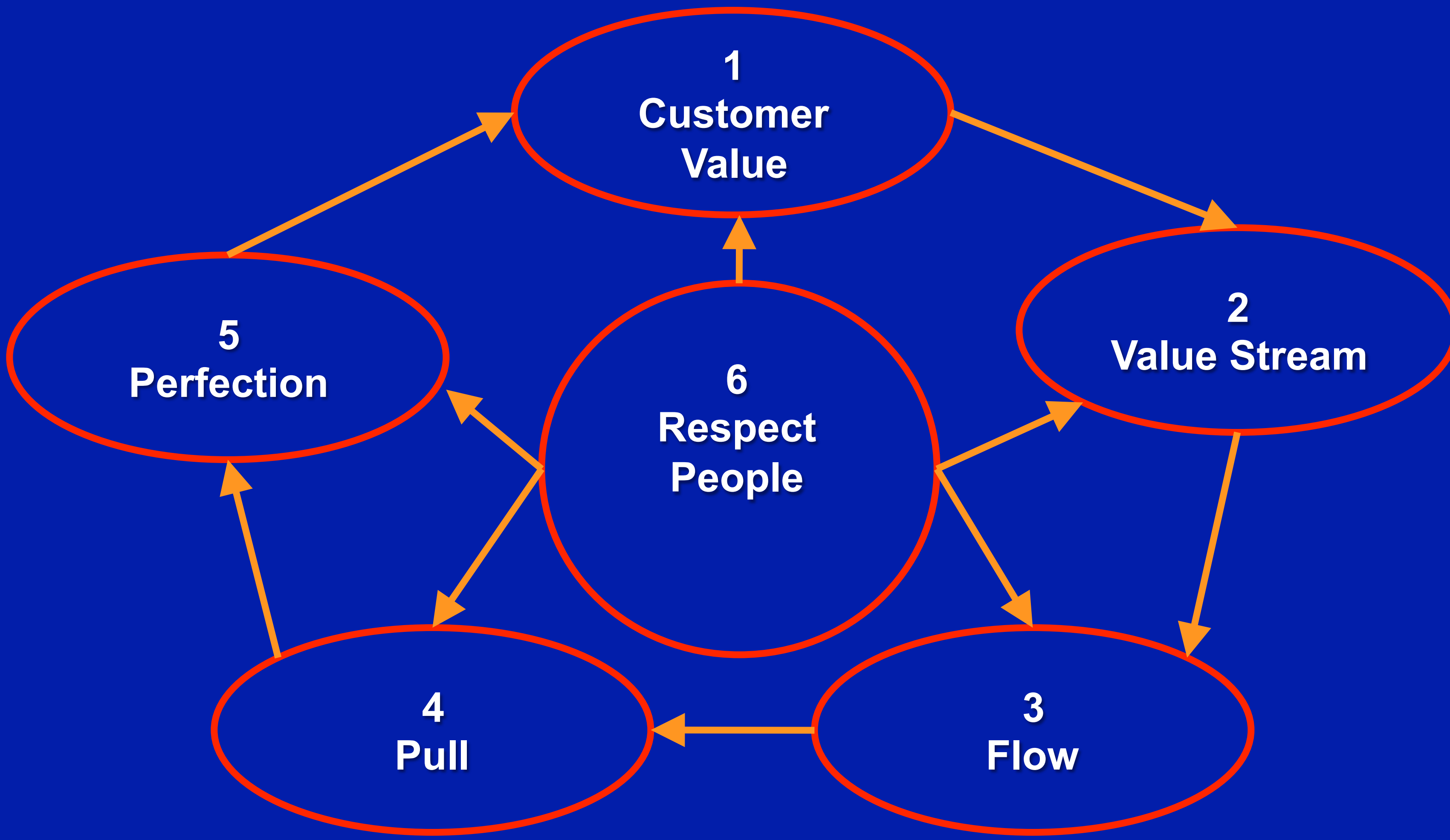
Principle 6: Respect for People

- 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.

Six Lean Principles Work Together

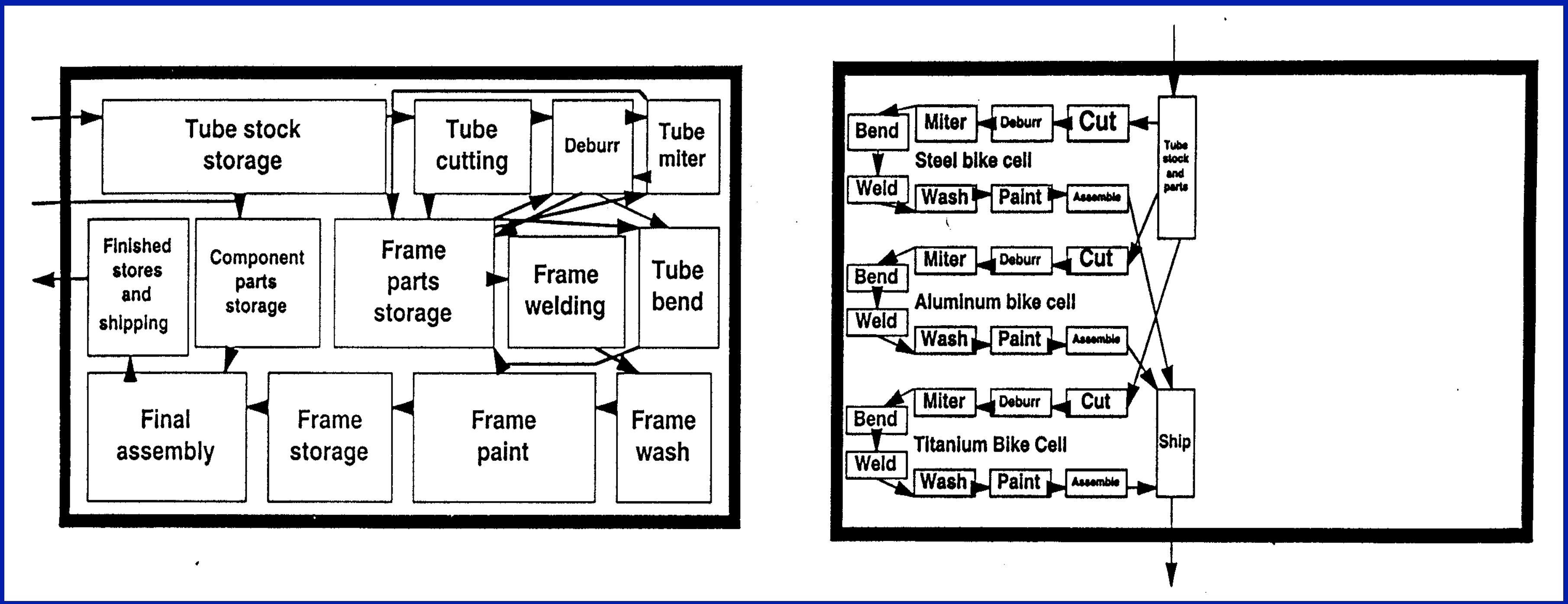


JIT/TPS Tools

- 5 S's
- Standard work and standard operations (capture the current best way to do work)
- Kanban
- Quick changeover
- Using Small, Simple, Slower, Less Automated Machines
- Work cells
- Total Productive Maintenance
- Poka Yoke (mistake proofing)
- Visual controls
- Gemba (go to the place where work is being done)
- Local in-line quality assurance

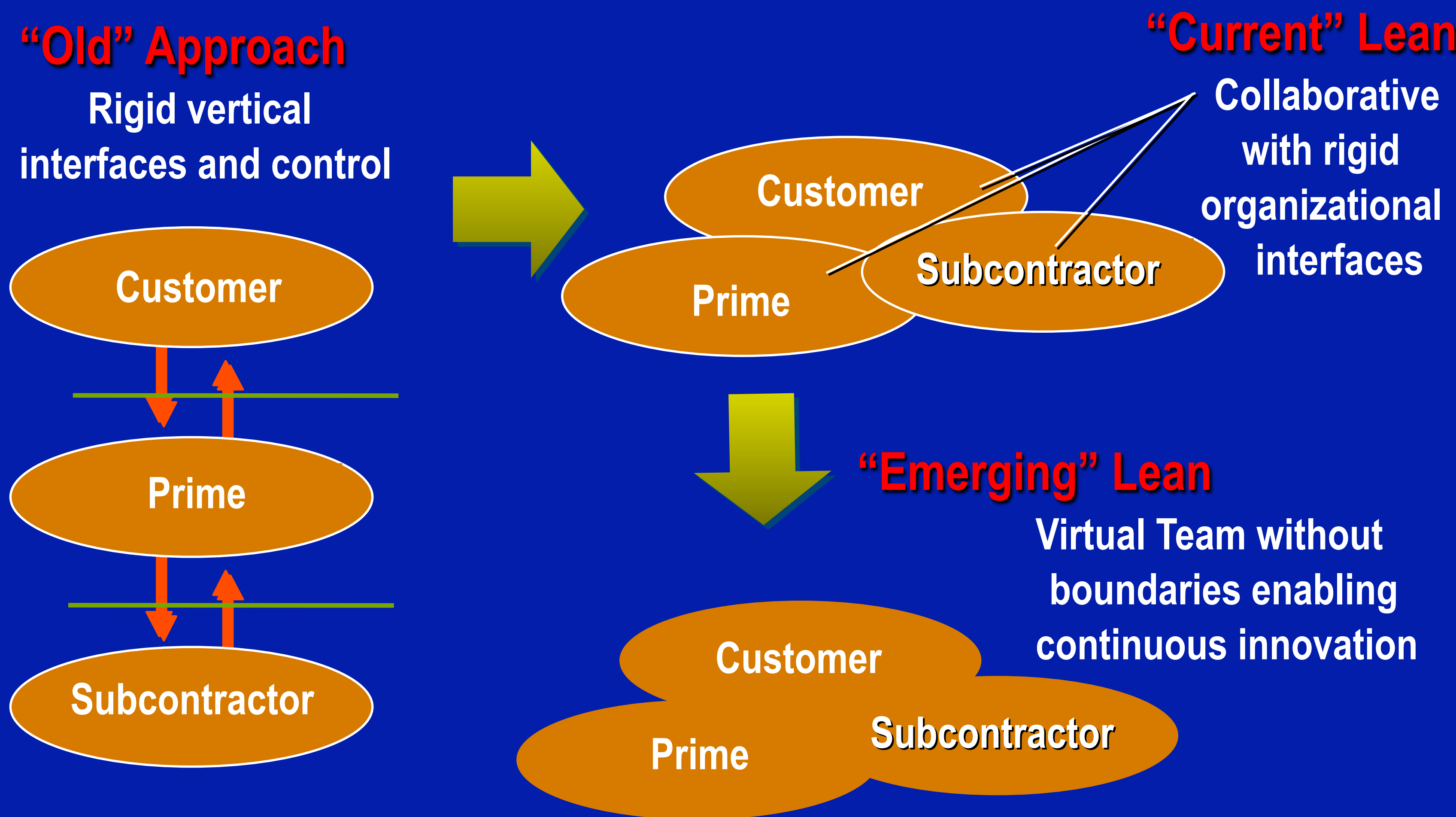
Example of Before and After Lean

- Womack's bicycle factory



Lean Supplier Network

Evolution of Relationships with suppliers



Final Remarks about Lean Principles

Womack's Maxim for Lean in Manufacturing

- Converting a traditional batch-and-queue production system to lean flow yields these effects:
  - Doubles the productivity in the entire system
  - Cuts production throughput times by 90%
  - Reduces inventories in the entire system by 90%
  - Cuts errors in half
  - Vastly improves work morale

50% !   90% !   2x !

CASE STUDY

The Incredible NUMMI Factory in Freemont, California

NUMMI

Two Quotes From Union Agreements

1. "The management of the plant and the direction of the working forces, including but without being limited to the right to hire, promote, demote, transfer, classify, reclassify, make layoffs for lack of work or other legitimate reasons, release for just cause, and for just cause to discharge, suspend, or otherwise discipline employees are vested exclusively in the Company.."
   - *National Agreement between McDonnel Douglas Aircraft Company and their unions*

2. "The parties recognize that this is an historic endeavor and that progress for the Company and the members of the Union is to a large extent interdependent and therefore together we are committed to building and maintaining the most innovative and harmonious labor-management relationship in America.

In the administration of this Agreement, and in our day-to-day relationship, we will exhibit mutual trust, understanding and sincerity, and, to the fullest extent possible, will avoid confrontational tactics.

Should differences or misunderstandings occur they will be resolved through full and open communication. The work environment will be based on teamwork, mutual trust and respect that gives recognition to the axiom that people are the most important resource of the Company.

...

Before laying off any employees, the Company will take affirmative measures, including the reduction of salaries of its officers and management, assigning previously subcontracted work to a unit capable of doing this work, seeking voluntary layoffs, and other cost measures. "

- *Agreement between New United Motor Manufacturing, Inc. (Toyota) and the United Auto Workers (union), August 1, 1998*

The Incredible Freemont Factory

(from D. Levine, The Brookings Institution, 1995)

- 1963-82 Freemont (near Oakland, CA) modern automobile plant operated by GM
- GM's "scientific management" based on Taylor: brutal contempt for workers
    - "You, new employees have been hired in the same way we buy sandpaper. We'll put you back on the street whenever you aren't needed any more" - a GM manager to new workers
    - Growing mistrust and hate between workers/UAW and managers
    - Conflicts, stoppages, strikes, militancy on both sides are frequent

The Incredible Freemont Factory

- Unions militantly defend all workers, even after theft
- Absenteeism at 20%, plant could not operate Fridays and Mondays
- Over 4000 unresolved union grievances
- Quality and productivity well below the poor GM standard
- 1982 GM declares the plant "the worst in the world" and closes it. Layoff of 5700 workers
- Toyota was seeking to open the first ever American plant as an experiment with TPS under American conditions
- Toyota and GM hesitantly agree to open a joint venture New United Motor Manufacturing Co.
- Toyota reserves all management roles, contributes 200 M$ and new car designs, and GM contributes the plant
- UAW recognized and asked to be a partner under new principles.   Extraordinary union contract.
- Job security
- Old workers rehired, interviewed jointly by managers and UAW (management NOT rehired).

The Incredible Freemont Factory

- Workers trained both in Japan and locally for min 60 days, some for 9 months
- Massive training in job skills, human relations, respect, empowerment, quality, TPS
- Each worker called a "team member" and a gentleman (lady)
- Strong employee involvement expected and realized in all activities. Workers not engineers define best procedures.
- Initial reservations about the abuse of Andon cords stopping the line never materialized
- NUMMI soon achieves Japanese quality levels, productivity 40% better than all-GM
- Workers satisfaction at 90% in 1991 (formerly disastrous).
- 94% of workers contribute Kaizen suggestions, receive bonuses
- Toyota likes the results and opens several large American plants

The Incredible Freemont Factory

- NUMMI destroyed several myths
  - "Primitive lazy worker"
  - "Japanese mentality not transferable to US"
  - "Japanese quality level cannot be achieved in the US“
- NUMMI is the absolute proof that the guilty party was the traditional management and not the workers or the unions.

The Incredible Freemont Factory

NUMMI Mission

Through teamwork, safely build the highest quality vehicles at the lowest possible cost to benefit our customers, team members (=employees), community and shareholders.

Note the priority of the above words

Part II: The Basics of Lean Product Development

Lean PD

Lean PD= The application of lean wisdom, principles, practices and tools to PD in order to enhance the delivery of value to system's stakeholders.

- Lean SE Working Group

Value in Lean PD

Value in PDis defined as a flawless system, product or mission delivered at minimum cost, in the shortest possible schedule, fully satisfying the customer and other stakeholders during a product or mission lifecycle. *- Lean SE Working Group*

Waste

- Waste = all resources (human effort, time, machines, materials) over and above the absolute minimum required to create the needed value
- Value in Lean must be assured
- Everything and anything needed for value is not waste
- Lean does not mean "cutting corners"
- Lean means identify waste and eliminate it

Waste is often difficult to recognize in PD.
It is a required skill in Lean.

Incredible Power of Lean PD

- Example: Toyota Prius designed in 9 months
  = 2-3 times shorter then next best in class

- Lean PD/SE cuts program time and cost by 40-90%
- Vastly increased customer satisfaction and system quality.

Maturity of Various Area of Lean

- 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 (1-5)
Lean Manufacturing (where it all started)	Very Mature, 5
Lean Enterprise	Very Mature, 4-5
Lean Supply Network	Mature, 3-4
Lean Office	Mature, 4-5
Lean Final Engineering	Mature, 3-4
Lean Systems Engineering/PD	Released in 2009, 4-5
Lean Health	Growing fast, 3
Lean Banking	Growing fast, 3

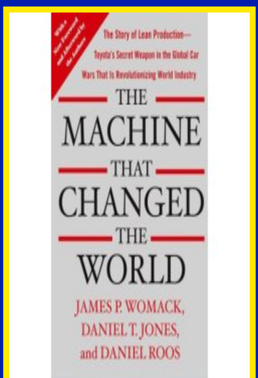
Leaders in Lean Research

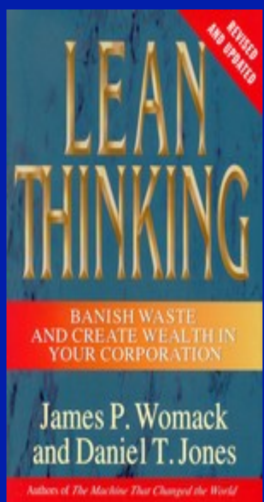
Most of Lean Enterprise research is performed at MIT: PD, Supply Network, Enterprise, Health, PM

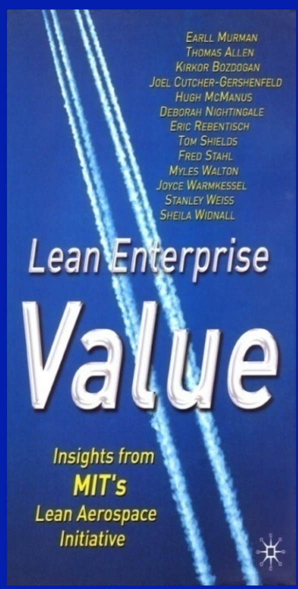
Significant amount of research on Lean Systems Engineering, Lean Project Management , Lean Health, Lean Banking at LMU

Selected Lean PD/PM/SE Milestones

Cars	Manufacturing	Enterprise, Supply Chain	VSM and LPDF	Lean Engineering Design	Lean Systems Engineering	Lean Enablers for MEP
1990	1996	2002	2004	2007	2009/11	2012



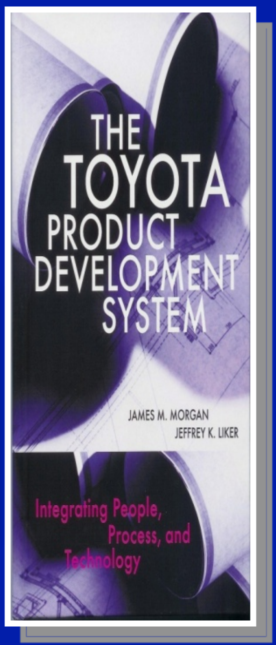


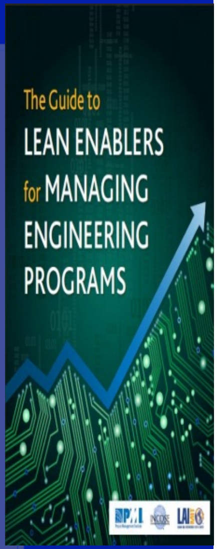


Lean Product Development Flow

-Oppenheim

PD VSM Manual
-
McManus





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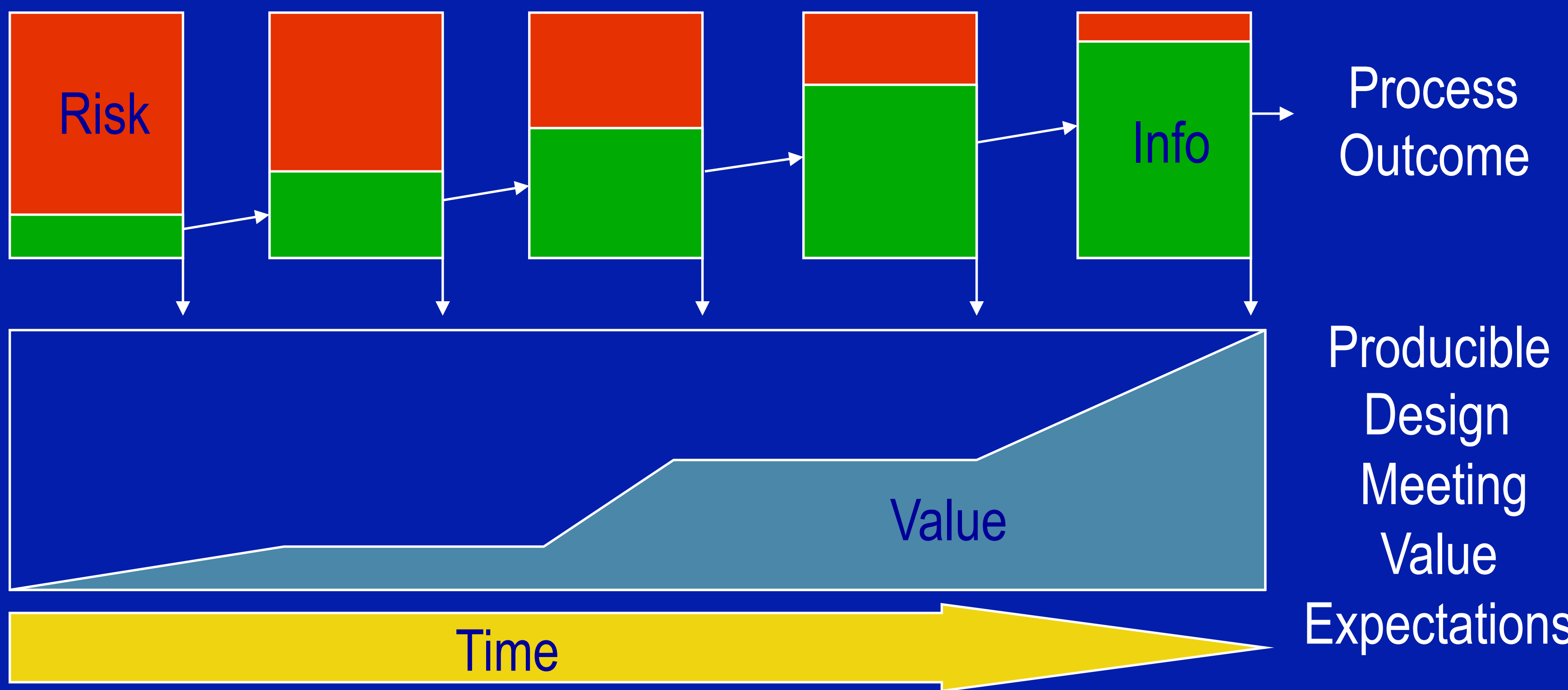
PD Phases

- Product Development process includes the following phases
  - Studies of Needs by the Customer (hugely complex bureaucracy in federal programs) and formulation of customer requirements
  - Funding Requests to Congress
  - RFP, Proposal and Contract
  - Architecting and Conceptual Design
  - Development of Needed Technologies
  - Requirements Allocation, Analysis
  - Detailed Design (Final or Parts Engineering)
  - Production (Fabrication, Assembly, Integration, Verification Tests)
  - Validation
  - Logistics, Operations and Maintenance
  - Disposal
- Involvement of thousands of world-class professionals

Definition of PD

- Engineering development of knowledge about the product…
- or a process of eliminating the uncertainty about the product
  - What to build (shape, material, fit, tolerances, assemblies,...)
  - How to build it (technology, processes, machines, ..)
  - The exact resources needed to build it (who does what, which suppliers, cost, schedule)
  - So that the Value is Achieved

PD = Elimination of Risk



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

Value and Waste in PD

Value Proposition

1. Robust System Success

- Value is what the Customer decides it is
- In space programs– only one chance to get it right
- Huge stakes in cost, national security, prestige
- Systems must work robustly right the first time
- All life cycle phases must work right the first time

Value Proposition
2. Minimum Schedule and Cost

- The PD schedule = critical part of the competitive value proposition
- Short program schedule = most important aspect of competitiveness
- In aerospace PD, most of the costs are engineering labor, i.e., "labor = time = money", so schedules should be as short as possible

Value Proposition

3. Stakeholder Satisfaction

- Satisfaction of the customer and end user
- Satisfaction of the employees
- Satisfaction of the suppliers (60-95% of value)
- Satisfaction of the taxpayer and the nation!!!
- Satisfaction of shareholders (profits)

Ohno's Seven Categories of Waste in Projects

(All Dealing with Information, adopted by Oppenheim)

WASTE	DESCRIPTION
1 Overproduction of Information 	• Creating unnecessary information • Performing work which is not needed • Creating documents that nobody requested • Pushing data rather than pulling data • Unsolicited emails • Too much detail • Sending a volume when a single number was requested • Reinventing the wheel, needlessly repetitive development • Useless data, meetings • Ignored expertise • Layoffs!

WASTE	DESCRIPTION
2. Information Transportation	• Inefficient transmittal of information • Communication failure: lost data, wrong format, information incompatibility • Transportation for approvals • Excessive sources or destinations • Security issues • Handoffs
3. Waiting "30% of design charged time, 63% of all tasks idle at any given time" - LAI	• People wait for data or data waits for people • Waiting for data, test result, information, decision, signature…

WASTE	DESCRIPTION
4. Information 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 too early • Unnecessarily serial effort • Uncontrolled iterations (too many tasks iterated) • Work on a wrong release (information churning) • Data conversions • 2D drawings • Too many detailed requirements • Complex software monuments (using PRO ENGINEER or NASTRAN where a spreadsheet would do)

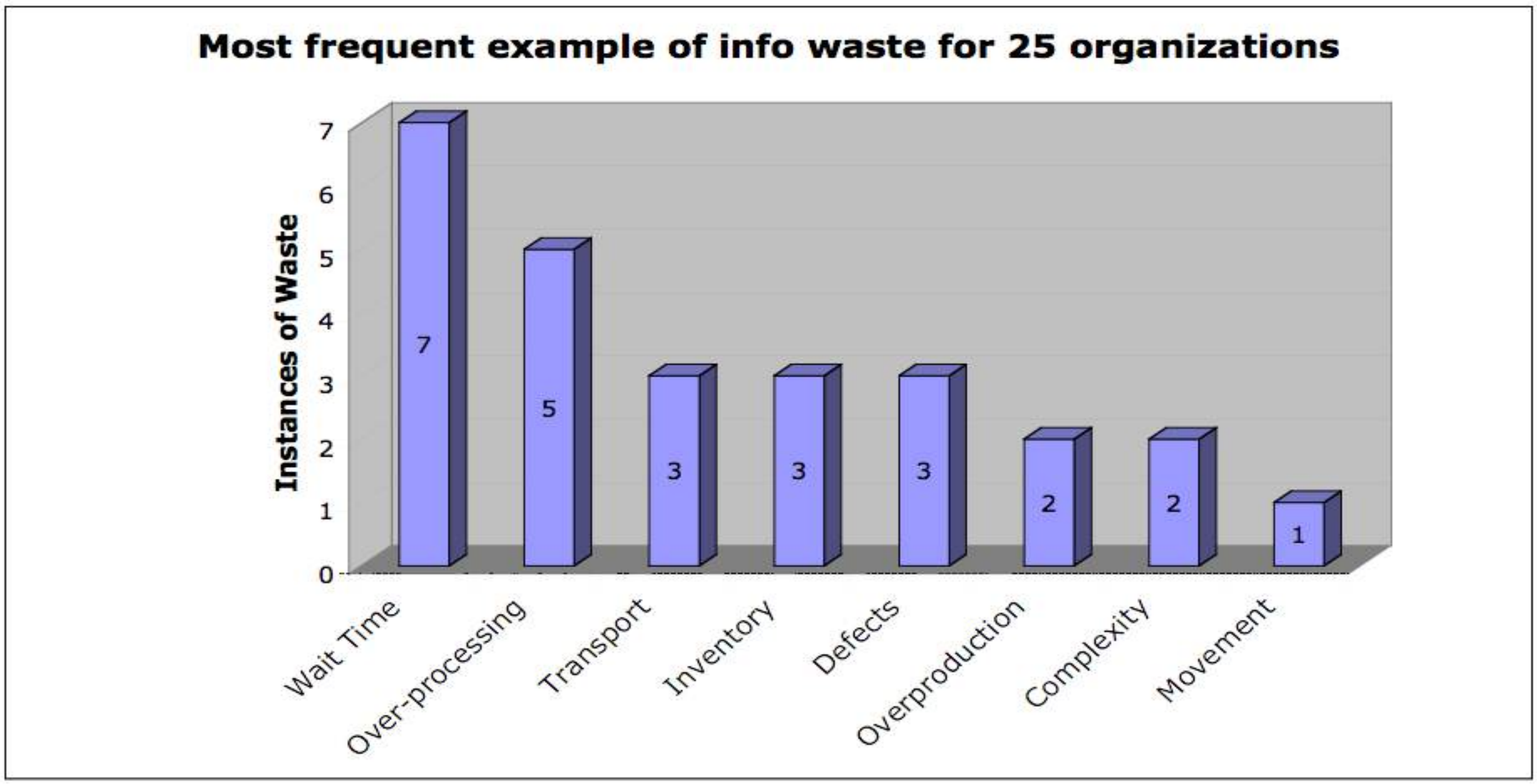
WASTE	DESCRIPTION
5. Information Inventory	• Keeping more information than needed for flow • Poor configuration management • Poor 5 S's in factory or office
6. Unnecessary movement of Information	• People having to move to gain or access information • Manual intervention to compensate for the lack of process • Hand-offs 
7. Information Defects 	• Insufficient quality of information • Incomplete, ambiguous or inaccurate information • The killer “re’ s”: Readjust, Reprocess, Reapply, Reprogram, Recalibrate, Rerun, Recertify, Reschedule, Recheck, Recondition, Reship, Restock, Retest, Re-inspect, Return, Re-measure, Rewire, Reorder, Rework

Waste Type 8: Talent

- Waste of Human Enthusiasm, Creativity, Talent
- Young employees burst with it
- Companies destroy it
- Think of resumes!!

Frequency of Info Wastes

Note added Complexity category



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.

So, Lean does not mean this…

PunditKitchen.com

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Part III: Systems Engineering Fundamentals (and Polish Needs)

Poland 2014: Strategic opportunities and threats

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Poland: Strategic Threats

- Poland achieved excellent economic growth since 1989, largely based on manufacturing
- But…it is only manufacturing!
- Grand designs are created abroad and sent to Poland for making
- Polish factories are superb, but become less competitive as Polish salaries approach the Western levels
- Therefore, Poland must climb on the added-value ladder

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How to climb the value-added ladder?

- Increase participation is European and Global space, Military and Infrastructure projects and new Technologies
- This needs competitive knowledge of Systems Engineering

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Poland: great opportunity

- Polish technical universities teach excellent "traditional politechnic knowledge"
- But not in large developmental programs
- I see this as a great chance for Poland: participation in EADS (Airbus Group), NATO, aircraft design, cosmos, great networks, great infrastructure, nuclear power, energy systems and grids
- In order to be effective, this knowledge must be at a high level and most competitive in terms of cost and schedule.

Polish creativity, initiative, and dynamic character are a great starting point!

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What is Systems Engineering?

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What is SE?

- SE is not hard engineering but rather technical multidisciplinary management of engineering effort focused on the performance of the system as a whole
- Started in the U.S. in the 1950s in the intercontinental missile business

- **Neither traditional engineering knowledge nor project management knowledge are sufficient**
- **SE is a rigorous process of managing details and interfaces so that the system will function perfectly**
- **Focus on Multidisciplinary Systems Thinking**

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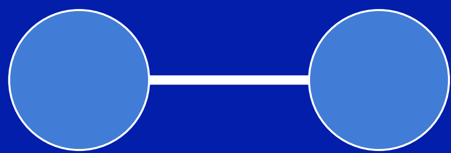
Why do we need SE? Simply…

Simplest system: N = 2

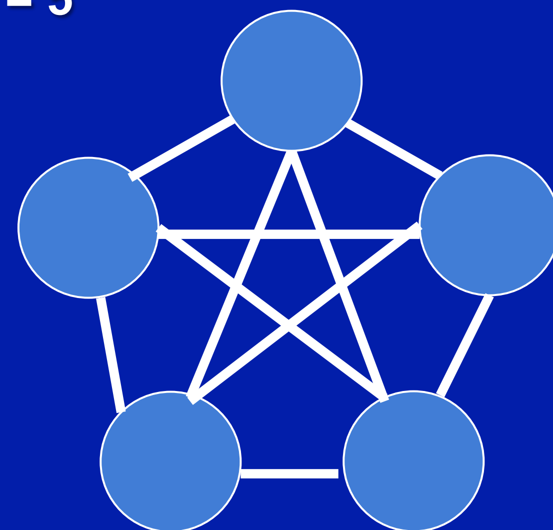


Number of connections = 1

Increases to

N(N-1)/2

Slightly more complex system
N = 5



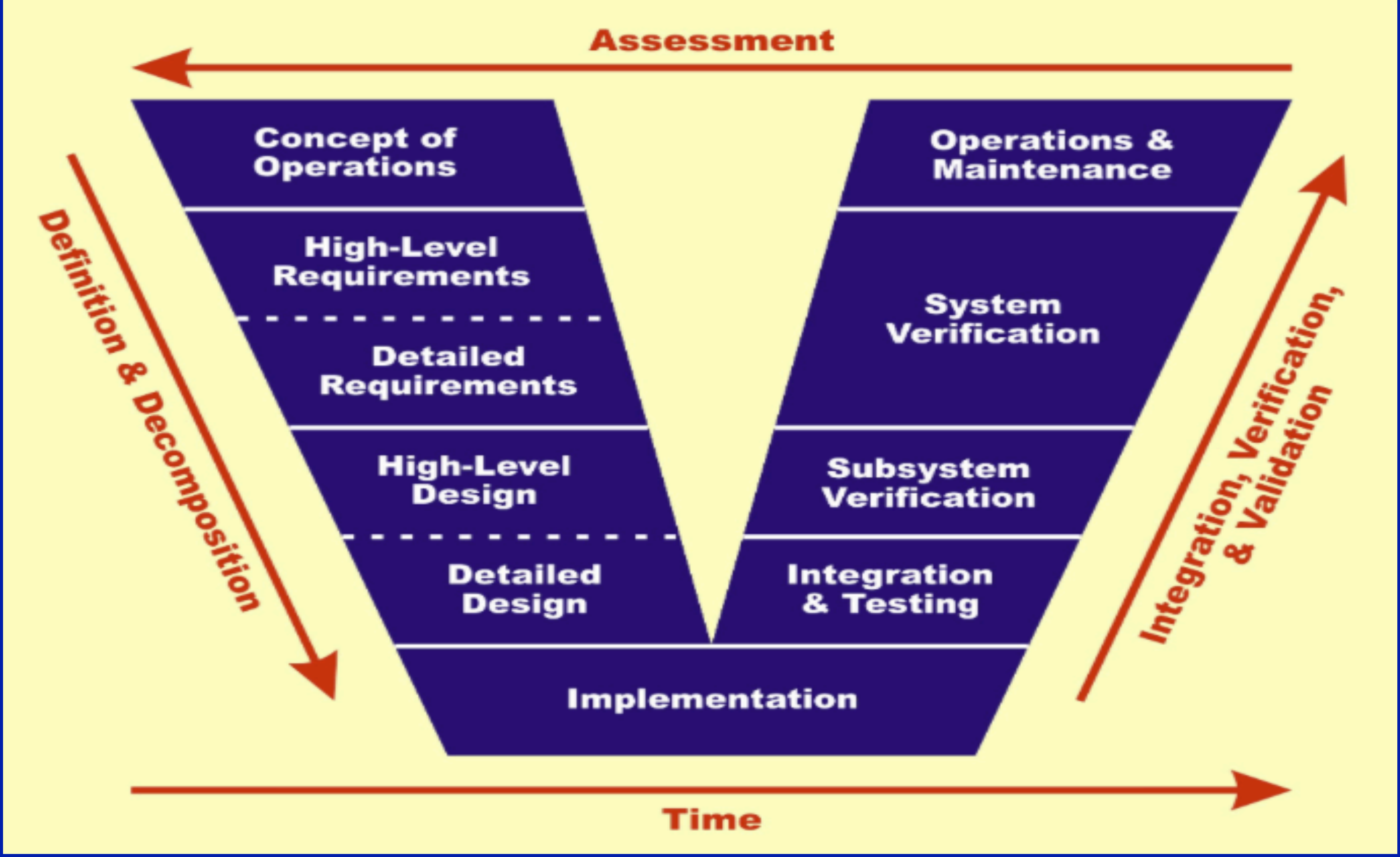
Number of interfaces = 10

J.Thomas, INCOSE

When we have millions of parts, tens of thousands of people working in hundreds of cooperating companies…neither traditional engineering nor traditional management are fit.

Examples: Polish infrastructure, Boeing Dreamliner, Iraq War, Euro crisis…

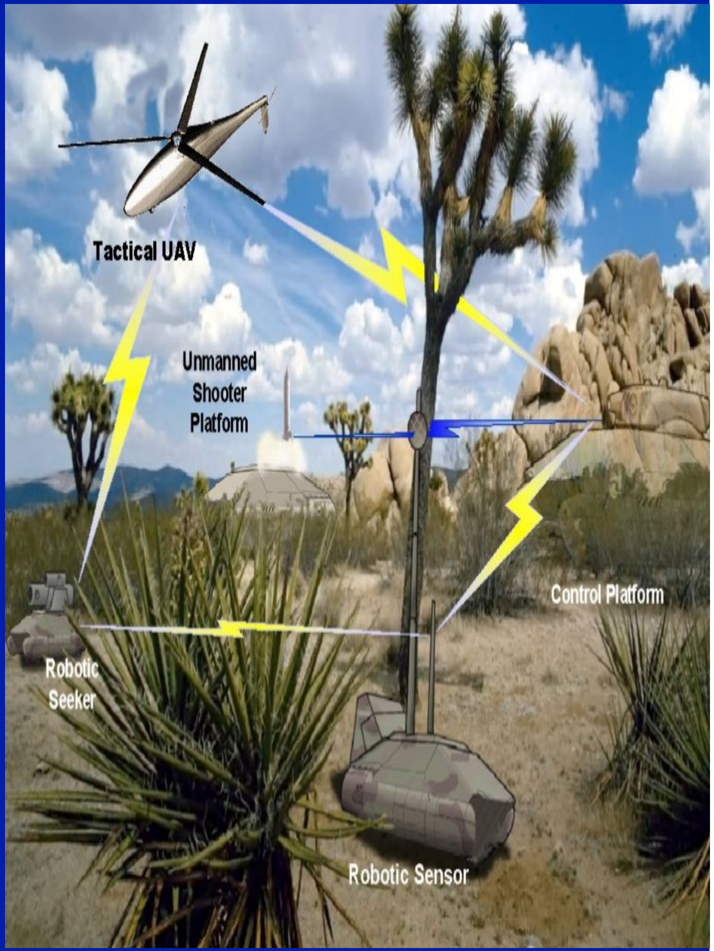
SE Process



Taken from Internet

What is SE?

- Main supportive processes
  - Requirements management
  - Systems architecting and interoperability
  - Functional allocation
  - Coordination with all stakeholders
  - Risk and opportunity management
  - Interface management
  - Configuration management
  - Traceability
  - The -ilities” (next page)
  - Increasingly Model Based SE
- Non-mathematical holistic knowledge based on heuristics



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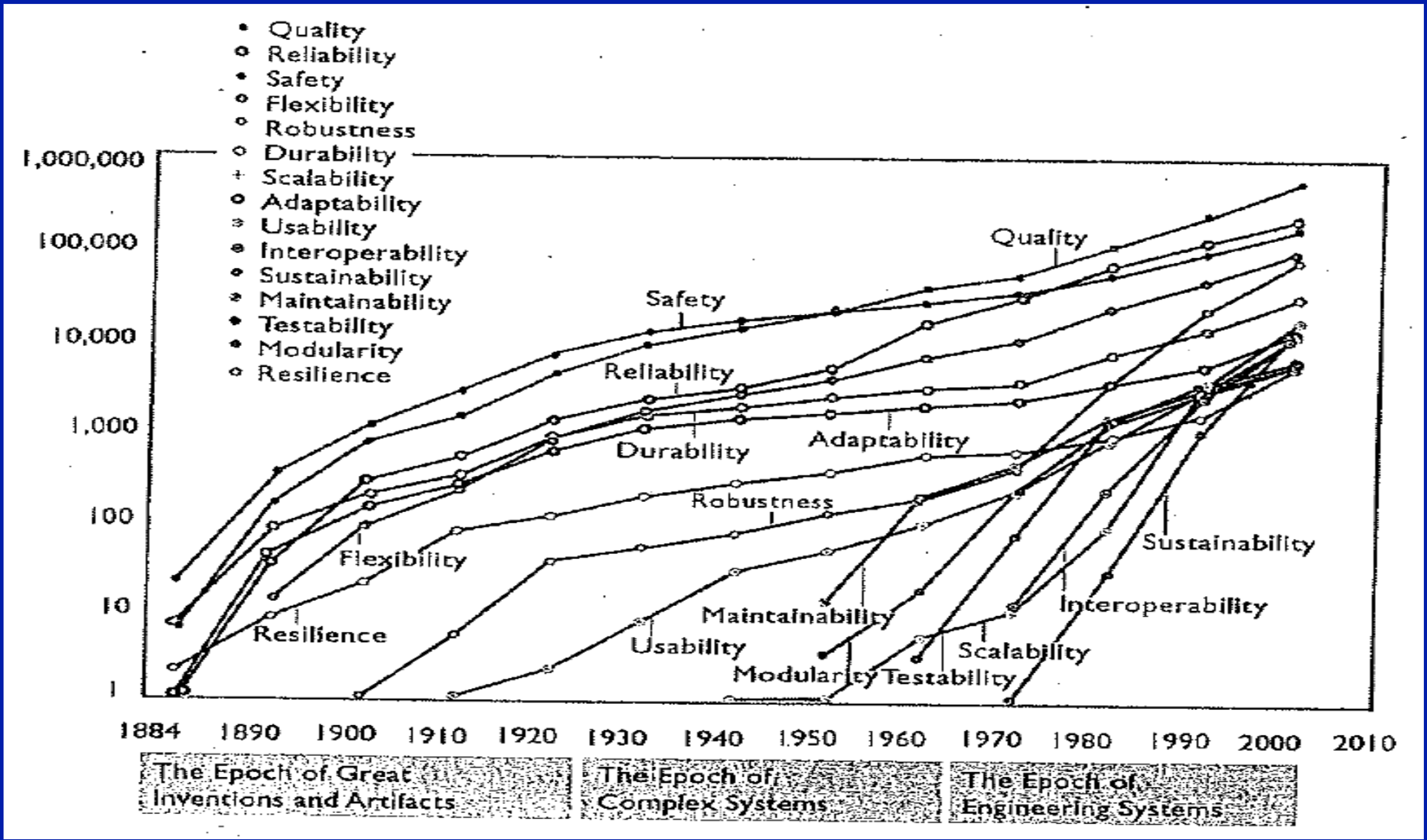
"…ilities" are the system life-cycle properties

Frequency of citations



Engineering Systems , de Weck, Roos, Magee, MIT Press

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SE is a Necessity forPoland

Mandatory process:

- In all weapons acquisition systems in US
- In NASA, Federal Aviation Administration
- In aero industry
- In NATO and European Aerospace and Defense Systems
- Increasingly in infrastructure and social transformation programs

Without SE, Poland has no chance to participate in great western developmental projects, in which the profits are the highest

(Small exceptions, e.g. IT noted)

Good news

INCOSE (International Council on Systems Engineering) has established the Polish Chapter

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INCOSE

- Professional Global Society of Systems Engineers
- 9000 members worldwide
- In 2013 I helped start the Polish Chapter
- Initial courses in SE, Lean SE, MBSE, Systems Thinking conducted in Poland by best US and Norewegian experts
- Support from PAN, Politechnika Wroclawska, Warszawska, AGH

INCOSE
International Council on Systems Engineering

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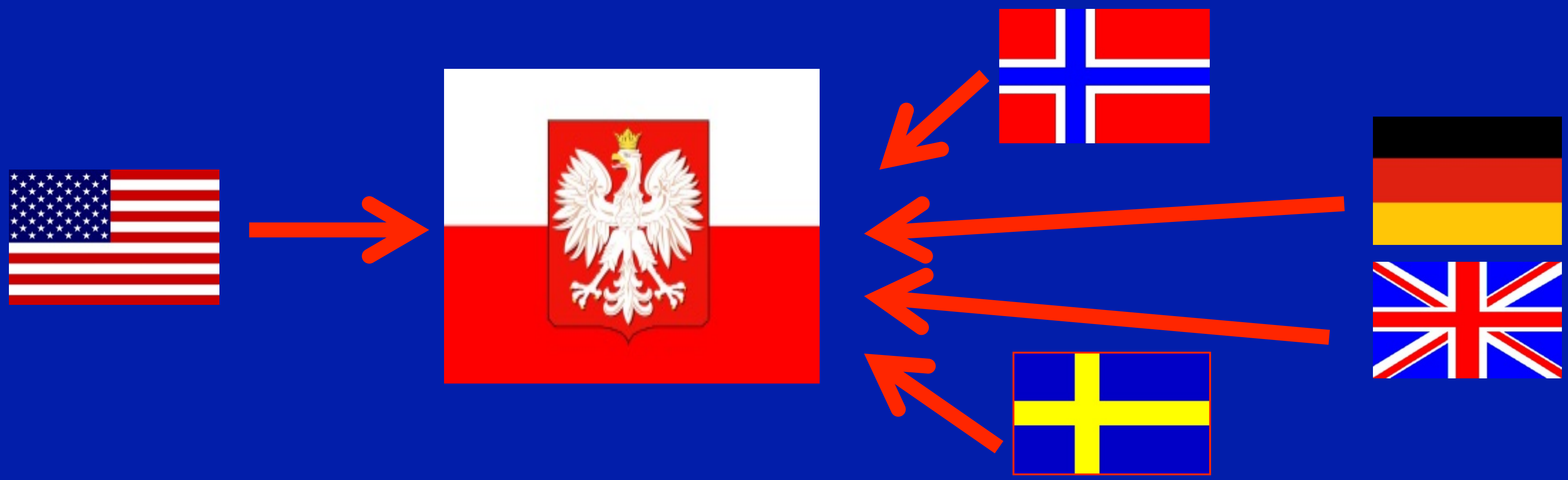
Western INCOSE Chapters Eager to Assist Poland



- Strong support for Poland from German, French, Norwegian, Swedish, and UK Chapters
- Opportunities for Internships leading to future projects!

SE Knowledge permits participation in great projects...

NORTHROP GRUMMAN

PunditKitchen.com

Without SE it ends like this…

PunditKitchen.com

Part IV: What Happened to Traditional Systems Engineering?

Early years of U.S. Aerospace (1950-1970) were quite Lean

- Small collocated group of enthusiastic engineers
- Little bureaucracy
- Great aircrafts, spacecrafts and ships developed in record times
  - The Manhattan Project
  - Skunk Works (SR71, U2, B52..) under Kelly Johnson
  - "The giants": Jack Northrop, Howard Hughes, Von Braun...
  - NASA Mercury, Gemini, Apollo, Mars exploration
  - Adm. Rickover's nuclear submarine

And now…In DoD Programs we are talking big bucks…

2012 Military expenditures of 10 biggest spender countries

711 b$ is not all:
- Nukes under DoE
- Civilian contractors in war zones under State Department
- Homeland Security (about b$250)
- Agencies with secret budgets: NRO, NSA, CIA,…

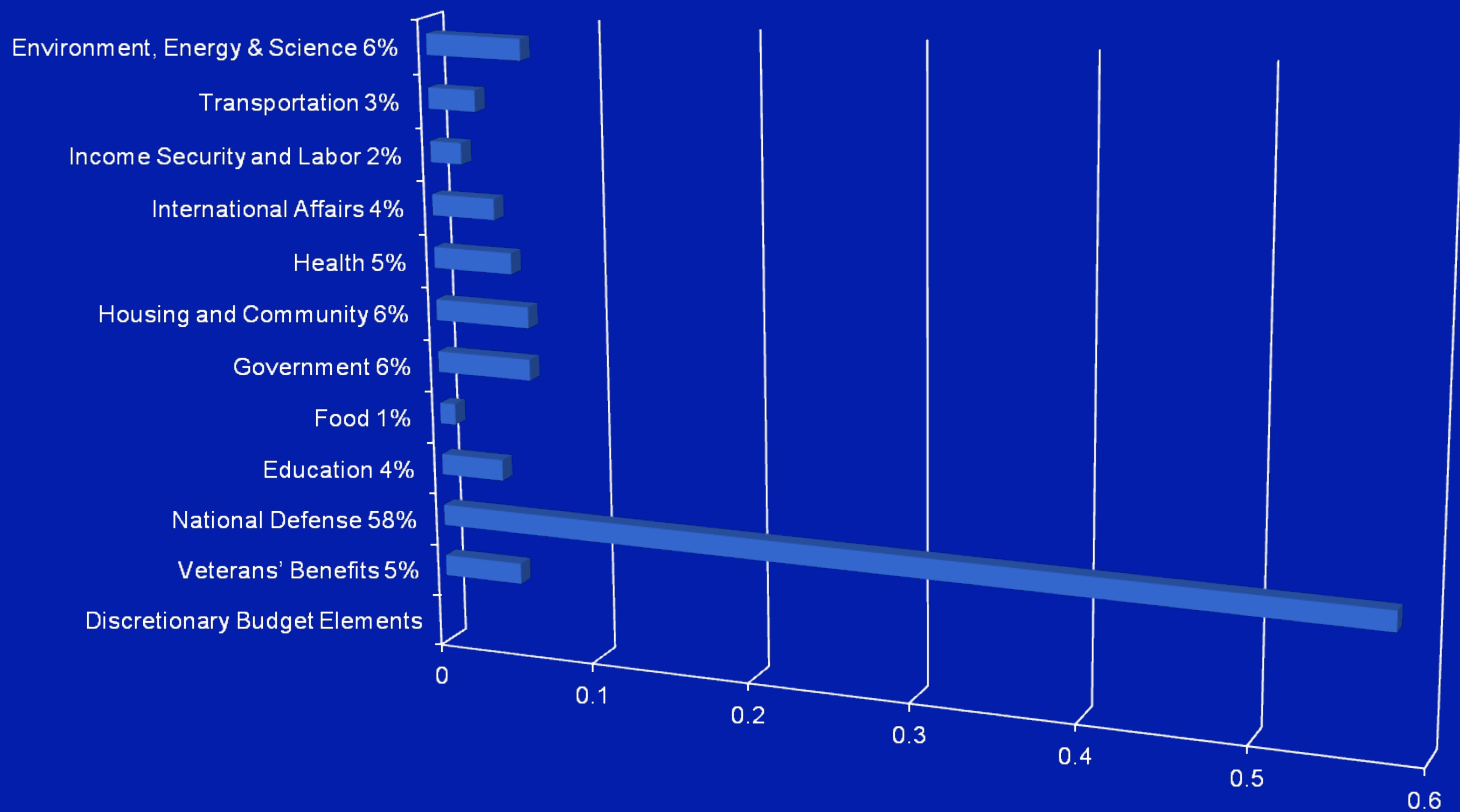
We support about 700 military bases in 130 countries

Federal budget of the U.S.

– 63% Congress mandated (Social Security, Medicare & Medicaid, National Debt)

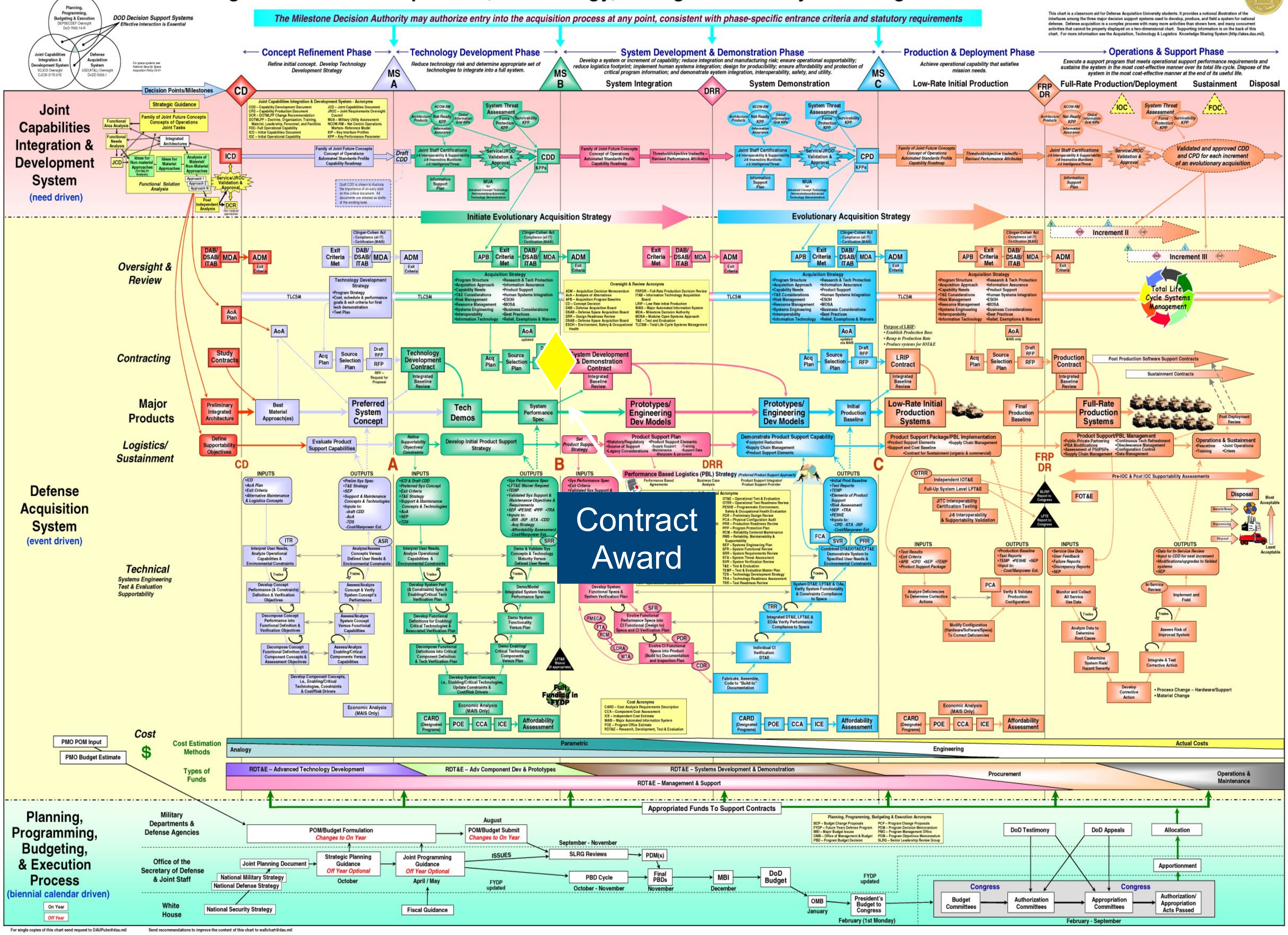
– 37% discretionary budget (allocated annually by Congress)

The DiscretionaryBudget



ver. 5.2. August 2005

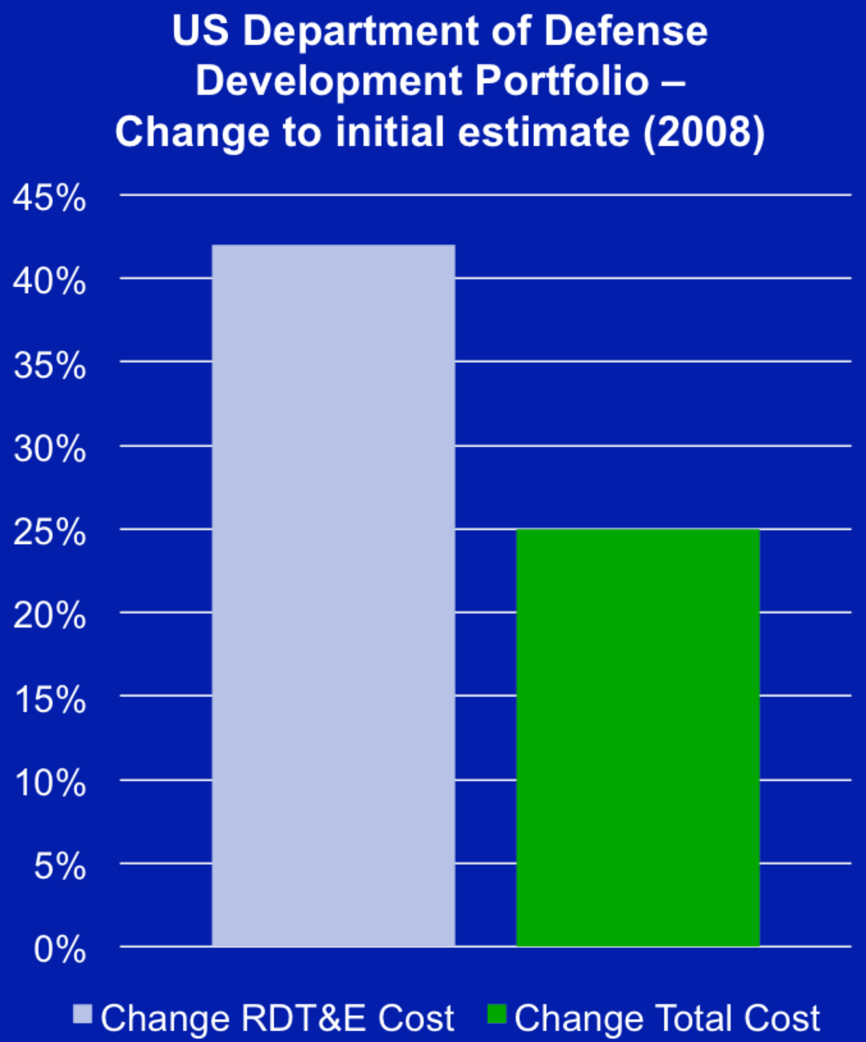
Integrated Defense Acquisition, Technology, & Logistics Life Cycle Management Framework



How are we in the U.S. doing in the management of large-scale engineering programs?

- Regarding cost?
- Regarding schedule?
- Regarding delivering the benefits we promised?

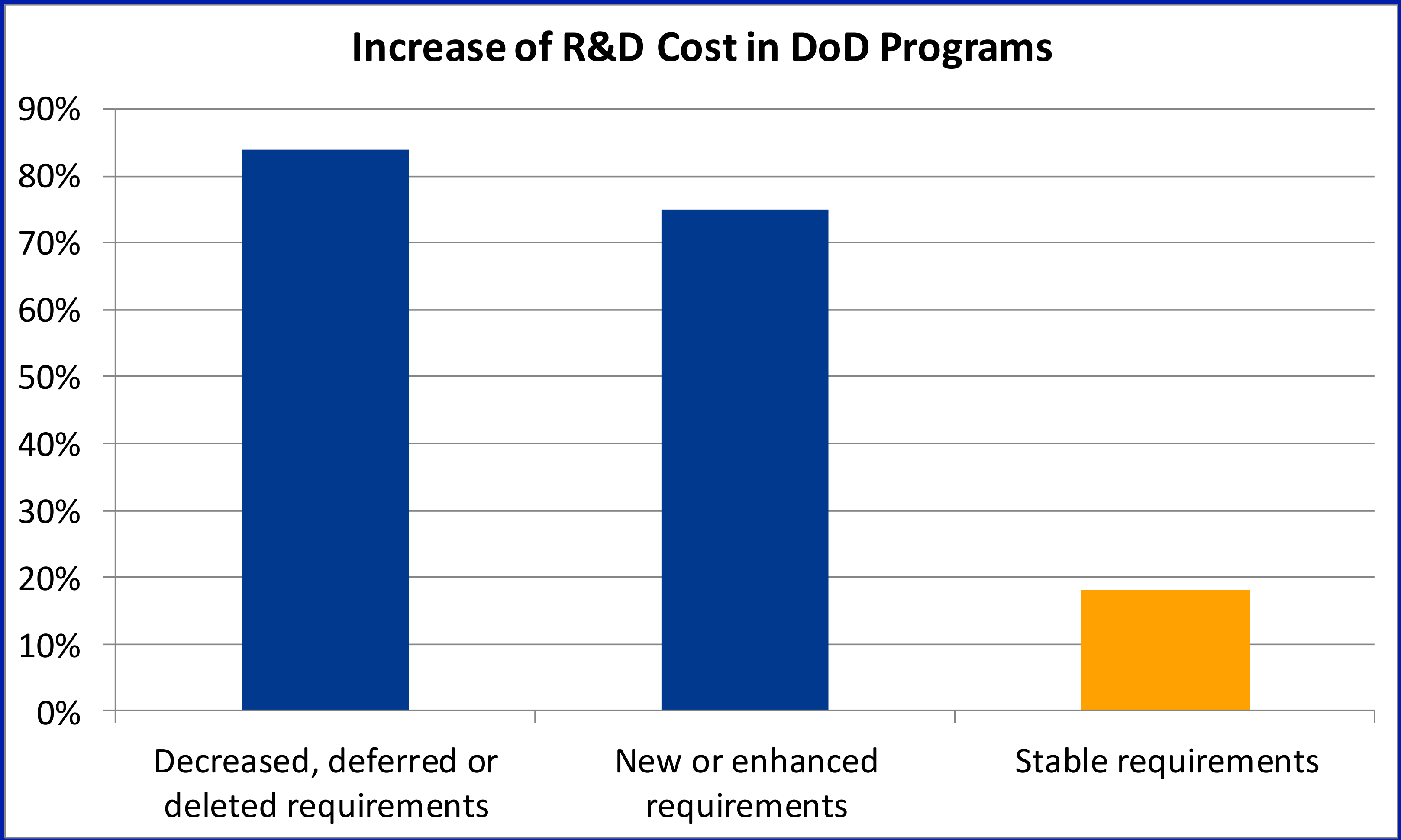
Management of Large-Scale Engineering Programs: DOD Example



- Total cost growth: **$296 billion**
- Average schedule overrun: **22 months**
- A number of major programs terminated for lack of progress
- Similar situation in other industries

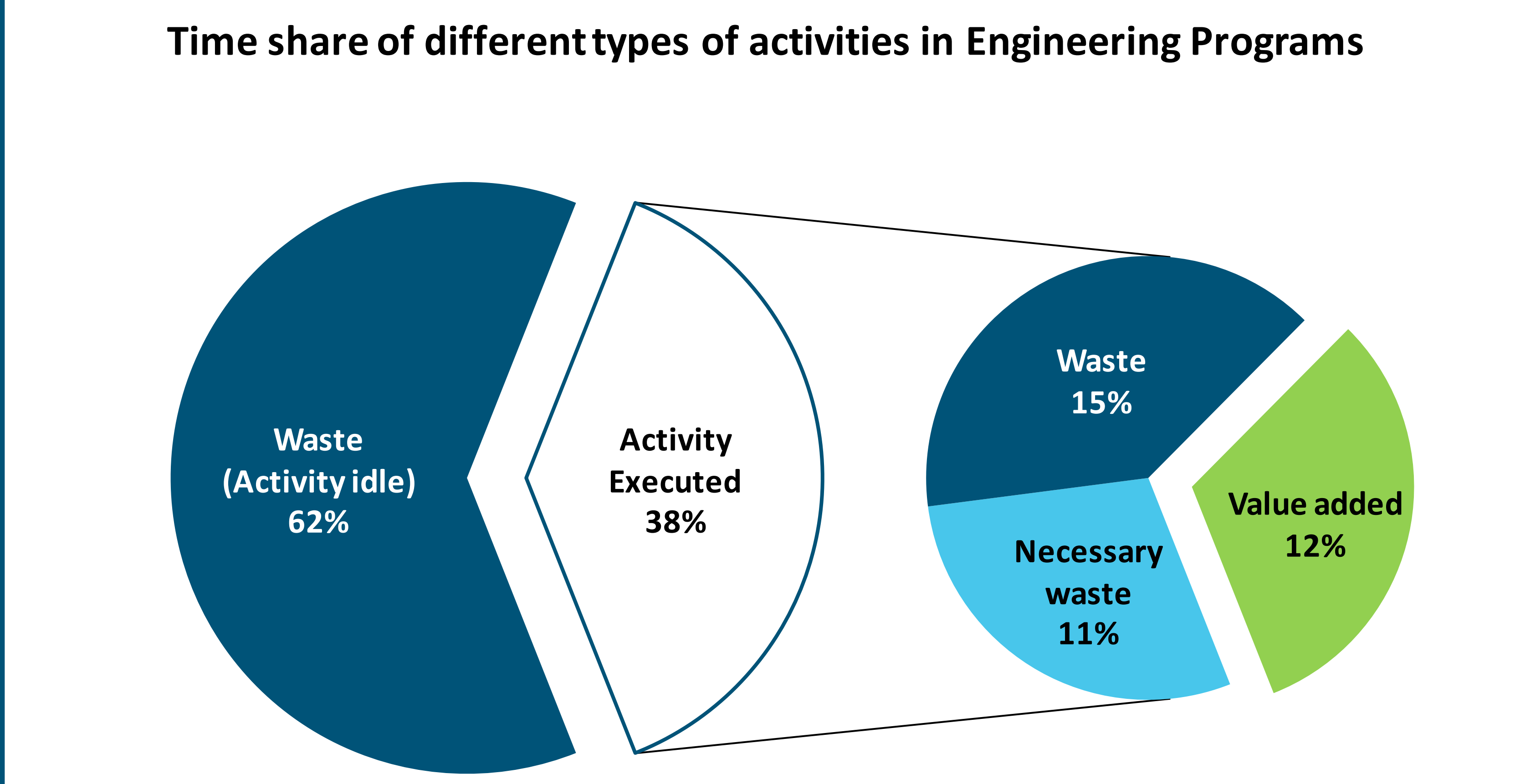
Sources: GAO 06-368, Bloomberg, GAO 10-374T

How bad are unstable requirements?



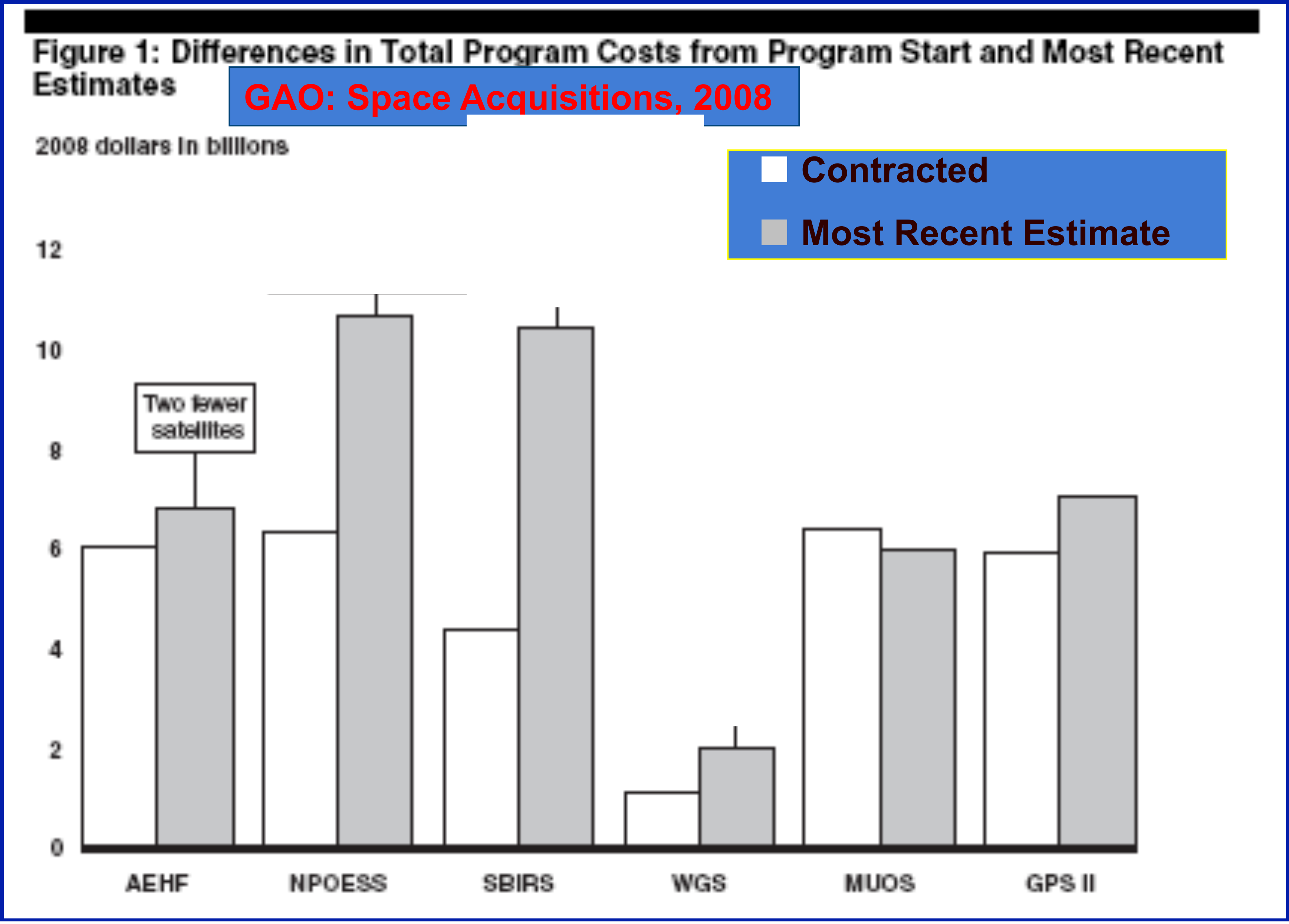
Source: GAO-11-233SP

Average of 88% of Productivity Reserve in Programs



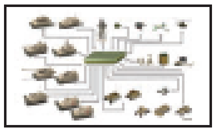
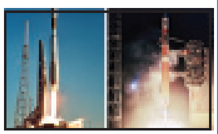
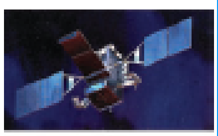
Source: McManus, 2005, Oppenheim, 2004

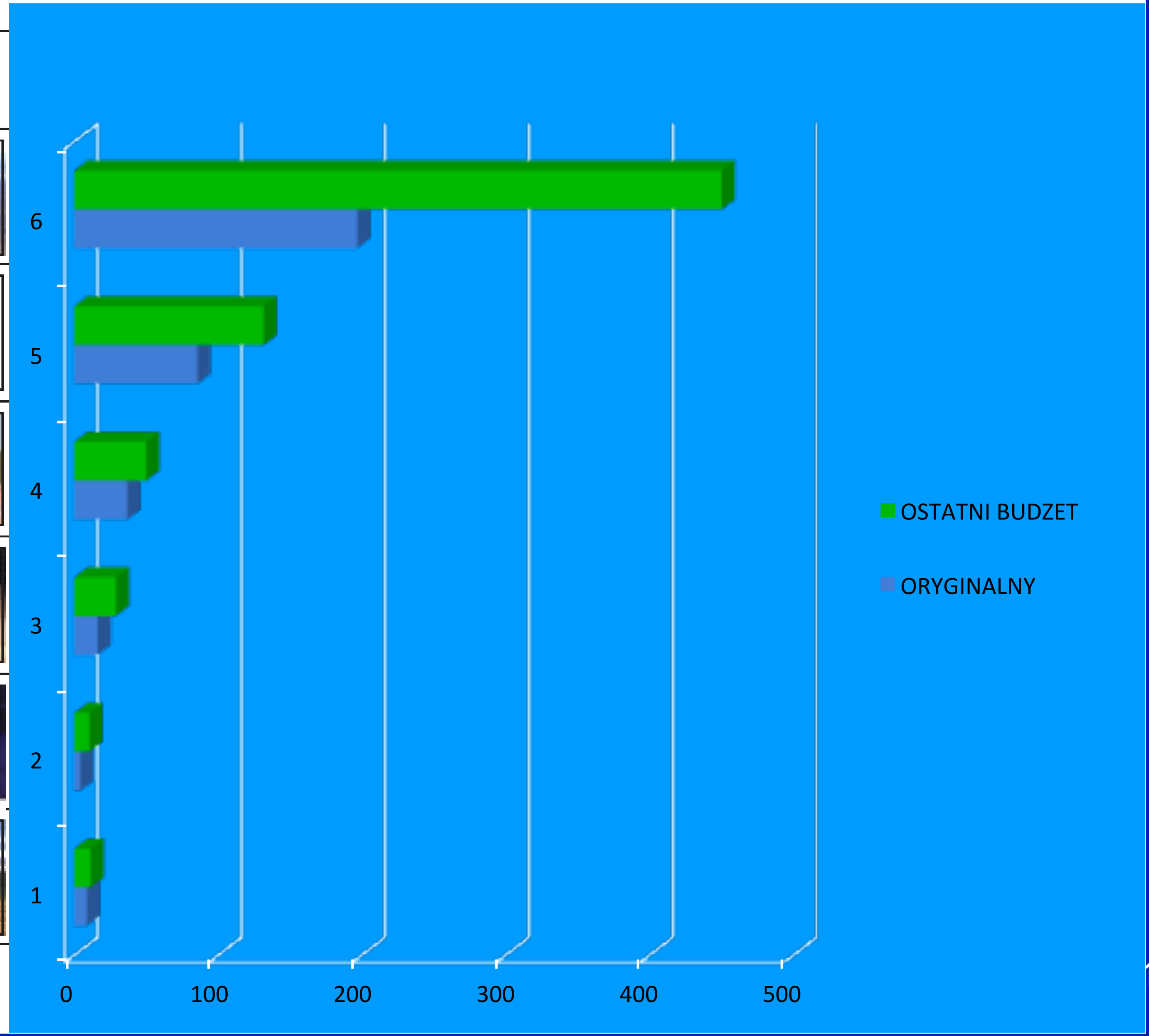
Present Programs Suffer from Huge Cost Overruns



Overruns Cause Reduced Buying Power

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

Program	
Joint Strike Fighter	
Future Combat Systems	
V-22 Joint Services Advanced Vertical Lift Aircraft	
Evolved Expendable Launch Vehicle	
Space Based Infrared System High	
Expeditionary Fighting Vehicle	



Senator John McCain (R) about defense programs

”This train is running towards a front-end collision. Runaway costs, prolonged delivery schedules and poor performance in the acquisition of major weapons are equivalent to a unilateral disarmament.”

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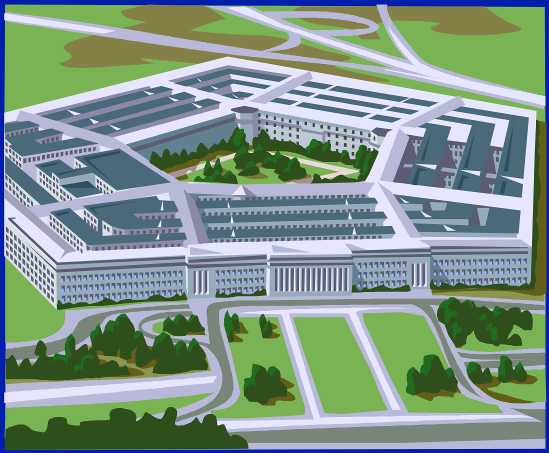
Why so much Waste?

Well known Political Reasons in Government Programs

- Terrible acquisition system (all wrong incentives)
- No incentives to save money
- Cost Plus cocaine
- Made in 50 States
- “Welfare for engineers”
- The defense budget bliss
- Powerful lobbying
- DoD eyes bigger than the stomach
- Pursuing latest, greatest and gold-plated



Why so much Waste?

Cultural Reasons

- Complexity of programs growing faster than the knowledge of management (our Lean PM project will help)
- Arrogance of one-off: "my thing is unique – leave me alone"
- Mixing:
  - Research (is it feasible?)
  - versus Development (of Robust Mature Technology modules)
  - versus Design (trading off modules together like Lego blocks)
- Engineering education, tradition, tenure favor analysis over design and process thinking
- SE has become a bureaucracy of artifacts
- Requirements are out of control
- Program management is terrible

Why so much Waste? Craft Mentality in PD

- We do engineering the way we did manufacturing before Henry Ford
- Manufacturing transitioned from craft to Lean saving 90% of costs, schedule, space and improved quality
- The huge PD waste offers **a huge untapped reserve of productivity** even in the best traditional programs
- Order-of-magnitude additional reserves of productivity in military developmental programs

<u>Conclusion</u>

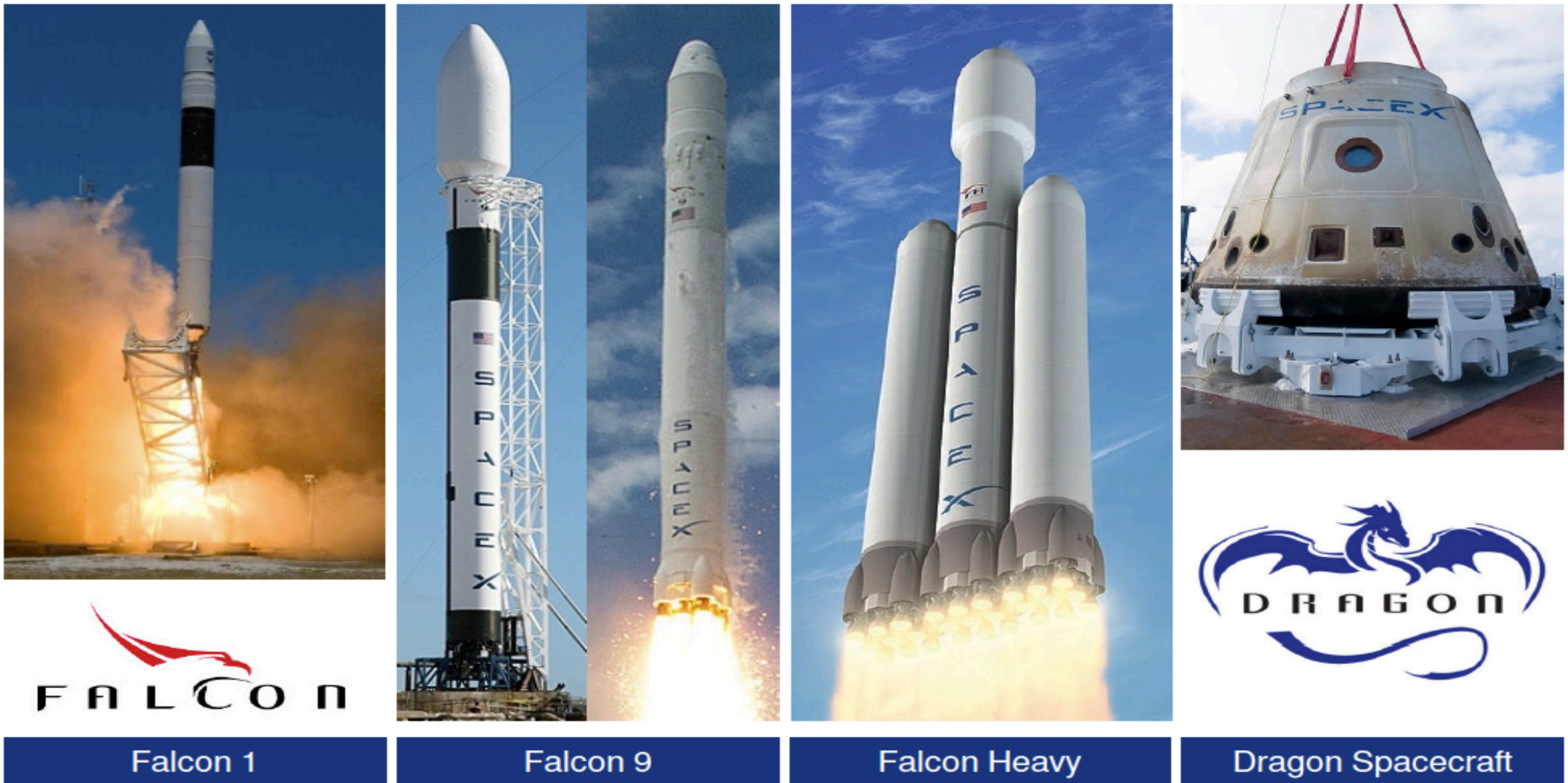
There is an urgent need to lean SE programs

Part V: Truly Lean PD & Systems Engineering at SpaceX

[Possibly the most profound company in aerospace industry – B. Oppenheim]

Based on a a lecture by John Muratore in SELP 694 at LMU on 23 Jan. 2014 "A Traditional Discipline of System Engineering in a Non-traditional Organization System"

SpaceX Large Scale Developments



SPACEX

Also: Grasshopper and F9R – prototypes for 1st stage on-land return landing

J. Muratore at SpaceX:

"I believe classical [SE] methods only work well when you are building something which is completely understood - otherwise you need a crystal ball to understand system interactions and I didn't get one issued to me in engineering school"

About Space X Company (Great Model for Poland)

- 3000 employees co-located in Hawthorne
- Flat organization:
  - "The boss" Elon Musk, billionaire of Pay Pal and Tesla fame
  - 4 VPs (Tom Mueller, Engine designer, LMU graduate)
  - Everybody else
- "Responsible Engineer" = responsible for the given item in all respects, across all disciplines
- Private company, everybody is a stock owner
- All profits invested!
- Engine and structure test facility in TX
- Launch site at VAFB and Cape Canaveral
- Lean organization, e,g. Propulsion: 80 design engineers, plus 300 people in production and 40 in test facility in TX (Rocketdyne: about 100 times more!)

Hawthorne (Los Angeles) Headquarters

SpaceX uses Next Generation Approach to Systems Engineering

- Rejecting formal classical methods [because "one needs a crystal ball to follow classical methods to develop and flow-down requirements"]
- Need to use alternative methods to understand system interactions and get system performance
- Rapid prototyping
- Communication through networking versus hierarchy [and ICD bureaucracy]
- Good traceability and configuration management
- Rapid change and excellent risk management
- Mapping to classical methods to explain – use classical methods for top level customer requirements [limiting the number of top level requirements]
- 70% vertically integrated company ["material in = sheet metal, wire, and chips"]
- Engineering is 100% co-located (testing of engines in TX)
- Super-flat management structure
- Almost paperless

Premise versus Reality in SE

- Premise: Systems Engineering is a discipline established to protect the enormous investment of large scale, complex system development by anticipating and solving integration problems ahead of time
- Reality: History has shown that humans are very poor at anticipating all potential integration problems, especially in new systems

Central Philosophy of Space X

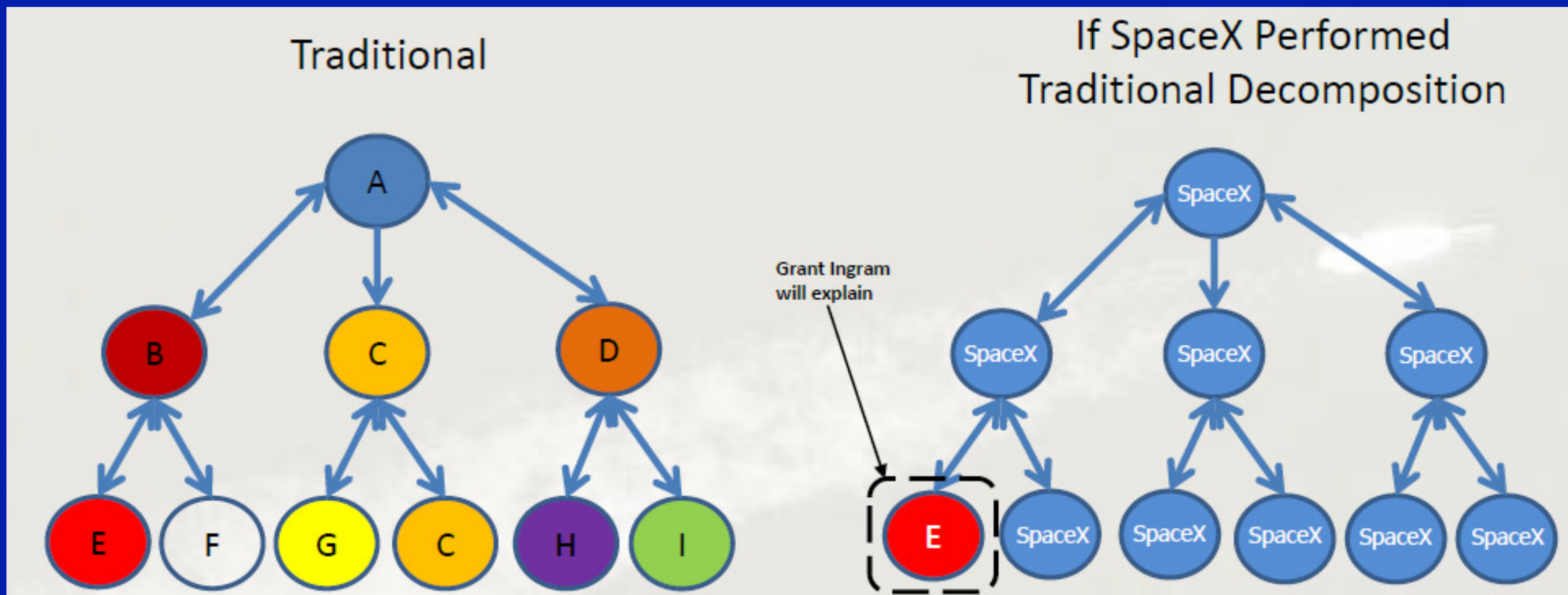
- SpaceX is a systems oriented culture whose goal is the engineering and integration of reliable and safe systems
- SpaceX operates on the philosophy of Responsibility—no engineering process in existence can replace this for getting things done right, efficiently
- There is an important balance between heavy up front systems engineering and rapid prototyping to reduce systems risk—tipping point heavily dependent on organizational agility, cost of iteration, and the ability to trade lower level requirements
- Because we can design-build-test at low cost (21st century infrastructure) we can afford to learn through experience rather than consuming schedule attempting to anticipate all possible system interactions
- Design a testable system and **test what you fly**!
- Test rigorously and at multiple levels of integration—including right before service.
- Most prototype tests done three times in a row!

Inhouse Development is Key to SpaceX Success

- Over 70% of the Falcon 9 rocket by mass is manufactured inhouse
- Incoming parts: chips, sheet metal, wire
- SpaceX builds components inhouse that most aerospace companies buy
  - Fairings, tank domes, stage tanks, flight computers, engine controllers, batteries, engines and thrusters, turbopumps, valves, Star Trackers and Lidars, radios, Composite Overwrap Pressure Vessels (COPVs), (designed and initial builds inhouse – wound by outside vendor for production), and many many more
- This allows SpaceX to escape the traditional aerospace cost structure
- No need to renegotiate multiple contracts when optimizing design)vides superior insight into the design and qualification of all the system parts
- Having active production and test of all major components provides superior ability to respond to issues and ensure mission success.

Strong inhouse build allows alternate approaches to SE (rapid optimization)

Much Easier Optimization

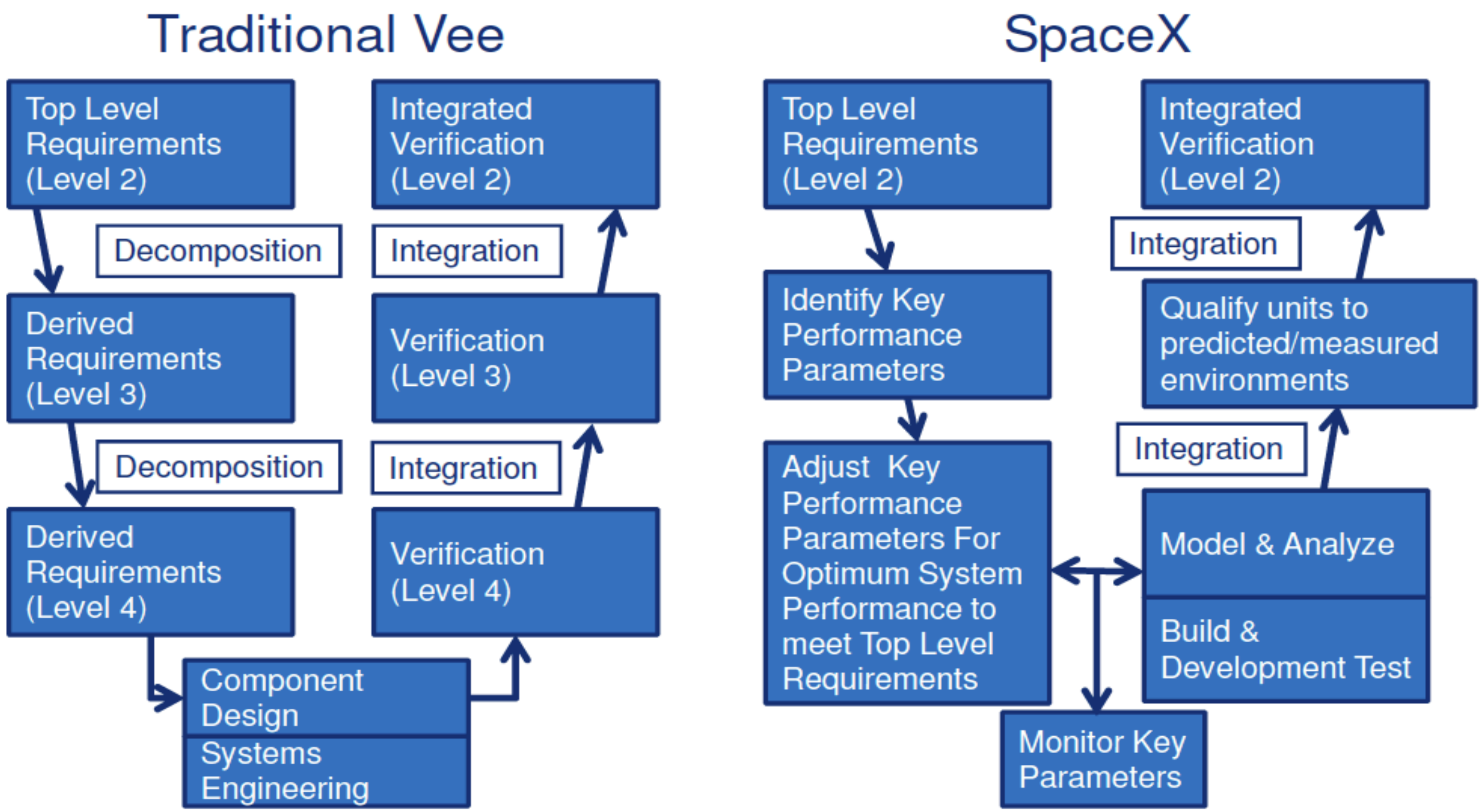


- Traditional model supported subcontracting at subsystem and unit level. A prime writes specification to ensure that the products it subcontracts for will work in the design. Specifications are part of contract with subcontractors.
- SpaceX limits subcontracting which enables a more fluid approach to subsystem and unit requirements and more focus on meeting integrated system level requirements, typically through integrated test. If SpaceX wrote specifications, it would be writing specifications to itself.
- In the rare cases where SpaceX subcontracts, it does provide specifications and tests units to determine if they meet specification (usually in qualification test).

More Specifics

- Distribute system-level tasks to departments and follow up with a network of integrators
- Placing system-level integration responsibilities inside departments builds departments with system-wide thinking
- User requirements are tracked and verified but everything below these requirements is constantly traded and optimized during the design phase
- Use modern 21st century information system tools to replace traditional control boards as forum for discussion and integration – use a paradigm more similar to social networking
- Focus on TOOLS NOT RULES
- Test rigorously and often
- Be creative: e.g., replaced pyro devices (which cannot be tested "as you fly") with pneumatics, which can be tested.

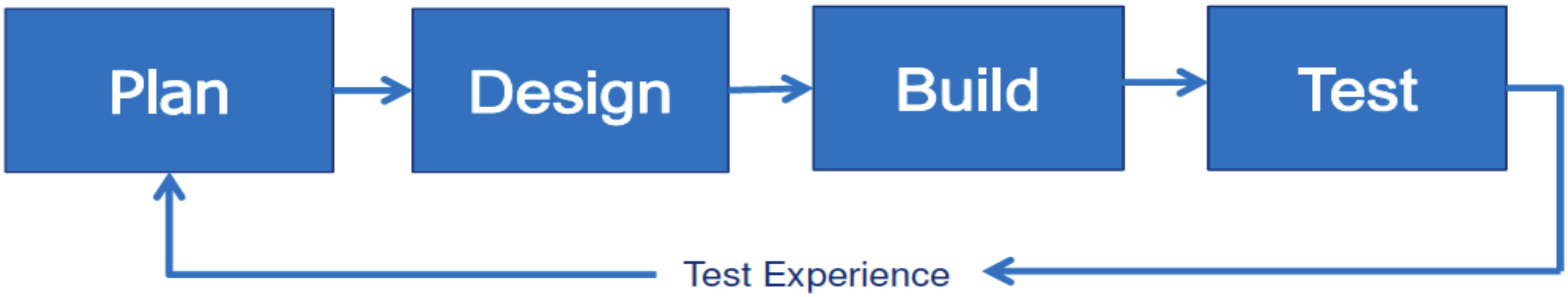
User requirements are tracked and verified but everything below these requirements is constantly traded and optimized during the design phase



Possible to trade key parameters between subsystems to optimize results because designers not separated by contract-subcontract bounds

SpaceX learns through experience rather than attempting to anticipate all possible system interactions

Traditional Developments Use Single Cycle to Product—This Mandates Heavy Systems Engineering to Protect the Design-Build-Test Investment

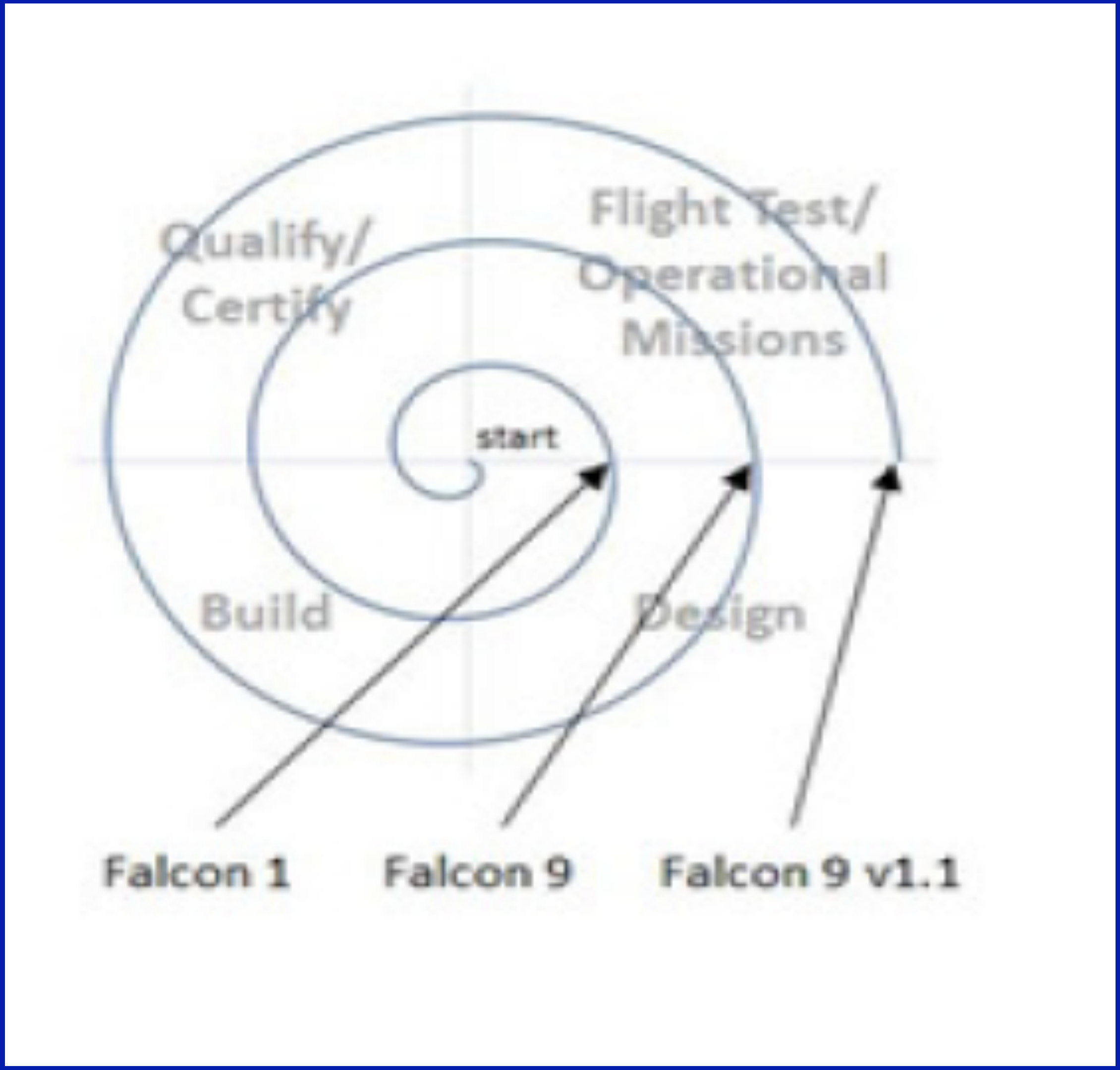


SpaceX relies on rapid design-build test cycles to inform design by experience

Documentation and process becomes more formal as systems move into later cycles
Final qualification, first flight and production

SPACEX

Approach can be viewed as rapid spiral development methodology



Not only “Test Like You Fly”, but “Test What You Fly”

- Integrated testing tools are a key investment and provide points where integration is assessed
- Using a “Test Like You Fly” approach
  - Ironbirds at Hawthorne – hardware–software integration
  - McGregor engine test – engine and avionics integration in real dynamics environment
  - McGregor stage test firing– tanks, plumbing, avionics and propulsion integration in real dynamics environment
  - Launch Site Hardware in the Loop Simulations - hardware-software integration with all system components
  - Launch Site Wet Dress Testing and Static Fire - hardware-software integration with all system components in real dynamics environment
- Verbal comments:
  - Most tests performed 3 times, for experience and to allow optimization
  - Very little testing of electronic components – no need, they have fantastic reliability
  - No obsession in getting it right the first time [Lean Enabler: “test often, test early”!]

Effectively, Space X replaces SE bureaucracy with Testing!

Flexible test hierarchy increases formality as product matures

- Development Tests used to determine hardware capability in excess of requirements and to find weaknesses (running at extended temperatures, ultimate strength tests)
- Qualification tests demonstrate hardware performance limits (worst case flight conditions plus required factor of safety or margins).
- Qualification tests are performed every design/environment combination
- Acceptance Tests verify workmanship and functionality. All hardware acceptance tested
- HITL – Hardware in the Loop – shows hardware-software integration. Run for every hardware-software change

POGO

- I (B. Oppenheim) wrote the POGO simulator for Aerospace
- Distributed to all U.S. rocket makers
- Complex simulator took four years of work
- POGO assurance: several month of simulations per vehicle, plus several month for design and build of an accumulator
- Space X: tested the rocket for 1st frequency
- Rapid prototyped and tested an accumulator. Total of three days.

Top Level Requirements [verbal statements]

- Top-Level Requirements
  - AF: thousands at RFP, [most of them are garbage – B.O.]
  - NASA: similar, a bit more efficient than AF
  - Space X" 200-300 max on government programs, 20 on commercial. Refusing to accept more.
- Standards
  - Technical standards: Yes (TCP-IP, Mil Std 1540...)
  - Review/bureaucracy standards: “No way"

Space X Flight Control Room

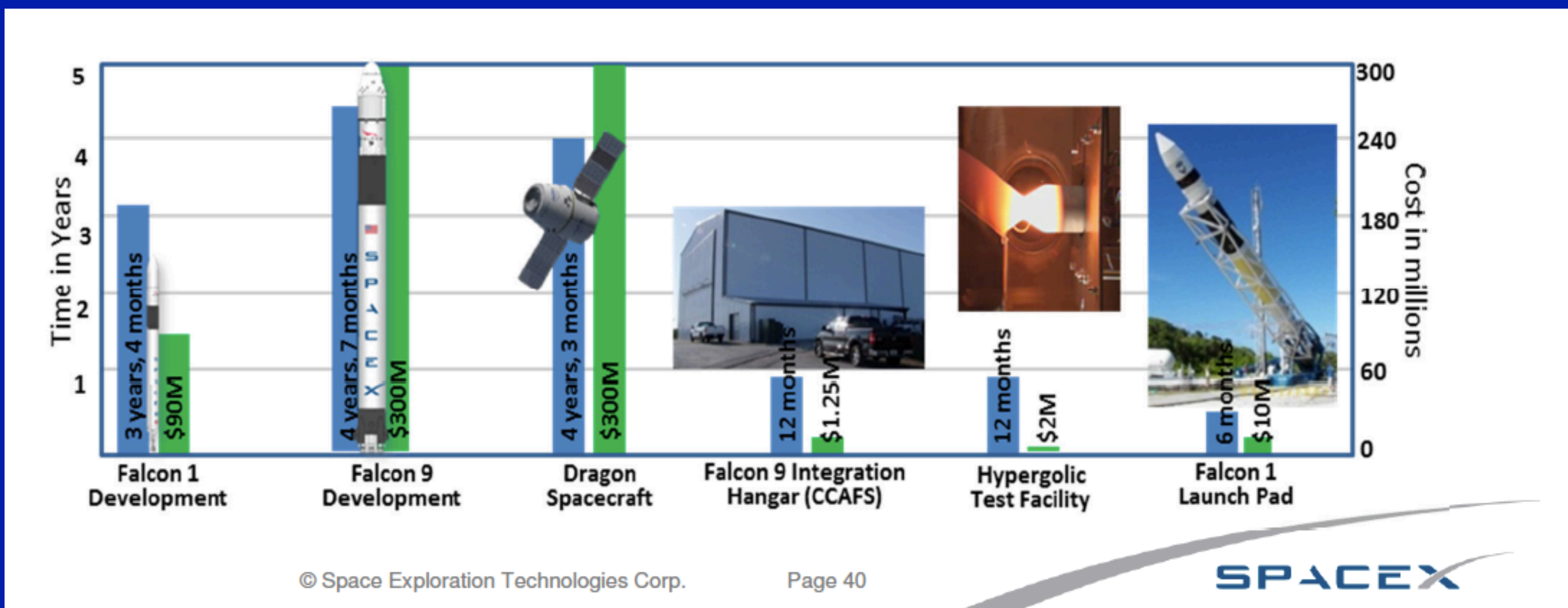
- SpaceX: 5 people built it w/o requirements, operated by two people
- NASA: 700 people and tons of computers

Early Failures and Subsequent Successes

- Three Falcon 1 failures
- Then 10 successes in a row
- Five flights of Falcon 9 – all successful
- Three flights of Falcon 9 V1.1 – all successful
- Over $5B in business backlog through 2017
- Free cash flow positive and profitable since 2007
- Diverse customer case (Government, commercial, international)
- Over 50 Falcons ordered

Closing Thoughts

- It is difficult to build a creative high performance engineering culture
- It is really easy to ruin the creativity and performance by too much organization, rules and process
- SpaceX is achieving a good balance of creativity and systems engineering for agility and affordability



Part VI: Lean Product Development Flow (LPDF)

Adopting Manufacturing flow ideas to PD and projects

From Chapter 4 of the book:

B. Oppenheim, *Lean for Systems Engineering with Lean Enablers for Systems Engineering*, J.Wiley & Sons, 2011

Value in LPDF

- The same as Value in PD already discussed above

Qualifying criteria for LPDF Applicability

- Qualifying top-level criterion for LPDF: detailed high-fidelity VSM can be formulated.
- In practice, this means:
  - A mostly low-risk low R&D project or program milestone
  - Need for R&D recognized early, separated from the critical path
  - Short enough to avoid technology changes in midstream
  - Smaller effort (co-located Core Team for frequent coordination)
  - Corporate support

VSM Steps for LPDF

1. Legacy VSM: Map the legacy project
   - Best managed by its Chief Engineer
   - Just lay out the tasks performed in the legacy project
   - To learn and benefit from the huge knowledge
2. Current State (CS) VSM: Adopt the Map to the current contract
3. Ideal State (IS) VSM: If all our lean dreams could be realized...
4. Future State (FS) VSM: Remove waste from CS VSM
5. Parsed VSM: Parse FS VSM into weekly (or so) Takt Periods
6. Iterate 2-5 until Core Team consensus is reached.
   Best tools: brainstorming, team work, consensus building
7. Flow the work

Good source for (2-4): PDVSM Manual by Hugh McManus

Task Sheets in VSM

The Tasks must show:

- Task Number, week of execution (blank till FSVSM)
- The person responsible (name, title, phones, email, location) – blank until FS VSM
- Major inputs, each indicating source Task
- Major outputs, each indicating destination tasks and approval
- SE and control nodes
- Planned effort, resources, scope (ask competent engineers)
- Data on Legacy waste: time of waiting and chasing data, handoffs, miscommunications, rework, reinventing the wheel, changes, ...
- Space for issues, notes, comments
- Lay out the sheets in the concurrent "swimming lanes" that correspond to the resources used.

Class exercise: design a Task Sheet by hand

VSM Iterations

- Iterate task scopes, durations, deliverables, effort, precedence
- Understand the tasks and flow; Only understood processes can be improved
- The iterations must be done by the "Core Team" of experienced competent engineers who understand all "raw materials", deliverables, effort and scope, and can make reliable estimates
- Everybody in the Core Team walks around the walls, reads the Task sheets, discuss and negotiate with authors, post their ideas, comments, and corrections.
- Utilize Lean Thinking from start
- Define tasks with Precedence Network in mind
- Break longer tasks into Takt-Period long (logically if not otherwise)

Skills for Lean

- Teamwork
- Leadership
- Consensus building
- Active participation
- Facilitation
- Negotiation
- Marketing and persuasion
- Communication
- Conflict resolution
- Project management
- Competence in the domain
- Thinking in the largest context

(Adopted from Lean Academy, Jan.12-19, ASU)

Class exercise: list how many of the skills you have now, and how many are lacking, and how would you build up the lacking skills.

Mapping the Future State VSM

- Start with a consensus-based Current State VSM
- Perform FS VSM comprehensively - potential for huge payback (often $millions/hr) – so do not rush it!
- Forget about formal math optimizations for the program: too many stakeholders and intangible human factors
- Just focus on Value, waste, best engineering practices, integrity, great communications
- Even an approximate VSM is better than none.

Mapping the Future State VSM - continued

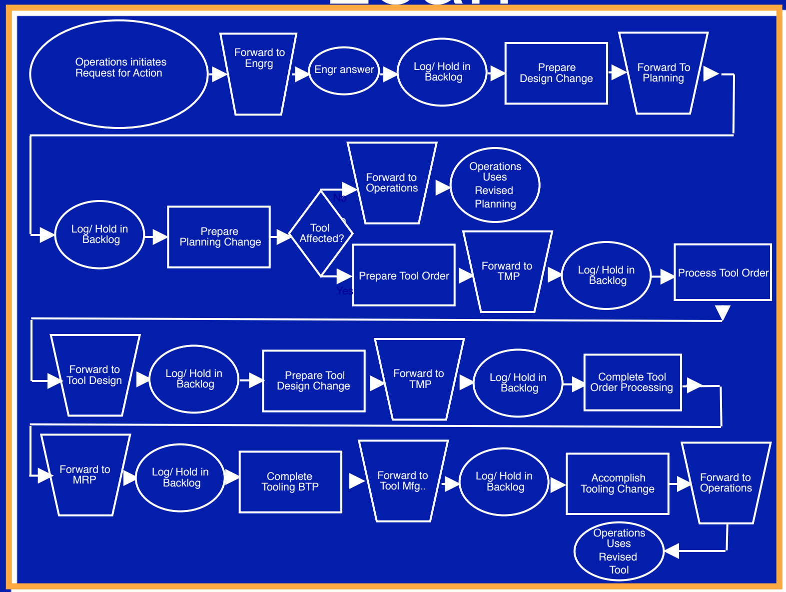
- Identify all frustrations in the Legacy program well = goldmine of opportunities to improve the current program
- Iterate and negotiate among the Core Team until consensus
- Any "stubborn unknown" is a signal to bring in an additional expert, study the issue more, or to define it as a research task, or a risk, to be removed from critical path
- Identify and isolate any big uncertainty, call it R or D, place on separate track, assign to separate team, staff to resolve the uncertainty in time to deploy in the Flow.

Allocate Enough Time for VSM

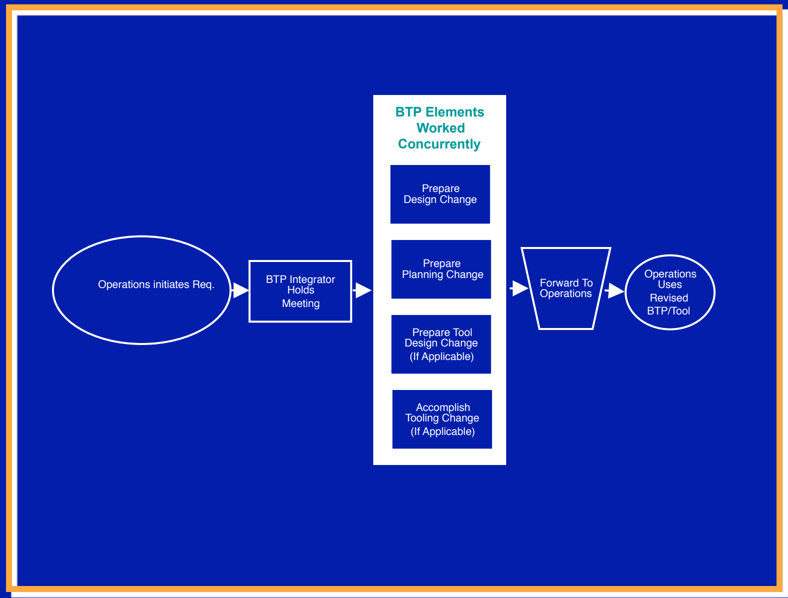
- Final VSM is simply the ultimate good plan for the project
- It must show total work parsed into concurrent Tasks in Takt Periods.
- Allocate a liberal period for the VSM effort. Do not allow it to be rushed. This must be done right. Rough estimate: 10-25% of program time
- Protect the VSM effort from those shortsighted managers who want to rush it
- Final VSM should address all relevant aspects of the workflow:
  - Concurrency and precedence
  - Control points
  - The split of work between functions, teams, contractors, and individuals, i.e., "who is to do what and when, and how to flow the work".

PDVSM Used For F16 Forward Fuselage Build-to-Package Process

Process Before Lean



Process After Lean



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

VSM Discipline

- The entire Core Team + Major Suppliers + SE engineers to participate
- Categorically demand perfect attendance (qualified deputies to attend if someone is sick)
- Like a football team – must be complete in order to play
- With so many expensive people in the room, every minute is hugely expensive, so waiting for late comers is unacceptable

Flow in LPDF

Memory Jogger: Lean Production Line

- Flow = uninterrupted motion of work pieces at a steady takt time through all processes with no backflow or rework (a moving line)
- Takt time = the time for each workstation to complete its task on the line
- All processes must work to the common takt time; otherwise pileups or gaps occur

Memory Jogger: Lean Production

- Making complex production flow according to the takt pulses is difficult
- We take it for granted, yet it takes extraordinary detailed planning
- Implementation requires carefully splitting and balancing the total work among the workers/processes, perfecting each process, and providing each worker with adequate parts, tools, training, and ergonomics to make timely and robust completion of the task possible
- **Key to success, also the key to the present method:**
- The ability to plan, balance, and split the total PD work into tasks of equal duration, and small enough that each task becomes totally predictable in terms of quality, outcome, effort, and cost.

LPDF Overview

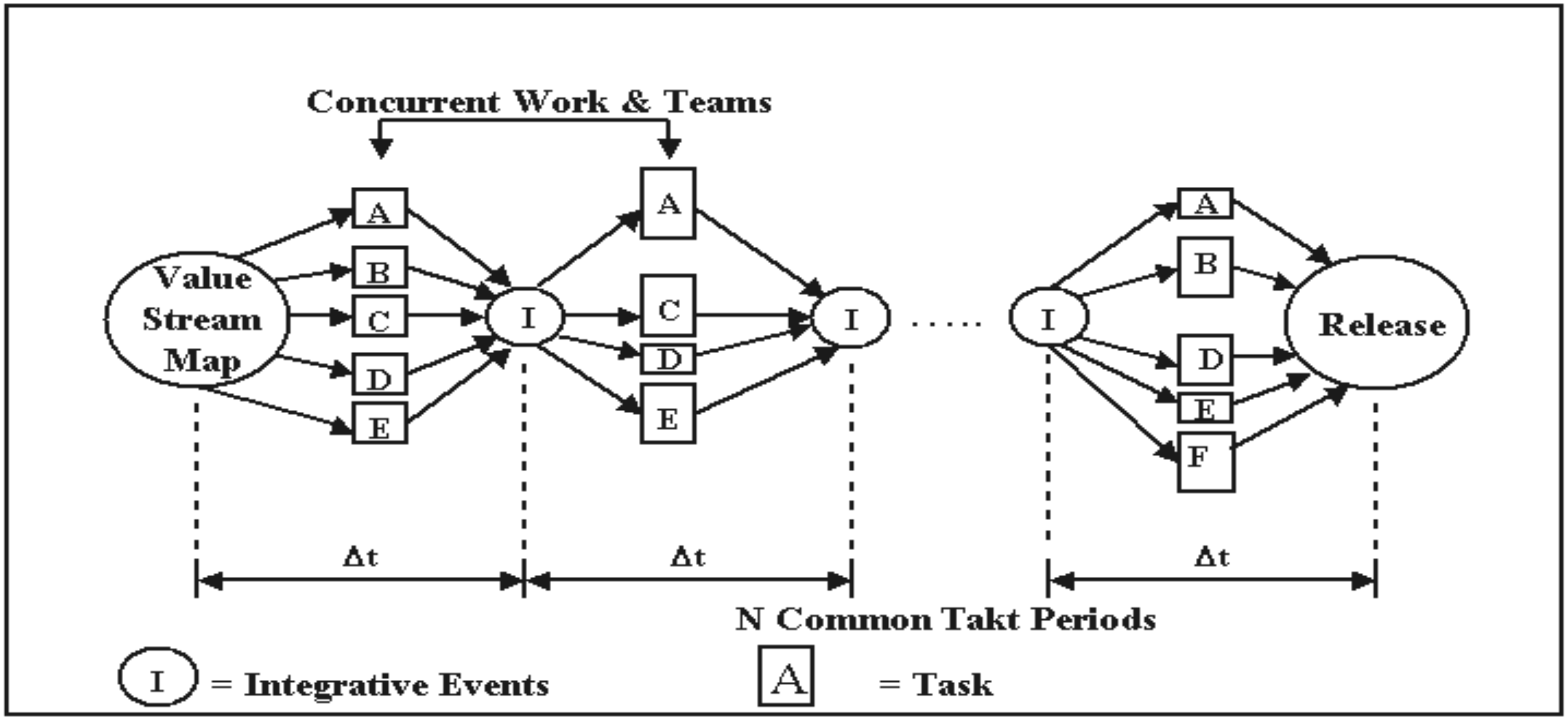


Fig.1 Schematics of Lean Product Development Flow

The flow proceeds through the alternating work periods called Takt Periods (short and of equal duration) and Integrative Events, providing common, frequent rhythm and flow to the entire team.

Flow

- The "Flow" denotes uninterrupted progress of work at a steady rhythm through all Tasks, with no stoppages, backflow or rework (planned and controlled iterations are OK)
- The Takt Periods provide the common rhythm of work assuring predictable flow of the value stream with maximum coordination and minimum waste
- Non-negotiable common deadlines for all team members to robustly complete all the tasks assigned for the given Period

Flow

The practices which enable the flow and reduce waste

- Discipline of the common rhythm of deadlines for entire team
- Comprehensive frequent periodic coordination (never enough)
- Comprehensive early identification and mitigation of risks, issues
- Dynamic allocation of resources (tasks are of equal duration but uneven effort)
  - Some engineers to stay for the program duration, but well-defined tasks should be staffed dynamically, from the matrix
- Exploration of design spaces, set based designs
  - Point designs and small margins cause huge iterations and gigantic labor costs
- Addressing tradeoffs early: old/new, margins/labor cost, test/cost...
- Separation of Research, Development, Design
- Optimization of limited iterations
- Building consensus in the Core Team

Integrative Event Checklist

- The scope of Integrative Events should extend significantly beyond the frequent practice of mostly lip-service weekly status reviews
- The Integrative Event Checklist
  - Efficient review of progress
  - Chief or Assistant Chief asking pointed, knowledgeable questions, including the numerous questions "why?" asked in a non-confrontational style
  - Comprehensive coordination of work

Integrative Event Checklist - continued

- Resolution of tradeoffs, concerns, issues
- Building consensus - if practical, in breakaway sessions, involving only the needed individuals
- Identification, management and retirement of program risks
- Identification and flexible mitigation of uncertainties (=opportunities for creative solutions)
- When appropriate, treating uncertainties as opportunities for creative and entrepreneurial solutions

(see Hastings and McManus, 2004)

Integrative Event Checklist - continued

- Exploration of design spaces and set designs to flow the work along without having to wait for 100% complete complex inputs or iterations
- Decisions whether to insert knowledge from legacy programs or create new knowledge
- Involvement of suppliers and other stakeholders
- Balancing between new and mature technology, and between creativity and standards

Integrative Event Checklist - continued

- Reuse of modular subsystems (pre-designed or pre-built) and checklists from former programs
- Balancing tradeoffs between design margins and the analysis fidelity
- Decisions on which analyses, tests and documents are needed, resisting those deemed wasteful
- Adjustments of VSM, work assignments, and allocation of resources
- Emphasis on information integrity (coordinated, flow between the right nodes, minimum of handoffs, handoffs well explained; right scope, completeness, correctness, robustness)

Integrative Event Checklist - continued

- Focus on engineers' and suppliers' competence and experience
- Addressing any and all big relevant questions
- The Chief Engineer is the final authority on the Integrative Event agenda and scope

Takt Periods. Recommended: Weekly

- The vast majority of PD waste has as the root cause some miscommunication or not enough of communication
- Remedy: build in frequent opportunities and culture to communicate both informally and comprehensively in a structured manner.
- One-week Takt Periods:
  - Actual work performed Monday-Thursday
  - Thursday afternoon: bring all issues to the attention of the Chief using A3 format
  - Thursday evening: Chief's staff designs agenda for IE on Friday
  - Integrative Events on Fridays, as long as it takes
  - The weekend buffer for rare catch up tasks
- This schedule is already practiced by many organizations
- In addition: daily stand up 15 min meetings to refresh memory and coordinate daily tasks

Communications

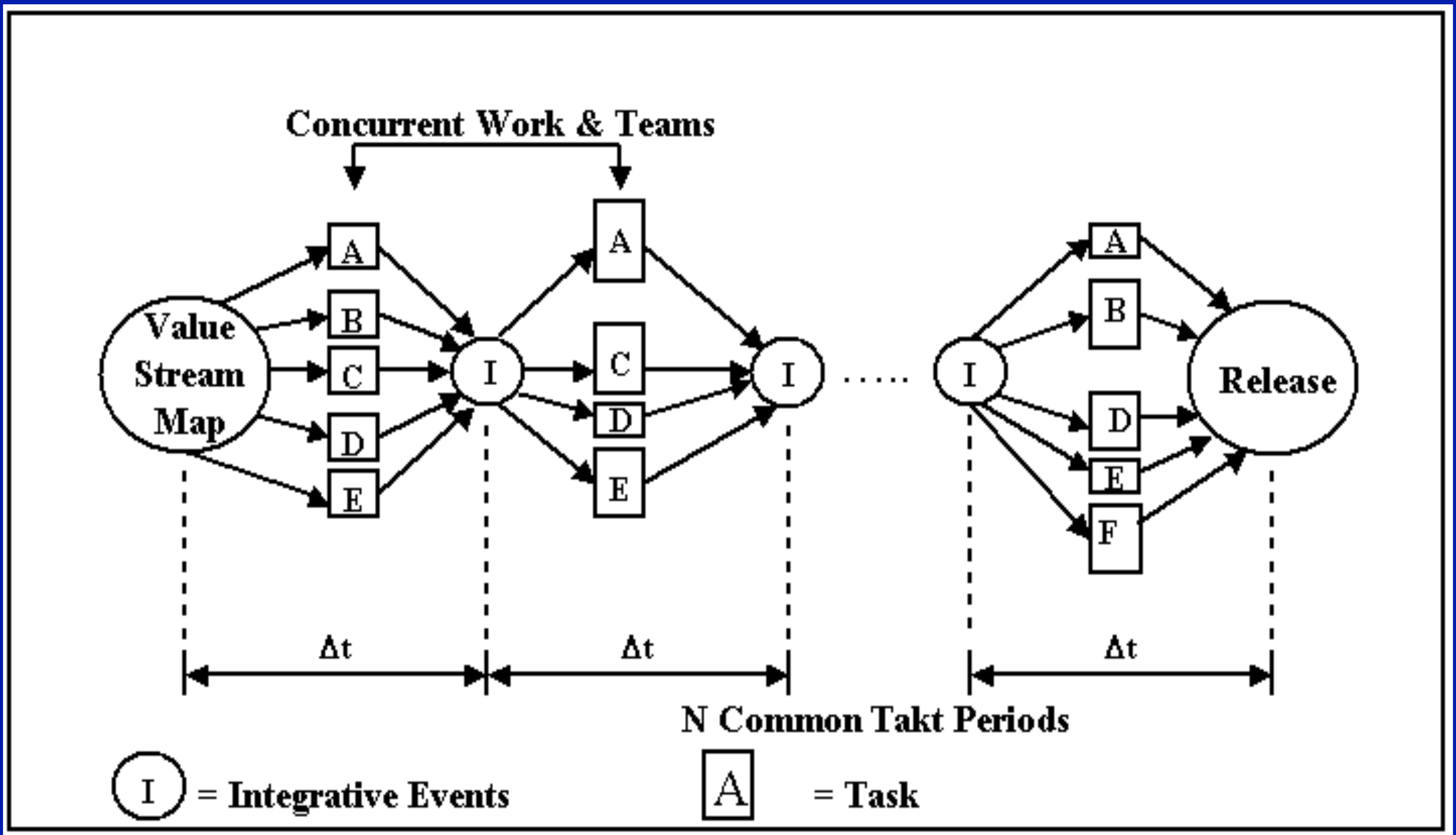
- Looking at PD Waste – lots of it can be traced to inadequate communications

- LPDF vastly elevates good communications

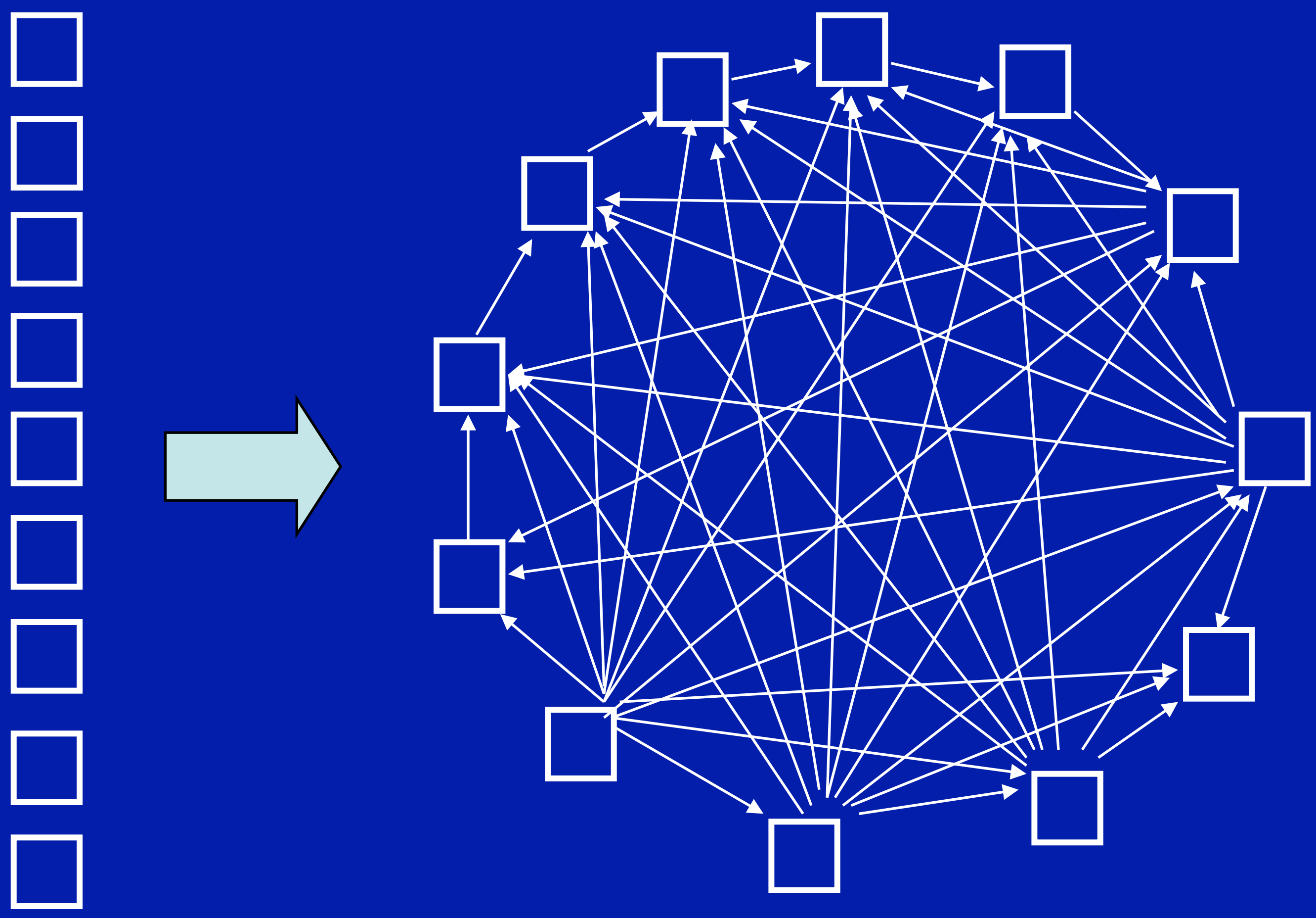
Minimizing the Waste of Handoffs by Direct Communications (Toyota model)

- Hand-offs (passing off a document, a question, a request, information...) are a huge waste
- Hand-offs separate responsibility, knowledge, action
- In many cases as much as 50% of knowledge is wasted in each hand-off
- In a five-level vertical structure: 50% * 50% * 50% * 50% = **6.25%** of original information survives !
- Nobody reads carefully a long document or hyper-detailed requirements - so why write it and why disseminate it? A3 summary works best!
- 2D drawings represent classic waste of handoffs (use a solid model instead)
- If a question can be asked directly - why go through two managers?

Structured Reviews During Integrative Events & Informal Communications During Takt Periods



Informal Efficient Communications as needed during Takt Periods (never enough! nuances, clarifications, new questions…)



Pull in LPDF

Pull

- The tasks assigned to each Takt Period should utilize the Pull principle to the maximum degree:
  - The task should be specified only if it is (will be) needed by a downstream process, or the end customer
  - And that process should define the work scope, consistent with the value definition
  - Every employee (the "giver") must understand who is his/her "receiver" and must contact him/her asking about the needs: when, how, scope, format, etc.
  - Plan the task/transaction with the recipient, if not totally routine, so that it can be executed right the first time

Insist on first-time perfection of tasks

Perfection, Respect and Implementation in LPDF

Implementation Steps

1. Define the Project Value
2. Select the Chief Engineer
3. The Chief free to select a few Assistant Chiefs and the Core Team (major functions, suppliers, stakeholders; 10-15 max)
4. Perform training in LPDF (and Waste)
    - Best: All individuals to be involved in LPDF
    - Minimum: The Core team, Department heads, key suppliers
    - Highly desirable: top company managers
    - Scope: this handout
    - Even the smartest team members must be trained
5. Give the LPDF Core Team a large enough "war room" with walls for paste-ups, A / V tools, tables, computers. Breakaway rooms desired.
6. Give the Chief a small staff to free him/her from chores, and an office close to the War Room
7. Develop VSM
8. Flow the work

Select the Program Schedule

- If schedule is specified - no issue
- LPDF is capable of trading off schedule with allocated resources
- Therefore, <u>radical</u> schedule cuts are inherently possible
- Best: the schedule to beat <u>the best</u> competition
- Start by cutting 33% off the traditional schedule
- The traditional PD has 60-95% <u>or more</u> of waste, so cutting 33% is imminently realistic (this much waste is self-evident and easy to remove, e.g., waiting and rework)
- Be aggressive (easy to slow down later, but difficult to speed up)

Chief Engineer

- The Chief must be a great inspiring leader
- Guides the effort and negotiations, builds consensus
- The team keeps iterating until consensus for the VSM is reached by all managers (not a single veto or big unknown should be permitted)
- The Chief uses his authority only as a last resort
- The Chief to be the domain expert and a SE expert
- The Chief always thinks in the larger context
- Gets the group to arrive at conclusions
- Makes the project fun!

Grooming Chief Engineers

- Early aerospace programs used the equivalent of a Chief Engineer
- Unfortunate recent practice dissolved the position among several offices
- The company should groom several Chiefs for each major product type
  - Supporting their professional growth and education
  - Exposing them to challenging experiences
  - Rotating them through major departments
  - Offering them sabbatical periods for work-related internships and life-long learning
- Candidates carefully selected from among the most promising for both technical and interpersonal skills (the latter more important)
- Extrapolating from Toyota: aerospace firm of 100,000 employees may groom 10-20 Chiefs
- Best education: M.S. in a domain plus M.S. or equivalent in Systems Engineering
- Compensation and prestige must be proportional to the vast responsibility.

Grooming Chief Engineers-continued

- Grooming new Chiefs may take years.
- What to do in the meantime?
  - Select the best available engineer
  - Allow the person to select a small group of assistants complementing the person's knowledge whose loyalty will be to the program and not to their departments
  - Offer the Chief-Engineer-in-Training the maximum high-level corporate support (consultants, experts)
  - A steep learning curve is likely

Separation of Research, Development and Design

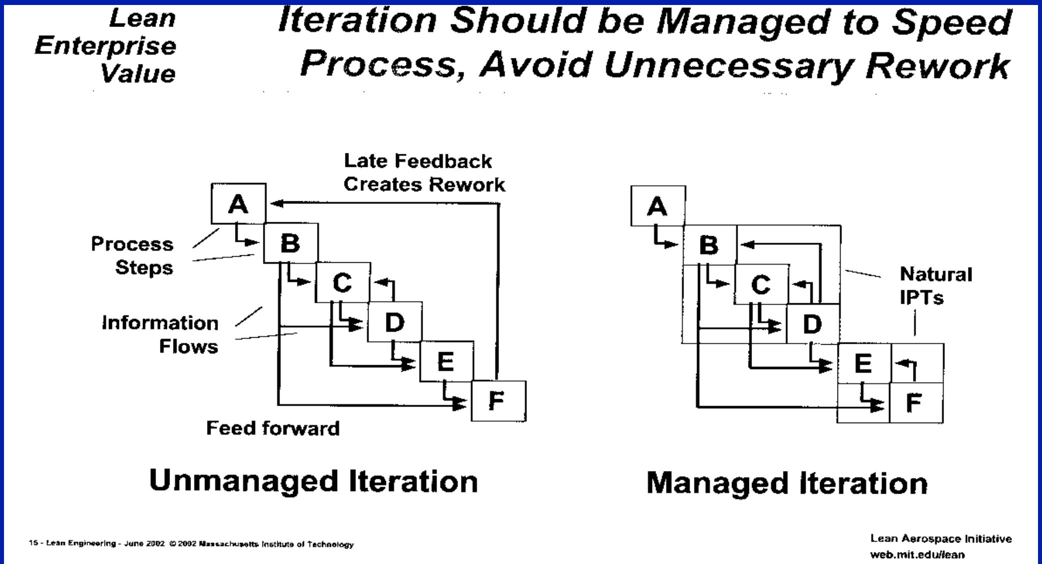
- In general, companies must perform all three: research (needed in order to stay competitive), development, and design, but should clearly separate them, as follows
  - Research: focus on developing the technology
    - Separate project by a small team of top scientists
  - Functional Departments: translate research output into Robust Mature Modules, modularized, tested, packaged for easy use in designs, easy manufacturability and low cost
  - Design team: trades and applies the RMT into the design (as in car design)
- Functional Departments should support the teams, and research staff should support the Departments
- The teams should evaluate the function heads for the degree of support provided
- The key is to organize an efficient flow of knowledge from Research, to Departments, and on to the LPDF team.

Set -based Design and Trade Space Exploration

- Set-based = analyze/test several alternatives, then narrow your choice until one is left
- Trade Space Exploration = explore the domains where constraints are satisfied, then look for the *product* of the domains
- This obviates the need to wait for 100% complete and accurate inputs
- The method reduces the need for iterations, delays, risk and increases concurrency
- Effect of set design: reduce risk by 10, reduce waste and time by 10, optimize
- Edison: using set-based, you can schedule innovation

Optimize Iterations

- Engineering processes often are interdependent (the chicken/egg problem)
- Iterations help to zoom in on best design and drive out risk
- But needed iterations should be managed for minimum steps, time, cost
- Not justified for design that started with too small design space, or as a remedy for the lack of planning
- Iterations across functions or teams are hugely expensive
- They must be planned



Provide Adequate "War Room"

- A room large enough to allow about 30 cm of wall length per week of project + 30%
- Draw the vertical lines for weeks, and horizontal lines for swimming lanes; leaving space for notes
- Enough chairs and table space for the Core Team + aids
- Secretarial and gofer support
- Computers, A/V, phones, drawing readers, etc.
- A few side rooms for break away sessions
- Chief's office nearby

Responsibilities of Team Members

- Complete the training
- Know who is the internal customer for every task (not the boss or the Chief)
- Learn and understand the needs and goals of the internal customer for every task
- During the Task execution, communicate with the internal customer and other nodes as needed
- Prepare for the Task ahead of schedule in order to be fully effective, verify that the needed inputs will be available on time
- Complete the Task during the assigned Period
- Communicate fully and timely with others as needed
- Practice superb communications with other relevant nodes, within periods: ask questions, if not sure; ask the Chief's staff who to address questions to, if uncertain

Responsibilities of Team Members

- Attend all required Integrative Events, be punctual
- If any anomaly, issue or delay arises, prepare an A3 briefing note and send to the Chief.
- Monitor the VSM flow in the War Room
- Never hesitate to suggest improvements
- Rebel against waste
- Never hesitate to notify others of problems
- Practice consensus building

LPDF is an exciting and inspiring experience.

C-2013 Bohdan W. Oppenheim
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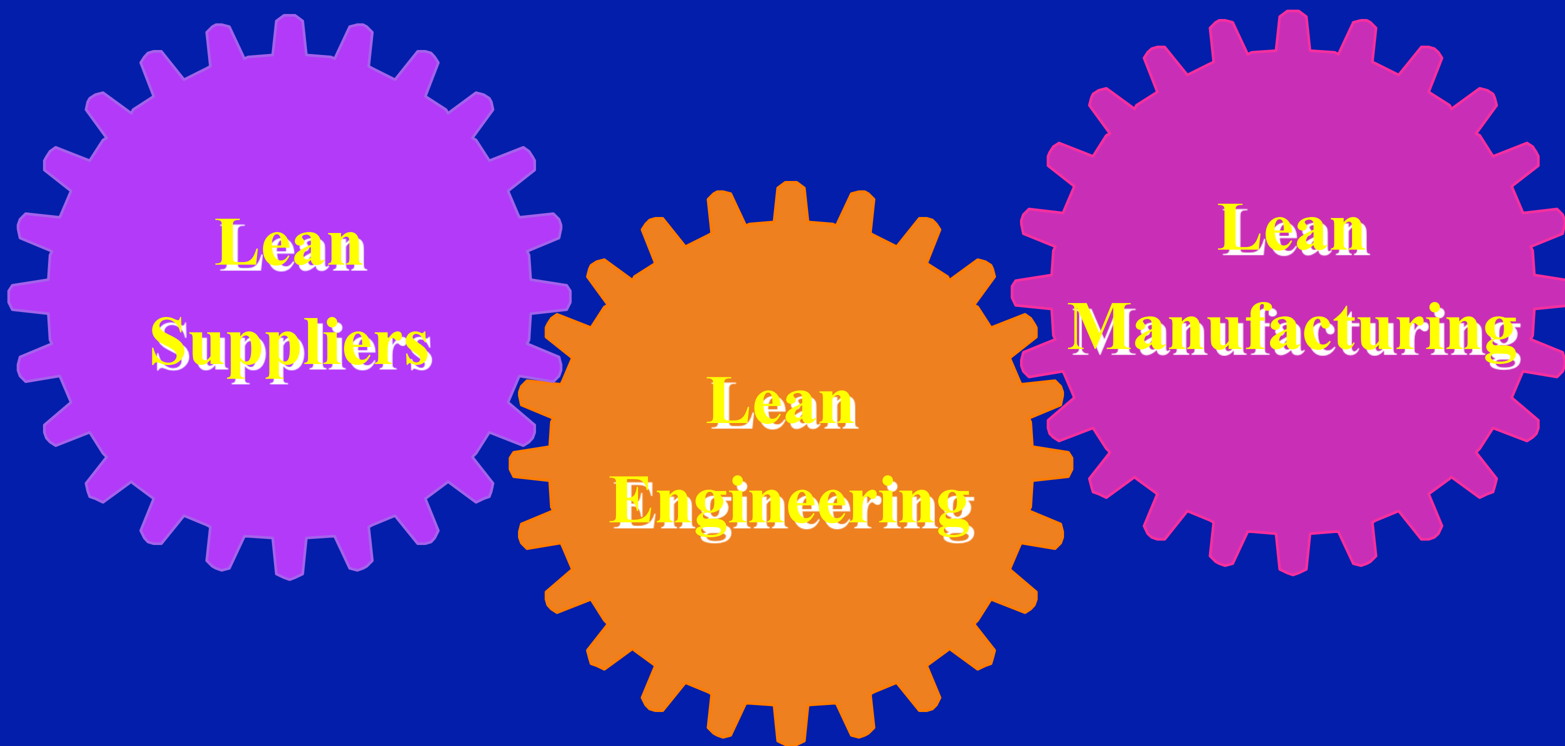
Part VII: Lean Final (Parts) Engineering

Final ("Detailed" or "Parts" Engineering Design Drives Manufacturing and the Supply Chain!



Engineering Drives Cost !

80% of a product's cost is determined by the engineering design:

- Number of parts / tolerances
- Assembly technique (fasteners, EB welding, co-cure)
- Processes (heat treat, shot peen, CAD plate, etc.)
- Tooling approach (matched metal dies, injection molding, etc.)
- Materials (titanium, aluminum, composites, etc.)
- Avionics / software
- Design complexity
- Design re-use

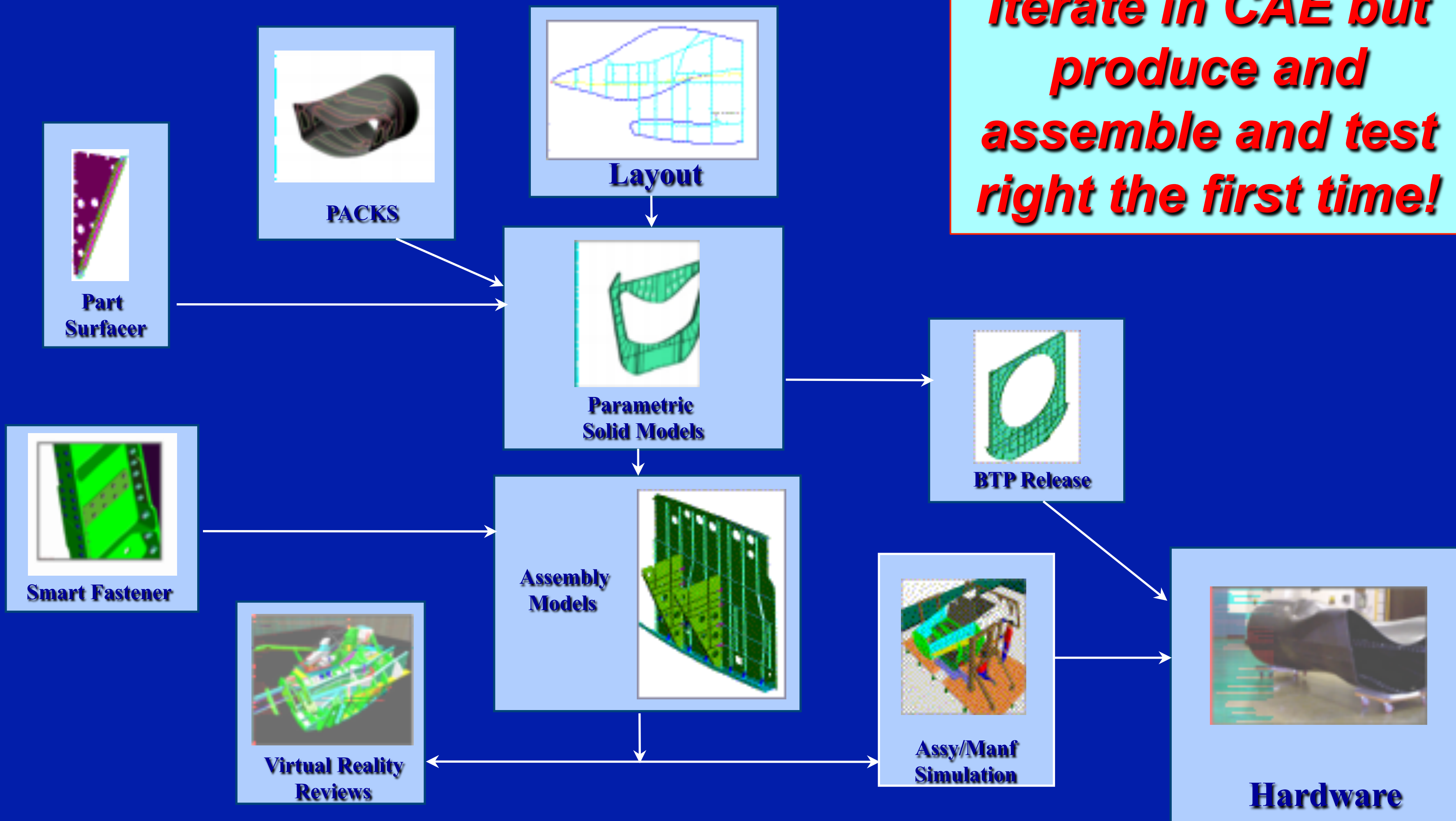
"Lean" Engineers must design for manufacture/ assembly/testing/life cycle !

Tools of Lean Engineering

- Reduce wastes of handoffs and waiting and increase quality using integrated CAE tool sets
  - Mechanical: 3-D solids-based design
  - Electrical: VLSIC toolsets
  - Software: s/w development environments
- Common parts / specifications / design and module reuse
- Design for manufacturing and assembly and testing (DFMAT)
- Dimensional/configuration/interface management
- Variability reduction
- Production simulation (and software equivalents)

Integrated CAE Based Design, Validation, and Build

Iterate in CAE but produce and assemble and test right the first time!



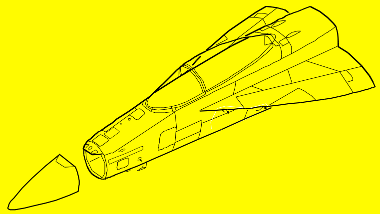
Major Elements of DFMAT

Give manufacturing and supplier management:

1. Fewer parts / common parts / multi-use parts
2. Designed with high quality (that fit the first time!)
3. Robust fabrication/assembly processes
4. Reduce cycle time wherever possible!
5. Design for ease and speed of testing!

Reducing the number of parts in F/A-18E/F

Forward Fuselage and Equipment



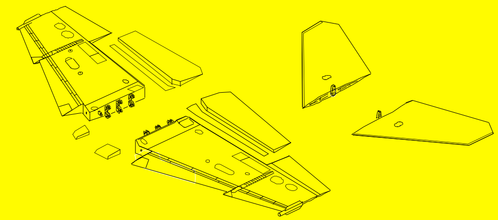
C/D Parts
5,907

E/F Parts
3,296

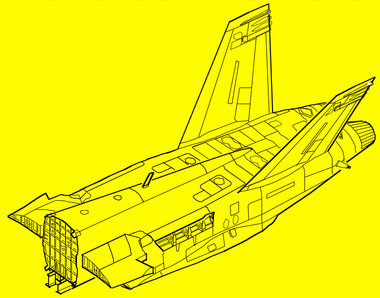
Wings and Horizontal Tails

C/D Parts
1,774

E/F Parts
1,033

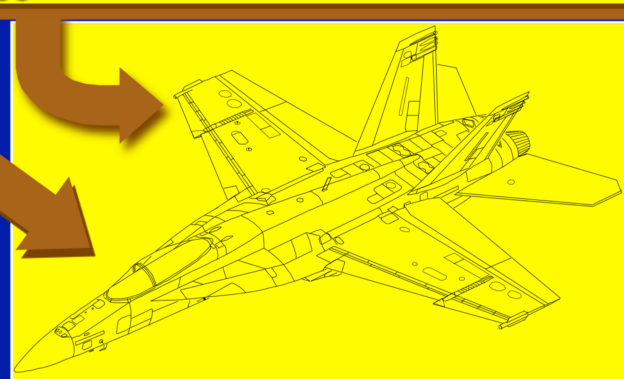


Center/Aft Fuselage, Vertical Tails and Systems



C/D Parts
5,500

E/F Parts
2,847



*Total**

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

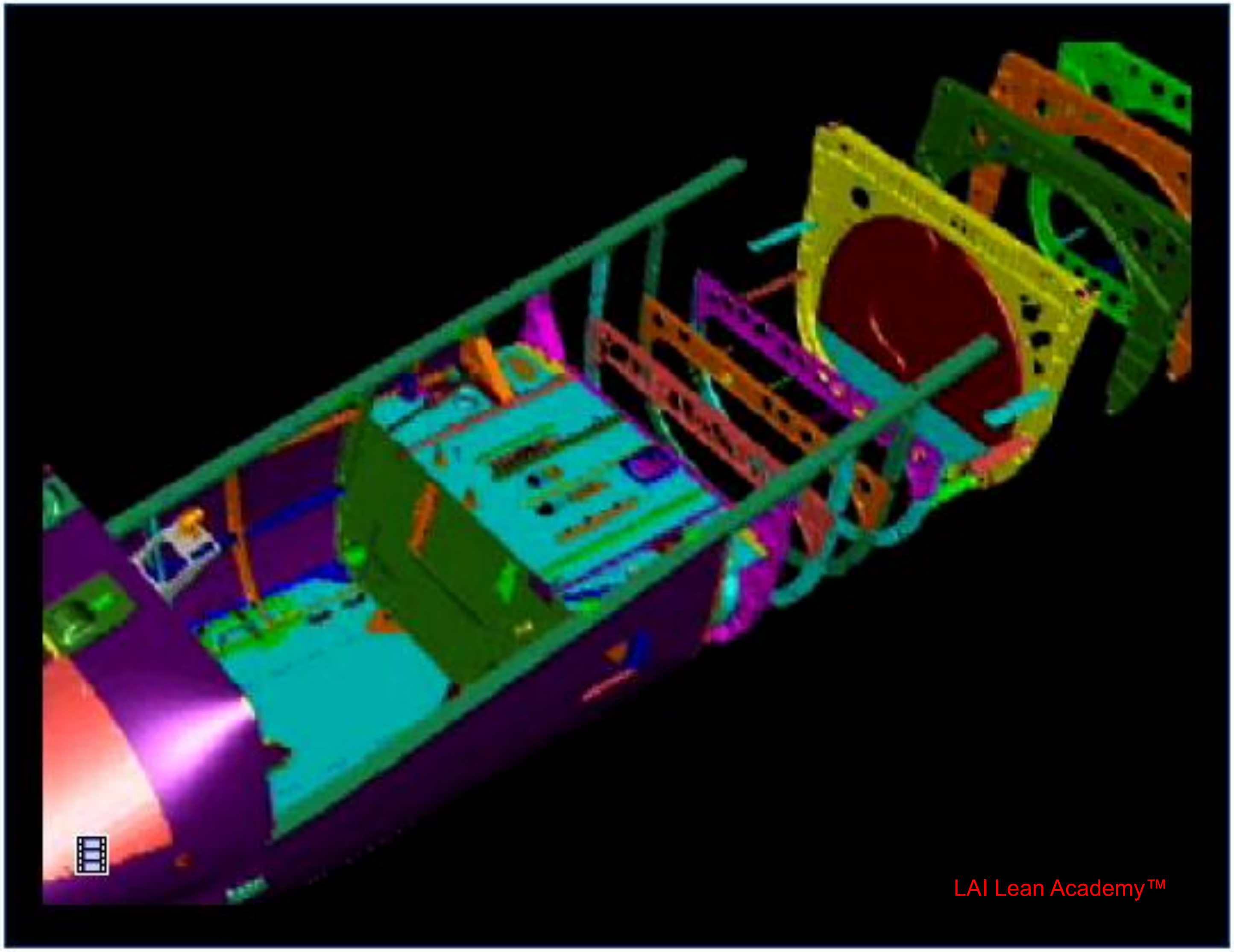
*Includes joining parts

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

Final Check: Production Simulation

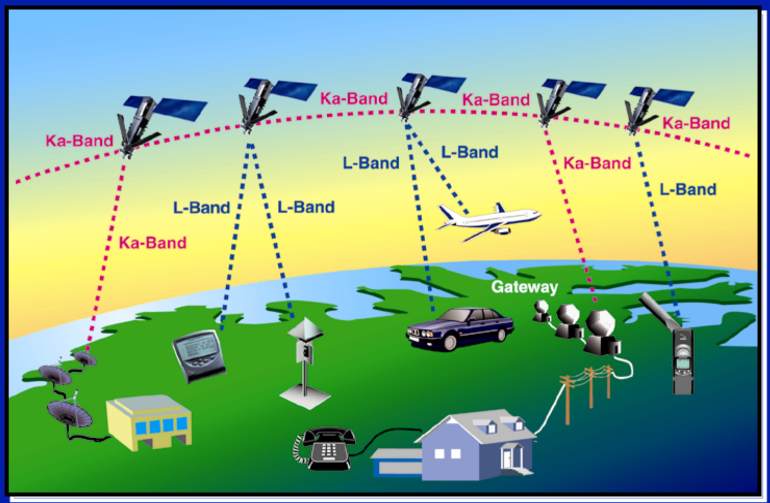
- An engineer's job is not done until we have successfully conducted a 3D production, assembly and test simulation
- Objective: Reduce wasteful, unnecessary, engineering changes and rework!!

Production Simulation



Examples of Two Former Programs Executed almost the Lean Way

- FA-18 Military
- Irridium engineering (not the business side)



- Adopted from E. Murman, MIT LAI Ed Net, Rockwell Collins, Aug. 2, 2008

F/A-18 E/F **Iridium Execution**

FA-18 E/F

Requirements

- 25% greater *payload*
- 3 times greater ordnance *bringback*
- 40% increase in unrefueled *range*
- 5 times more *survivable*
- Designed for future *growth*
- Replace the A-6, F-14, F/A-18 A/B/C/D
- Reduced support costs
- Strike fighter for multi-mission effectiveness

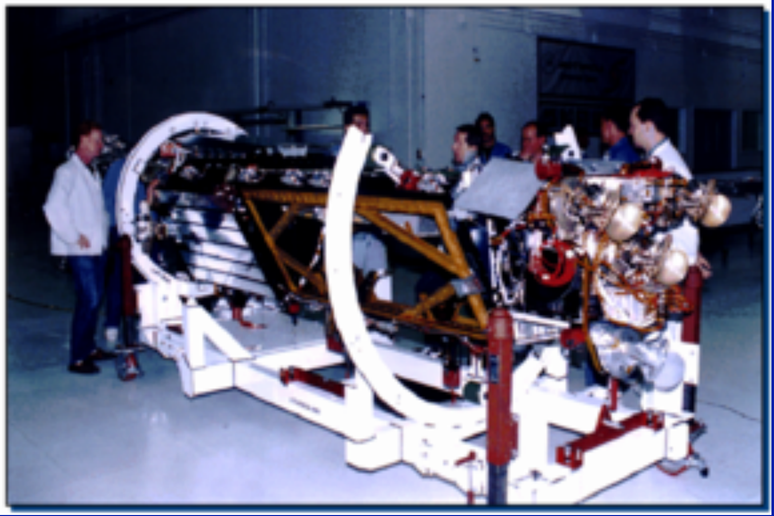
Program Execution/Outcomes

- **Development completed on budget - $4.88B**
- **Completed on schedule - 8.5 years from "go-ahead" to IOC**
- **Program was never re-baselined**
- **Aircraft 1029 lbs underweight**
- **42% fewer parts**
- **1st flight ahead of schedule**
- **Won 1999 Collier Trophy**

Iridium Execution

Iridium Manufacturing

- Cycle time of 25 days vs. industry standard of 12-18 months
- Dock-to-Dock rate of 4.3 Days



Iridium Deployment

- 72 Satellites in 12 Months, 12 Days
- 14 Satellites on 3 Launch Vehicles, from 3 Countries, in 13 Days
- 22 Consecutive Successful Launches !

Source: Ray Leopold, MIT Minta Martin Lecture, May 2004

Video:
Minta Martin Lecture at MIT, 2004
by Al Haggerty

Part VIII: Lean Enablers for Managing Engineering Programs

Contents

Project I : Lean Enablers for Systems Engineering by INCOSE Lean SE Working Group

Significant success, followed by...

Project II : Lean Enablers for Managing Engineering by INCOSE+PMI+MIT LAI

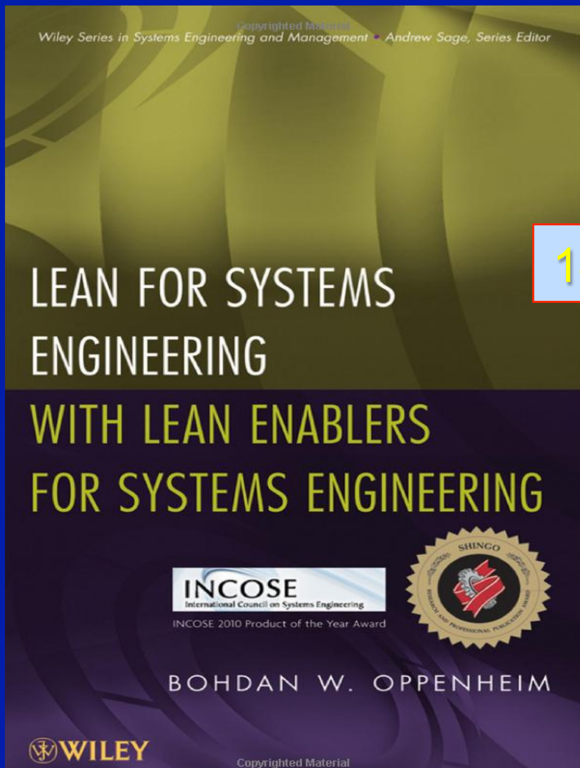
Lean SE WG Charter

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.

Project I: Lean Enablers for Systems Engineering

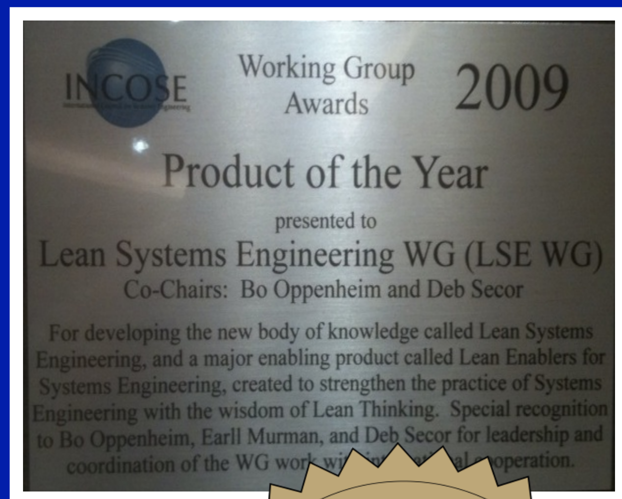
- 147 Enablers and Sub-Enablers
- Each is a best practice, a "do" or a don't
- Based on Lean wisdom
- Organized into 6 Lean Principles
- Not taking away anything from SE

INCOSE 2006-2010 Lean Enablers for SE

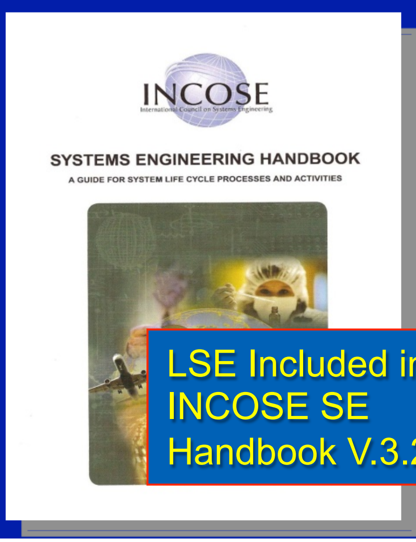


147 Lean Enablers

Four Prestigious Awards



Fulbright Award



LSE Included in INCOSE SE Handbook V.3.2

50 worldwide lectures, seminars

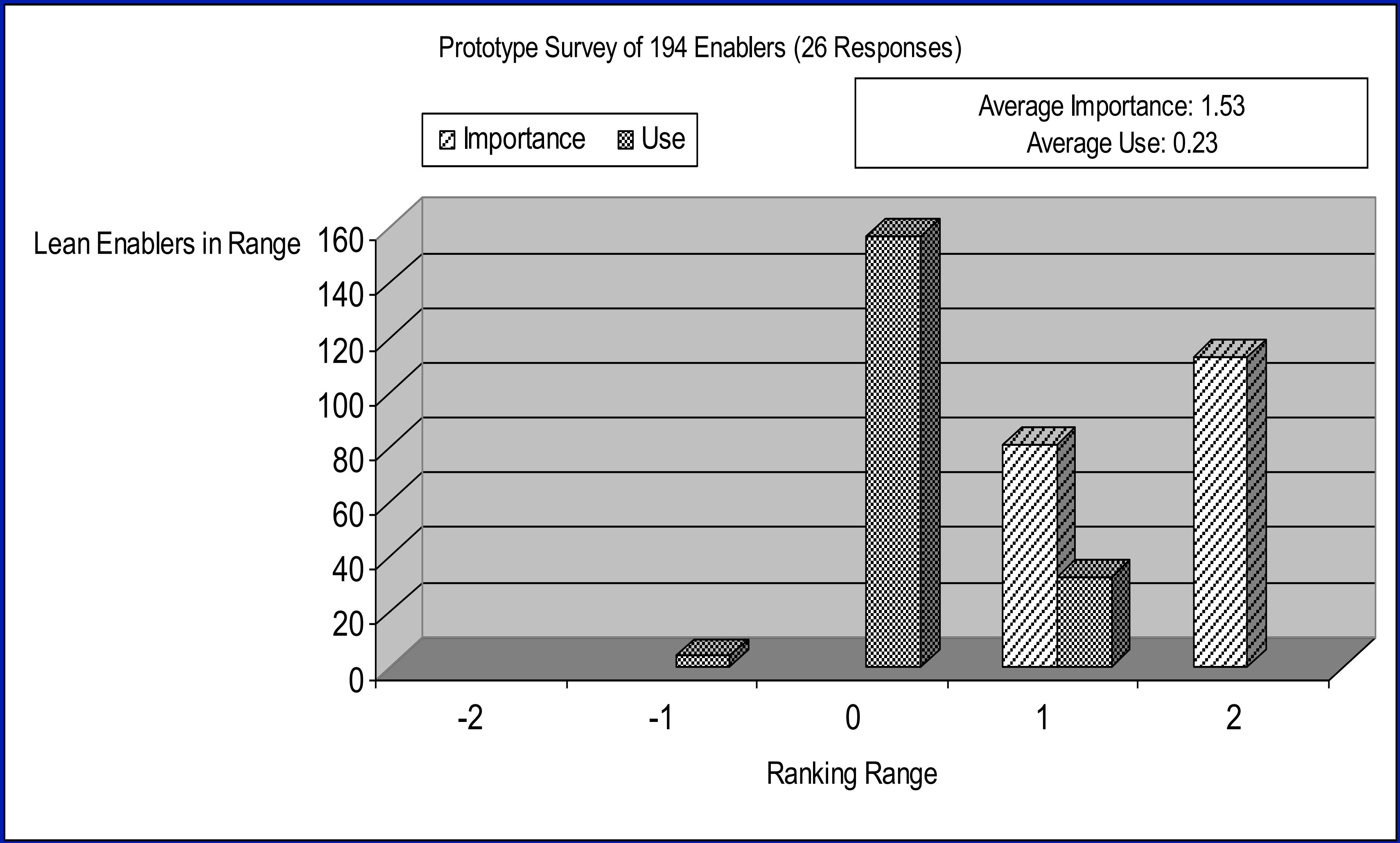
U.S:

- The Aerospace Corporation
- Am. Soc. Manufacturing Engineers
- Boeing Lean Conference
- Booz Allen Hamilton
- LMU (6)
- INCOSE, USA (7)
- INCOSE-wide webinar
- Lean Software and Systems Symposium
- MIT LAI Knowledge Exchange Event
- Naval Postgraduate School (2)
- Northrop Grumman
- Partners in Business, Utah State Univ.
- Rockwell Collins, Cedar Rapids (4)
- Stevens Institute of Technology

OVERSEAS:

- China: CETCA
- China: Shanghai Jiao Tong University
- Finland: Int. Conf. Lean Ent. S/W & Sys.
- France: EADS and AFIS
- Israel (2)
- Norway: Kongsberg Defense Systems
- Norway: Industrial Forum of Kongsberg
- Poland (5 Universities, Academy of Sci.)
- Sweden: EuSec
- UK: University College London
- Italy: Bari, Rome, Milano Polytechnics
- Moscow

Validation of LEfSE by Survey



All enablers passed the Importance test

Additional Validation: 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 major aerospace companies in an attempt to capture the key enabling factors and best practices that lead to their success.
- The companies chosen are world leaders in their industry with proven outstanding achievements in producing complex systems.
- 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"

The Key Enablers	Lean 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, 5.5, 5.7
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, 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".	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"

Best Practices	Lean Enabler #
Leading with Vision: Sharing the Vision, Providing Goals, Direction & Visible Commitment	5.5, 6.2.1, 6.2.10
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	handbook
Models & Simulation: Model-based Systems Engineering with "seamless" models, validated with Experts	handbook
Visible Metrics: Effective measures, visible supporting data for better decisions at each org. level	2.6, 3.7
Systems Management: Managing for Value & Excellence through the Life-cycle	5.5
Building Culture: Based on Foundation "Systems" Principles, Continuous improvement	5.2, 5.6, 5.7, 6.2, 6.3

One More Validation: 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

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.	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.	
•Empower program managers to make decisions on the direction of the program and to resolve problems and implement solutions.	5.5
•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

Project II: 2011-2013Lean Enablers for Managing Engineering Programs, by INCOSE-PMI-MIT LAI

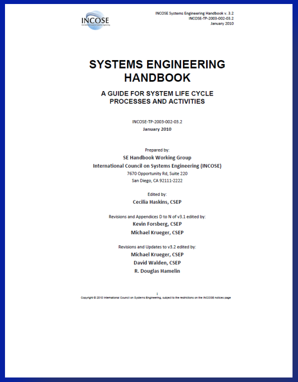
INCOSE and PMI

INCOSE

Not-for-profit, 8000 member organization

SE Handbook v. 3.2.2, (consistent with ISO/IEC 15288)

www.incose.org



PMI

Not-for-profit 600,000+ member association

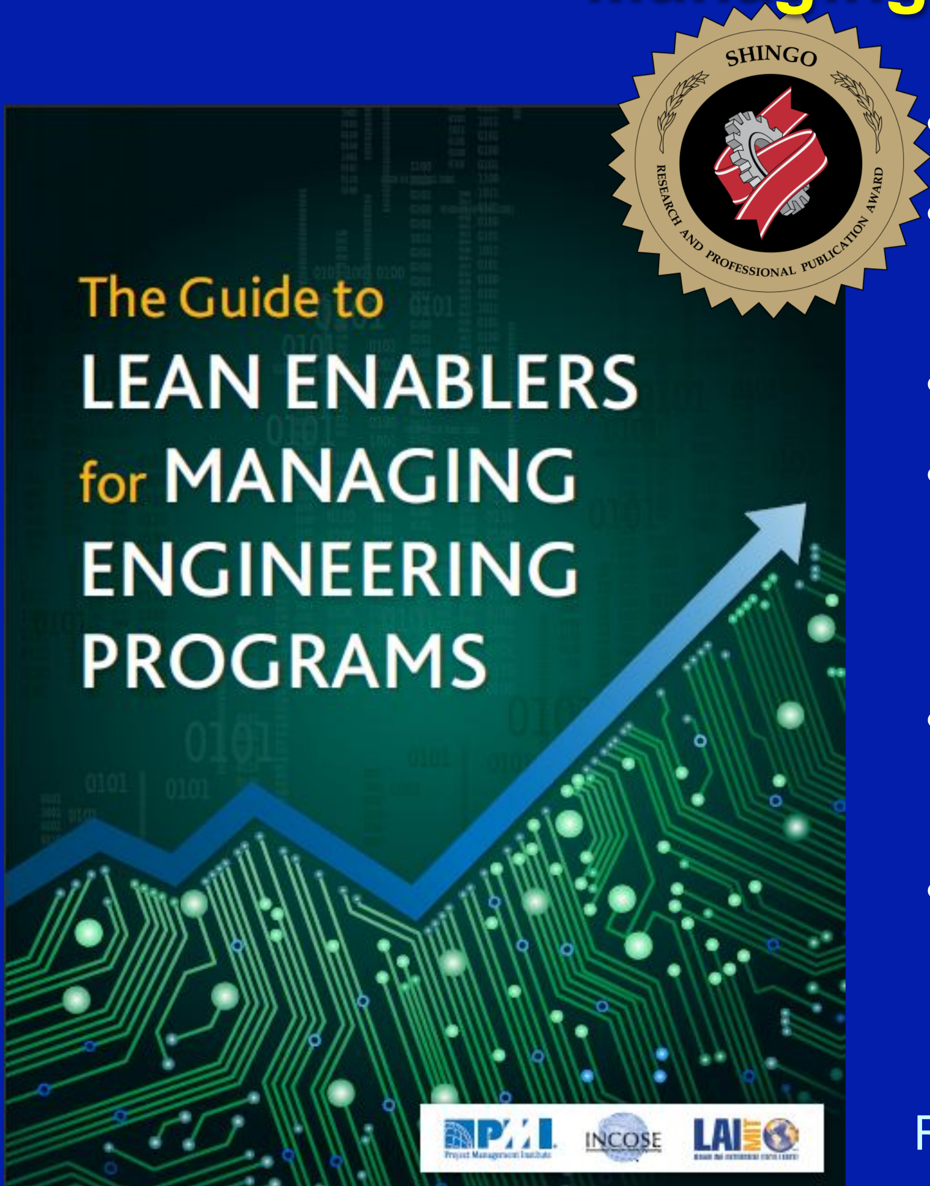
Globally recognized PM standards

www.pmi.org

Development Process

- Based on **concrete challenges**, not thin air
- Incorporates **start-of-the-art knowledge** from literature
- Developed by group of **15 subject matter experts** through weekly meetings
- Feedback through wider **community of practice** (180+ members)
- Discussed at **4 large and very successful workshops**, involving both PMI and INCOSE members
- Backed-up by **two validation surveys**
- Validated by **content analysis** of highly successful programs

INCOSE-PMI-MIT Research on Lean for Managing Engineering Programs



- Published in 2012
- 329 enablers and sub-enablers "LEfMEP"
- Integrated SE and PM
- Applicable to all types of projects and programs (not only military)
- Captures the wisdom of the profession
- Praised by INCOSE and PMI Presidents

Free Download at
http://hdl.handle.net/1721.1/70495
Read the Press Releases from LAI, PMI, and INCOSE

LEfMEP Developed by 15 experts and 180+ practitioners representing 35+ organizations

Identified and Prioritized Challenges in Engineering Programs

1. Reactive Program Execution
2. Lack of stability, clarity and completeness of requirements
3. Insufficient alignment and coordination of the extended enterprise
4. Value stream not optimized throughout the entire enterprise
5. Unclear roles, responsibilities and accountability
6. Insufficient team skills, unproductive behavior and culture
7. Insufficient Program Planning
8. Improper metrics, metric systems and KPIs
9. Lack of proactive management of program uncertainties and risks
10. Poor program acquisition and contracting practices

Lean offers a comprehensive waste-free approach to Programs

- Enterprise and portfolio preparation for programs
- Development of people for programs
- Detailed program/project planning
- Rigorous separation of Research from Development and from Design and Implementation
- Rigorous management of requirements, promoting stability
- Perfect management, single-person overall Chief with RAA
- Perfect quality, making imperfections visible
- Perfect coordination and communication tools and habits
- Perfect partnership with suppliers
- Perfect program metrics (few, measuring what is important)
- Perfect risk management
- Perfect lessons learned, communities of practice
- Perfect final engineering (3D CAE for "first time right" assembly)
- Brutal elimination of waste, bureaucracy, unneeded tasks, waiting

Lean is a General Comprehensive Holistic Process for Programs

In comparison: Traditional Programs are a monstrous wasteful overkill

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INCOSE organizes SE activities into 26 processes

Process Name

4 Technical Processes

4.1 Stakeholder Req's Definition Process

4.2 Requirements Analysis Process

4.3 Architectural Design Process

4.4 Implementation Process

4.5 Integration Process

4.6 Verification Process

4.7 Transition Process

4.8 Validation Process

4.9 Operation Process

4.10 Maintenance Process

4.11 Disposal Process

5 Project Processes

5.1 Project Planning Process

5.2 Project Assessment and Control Process

5.3 Decision Management Process

5.4 Risk Management Process

5.5 Configuration Management Process

5.6 Information Management Process

5.7 Measurement Process

continued

6.0 Agreement Processes

6.1 Acquisition Process

6.2 Supply Process

7 Organizational Project-Enabling Processes

7.1 Life Cycle Model Management Process

7.2 Infrastructure Management Process

7.3 Project Portfolio Management Process

7.4 Human Resource Management Process

7.5 Quality Management Process

8 Tailoring Processes

8.1 Tailoring Process

Additional Process Categories

ALL = Lean Enablers that refer to all Systems Engineering processes

EPP = Enterprise planning and preparation processes

A sample of Lean Enablers for SE and PD

Examples of LEs for ALL Processes

- Promote direct, informal, and face-to-face communications
- 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.
- Develop a system that makes imperfections and delays visible to all.
- Maintain counterparts with active working relationships throughout the enterprise to facilitate efficient communication and coordination among different parts of the enterprise and with suppliers.
- Ensure the use of consistent measurement standards across all projects and database commonality.
- Stay connected to the customer during the task execution.
- Use concise one-page electronic forms (e.g., Toyota's A3 form) for standardized and efficient communication, rather than verbose unstructured memos. Keep underlying data as backup in case it is requested by the receiver.

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Examples of LEs for Requirements Process

- Develop a robust process to capture, develop, and disseminate customer stakeholder value with extreme clarity.
- Listen for and capture unspoken customer requirements
- Create effective channels for clarification of requirements (e.g., involving customer stakeholders in program teams)

Examples of Les for Architectural Design Process

- Keep activities during early program phases internal and co-located, as there is a high need for coordination
- Set up a single, co-located organization to handle the entire Systems Engineering and Architecting for the entire effort throughout the life cycle, in order to increase RAA.
- Explore the trade space and margins fully before focusing on a point decision and too small margins.
- All other things being equal, select the simplest solution.
- Fail early and fail often through rapid learning techniques (e.g., prototyping, tests, simulations, digital models or spiral development)

Examples of Les for Project Planning Process

- When staffing the top leadership positions (including the program manager), choose team players and collaboratively-minded individuals over perfect-looking credentials on paper.
- Prefer physical team co - location to the virtual co - location.
- Heavily involve the key suppliers in program planning and at the early phases of program.
- Plan below full capacity to enable flow of work without accumulation of variability, and permit scheduling flexibility in work loading, i.e., have appropriate contingencies and schedule buffers.
- Publish instructions for e-mail distributions, instant messaging, and electronic communications.
- Publish a directory and organizational chart of the entire program team and provide training to new hires on how to locate the needed nodes of knowledge.

Example of LE for Risk Management Process

- Anticipate and plan to resolve as many downstream issues and risks as early as possible to prevent downstream problems.

Examples of LEs for Information Management Process

- Use only few simple and easy to understand metrics and share them frequently throughout the enterprise.
- Use metrics structured to motivate the right behavior. Be very careful to avoid the unintended consequences that come from the wrong metrics incentivizing undesirable behavior.
- Develop an effective body of knowledge that is easily accessible, historical, searchable, and shared by team and a knowledge management strategy to enable the sharing of data and information within the enterprise.

Examples of LEs for Acquisition Process

- Enssure that the customer-level requirements defined in the request for proposal (RFP) or contracts are truly representative of the need, stable, complete, crystal clear, deconflicted, free of wasteful specifications, and as simple as possible.
- Require an independent mandatory review of the program requirements, concept of operation, and other relevant specifications of value for clarity, lack of ambiguity, lack of conflicts, stability, completeness, and general readiness for contracting and effective program execution.
- Insist that a single person is in charge of the entire program requirements to assure consistency and efficiency throughout.
- Actively minimize the bureaucratic, regulatory, and compliance burden on the program and subprojects.
- Remove show-stopping research and unproven technology from the critical path of large programs. Issue separate development contracts, staff with co-located experts, and include it in the risk mitigation plan.

Examples of LEs for Supply Process

- Invite suppliers as trusted program partners to make a serious contribution to SE, design, and development.
- 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.
- Communicate to suppliers with crystal clarity all expectations, including the context and need, and all procedures and expectations for acceptance tests, and ensure the requirements are stable.

Summary of Lean Enablers

- LEs represent the current wisdom of world experts on how to manage complex engineering programs
- Polish engineering students are among the first to be exposed to them
- Suggestion for career: enroll into INCOSE, seek internship opportunities in the West, then bring high-value engineering work into Poland

You are studying engineering. You will want to have a career in engineering. Help Poland develop high-powered engineering.

IX. Lean Office

(We all work in Office Processes, so it applies to all of us)

Ideal Lean execution of office procedure

- The procedure contains only the Tasks which add value to the external customer or are required by law/regulations
- The employees are trained to execute each Task perfectly each time, satisfying each internal customer
- Each employee knows who is his/her internal customer and coordinates the work content and outcomes so as to be able to deliver what is needed on the first attempt
- The sequential Tasks are executed one after another without waiting, rework, or backflow
- The flow is continuous from the first Task to the last
- People coordinate and communicate in real time as needed and proactively to enable the flow of value added, and not reactively after a problem is found.
- The status of work is fully visible to all: where, how long, any problems?

The main sources of waste in office work

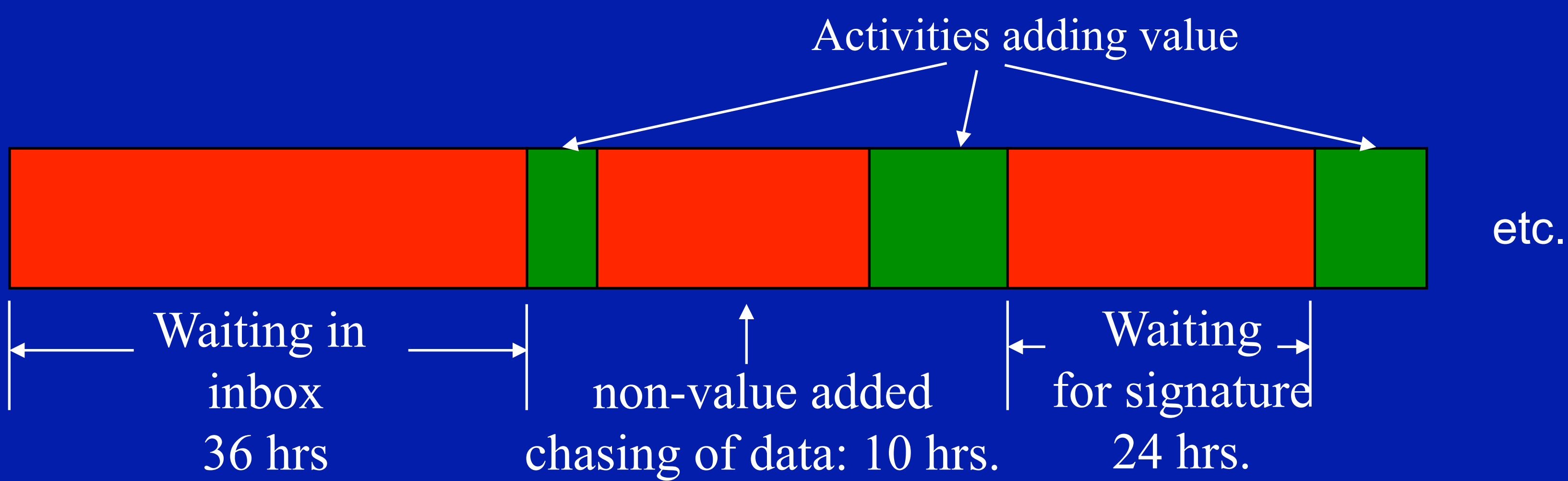
1. Waste due to rework = multiple execution of a Task(s) instead of a "correct on the first pass" (you know best how much of this waste exists in your process)
2. Waste of waiting (by people for data, or waiting for people to act (typically 50-75% of lead time)
3. Wasteful tasks and approvals that nobody needs and are leftover of previous processes (typically 20-30% of lead time)
4. Waste of unnecessary motion of documents between offices and of people between offices

Result: a process that should take minutes takes weeks or months

The Lean Challenge

- How to dramatically shorten the lead time without anyone working faster or harder?
- At the same time increasing satsfaction from work

Typical distribution of Task time



- Traditional methods focused on speeding up the Task work (green)
- With small positive effects but at a huge costs of frustrations, poor quality, and overtime
- Big improvement opportunities from the elimination of **"red", "yellow", and rework**

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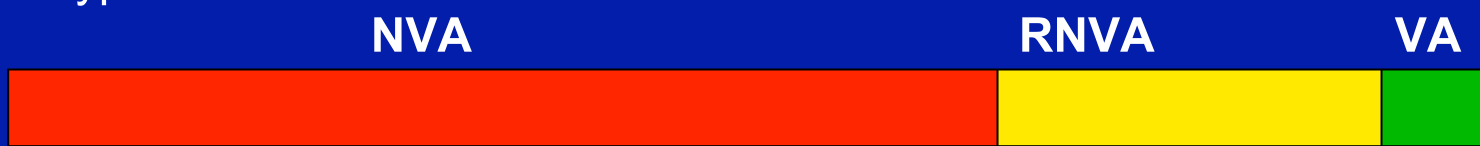
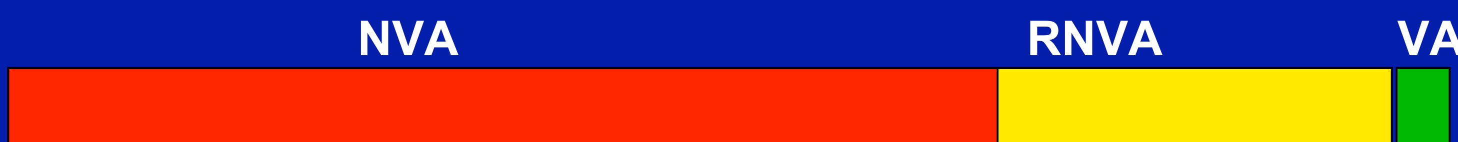
Where to focus the improvement effort

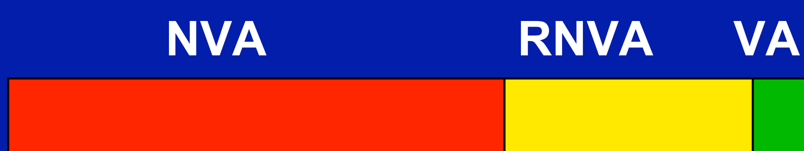
- VA = Value Added
- Other activities:
  - *RNVA*: Required non-value-added but required by law or regulations
  - *NVA*: Non-val;ue added (pure waste)
- Typical distribution before Lean:



- If we try to speed up the VA, the effect is minimal:



- If we focus on the elimination of NVA and reduction of RNVA:



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So, let us improve the Procedure

1. Eliminate rework
   - Make every effort to be able to execute Tasks right the first time (checklists, optimized procedures, training, good will, good communication and coordination..)
   - Internal customer is the only judge whether the given Task is done right
   - Everybody must know who is his/her internal customer, and coordinate the work with him
   - The coordination must occur in real time, proactively, rather than after the problem has occurred
   - Each task must be standardized with optimized procedures, easy, well checked, written by the employees
   - Internal customers are the best trainers: they know how things should be done!
   - Each employee has two jobs: to execute the task and to perform QA
   - Easy access to knowledge sources: (internal customers, managers who know))

So, let us improve the Procedure

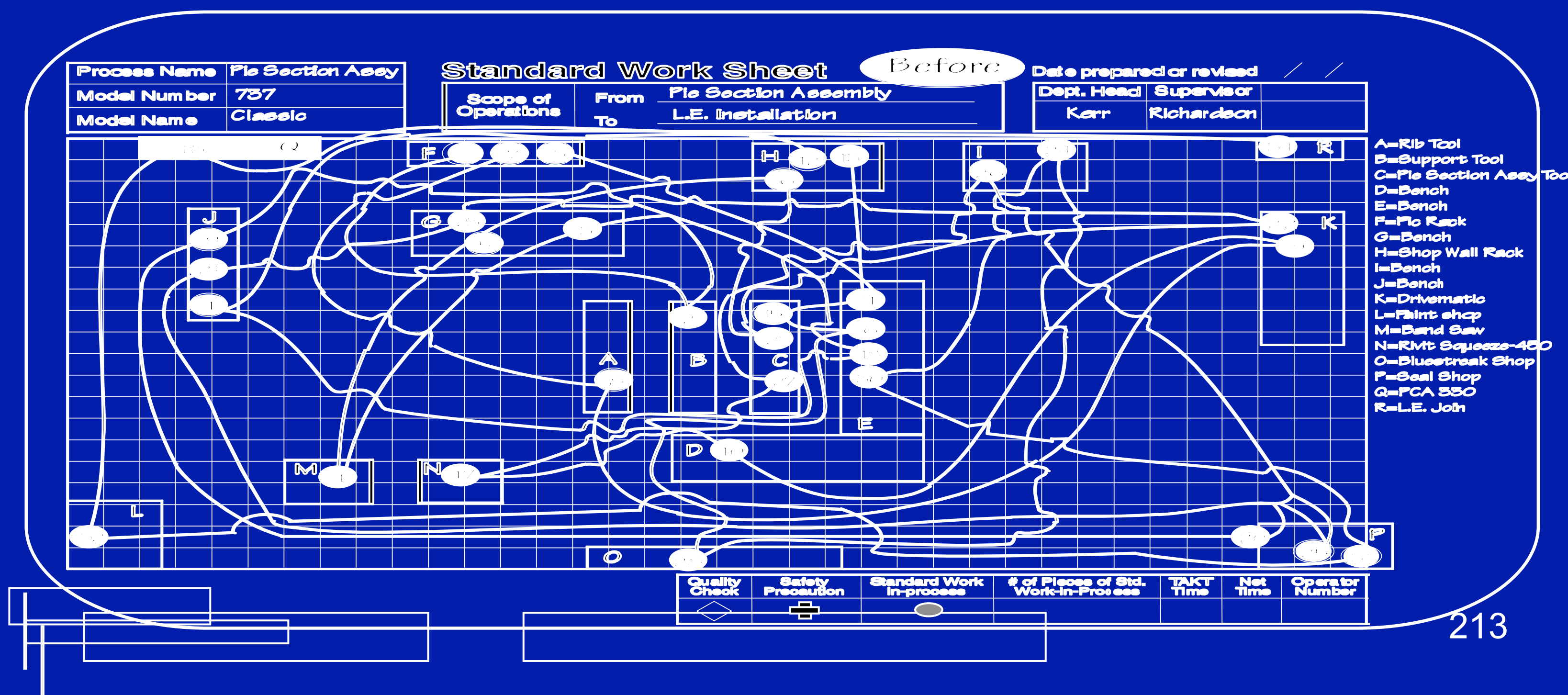
2. Eliminate Waiting
   - Pass the file (case, etc.) to the next Task immediately after completing the current Task, rather than in batches
   - Observe where pileups and gaps occur and balance the flow
   - Ideal: place people and their desks in sequence of Tasks, to minimize walking and eliminate silos
   - Send documents by fastest possible means – even expensive FedEx is cheaper than waiting for documents.

So, let us improve the Procedure

3. Eliminate Wasteful Tasks and Verifications
   - Study the procedures and keep asking questions:
     - Is this step necessary?
     - Is there a simpler way to do it?
     - Could we combine this step with another into one?
     - Can this approval be combined with other approvals to be done together at the same time, instead of sequentially?
   - And we immediately implement the opportune improvements
   - The best experts: the people who do the work, not necessarily their supervisors

So, let us improve the Procedure

4. Eliminate unnecessary travel of people and documents
   - Study the order of Tasks and offices
     - Is this the shortest way (draw the "spaghetti chart")?
     - What is the fastest way to move a file from one location to the next ?
     - How to reduce the number of handoffs (each handoff wastes 50% of information, and separates the responsibility from knowledge, action and feedback)



So, let us improve the Procedure

Training is critical

- If we have a supervisor who frequently rejects the work of employees, this suggests that he possesses the knowledge how to do the work right which they do not
- This supervisor should immediately train the employees in how to the work right the first time and every time
- Employees should be trained in all new procedures(how to do it, why are we doing it this way, who is the customer, the "do's and dont's", how to tell defects, what corrective actions to use immediately, what are the control points, who to call for help if needed, etc.)
- Multi-skilled training of all people in a given department, to avoid the situation that "Joe is absent today and he is the only one who knows"
  - Training in multi-skilles within each department
  - Raises for completing the training in many skills

So, let us improve the Procedure

Procedures

- All repeated activities should be standardized by procedures or checklists
- Procedures should be optimized and developed by employees, not managers
- All procedures must be easy to understand and follow, with examples of "do's and don'ts", and illustrations of documents
- All employees who are required to follow the procedure must be trained in it
- Implant the spirit of continuous improvement and the ease of changing the procedures

So, let us improve the Procedure

Continuous Improvement

- Each discovered problem (waiting, rework, mistake, etc.) should be regarded as a positive opportunity to improve the system
  - The best improvement system: an employee has a idea, brings it to the supervisor, obtains permission to try it, implements it and checks its effectiveness, and receives a bonus
  - We have as many of the potential "improvers" in the company as is the number of employees! All we need is motivation.
  - Kaizen for slightly bigger problems (often when we have conflicts between departments) : a small group of stakeholders brainstorms how to find the root cause, correct the problem, streamline the process, standardize it, and train people in it.
  - The method of "Six Sigma": for big problems that require effort by big bosses, or experts, or different departments/suppliers, etc.

The company culture is hugely important

- Trust people
- Make decisions at the lowest possible level
- Resolve conflicts at the lowest possible level
- Full respect for all
- Almost never blame the people, blame the system instead
- Treat problems as improvement opportunities
- Apply discipline only against those who claim that “it cannot be improved” instead of proposing how to do it
- Constant philosophy: the external customer is the most important
- If we do not satisfy external customers, the global competition will destroy us and we will loose our jobs
- Time means money for our clients
- Recommended incentives: those that reflect what is most important to the external customers, emphasize teamwork, and reward initiatives and creativity.

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Expected Results

- Lead time reduction: 50-90%
- Own cost reduction: 50%
- Mistake rate reduction: 90%
- Satisfaction from work improvement: huge
- Capacity increase: 50-90%

Thank you

and discussion.