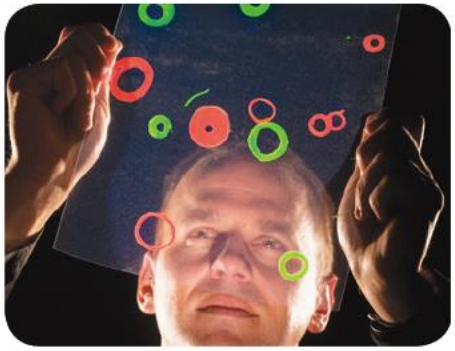
SAND2017-9770C

Exceptional service in the national interest

Sandia National Laboratories


Metrics for Measuring Model-based Systems Engineering

Model-Based Systems Engineering/Digital Engineering Workshop
RDECOM, US Army, Aberdeen Proving Grounds

SAND2017-9770 C

Ed Carroll, Principal Systems Research Analyst

September 19, 2017

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525

MBSE Initiative

What is the value of MBSE to Sandia?

- Principle Investigator: Ed Carroll
  - Retired Naval Aviator
  - 25 years in software / systems engineering
  - 15 years in systems analytics and data management
- Studied Four Questions about MBSE:
  - What does it look like? (Industry standards, guidelines, and manuals)
  - What can we learn from others? (Literature review & external visits)
    - Lockheed Martin, JPL, USAF, USN, DOD, & DOE
  - What are we currently doing? (SMEs and MGRs, & pilot projects)
    - 4 pilot projects, including: small, large, complex, hardware, software
  - What is the path forward? (based on conclusions from above)
- Our Path Forward:
  - Executive Sponsorship
  - Expanding Program

Agenda

Sandia National Laboratories

- What is Systems Engineering?
  - Industry description (iterative processes)
  - What is driving us toward MBSE?
- Why MBSE? - Findings from my Value Study
    - An MBSE approach provides significant advantage
    - Systems engineering improves engineering efficiency
    - MBSE Prevents Defects and Rework
    - Systems engineering needs to drive engineering processes
    - Skilled system engineers are needed
    - Prerequisites and Commitments

Sandia National Laboratories

WHAT IS SYSTEMS ENGINEERING?

Definitions - MBE vs. MBSE

- *Model-Based **Enterprise***
  - The tools, models, and infrastructure used to share design information across the enterprise that develops and supports the system
- *Model-Based **Engineering***
  - Integrated use of models to define the system technical baseline across the full life cycle, across all disciplines, across all program members [models as the authoritative definition of the system]
- *Model-Based **Systems Engineering***
  - A specialized descriptive modeling notation used to describe and analyze systems engineering information across the life cycle [the model is the authoritative definition for all systems engineering information]
- *Modeling and Simulation*
  - Mathematical algorithms or analytics used to model or simulate advanced engineering environments, concepts, or situations (electro-mechanical environments, physics of trajectory, telemetry, etc.)

The industry standard processes

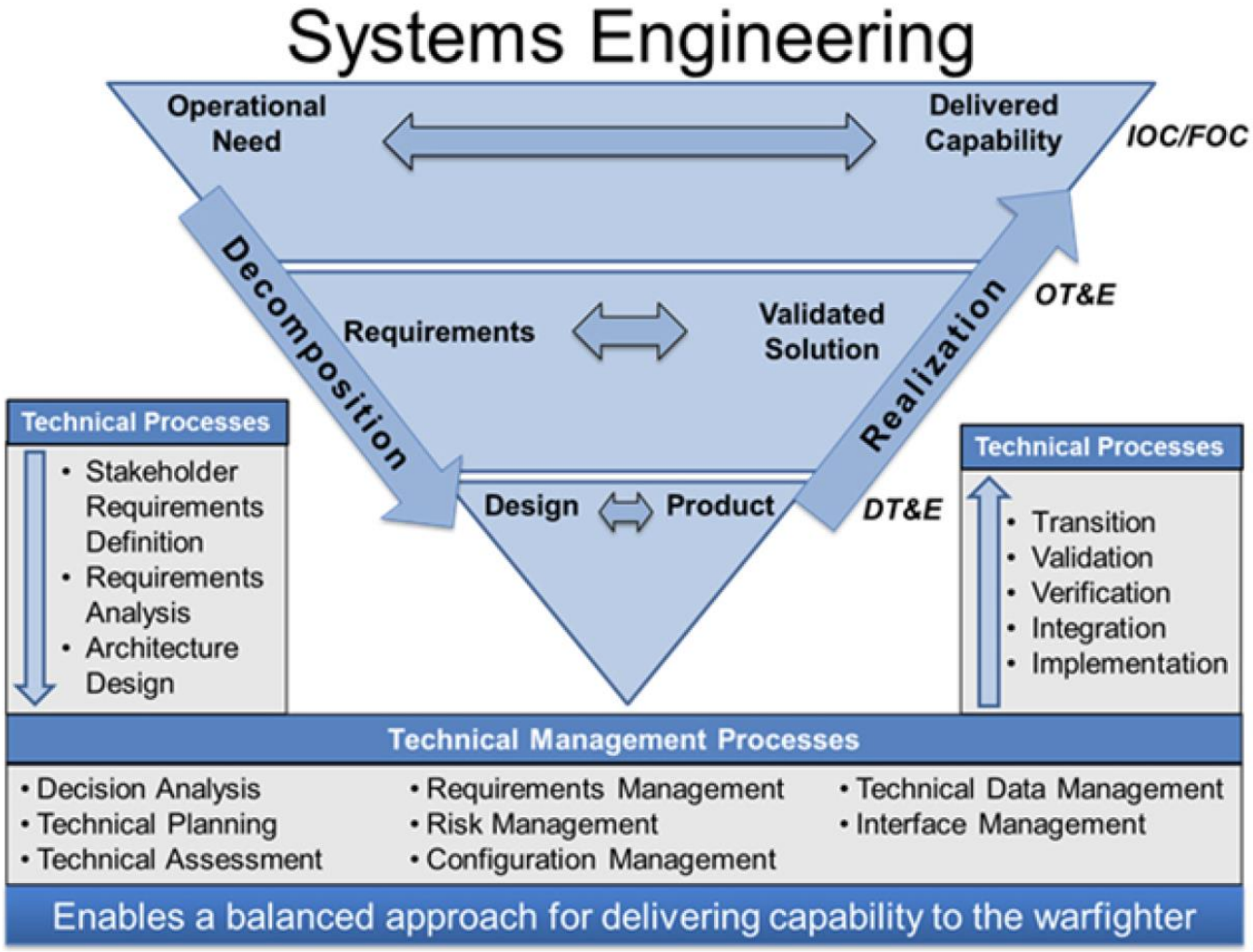


Figure 3: © the Defense Acquisition University

What are the Key SE Standards?

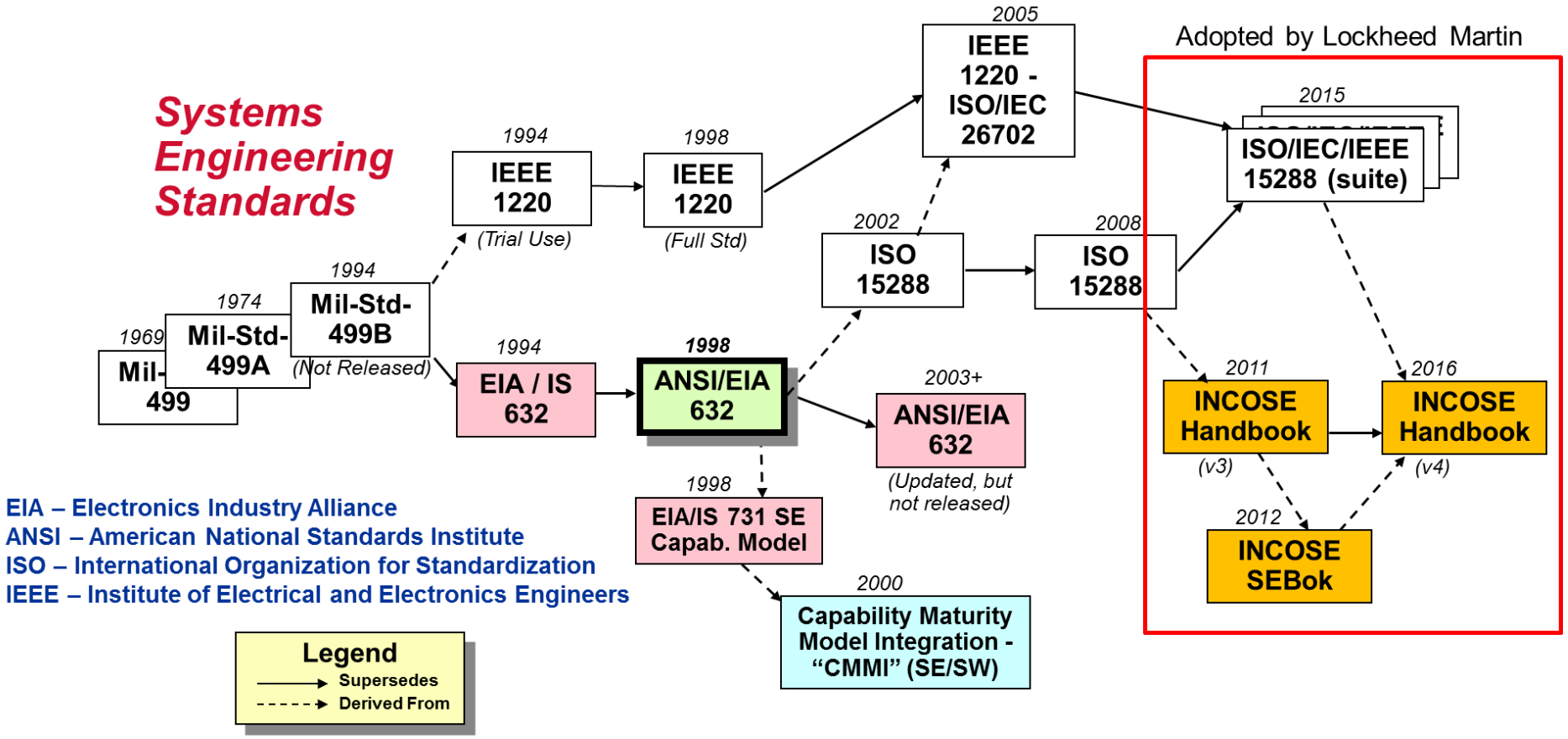


Figure 1: © Garry Roedler 2016 , adapted with permission

The applicable standards

The industry standards have converged into ISO/IEC/IEEE 15288

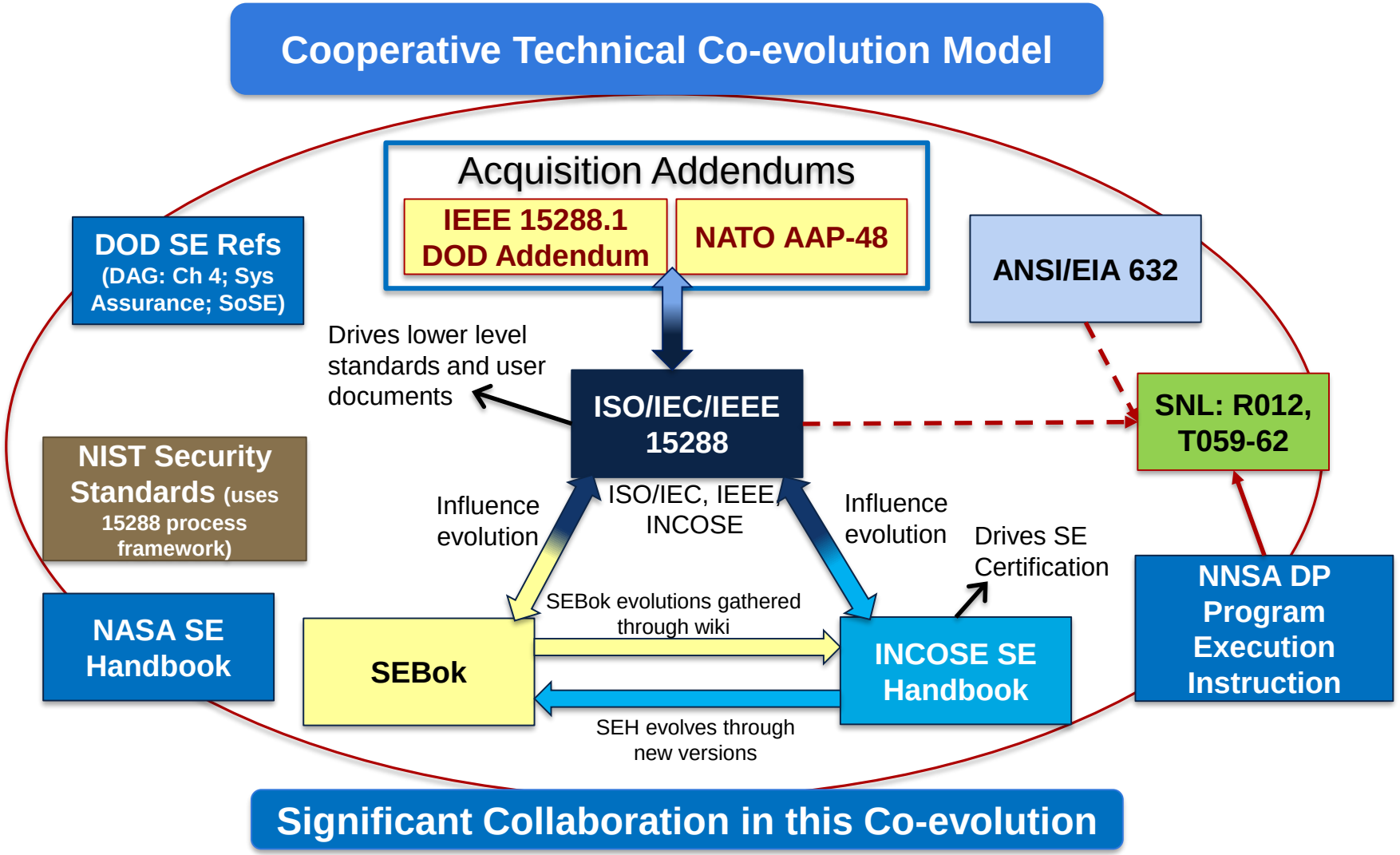
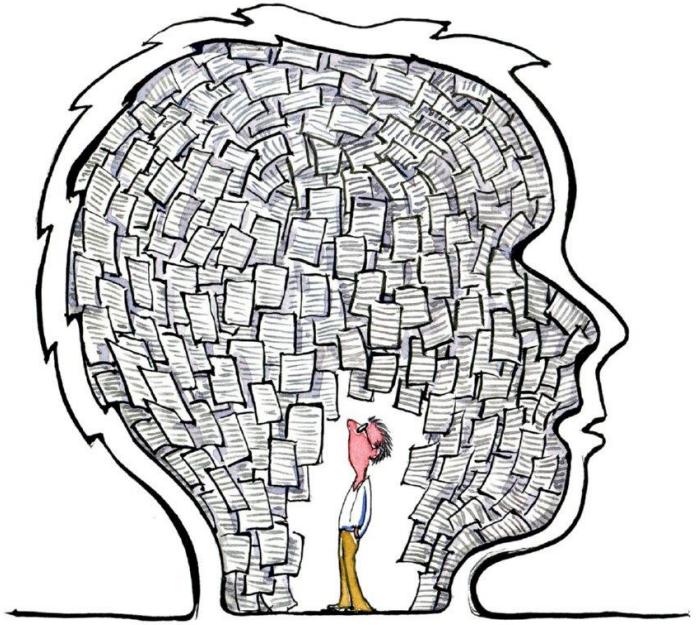


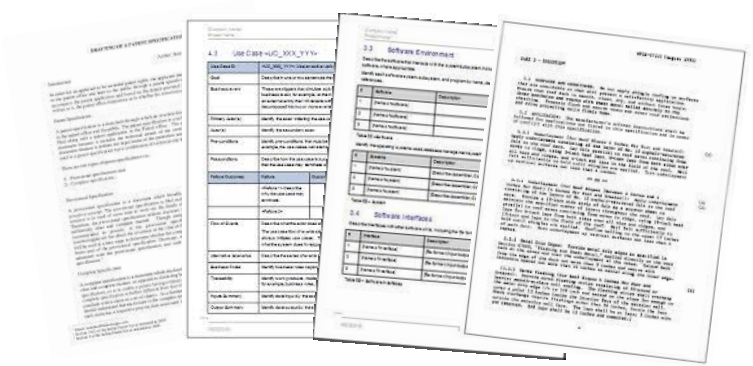
Figure 2: © 2016 Garry Roedler, adapted with permission

What is driving us toward MBSE?



A picture is worth a thousand words.jpg © 2012

How do I navigate this???



- Complex system example:
- Heavily document-based approach
- Over 6000 parts per system
  - Customer docs:
    - Text: 327 pages, over 750 mined requirements
    - Physical: 396 mined requirements
  - These led to system and major component requirements documents:
    - 832 pages of functional requirements
    - 232 pages of interface requirements
  - Documents do not address
    - Subordinate components
    - Environments
    - Dev Test plan
    - Qual plan
    - Maintenance/Ops Plan
    - Standards and Best Practices
    - Any production related requirements

Figure 4

What is driving the industry to MBSE?

Sandia National Laboratories

- Systems are getting more complex
- Customers want to reduce cost / schedule
- Customers want guaranteed reliability

Others have said "how can we not use an MBSE approach?" - Consider SNL's agile, adaptable, affordable initiative

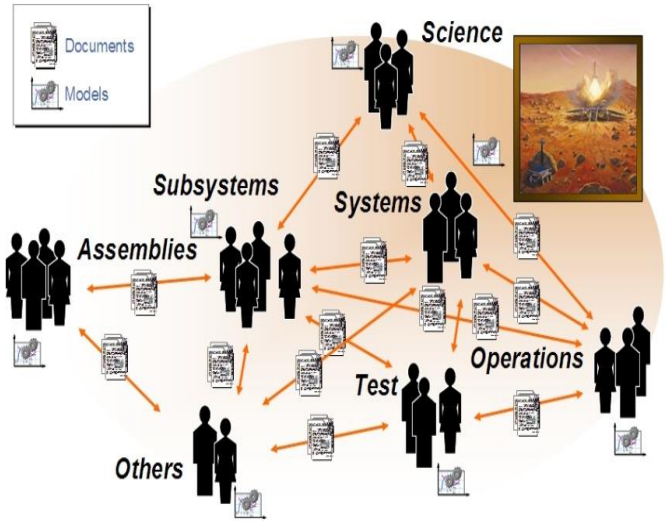
- Modeling is prevalent in all engineering disciplines
  - Electrical, mechanical, physics-simulation, software
  - Data shows a positive ROI for using models to solve the problems of complexity, cost, and reliability
- DOD is mandating models in contracts
  - The Ground Based Strategic Deterrent
  - CVN-80, LCS, F-35
  - Nunn-McCurdy breach on the GPS III program – due to inadequate systems engineering at program inception, the Air Force said in a press statement.
- Additive Manufacturing requires models

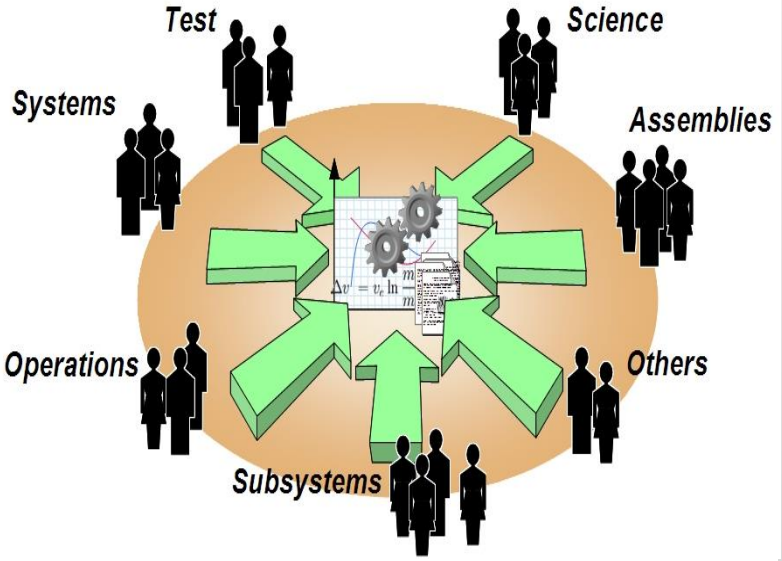
Metrics to measure MBSE

- Gathered from existing processes:
  - SME and MGR use characteristics and opinions
  - Defect rates
    - Failure mode analysis – tracing, mistake proofing
    - Halt/Hass, Fagen Inspections, CONOPS reviews
    - Interaction points, degree of completion, consistency
    - Compare to COQUALMO defect predictions
  - Level of Effort (cost and schedule)
    - compare man hours to $$ and schedule overage
  - Informal Assessment of SE Capability

gathered as a bi-product of project work already being conducted

What Would MBSE Look Like …
In Current Practice to Future Practice





Today: Standalone models related through documents

Future: Shared system model with multiple views, and connected to discipline models

INCOSE
International Council on Systems Engineering

MBSE Workshop

Figure 5: © INCOSE, adapted with permission 2014

What SE Processes does MBSE overlay?

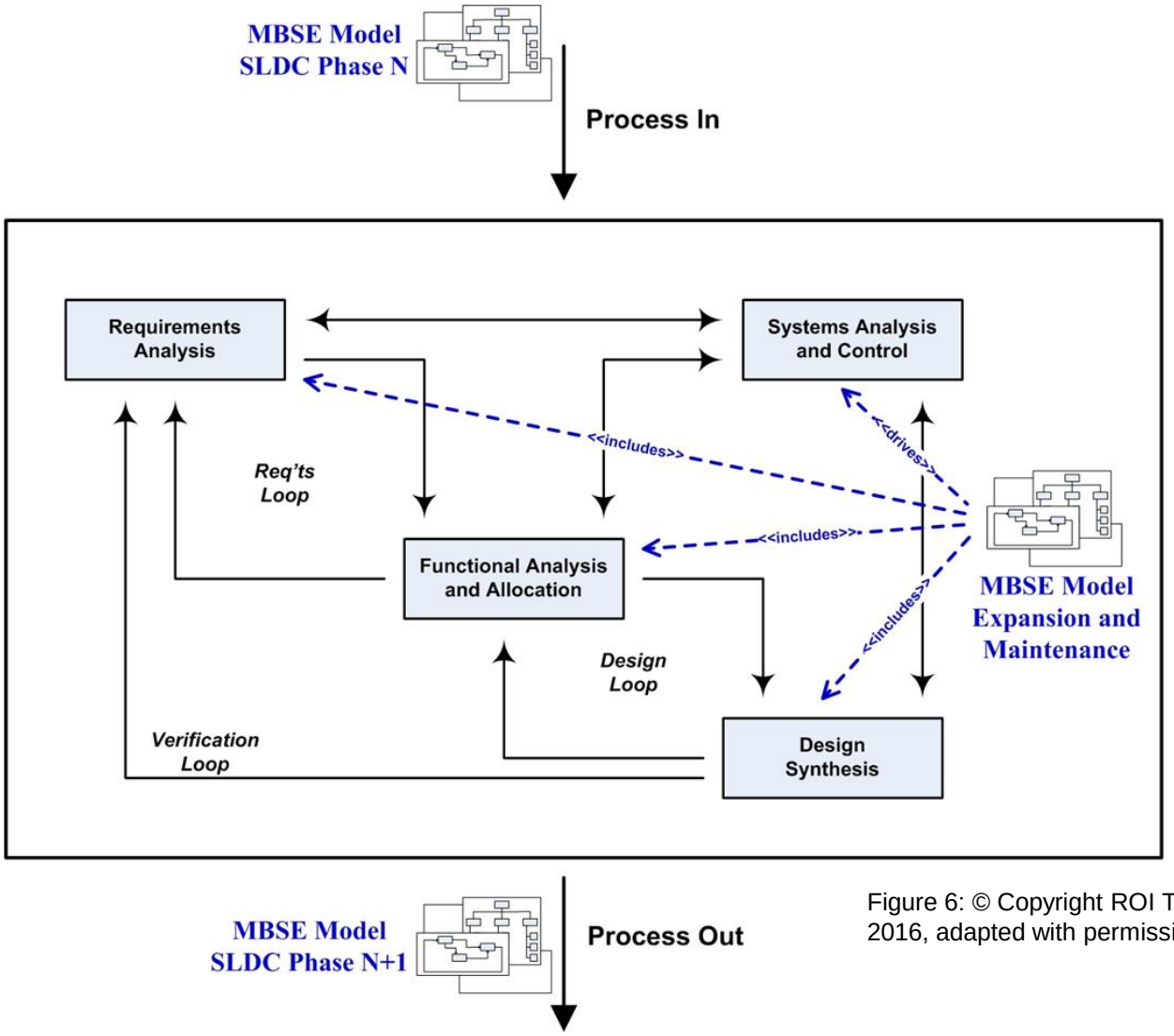


Figure 6: © Copyright ROI Training, Inc. 2016, adapted with permission

What is Different When Using MBSE?

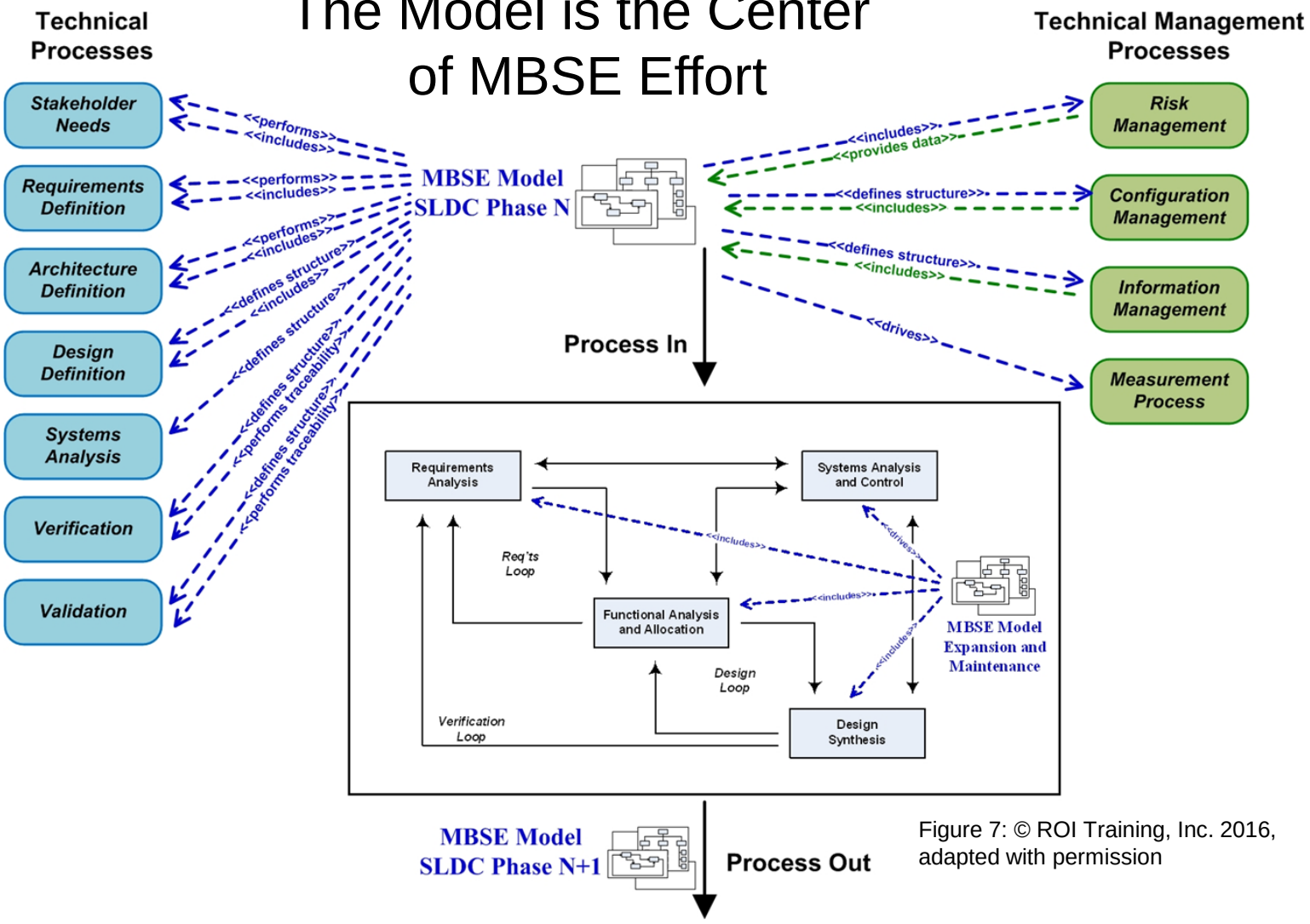


Figure 7: © ROI Training, Inc. 2016, adapted with permission

Overlaying MBSE to SE Foundation

Figure 8: © INCOSE, with permission 2012

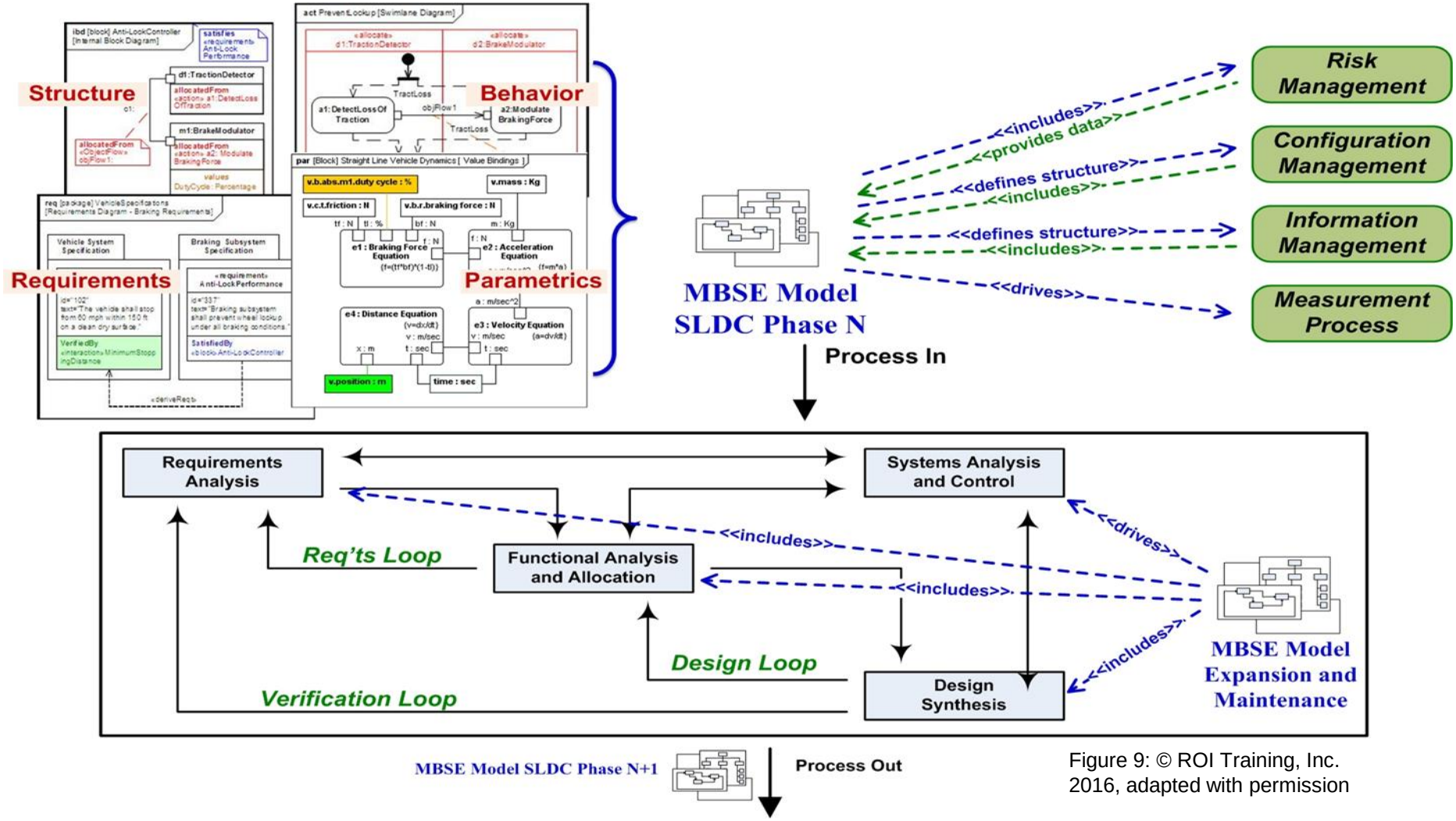


Figure 9: © ROI Training, Inc. 2016, adapted with permission

Sandia National Laboratories

WHY MBSE?
- FINDINGS FROM MY STUDY

My Value Study Process

- Literature Review
  - 67 case studies justified by claiming benefits of:
    - (67) 8 countries, 10 defense, 33 space, 5 non-defense, 6 commercial
  - 21 case studies justified with quantified results of:
    - (21) 4 countries, 12 defense, 5 space, 4 commercial, 6 used MBSE to develop complex weapon systems
- Standards Review
  - IEEE, ISO, ANSI/EIA, INCOSE, DOD, DOE, NASA
- Expert Elicitation
  - 33 SME's, 12 MGR's
- Pilot Projects
  - Small, Large, Shadowed Actual, Integral to SE Effort

My Value Study Key Findings

Sandia National Laboratories

- Primary Advantages:
  - Finding defects and preventing rework
  - Cost and schedule improvement – due to defect prevention
- Secondary Advantages:
  - Completeness, consistency, and improved communications
  - Contributes to test and evaluation, V&V, concept exploration, design reuse and systems margin analyses
- Standards have coalesced around the IEEE/ISO 15288
- Heavily dependent upon acceptance and support
- Must be integral to SE effort

MBSE Avoids Rework

	System f0 Phase	Success Probability [probOfSuccess]	Failure Probability [1 - probOfSuccess]
No change to design	Baseline	0.6	0.4
Without MBSE	Update 1	0.73	0.27
With MBSE	Update 2	0.93	0.07

From 73 % chance of success to 93 % chance of success

Figure 20: © Rafael Mareni Perez 2014, adapted with permission

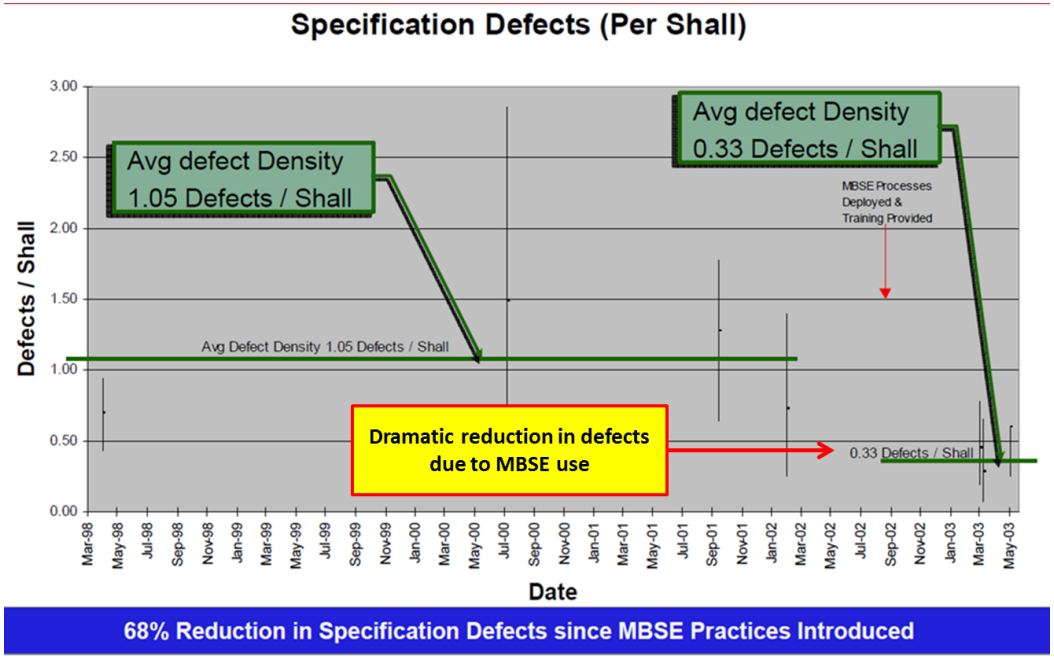
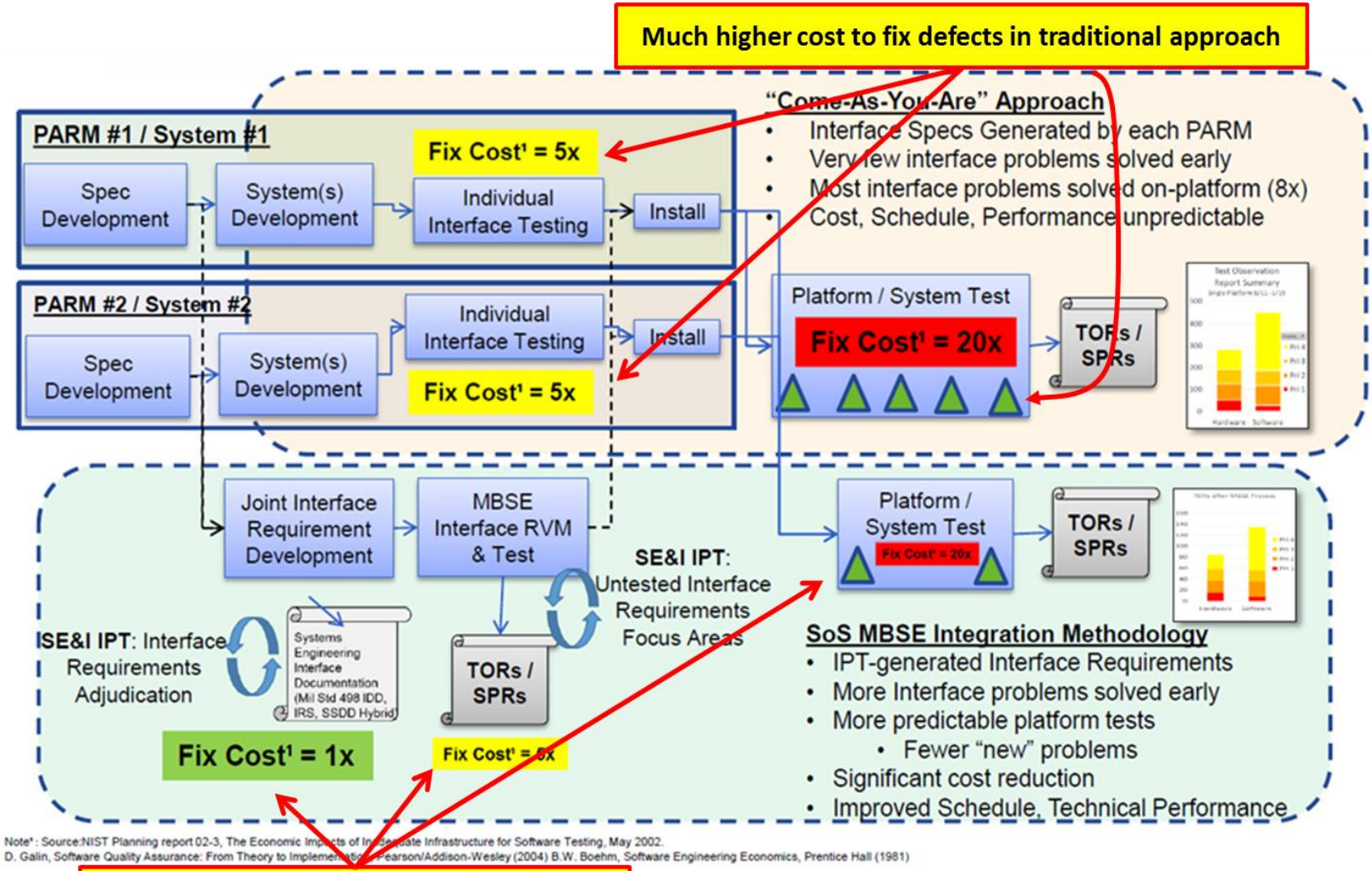


Figure 21: © Raytheon Company 2011 (DAT&L)

MBSE Avoids Rework



Note¹ : Source:NIST Planning report 02-3, The Economic Impacts of Inadequate Infrastructure for Software Testing, May 2002.
D. Galin, Software Quality Assurance: From Theory to Implementation, Pearson/Addison-Wesley (2004) B.W. Boehm, Software Engineering Economics, Prentice Hall (1981)

Figure 19: © Lockheed Martin Corporation 2015, adapted with permission

MBSE Provides Significant Advantage

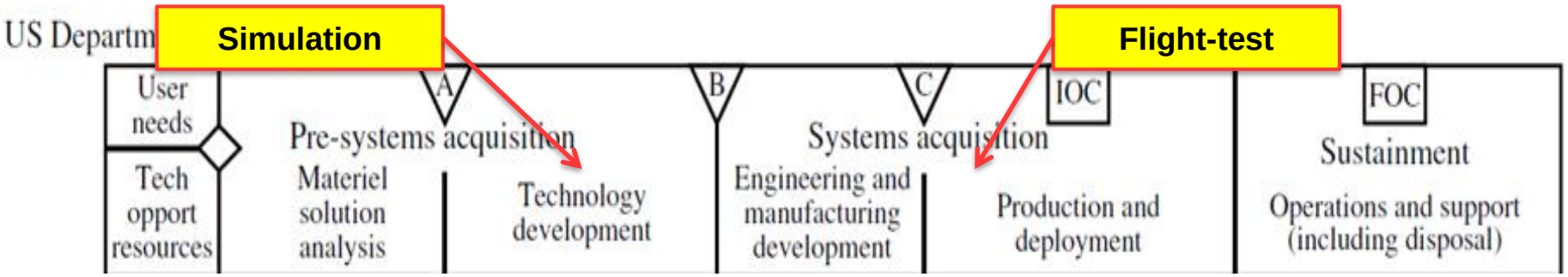
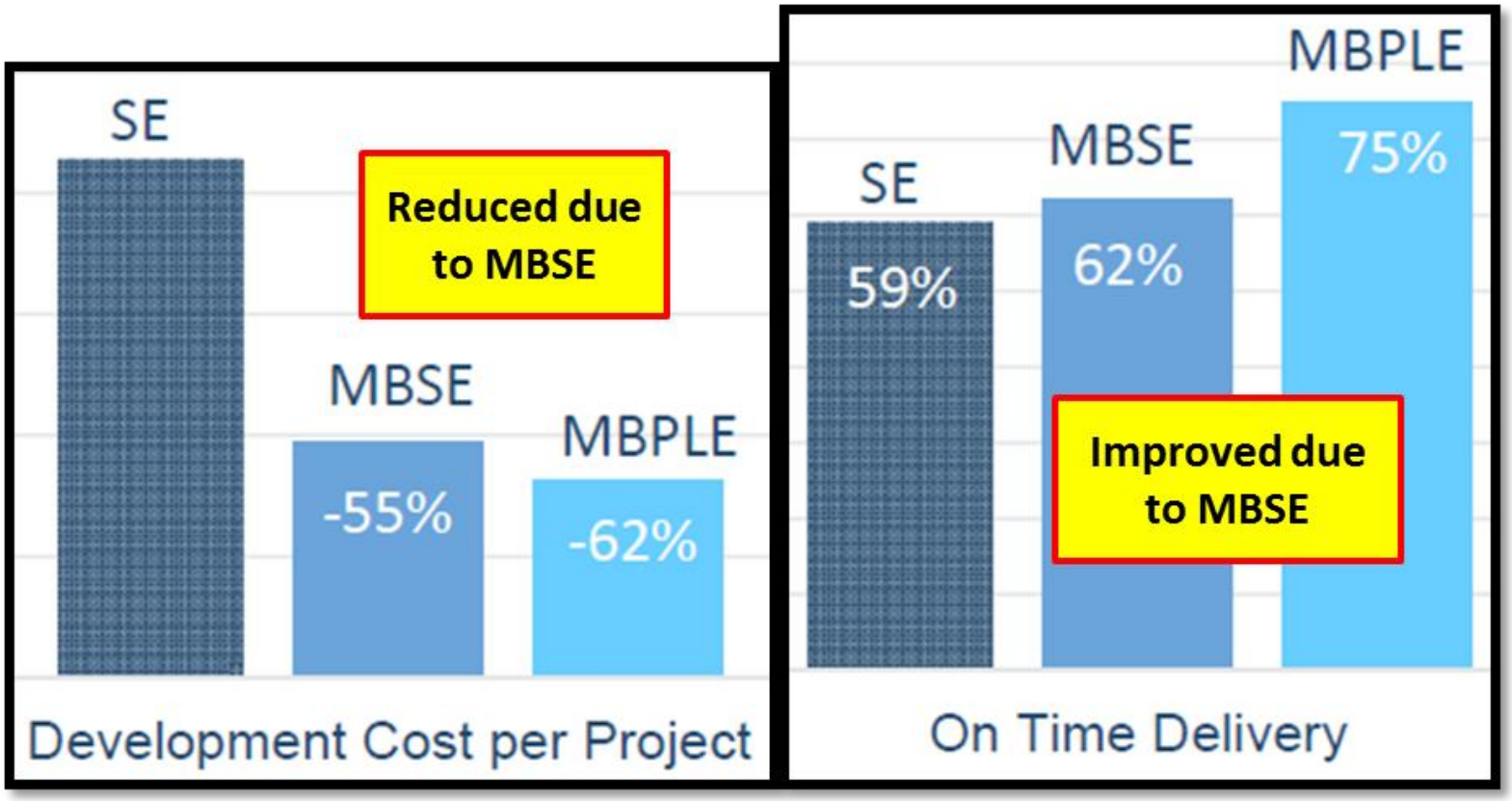


Figure 17: © *INCOSE* 2014, adapted with permission

Figure 18: © by-sa 2.0 Tim Felce – Gripen – RIAT 2010

MBSE Provides Significant Advantage



MBSE is an extension of Systems Engineering,
And model-based product line engineering is an extension of MBSE

Figure 11: © PTC inc. 2014, adapted with permission

SE Improves Engineering Efficiency

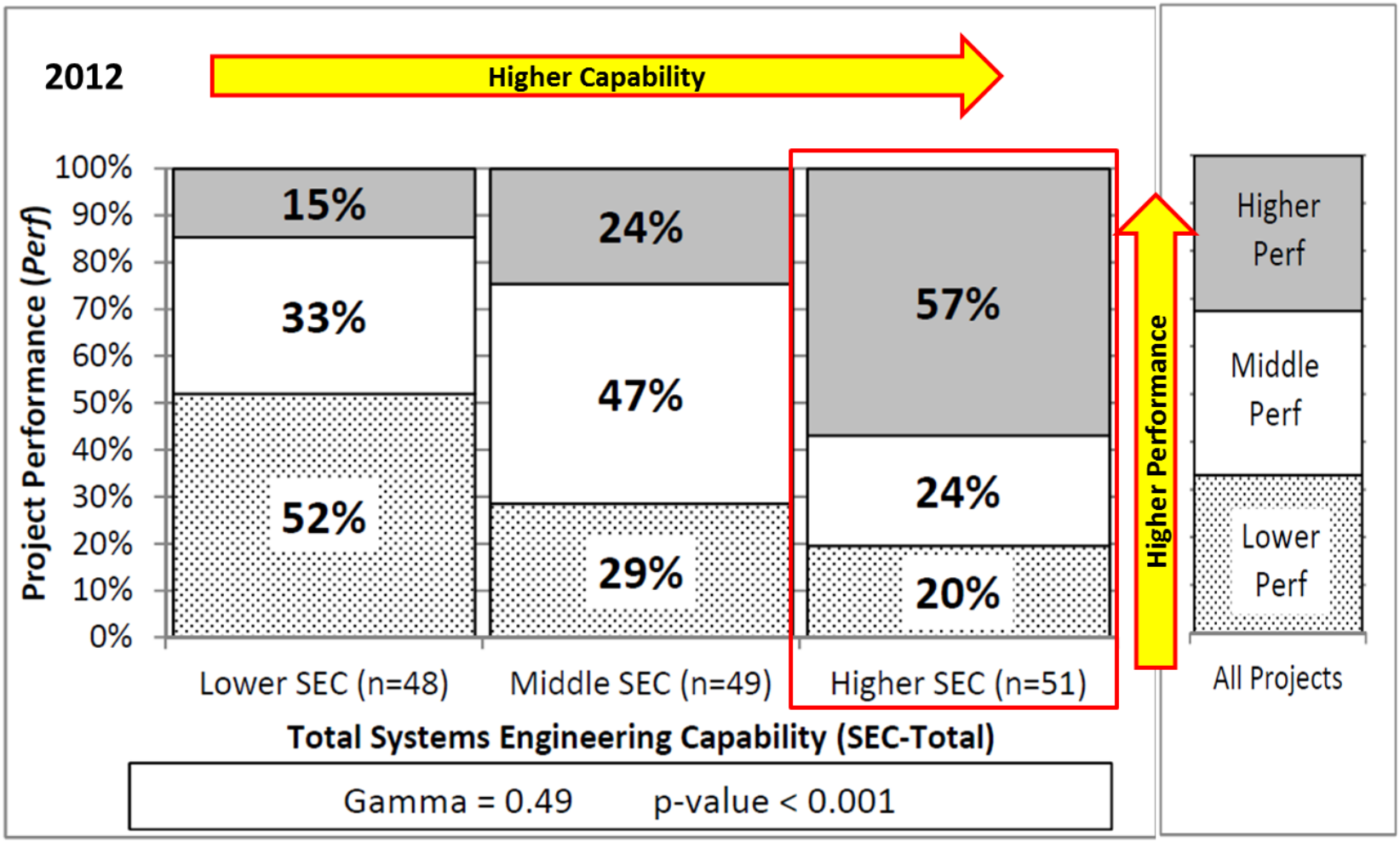


Figure 12: © Carnegie Mellon University 2012, adapted with permission

MBSE Prevents Defects and Rework

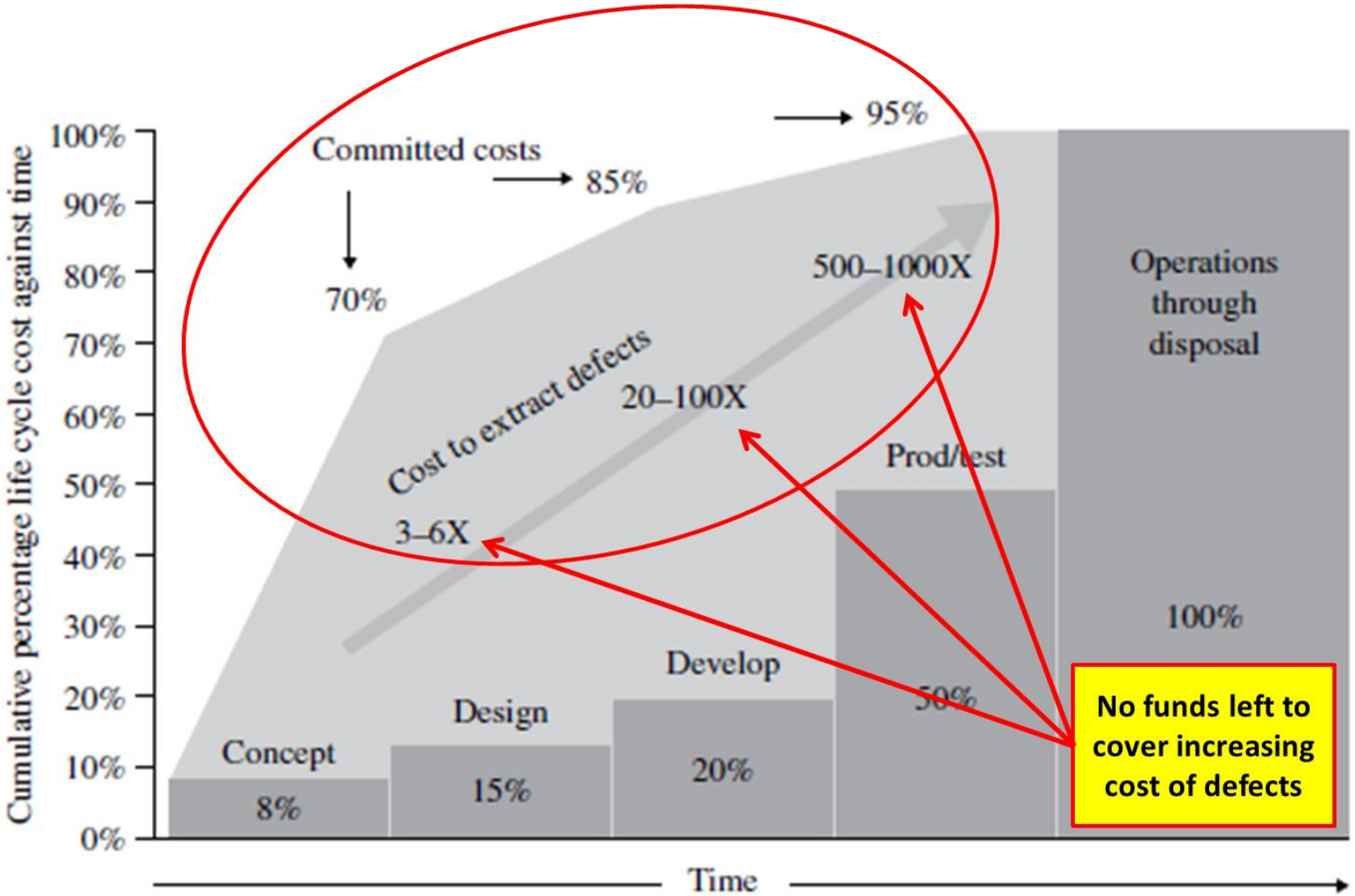


Figure 13: © Raytheon Company 2011, *Defense AT&L*

SEs Need to Drive Engineering Processes

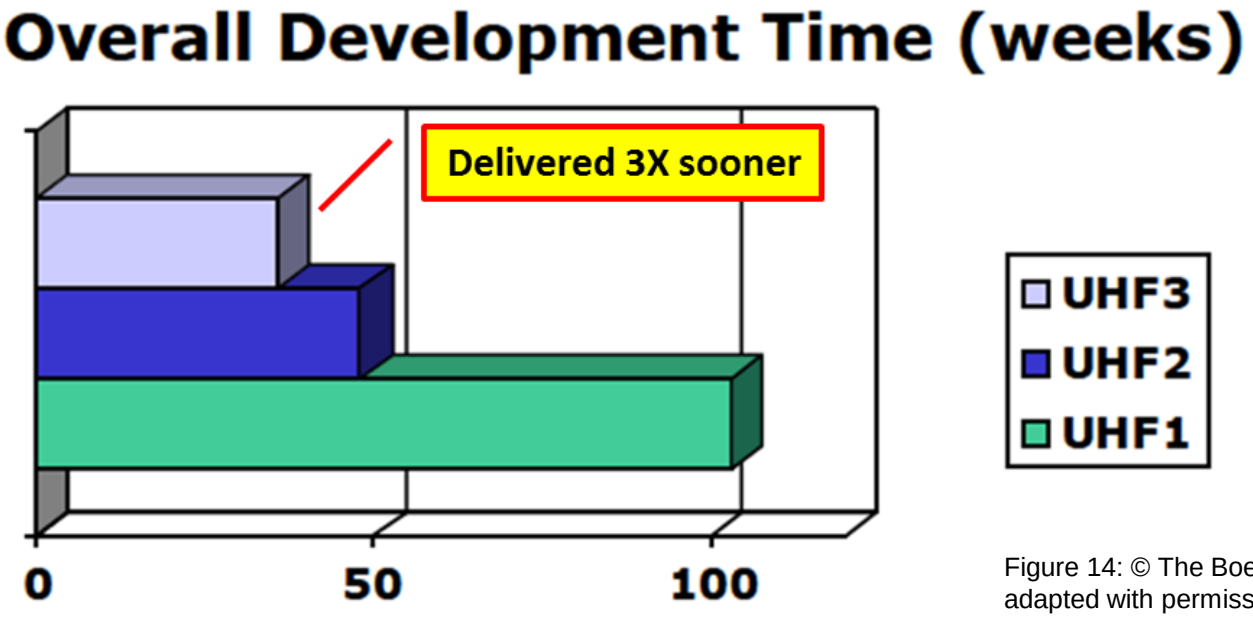
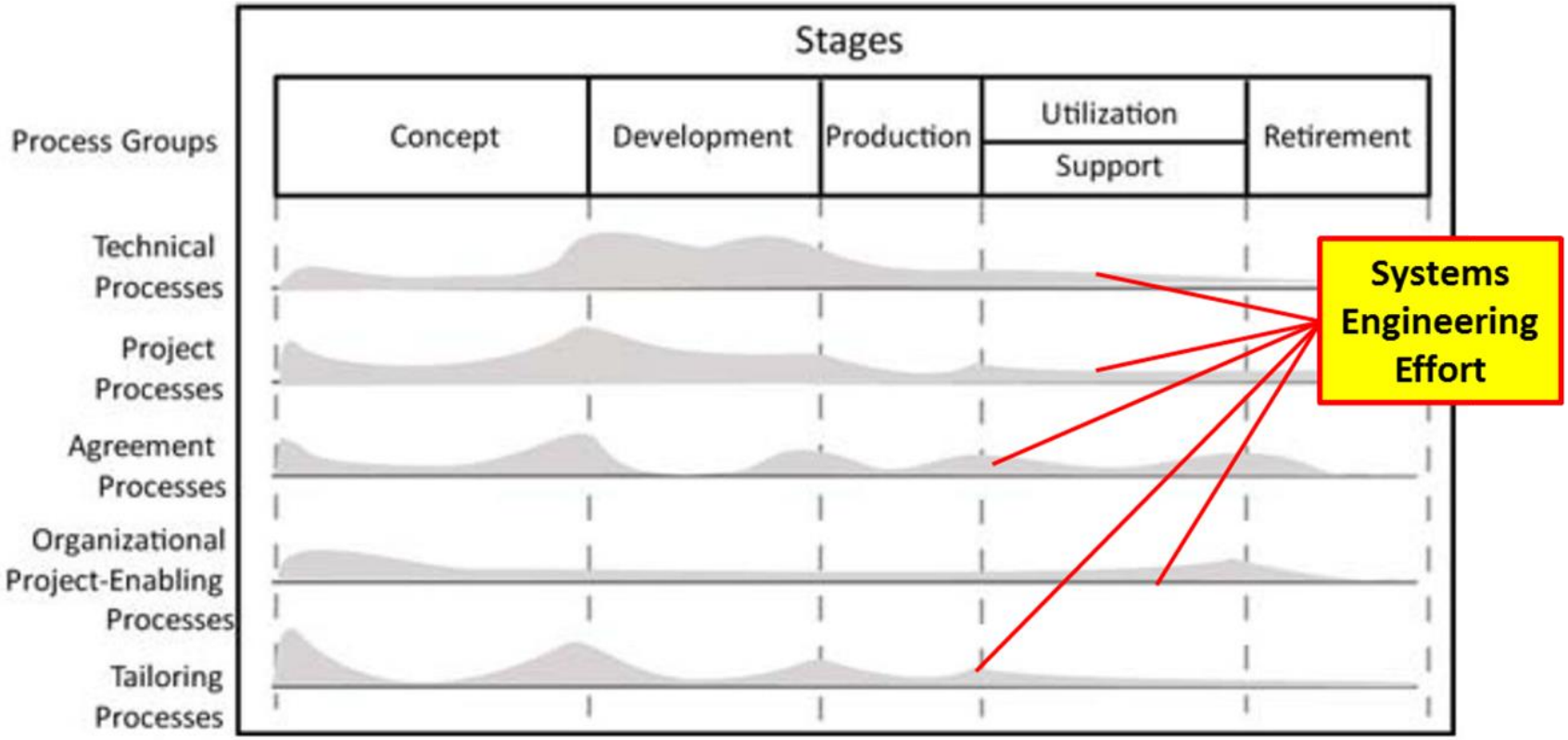


Figure 14: © The Boeing Company 1995, adapted with permission

- To effect delivery, SEs must drive their processes
  - First change the model, then change the system
  - High access to systems management, who pays attention

Skilled SEs are Needed to Drive Engineering Processes



- Delivery times are not effected by data entry clerks
- Systems Engineers must be well trained engineers
  - MBSE employs new techniques, tools, and processes

Figure 15: © INCOSE adapted with permission 2012

The data shows an optimal SE staffing at 12-17% of total

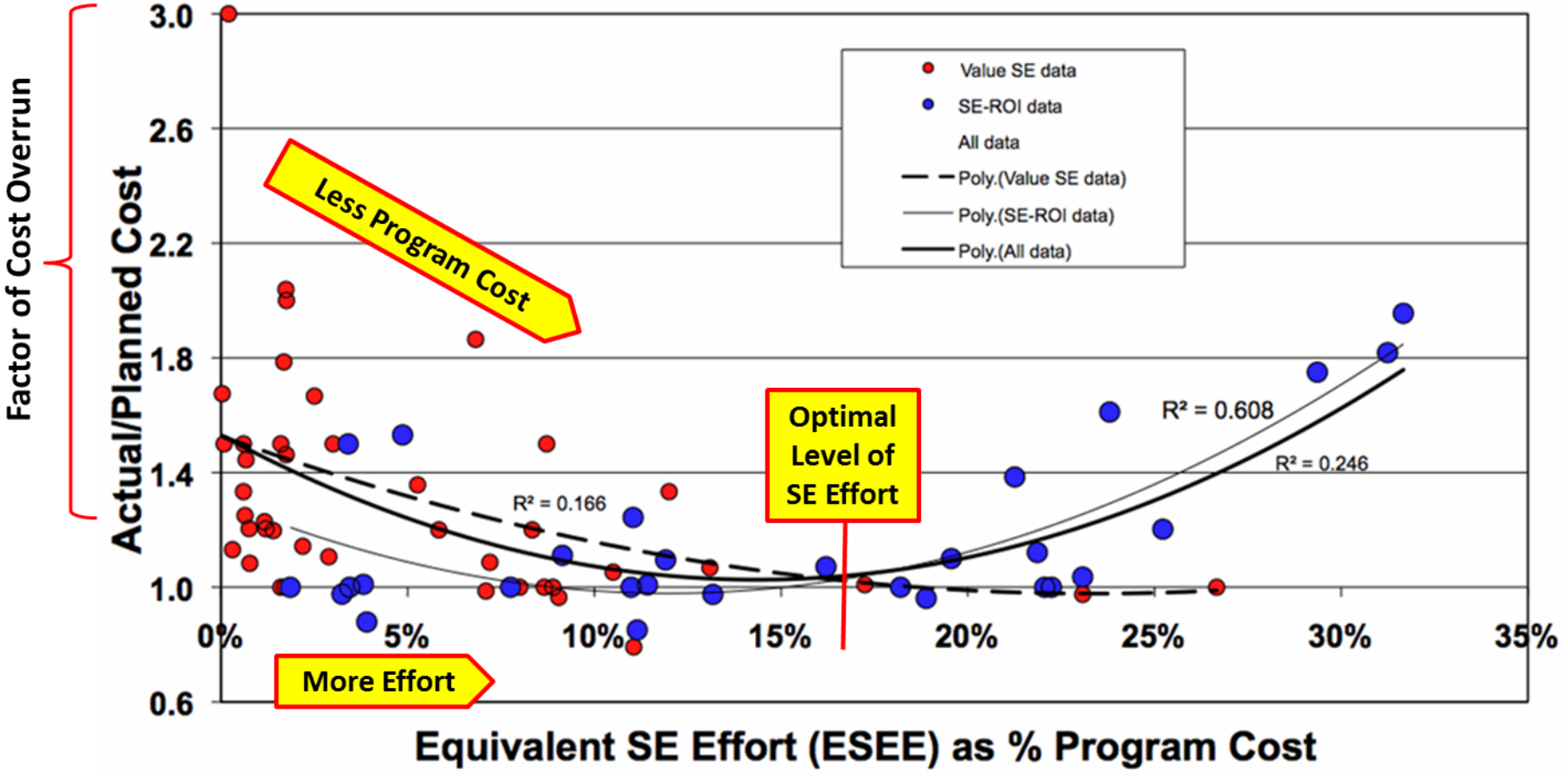


Figure 16: © Eric Honour 2013, adapted with permission

Adding MBSE to the SE Foundation?

- Good SE = Good Program Performance
- Good SE → begets → Good MBSE
- Good MBSE = Good program Performance

- The model becomes the center of information
  - For Communication – across team and across program
  - For Technical Process Performance
  - For Technical Management Processes

The Keys to effectiveness

- From our Systematic Literature Review of the industry, the following findings were reported as keys for effectiveness:
  - Engage Systems Engineers as engineering process leaders
  - Diligently perform defined (iterative) SE processes
  - Plan for Systems Engineering effort to be highest early in the project
  - Plan for an optimal SE staffing is up to 12-17% of total program staffing

Engage System Engineers as technical leaders of these processes

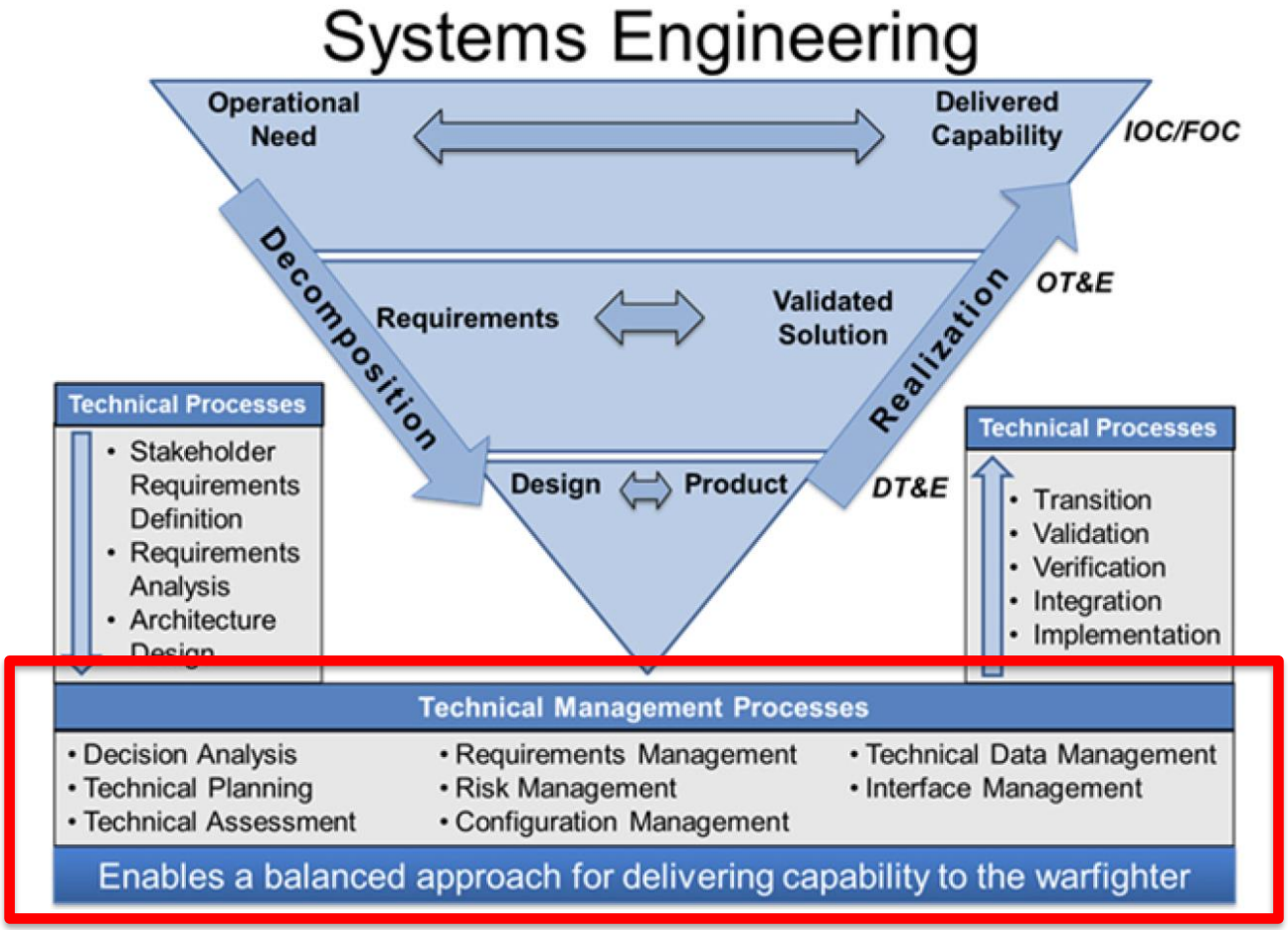


Figure 22: © the Defense Acquisition University

Systems Engineers Need Support

- Systems Engineers as Technical Leaders
  - They have the view of the entire system
  - They have the view of change impact
  - They have the understanding of requirements
  - They are responsible for risk, analysis, assessments, configuration, and interfaces

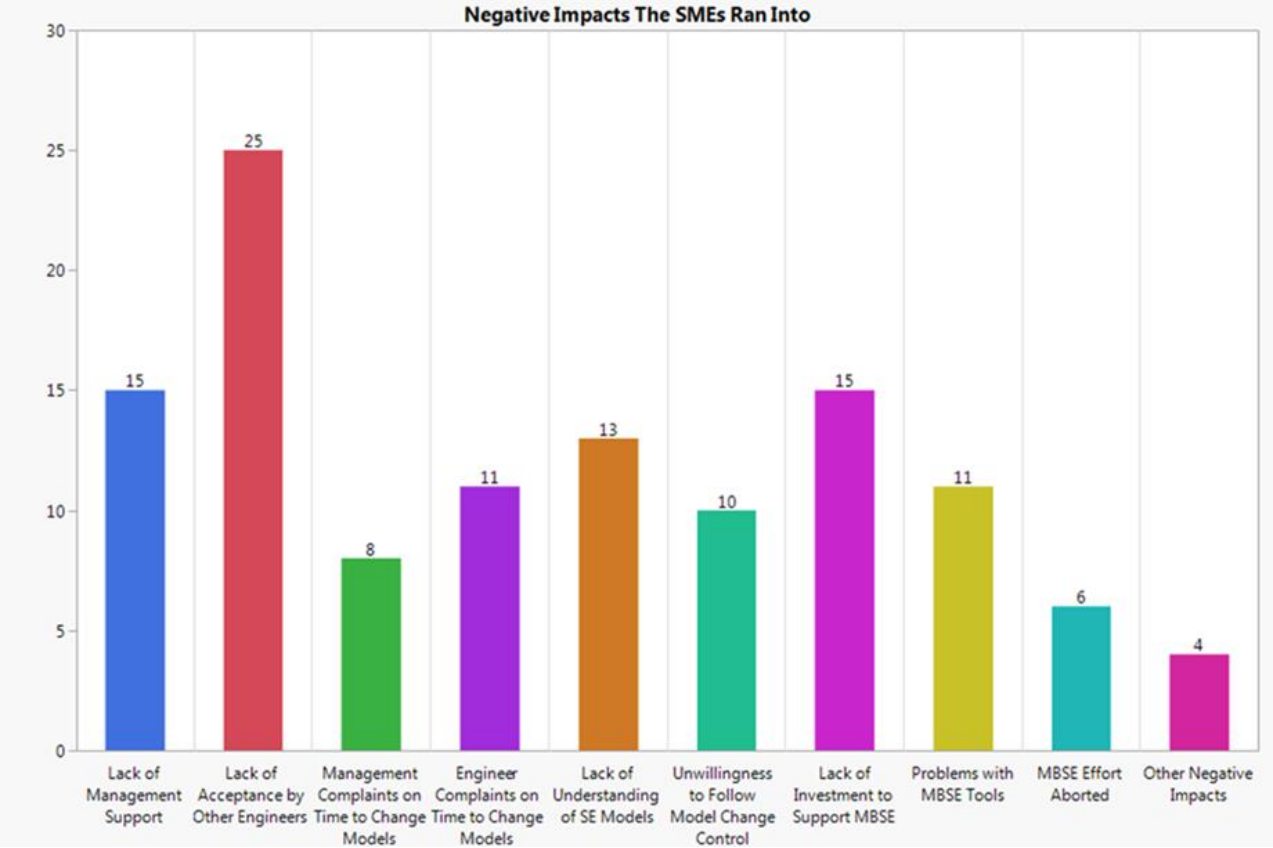


Figure 23

Key Processes – Iterate through feedback

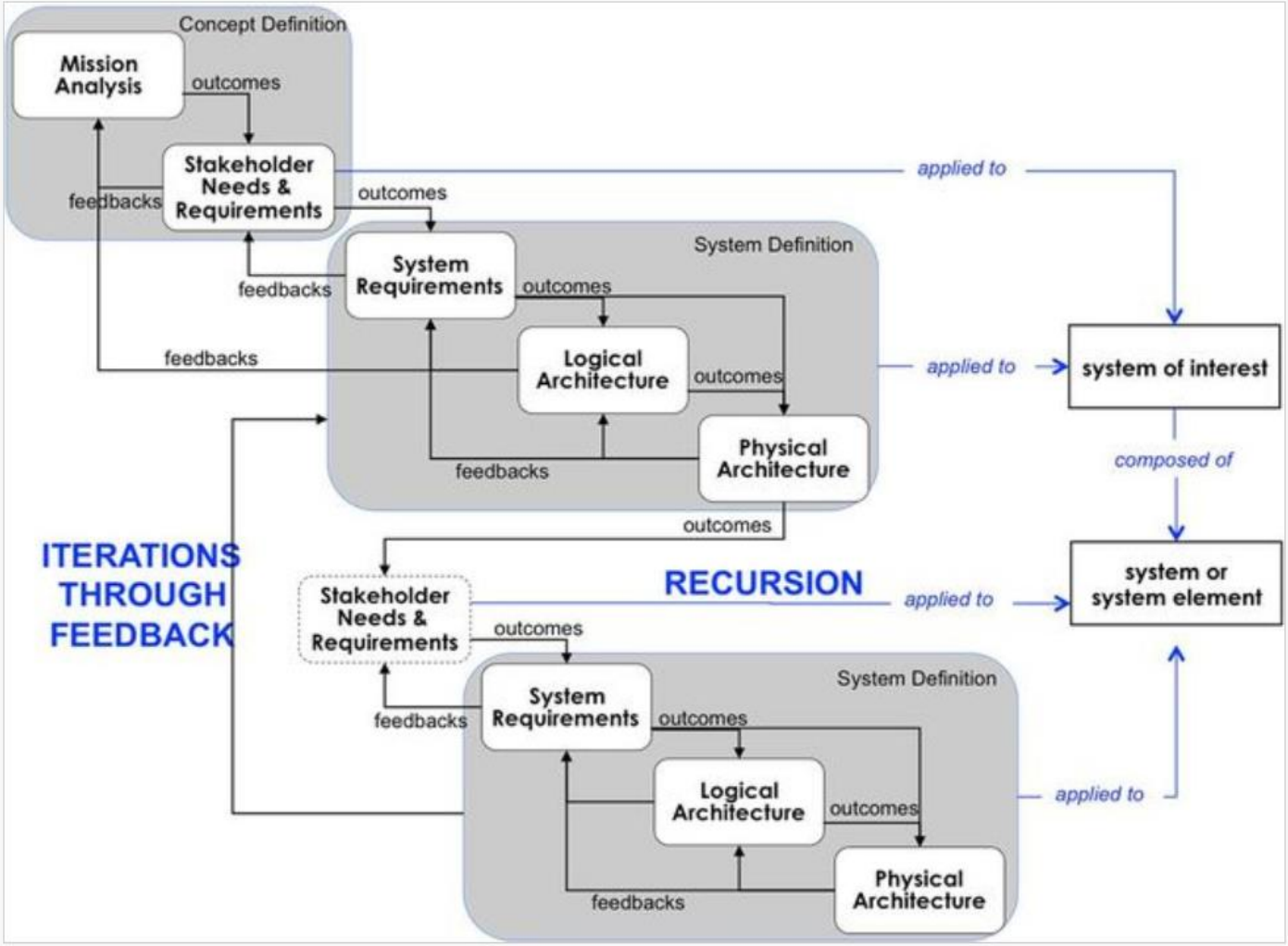


Figure 4. Recursion of Processes on Layers (Faisandier 2012). Permission Granted by Sinergy'Com. All other rights are reserved by the copyright owner.

Figure 24

SE Effort is highest early in project

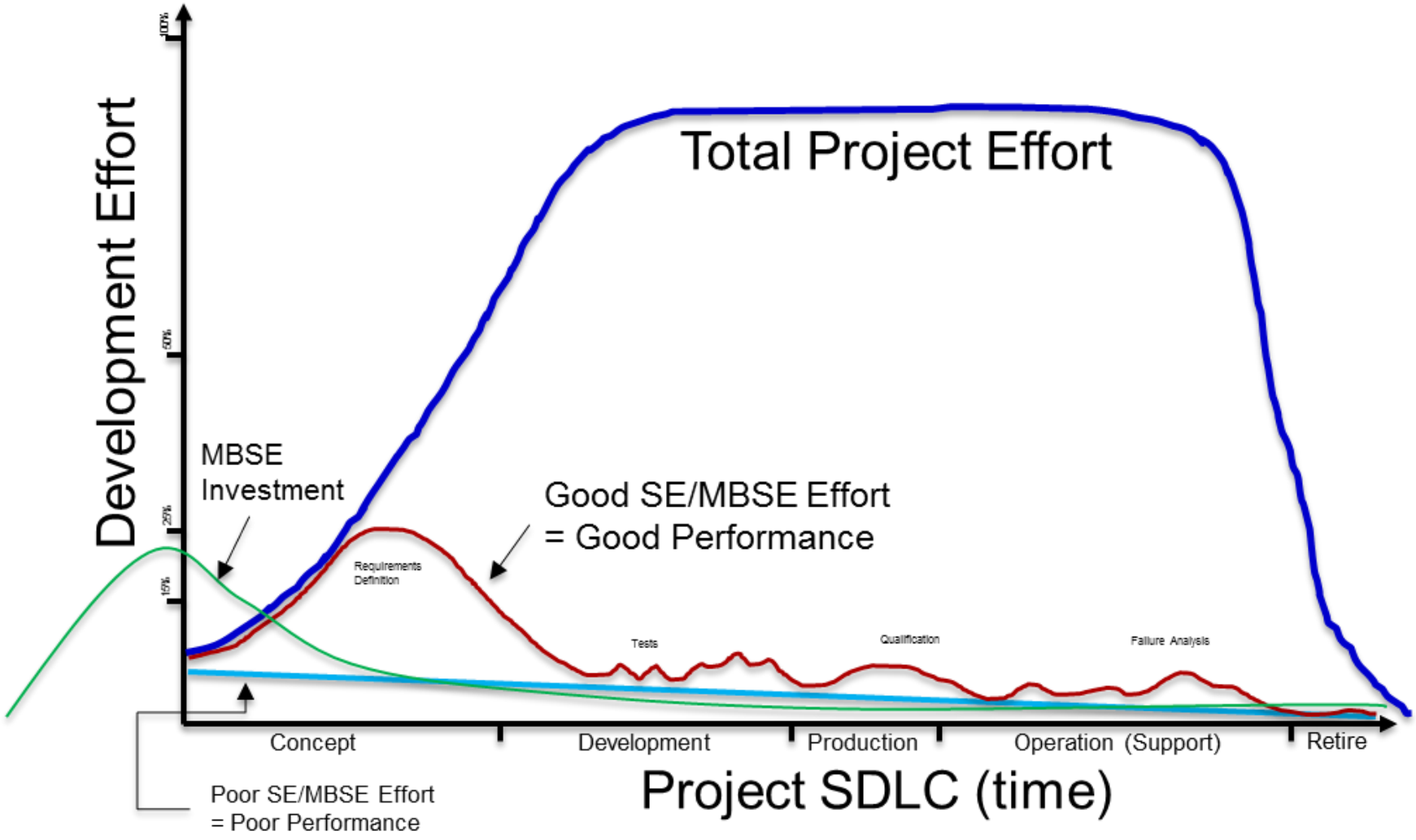


Figure 25

Prerequisites

Sandia National Laboratories

- Well documented SE processes that spans the SDLC
- Trained systems engineers
- Access to training in the SE processes at SNL
- Defined processes for model management throughout the SDLC
- Invest in full scale MBSE tools

Commitments

- Initiate modeling with appropriate staffing levels at the beginning of a program
- Configuration manage the model “change the model first, then the design”
- Provide continuous resources to maintain the models throughout the SDLC
- Provide MBSE resources and models to support qualification
- Provide appropriate computing infrastructure throughout SDLC

Orion - Human Space Flight

"Orion was designed from inception to fly multiple, deep-space missions. The spacecraft is an incredibly robust, technically advanced vehicle capable of safely transporting humans to asteroids, Lagrange Points and other deep space destinations that will put us on an affordable and sustainable path to Mars."

Lockheed Martin Space Systems

- Denver, CO
- 100% system reliability required
- Model-centric customer (NASA)
- Core MBSE Team

Figure 26: © NASA Photo

Europa Exploration Mission

Sandia National Laboratories

"This effort entails a highly complex integration of extensive modifications and numerous subsystems which must seamlessly interface with each other in order to meet the NASA 'no fail' mission."

JPL

Pasadena, CA
Model-driven customer (NASA)
100% digital design and documentation

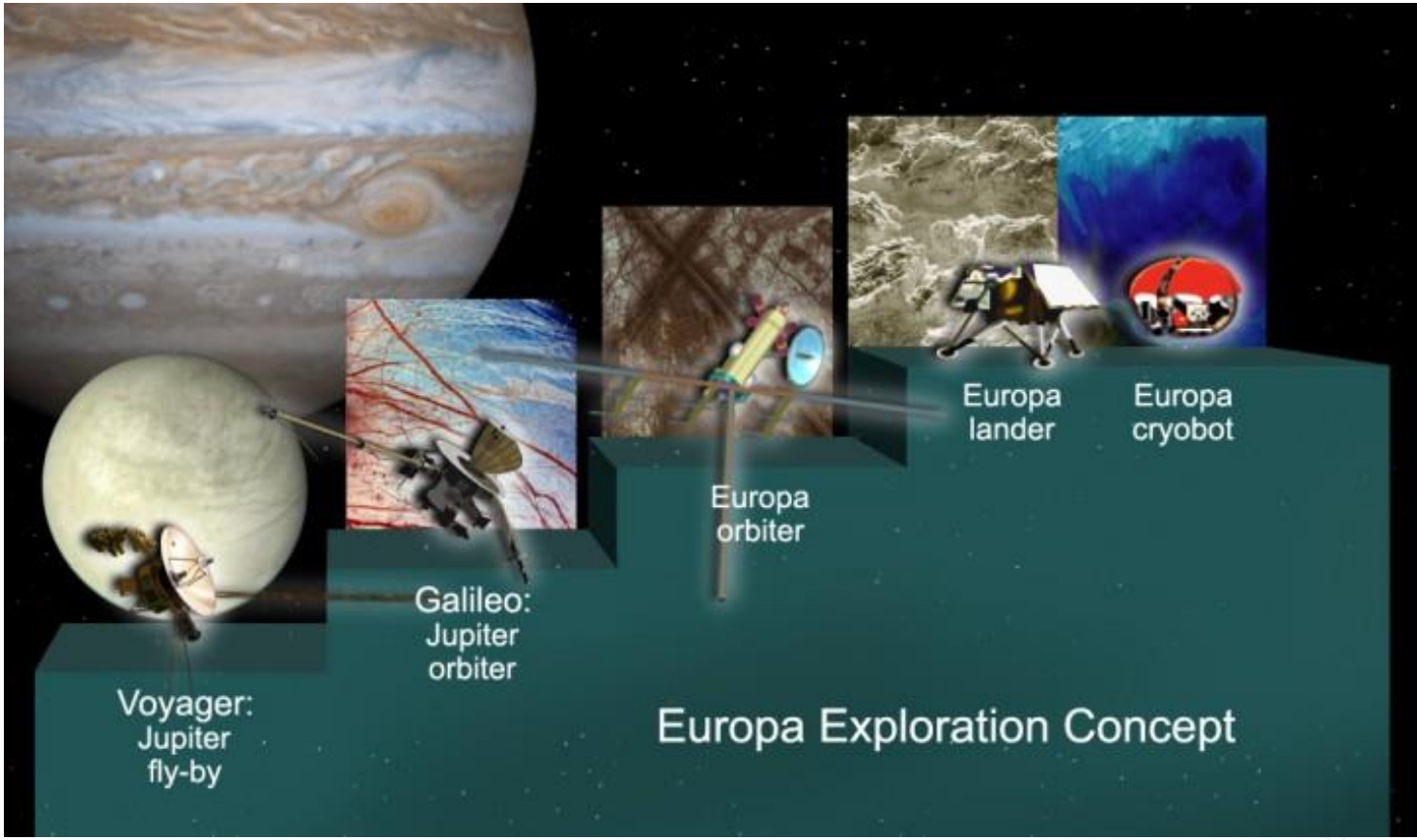


Figure 27: NASA/JPL photo

References

1. Key Systems Engineering Standards, © Garry Roedler 2016, adapted with permission
2. System Engineering Standard Relationships, © Garry Roedler 2016, adapted with permission
3. Systems Engineering "V", © The Defense Acquisition University
4. Wikimedia Commons contributors, "File:A picture is worth a thousand words.jpg," *Wikimedia Commons, the free media repository,*
5. What Would MBSE Look Like graphic © INCOSE, with permission 2014
6. What SE Processes, © ROI Training, Inc. 2016, adapted with permission
7. What is the Difference, © ROI Training, Inc. 2016
8. Overlaying MBSE on SE, © INCOSE 2012
9. SE Foundation, © ROI Training, Inc. 2016, adapted with permission
10. MBSE Advantages, © 2014 PTC Inc., Professional Paper, November 24, 2014, adapted with permission
11. SE Improves Efficiency, © Carnegie Mellon University. November 2012, adapted with permission
12. MBSE Cost Model, © Raytheon Company 2011, Published in the *Defense AT&L* (public domain)
13. Overall Development Time, © The Boeing Company 1995
14. Engineering Processes, © INCOSE, with permission 2012
15. Optimal SE Staffing, © Eric Honour 2013, adapted with permission
16. Early Defect Detection, © *INCOSE,* with permission 2012
17. JAS 39E Fighter Jet, © by-sa 2.0 Tim Felce – Gripen – RIAT 2010
18. Rework Avoided, © Lockheed Martin Corporation 2015, adapted with permission
19. Failure Probability, © Rafael Mareni Perez 2014, adapted with permission
20. Specification Defects, © Raytheon Company 2011, Published in the *Defense AT&L* (public domain)
21. Systems Engineering "V" (2), The Defense Acquisition University
22. Key Processes Iterate, © Faisandier 2012
23. Negative Impacts the SME's Ran Into, Ed Carroll, © Sandia National Laboratories 2016
24. SE Effort Early in SDLC, Ed Carroll, © Sandia National Laboratories 2016
25. Orion Human Space Flight, NASA photo
26. Europa Exploration Mission, NASA/JPL photo