A Few Words First

Courtesy – Please mute your phone (*6 toggle).

Socorro Summit – 48 attendees, high evaluations and attendees want another. Garry Roedler, INCOSE President-Elect, keynoted and recommended to INCOSE Board afterwards that the collaborative concept be replicated by other Chapters. Proceedings are posted on Chapter Website/Library/Summit.

Board elections are completed – Gained 2 from Sandia: Jason Jarosz and Evan Richardson. Lost 3: Regina Griego and Jeni Turgeon from Sandia declined to run, and Mike Gruer from Honeywell is moving away.

Dec 2, Holiday Social: Savoy Bar & Grill with 3-course dinner and speaker Jennifer Owen-White, manager Valle de Oro urban wildlife refuge. $20 cheap. 5:00pm-8:00pm. RSVP by noon 30-Nov. info on Chapter website.

Jan 11, Systems Engineering Transformation through Model Centric Engineering, Mark Blackburn, Stevens Institute of Technology.

Jan 28-31, INCOSE International Workshop, Torrance, CA (LA area).

**CSEP Courses by *Certification Training International:*
<u>Course details</u> | <u>Course brochure</u>
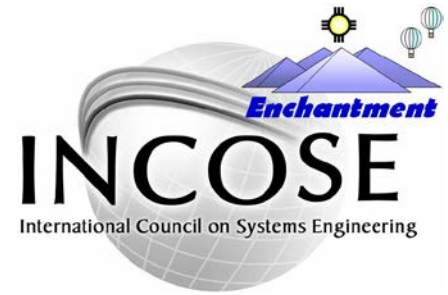2016 Course Schedule (close by, but many more locations and dates):
February 27 – March 3 | Las Vegas, NV
April 24-28 | Albuquerque, NM**

First slide, not recorded but retained in pdf presentation.

And Now - Introductions

Enchantment Chapter Monthly Meeting

<u>9 November 2016 – 4:45-6:00 pm</u>:

How is Model-based Systems Engineering Justified?

Ed Carroll, Systems Research and Analysis, Sandia National Labs
<u>ercarro@sandia.gov</u>

Abstract: The change process, investment, training, and tools needed to implement a model-based systems engineering (MBSE) approach across the engineering enterprise are substantial. How is the change from a document-based systems engineering approach (DBSE) to a model-based systems engineering approach (MBSE) justified? The primary conclusion from a literature review is that there is a significant advantage to project performance by applying an MBSE approach. An MBSE approach made the engineering processes on a complex system development effort more efficient by improving requirements completeness, consistency, and communication. These were seen in engineering processes involved in requirements management, concept exploration, design reuse, test and qualification, Verification and Validation, and margins analyses. An MBSE approach was most effective at improving defect prevention strategies. The approach was found to enhance the capability to find defects early in the system development life cycle (SDLC), when they could be fixed with less impact and prevented rework in later phases, thus mitigating risks to cost, schedule, and mission.

Download slides today-only from GlobalMeetSeven file library or anytime from the Library at <u>www.incose.org/enchantment</u>
NOTE: This meeting will be recorded

Today's Presentation

Things to Think About

How can this be applied in your work environment?

What did you hear that will influence your thinking?

What is your take away from this presentation?

Speaker Bio

Ed Carroll is a research analyst at Sandia National Laboratories and a hands-on data-strategy professional who works closely with senior stakeholders to discover opportunities deep in the data.

With more than 20 years of experience developing data-intensive solutiolytic models for strategic decision making (often proving engineering best practices), economic performance analyses and merchandising optimization, improved processes for manufacturing and supply-chain management through statistical process control, and defined statistical comparisons of clinical procedure effectiveness.

Ed directed his own consultancy for 14 years, and provided strategic leadership in executive roles in business development for Online Business Systems and Agilis Solutions, as well as technology roles as vice president of engineering for Egghead.com, director of technology at Nike, and director of software engineering at Boeing.

Ed received a Bachelor of Art's degree in Liberal Arts from Arizona State University in 1979, a Master of Science degree in Systems Management from the University of Southern California in 1988, and a Graduate Certificate in BioMedical Informatics from Oregon Health Sciences University in 2011. He lives with his wife Barbara in Albuquerque, NM.

Exceptional service in the national interest
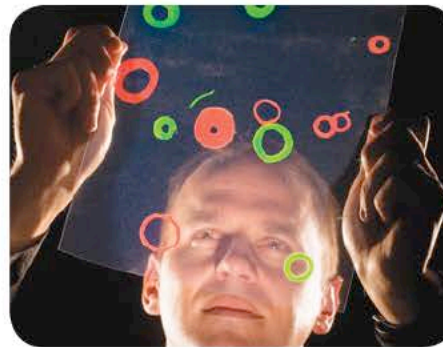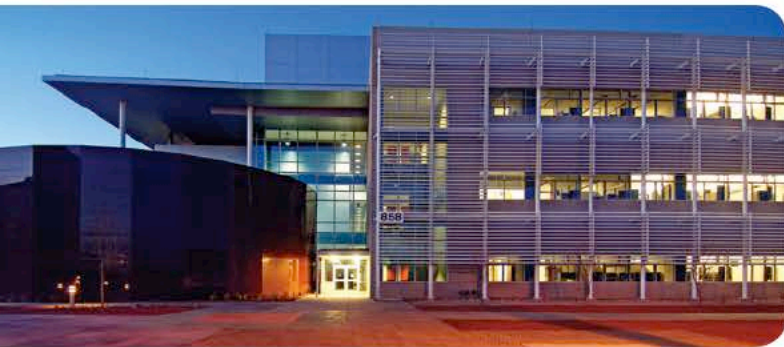
Systematic Literature Review:
How is Model-based Systems Engineering Justified?

Ed Carroll
Principal Systems Research Analyst
November 9, 2016

MBSE Study Introduction
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
- Four questions were outlined for the MBSE study:
    - What does it look like? (Industry standards, guidelines, and manuals)
    - What can we learn from others? (Literature review & external visits)
    - What are we currently doing? (SMEs and MGRs, & pilot projects)
    - What is the path forward? (based on conclusions from above)
- Pilots:
    - 4 pilot projects, including: small, large, complex, hardware, software
- External Visits
    - Lockheed Martin, JPL, Huntington Ingalls, USAF, US Navy, DOD, & DOE

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 are the authoritative definition of the system]

- Model-Based *Systems Engineering* – a specialized type of descriptive modeling used to create and analyze systems engineering information across the life cycle [the model is the authoritative definition for all systems engineering information]

Agenda

- Introduction – What is the value of MBSE to Sandia?

  - Gathering metrics about MBSE

- What is Systems Engineering?

  - Industry description (iterative processes)

  - What is driving us toward MBSE?

- What is Model-based Systems Engineering?

  - Conclusions and Key Findings from my Systematic Literature Review

    - 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
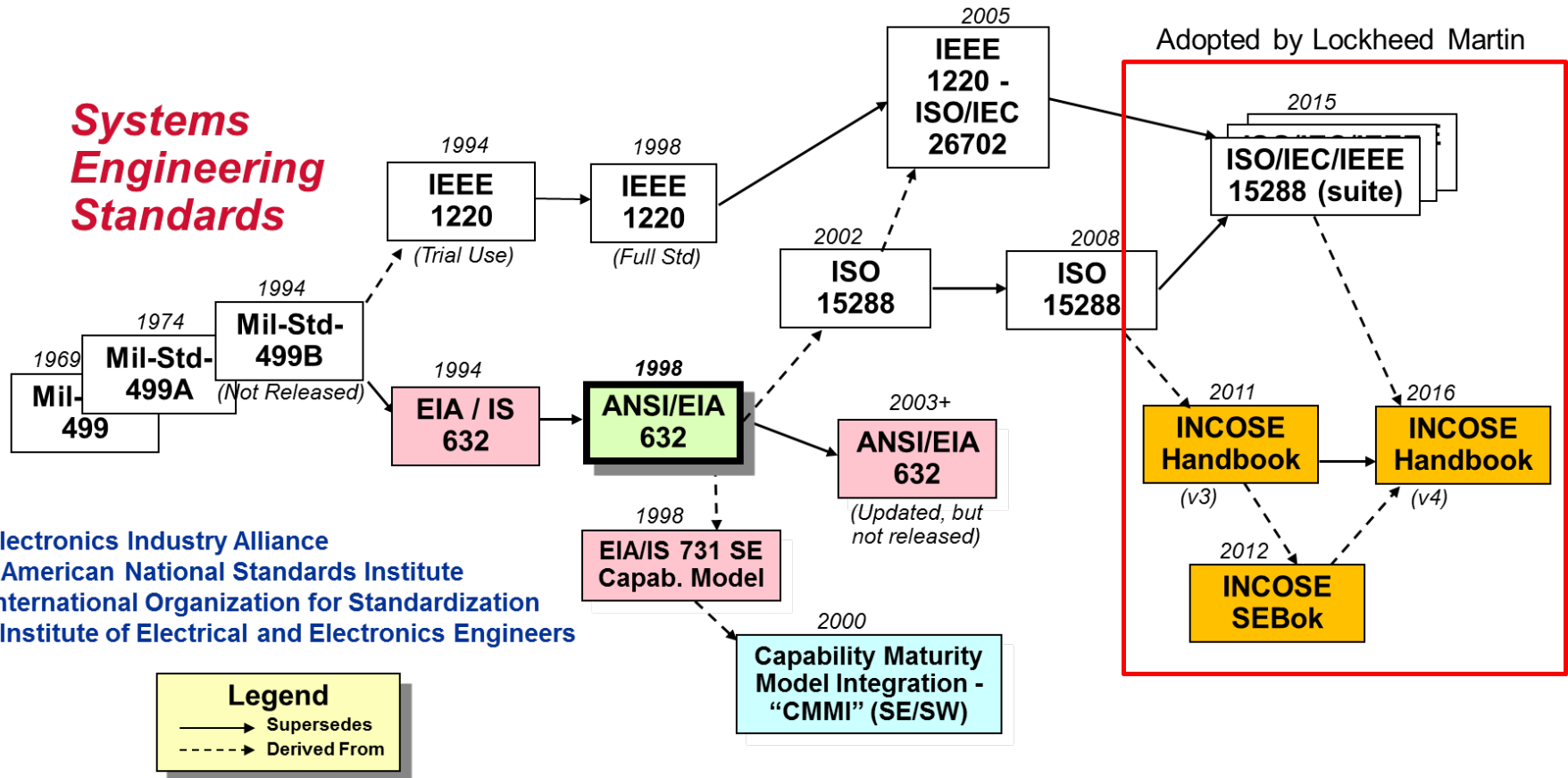
Metrics Being Gathered

- 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 manhours to $$ and schedule overage
  - Informal Assessment of SE Capability

gathered as a bi-product of project work already being conducted
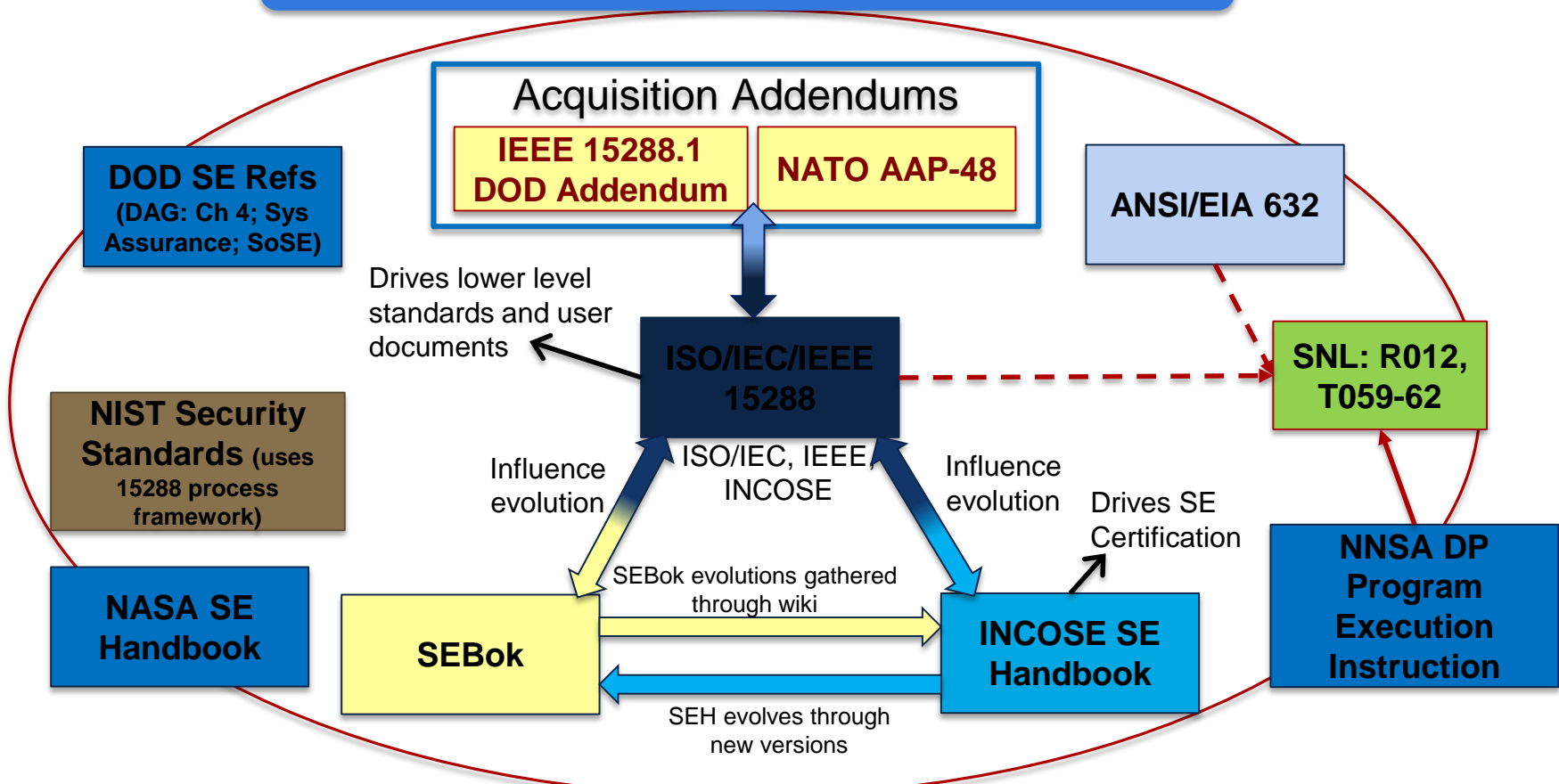
What are the Key SE Standards?

Figure 1: © Garry Roedler 2016 , adapted with permission

The applicable standards

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

Cooperative Technical Co-evolution Model

Acquisition Addendums

IEEE 15288.1 DOD Addendum

NATO AAP-48

DOD SE Refs (DAG: Ch 4; Sys Assurance; SoSE)

ANSI/EIA 632

Drives lower level standards and user documents

ISO/IEC/IEEE 15288

SNL: R012, T059-62

NIST Security Standards (uses 15288 process framework)

Influence evolution

ISO/IEC, IEEE, INCOSE

Influence evolution

Drives SE Certification

NASA SE Handbook

SEBok

SEBok evolutions gathered through wiki

INCOSE SE Handbook

NNSA DP Program Execution Instruction

SEH evolves through new versions

Significant Collaboration in this Co-evolution

Figure 2: © 2016 Garry Roedler, adapted with permission
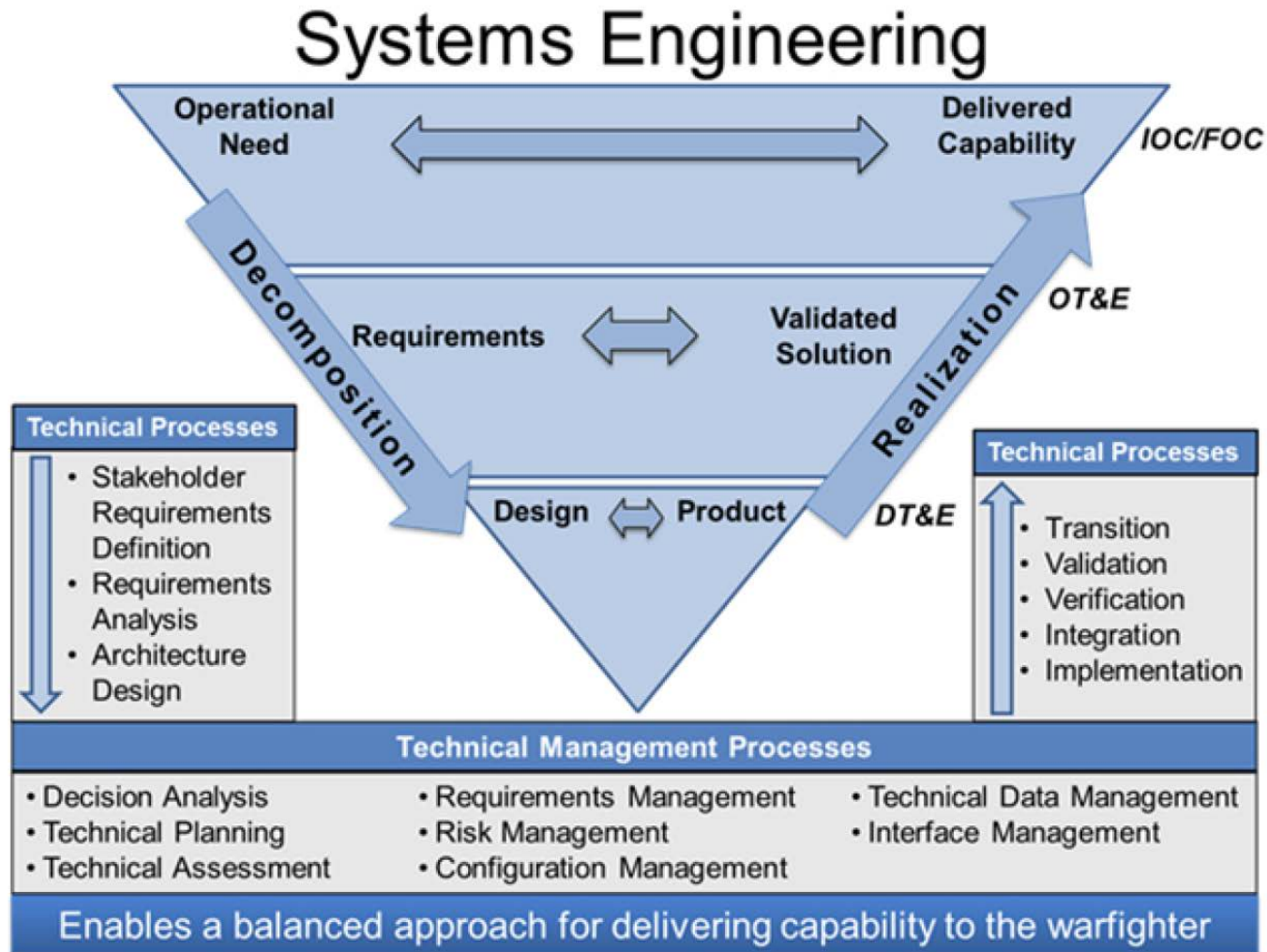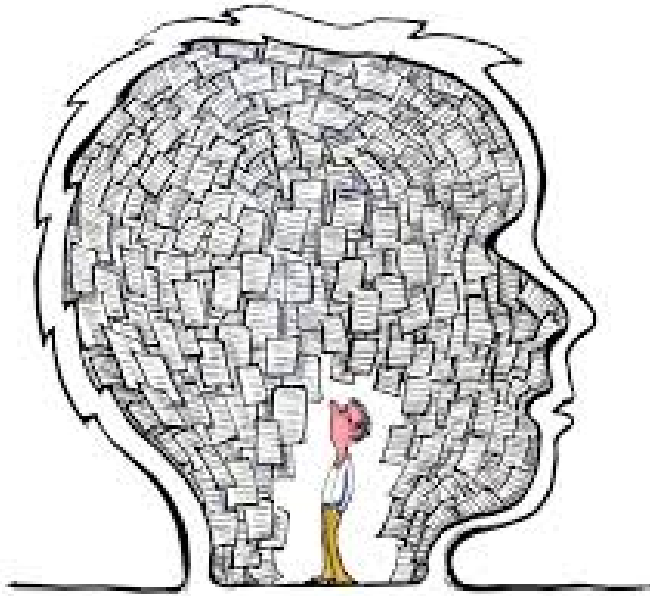
11

The industry standard processes

Figure 3: © the Defense Acquisition University

Why MBSE?

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
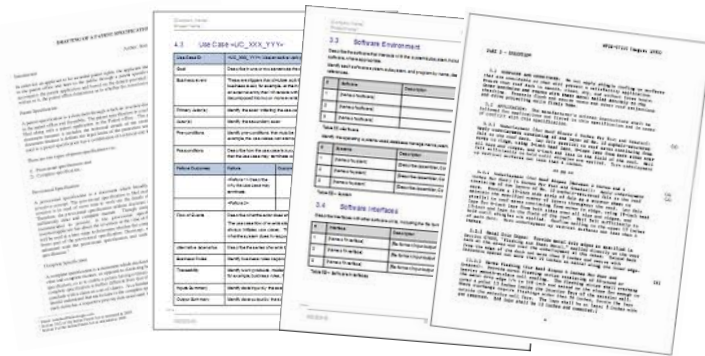
What is driving the industry to MBSE?

- 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
  - ie., The Ground Based Strategic Deterrent SOW (section 3.2.3)
  - 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

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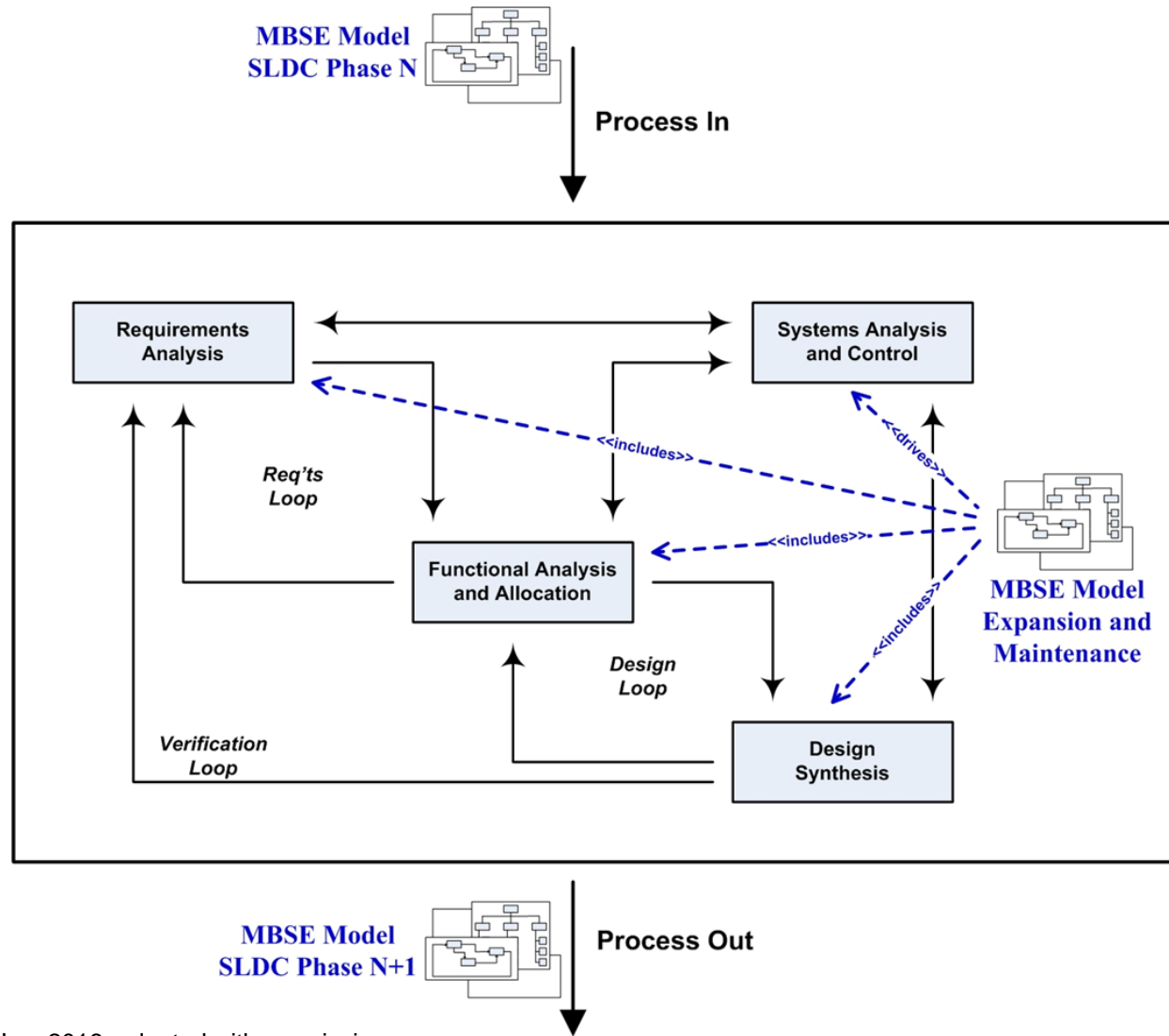# In Current Practice to Future Practice

Today: Standalone models related through documents

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

MBSE
Workshop

Figure 5: © INCOSE, adapted with permission 2014

What SE Processes does MBSE overlay?

What is Different When Using MBSE?

The Model is the Center of MBSE Effort
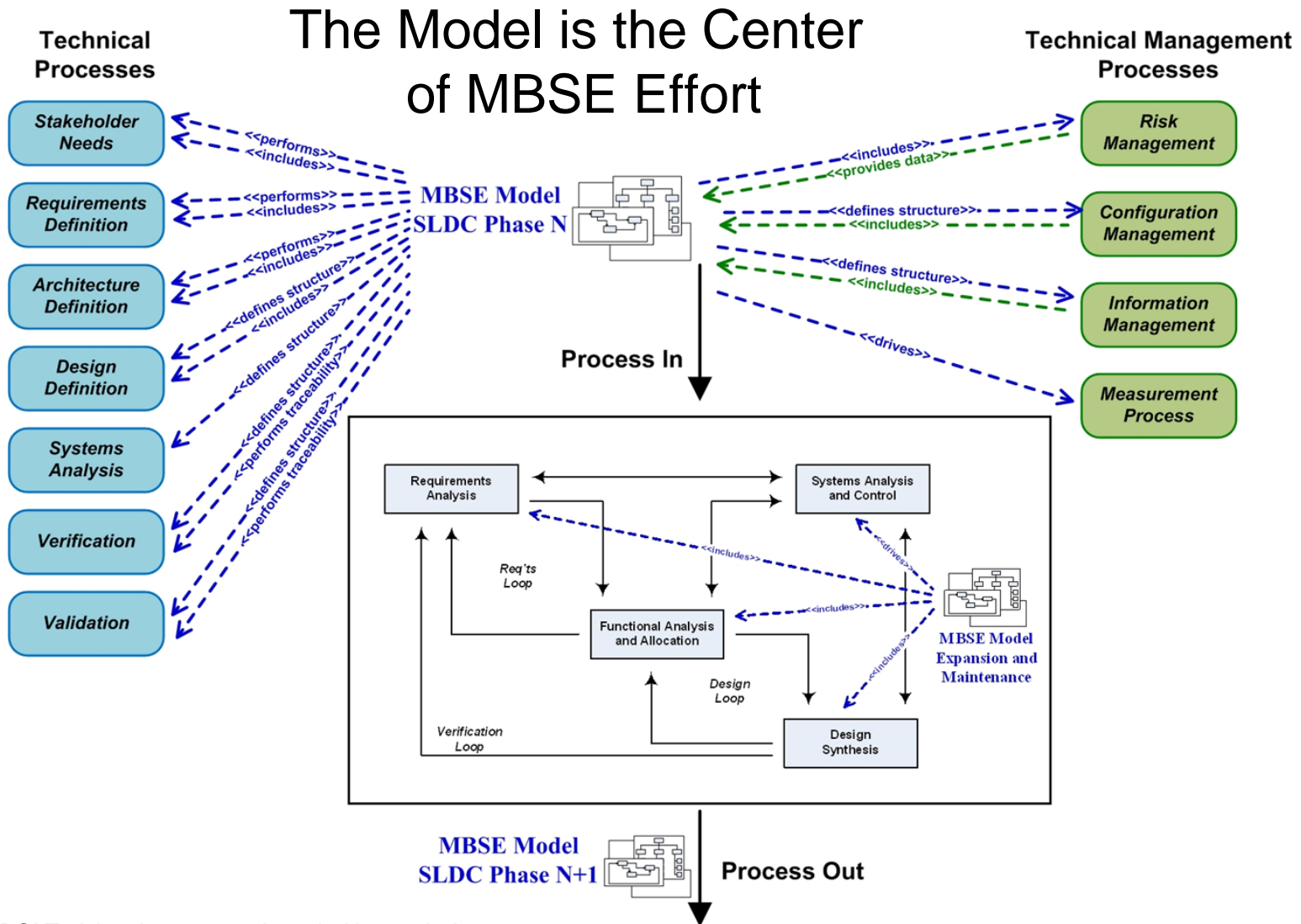
Overlaying MBSE to SE Foundation

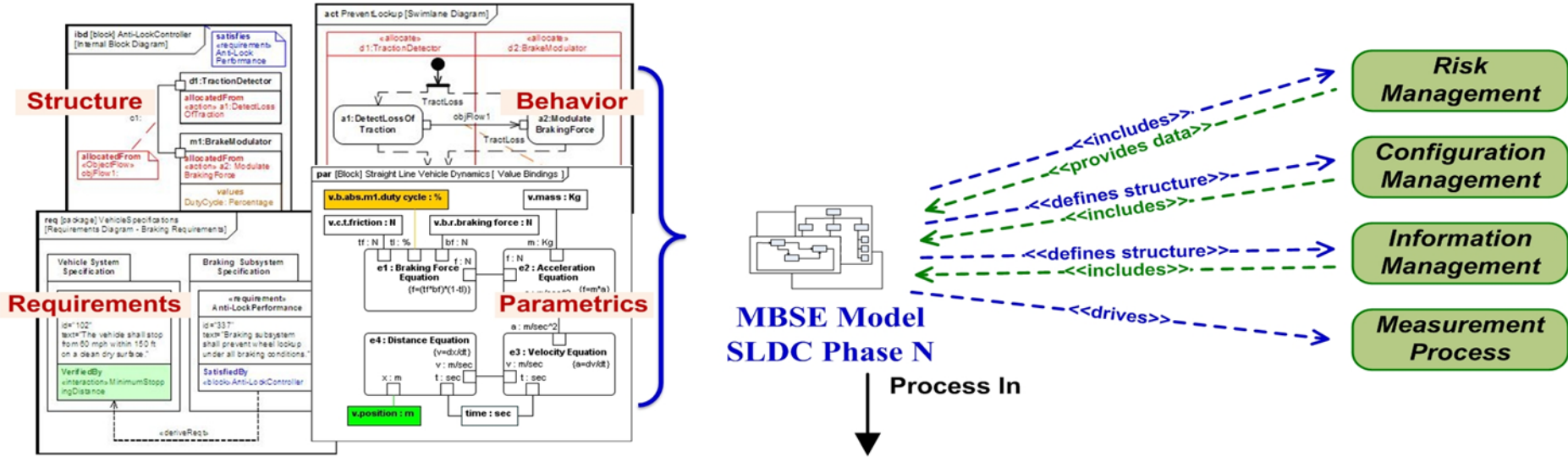
Figure 8: © INCOSE, with permission 2012
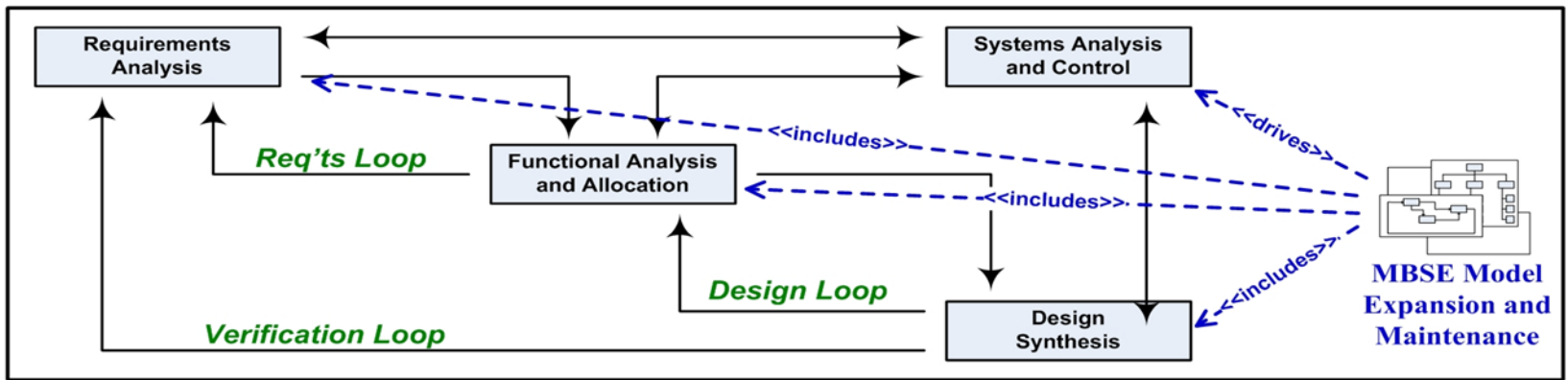
Figure 9: © ROI Training, Inc. 2016, adapted with permission

Findings and Conclusions from Lit Rev

- 67 case studies justified by claiming benefits of:
  - Completeness, consistency, and improved communications
  - Or highlighted contributions to test and evaluation, V&V, concept exploration, design reuse and systems margin analyses

- 21 case studies justified with quantified results of:
  - Cost and schedule improvement
  - Finding defects and preventing rework

- Case studies were from:
  - (67) 8 countries, 10 defense, 33 space, 5 non-defense, 6 commercial
  - (21) 4 countries, 12 defense, 5 space, 4 commercial, 6 used MBSE to develop complex weapon systems

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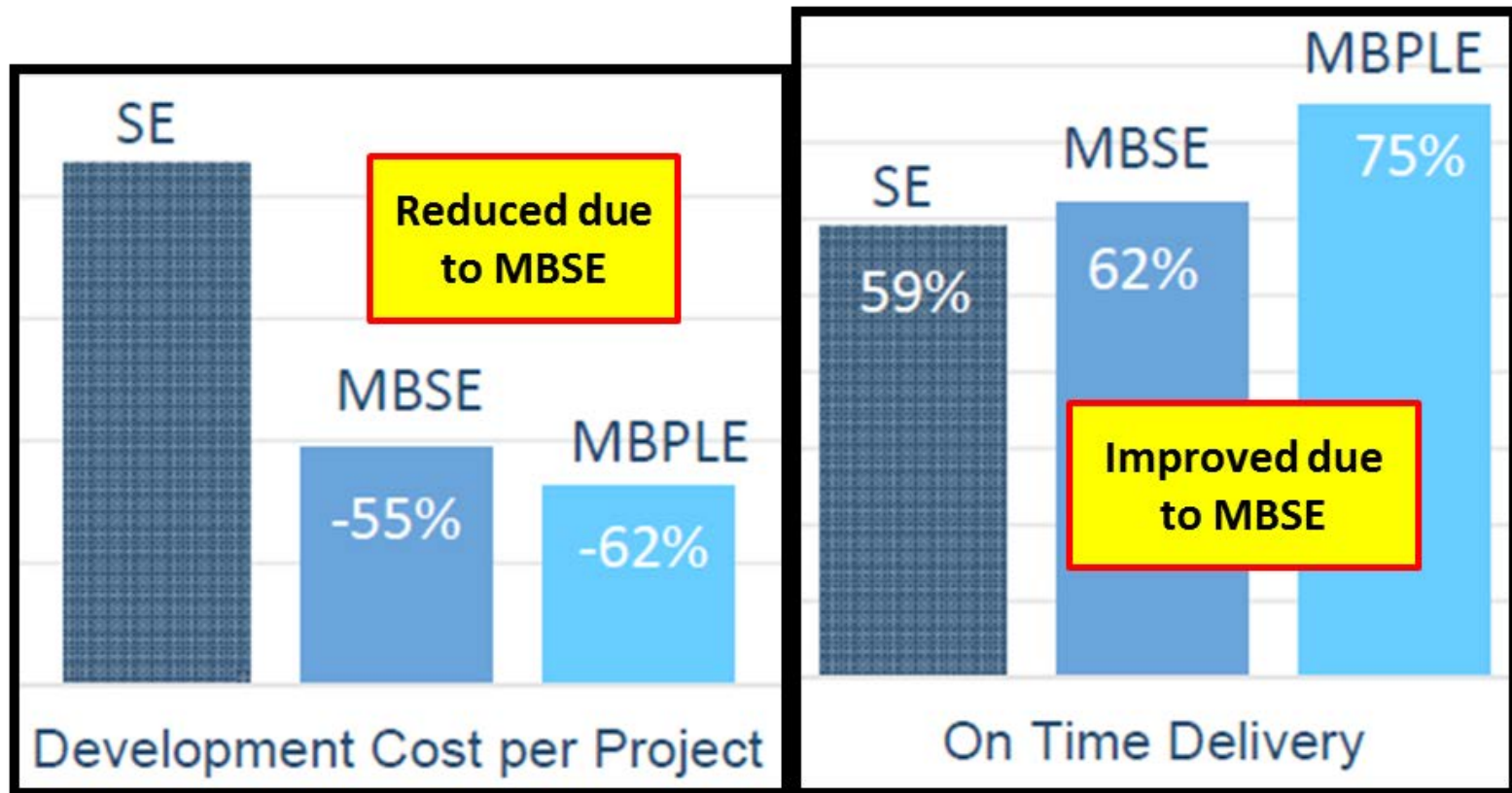
MBSE is an extension of Systems Engineering,
And model-based product line engineering is an extension of MBSE

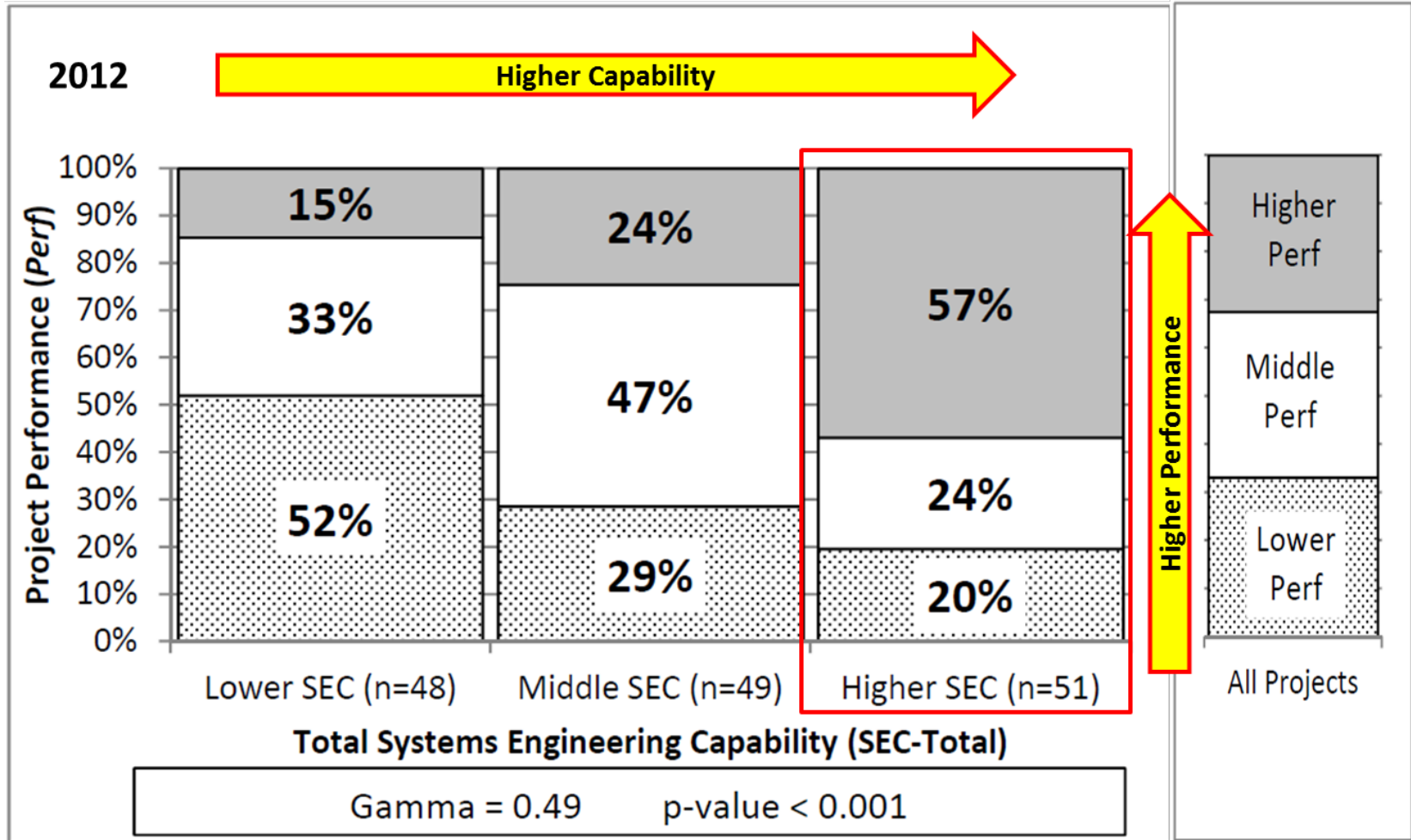# SE Improves Engineering Efficiency

Figure 12: © Carnegie Mellon University 2012, adapted with permission
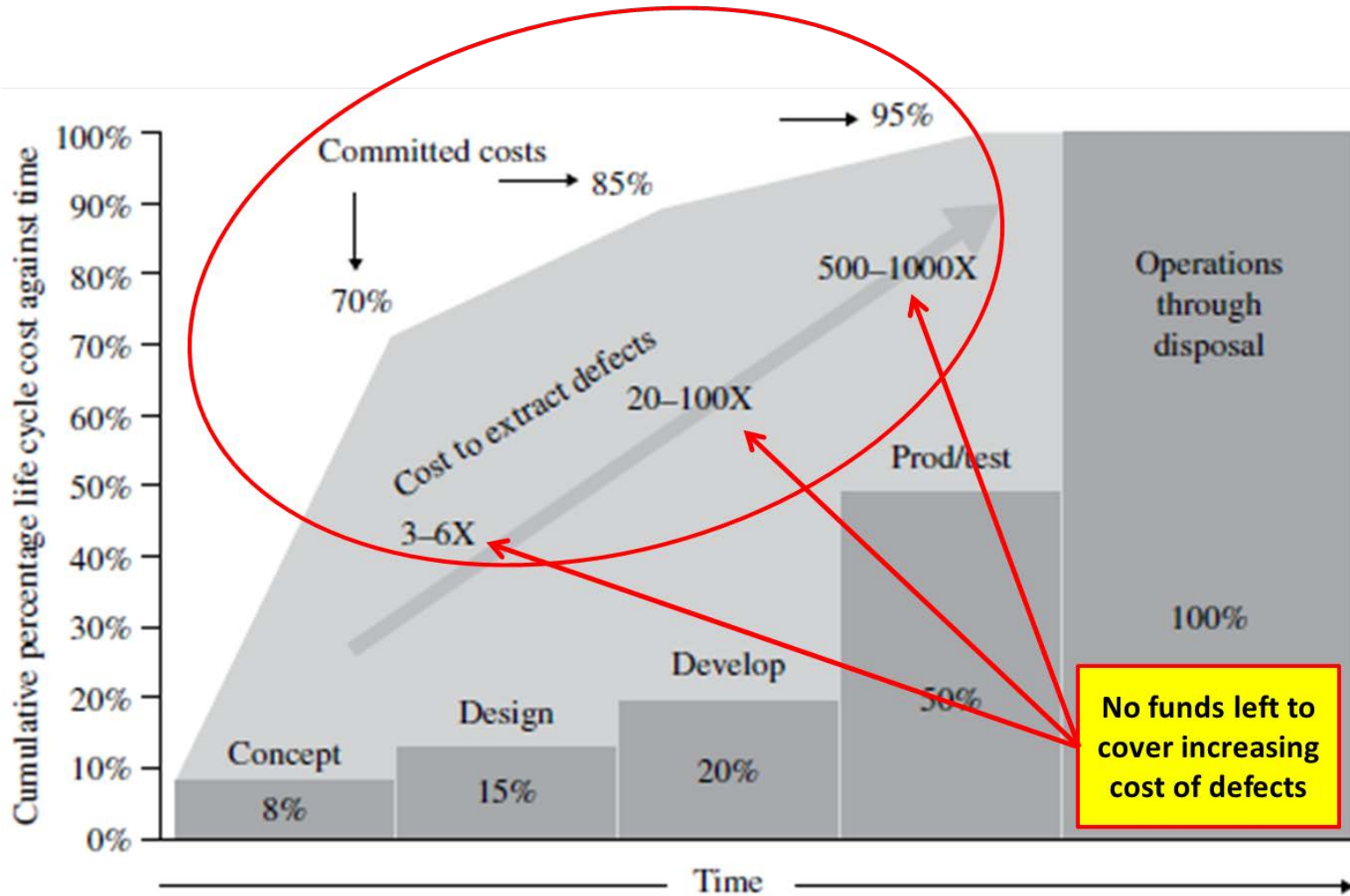
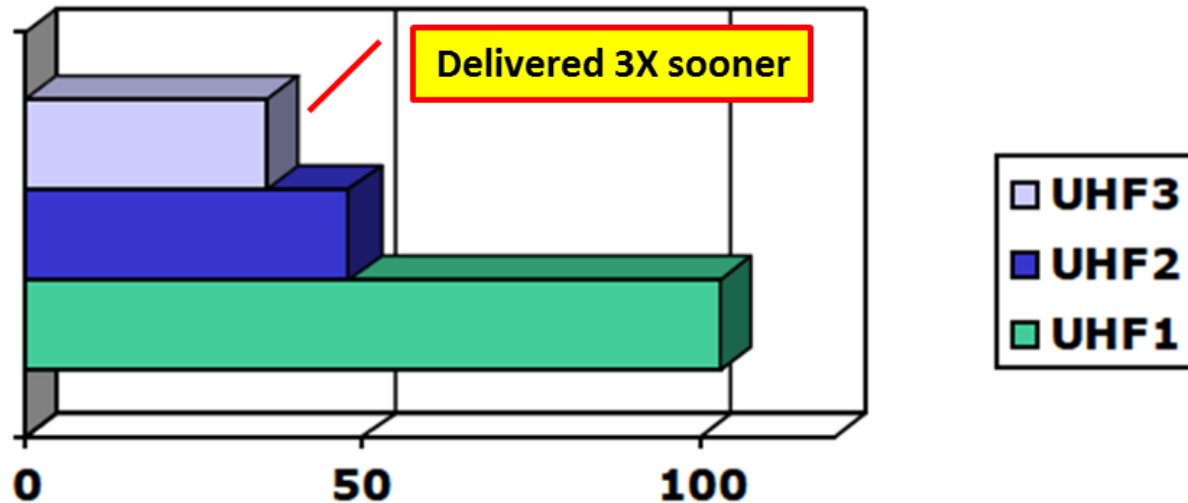# MBSE Prevents Defects and Rework

SEs Need to Drive Engineering Processes

Overall Development Time (weeks)

Delivered 3X sooner

- UHF3
- UHF2
- UHF1

0   50   100

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

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

Skilled SEs are Needed to Drive Engineering Processes

Figure 15: © INCOSE adapted with permission 2012
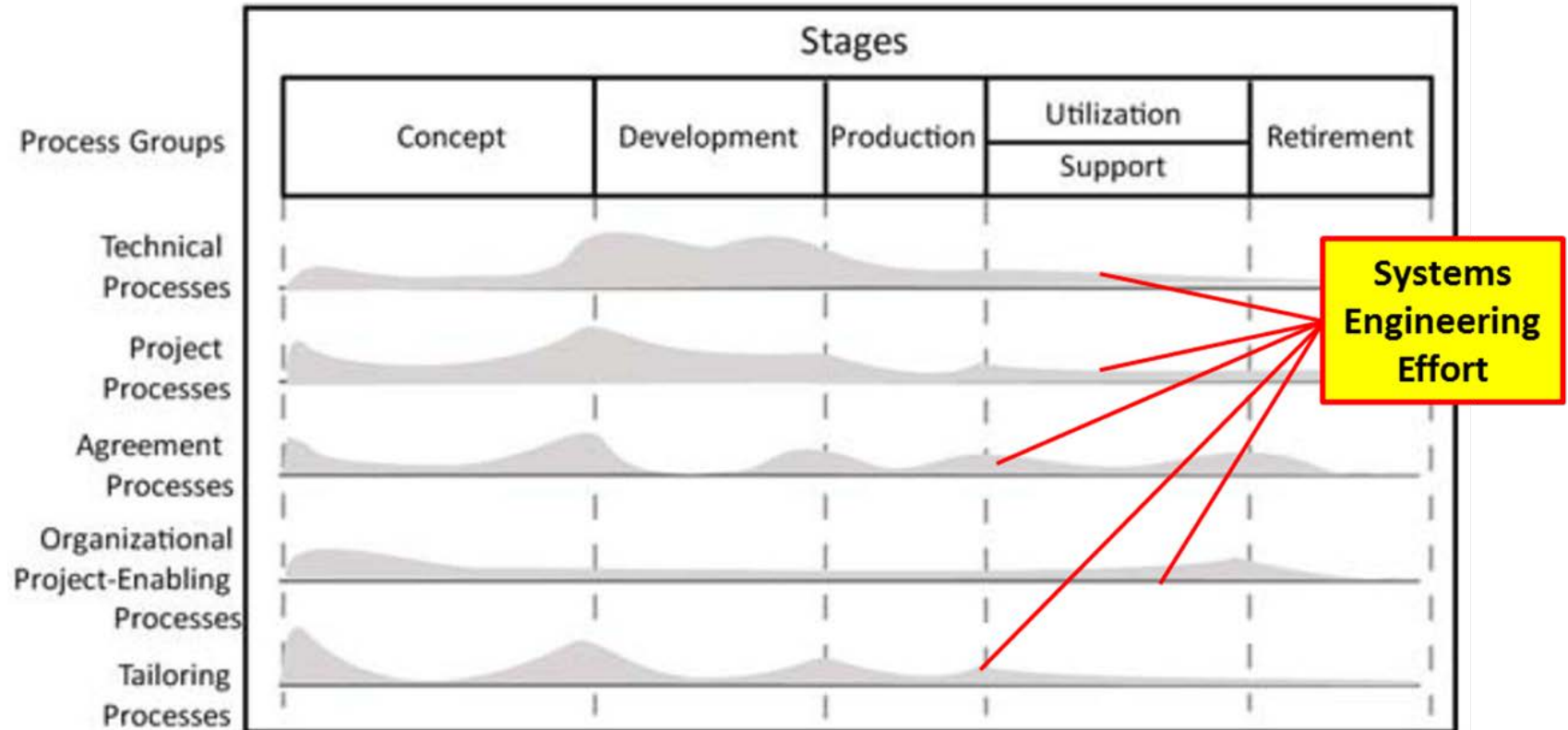
- Delivery times are not effected by data entry clerks
- Systems Engineers must be well trained engineers
  - MBSE employs new techniques, tools, and processes

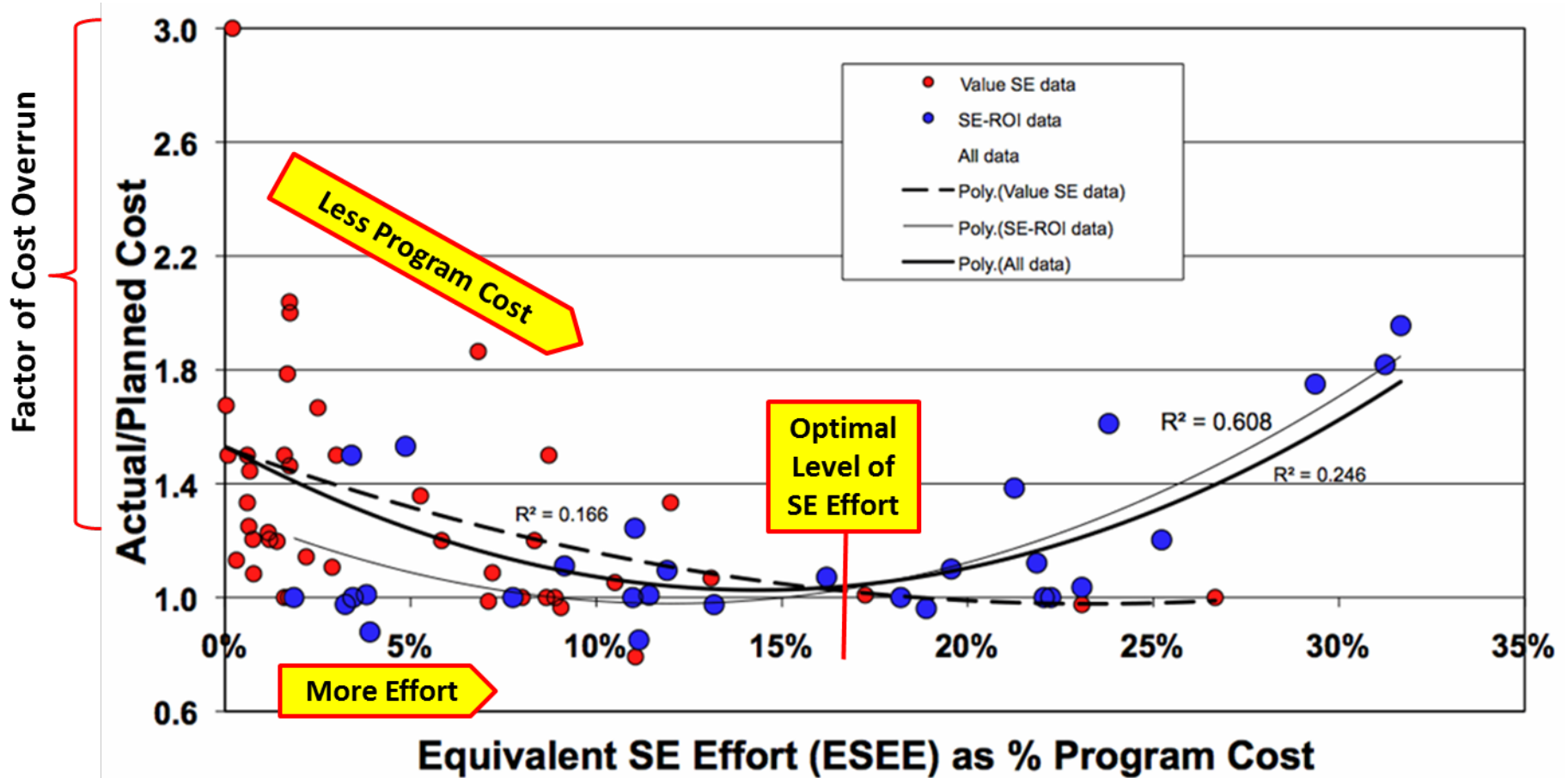# The data shows an optimal SE staffing at 12-17% of total

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
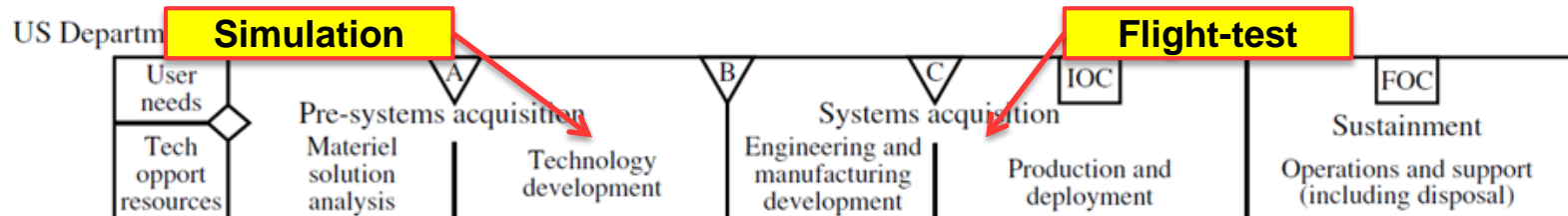
MBSE Provides Significant Advantage

US Department...

Simulation **Flight-test**

User needs		A	B	C	IOC		FOC
Tech opport resources	Pre-systems acquisition	Technology development	Systems acquisition	Production and deployment		Sustainment	Operations and support (including disposal)
	Materiel solution analysis		Engineering and manufacturing development				

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

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

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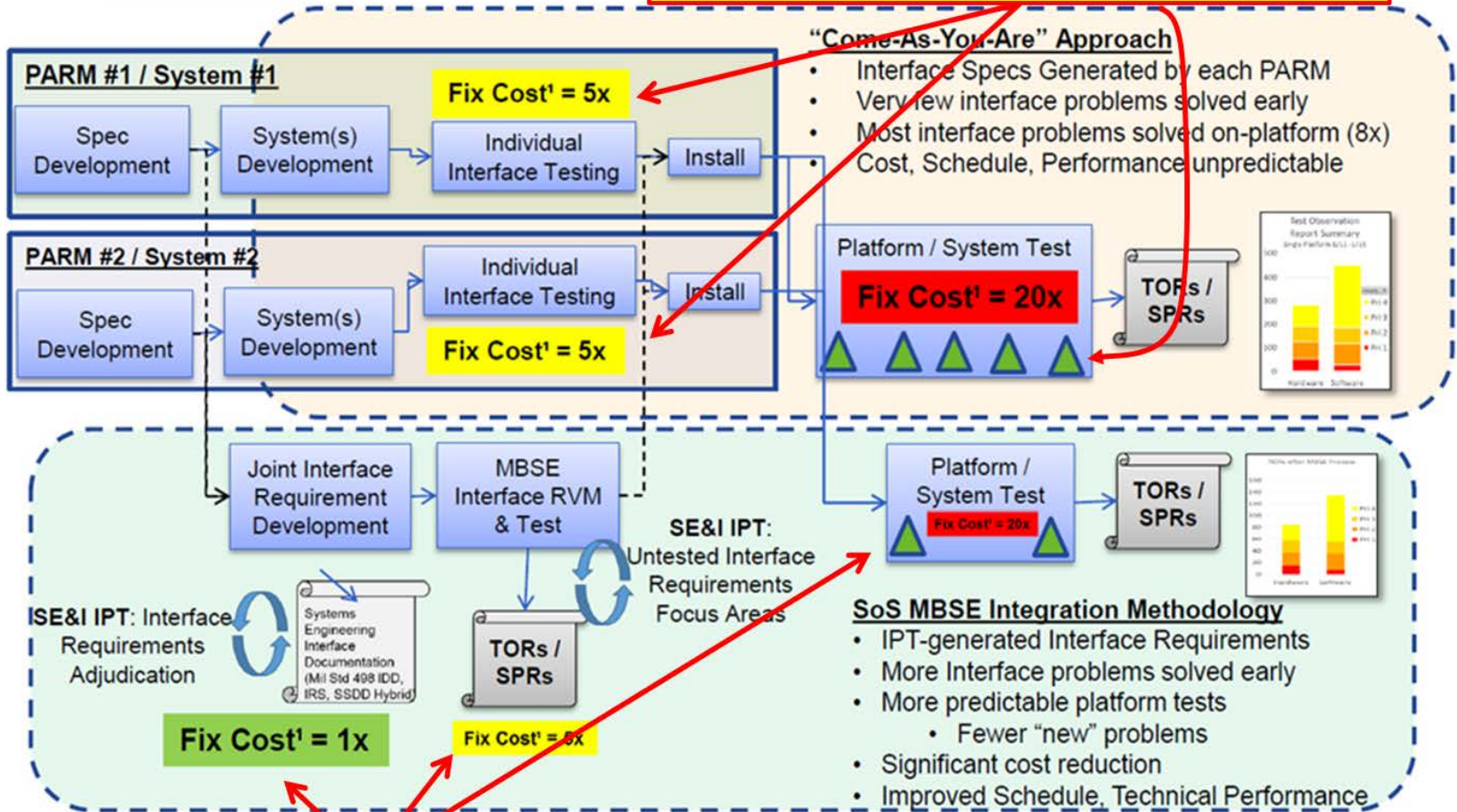
Figure 19: © Lockheed Martin Corporation 2015, adapted with permission

MBSE Avoids Rework

System f0 Phase	Success Probability [probOfSuccess]	Failure Probability [1 - probOfSuccess]
Baseline	0.6	0.4
Update 1	0.73	0.27
Update 2	0.93	0.07

No change to design

Without MBSE

With MBSE

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

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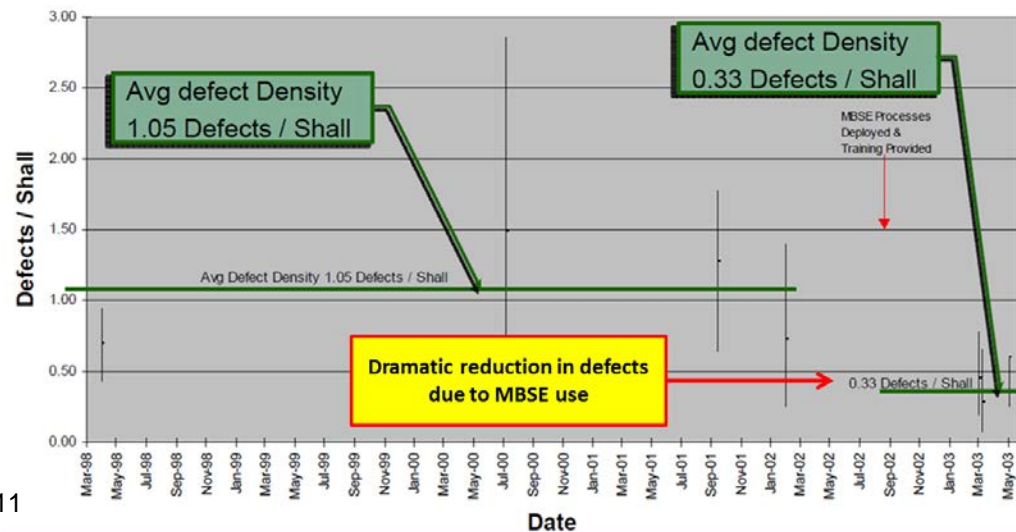

Specification Defects (Per Shall)

Avg defect Density 1.05 Defects / Shall

Avg defect Density 0.33 Defects / Shall

MBSE Processes Deployed & Training Provided

Avg Defect Density 1.05 Defects / Shall

Dramatic reduction in defects due to MBSE use

0.33 Defects / Shall

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

68% Reduction in Specification Defects since MBSE Practices Introduced

What are 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) processes
    - Systems Engineering effort is highest early in the project
    - The optimal SE staffing is up to 12-17% of total program staffing

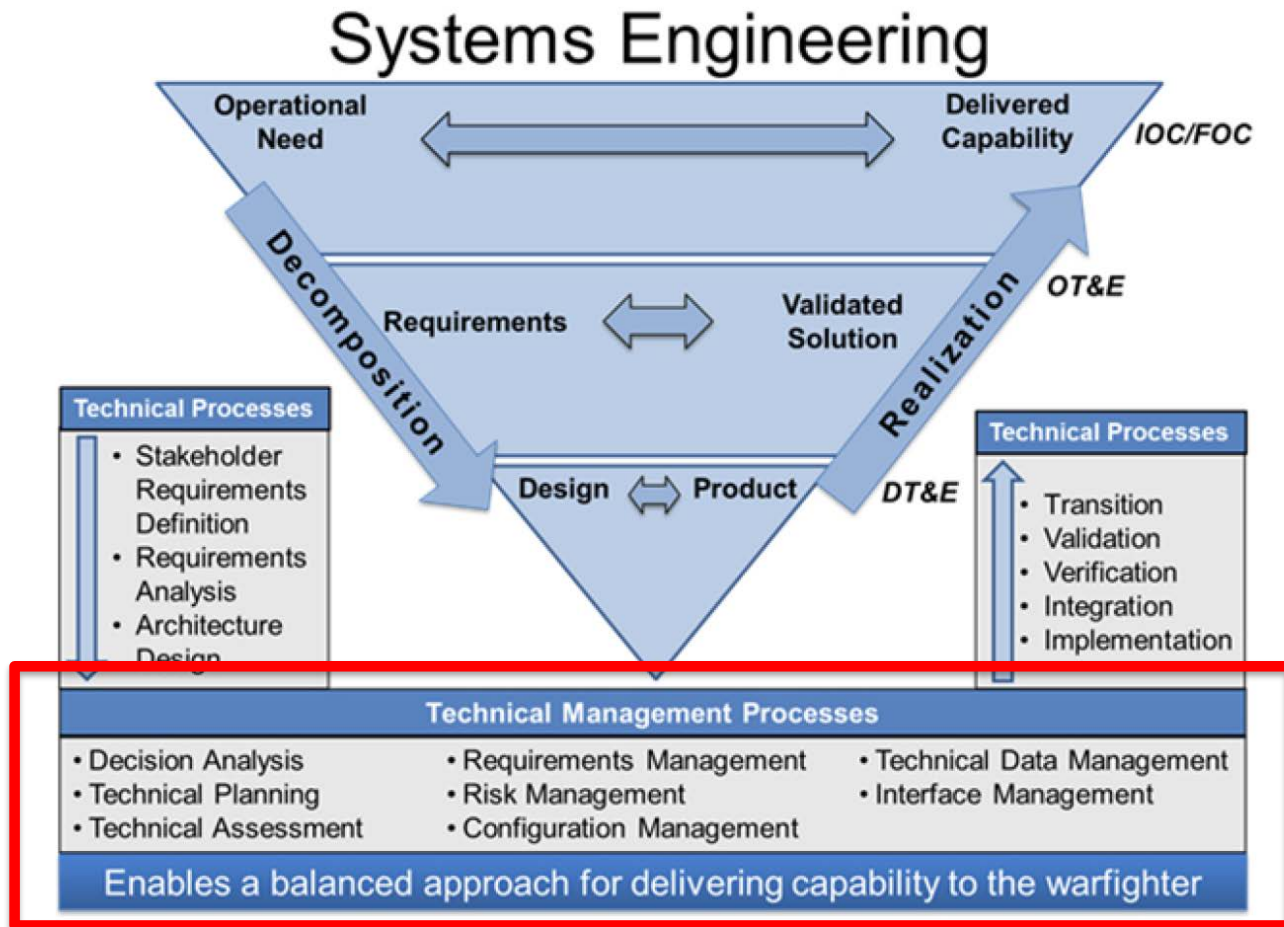# Engage System Engineers as technical leaders of these processes

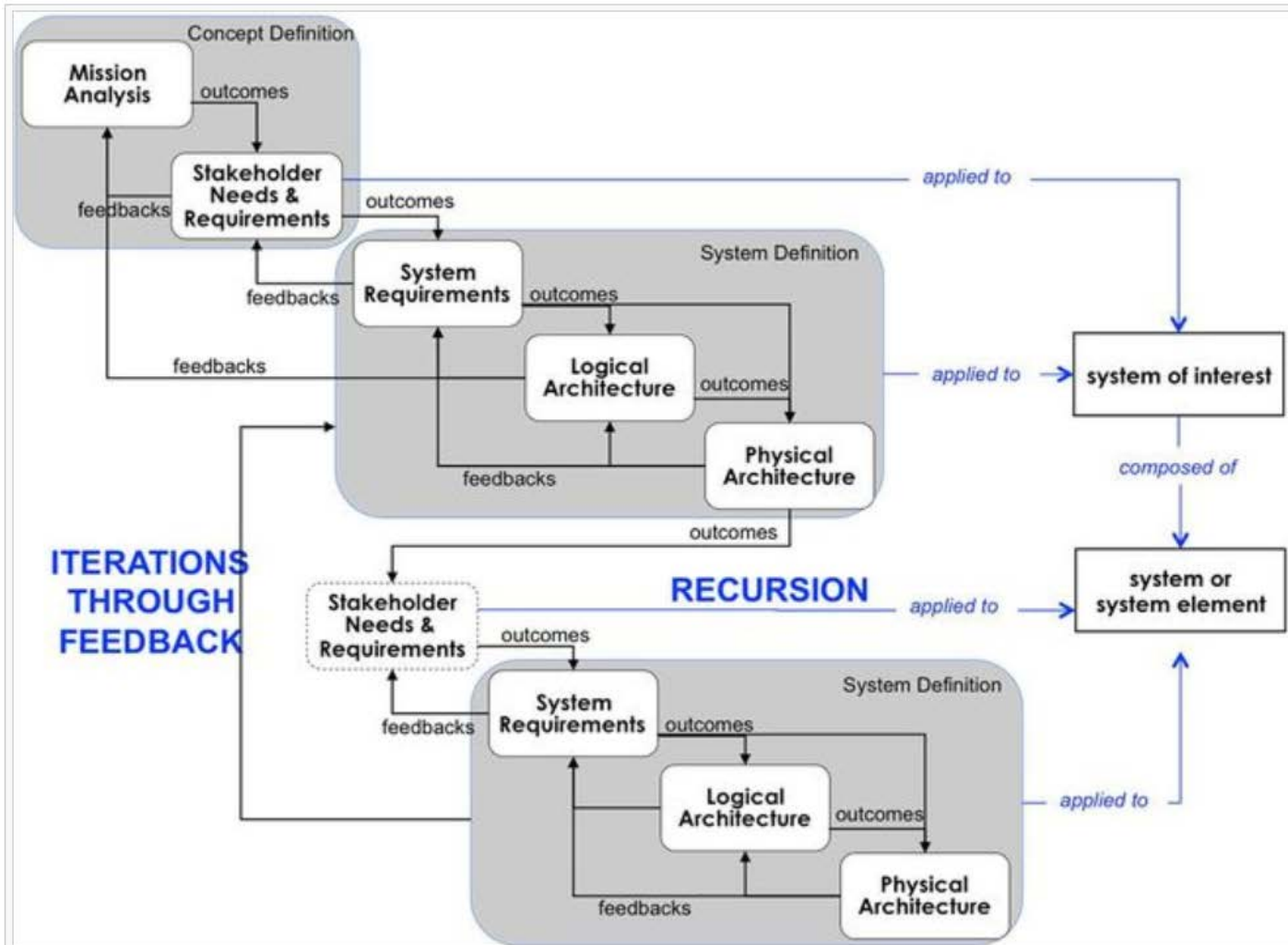Figure 22: © the Defense Acquisition University

Figure 23

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

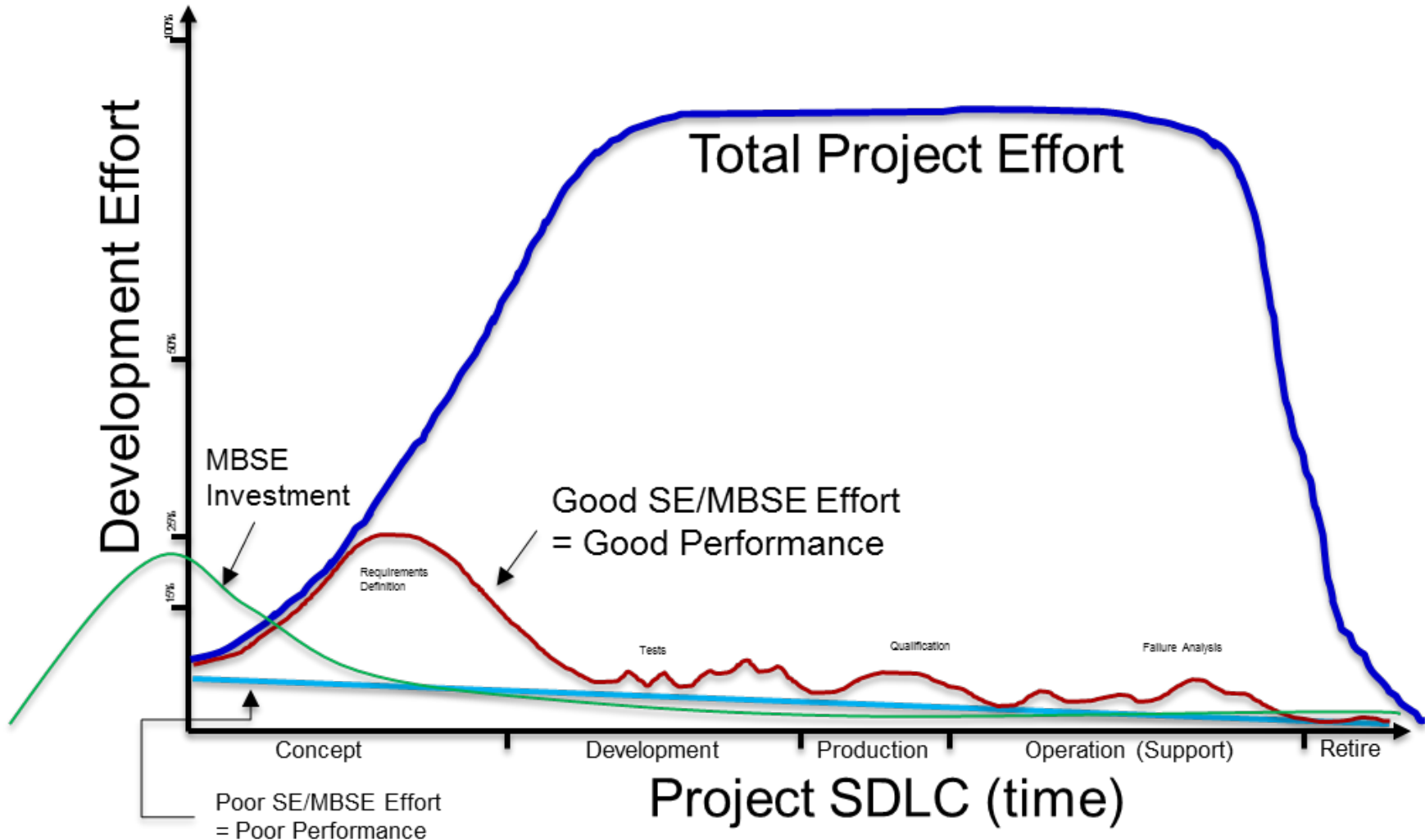# SE Effort is highest early in project

Figure 24

Prerequisites

- 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
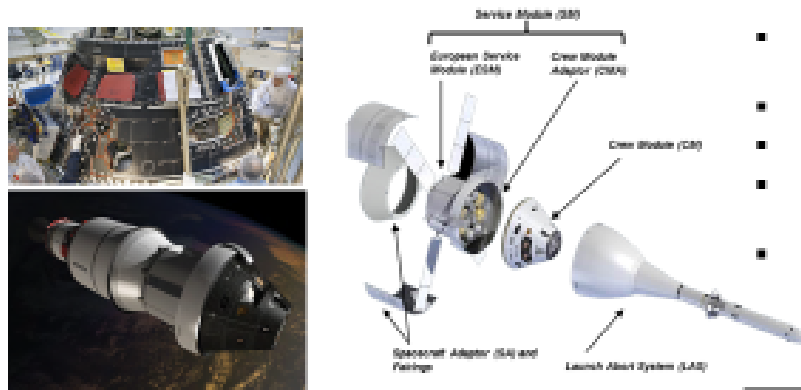
- Invest in full scale MBSE tools

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."

- NASA's human space exploration vehicle (CEV / Orion / MPCV)
- LM is prime contractor (2006 award)
- First orbital test flight Dec 4th, 2014
- Uncrewed test to DRO Lunar orbit (2018)
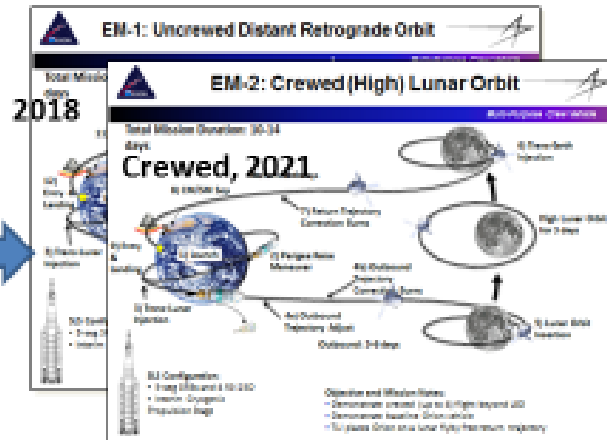- First Crewed flight, Lunar orbit, 2021

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

Europa Exploration Mission

"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 26: 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. How do I navigate
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. What does MBSE Look Like
11. MBSE Advantages, © 2014 PTC Inc., Professional Paper, November 24, 2014, adapted with permission
12. SE Improves Efficiency, © Carnegie Mellon University. November 2012, adapted with permission
13. MBSE Cost Model, © Raytheon Company 2011, Published in the *Defense AT&L* (public domain)
14. Overall Development Time, © The Boeing Company 1995
15. Engineering Processes, © INCOSE, with permission 2012
16. Optimal SE Staffing, © Eric Honour 2013, adapted with permission
17. Early Defect Detection, © *INCOSE,* with permission 2012
18. JAS 39E Fighter Jet, © by-sa 2.0 Tim Felce – Gripen – RIAT 2010
19. Rework Avoided, © Lockheed Martin Corporation 2015, adapted with permission
20. Failure Probability, © Rafael Mareni Perez 2014, adapted with permission
21. Specification Defects, © Raytheon Company 2011, Published in the *Defense AT&L* (public domain)
22. Systems Engineering "V" (2), The Defense Acquisition University
23. Key Processes Iterate, © Faisandier 2012
24. SE Effort Early in SDLC
25. Orion Human Space Flight, NASA photo
26. Europa Exploration Mission, NASA/JPL photo

Today's Presentation

Things to Think About

How can this be applied in your work environment?

What did you hear that will influence your thinking?

What is your take away from this presentation?

Please

The link for the online survey for this meeting is

www.surveymonkey.com/r/enchant_11_09_16

www.surveymonkey.com/r/enchant_11_09_16

Look in GlobalMeet chat box for cut & paste link.

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The library page at: **www.incose.org/enchantment**.

Recording will be there in the library tomorrow.