

# SYSTEMS ENGINEERING OF THE FUTURE



**GARRY ROEDLER**

LM SENIOR FELLOW, ENGINEERING OUTREACH PROGRAM MANAGER

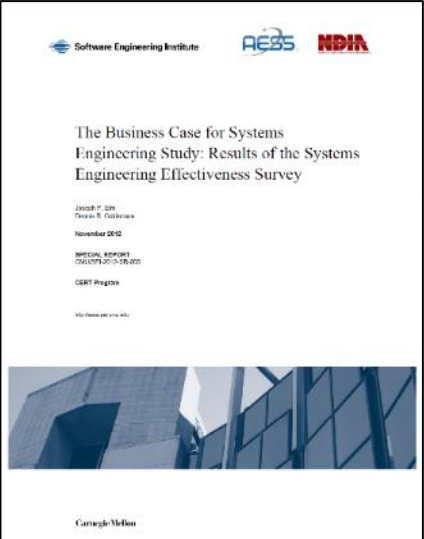
INCOSE PRESIDENT

# Evolution of Our Systems Environment

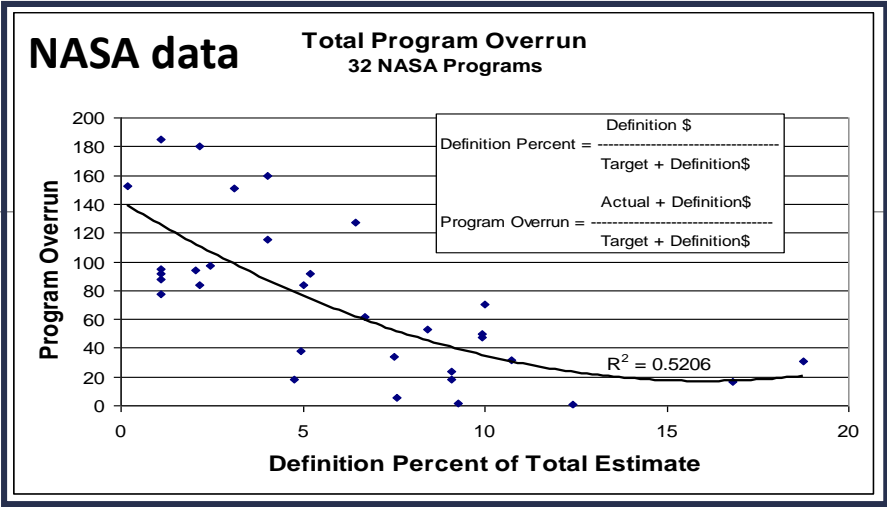
---

## OBSERVED TRENDS

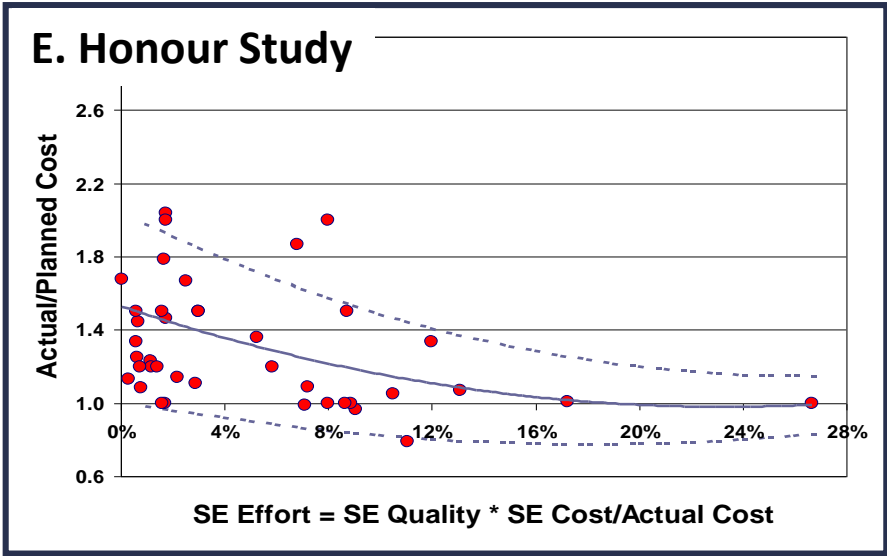
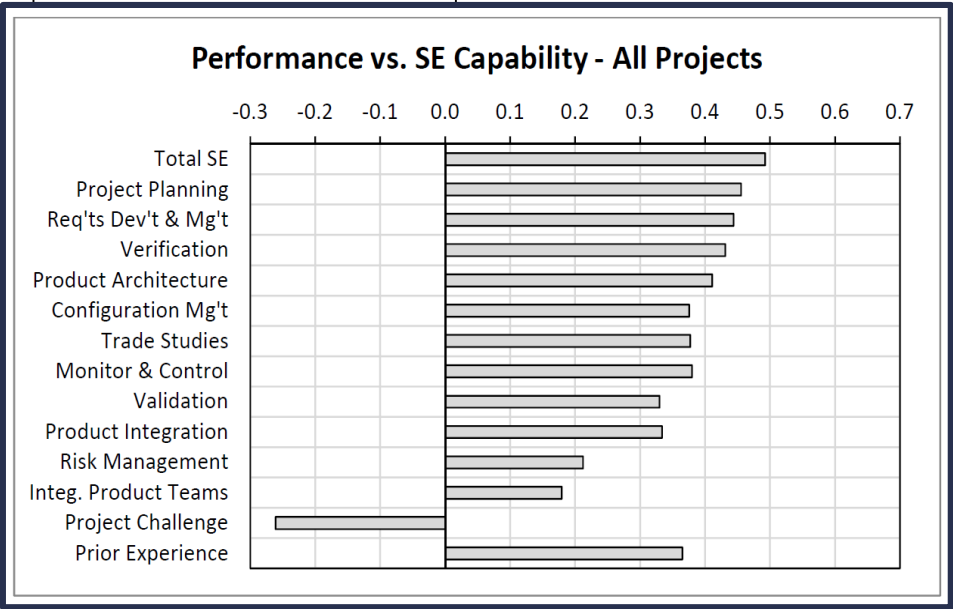
# The Value of SE: Relevancy



Elm, Joseph, et al "The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey", CMU/SEI-2012-SR-009, November 2012



W. Gruhl, Lessons Learned, Cost/Schedule Assessment Guide," Internal Presentation, NASA Comptroller's Office, 1992



E. Honour, "Understanding the Value of Systems Engineering," INCOSE, 2004

# Current Situation: Practices and Challenges

1

Mission complexity is growing faster than our ability to manage it . . . increasing mission risk from inadequate specifications and incomplete verification.

4

Knowledge and investment are lost between projects . . . increasing cost and risk: dampening the potential for true product lines.

2

System design emerges from pieces, rather than from architecture . . . resulting in systems that are brittle, difficult to test, and complex and expensive to operate.

5

Technical and programmatic sides of projects are poorly coupled . . . hampering effective project risk-based decision making.

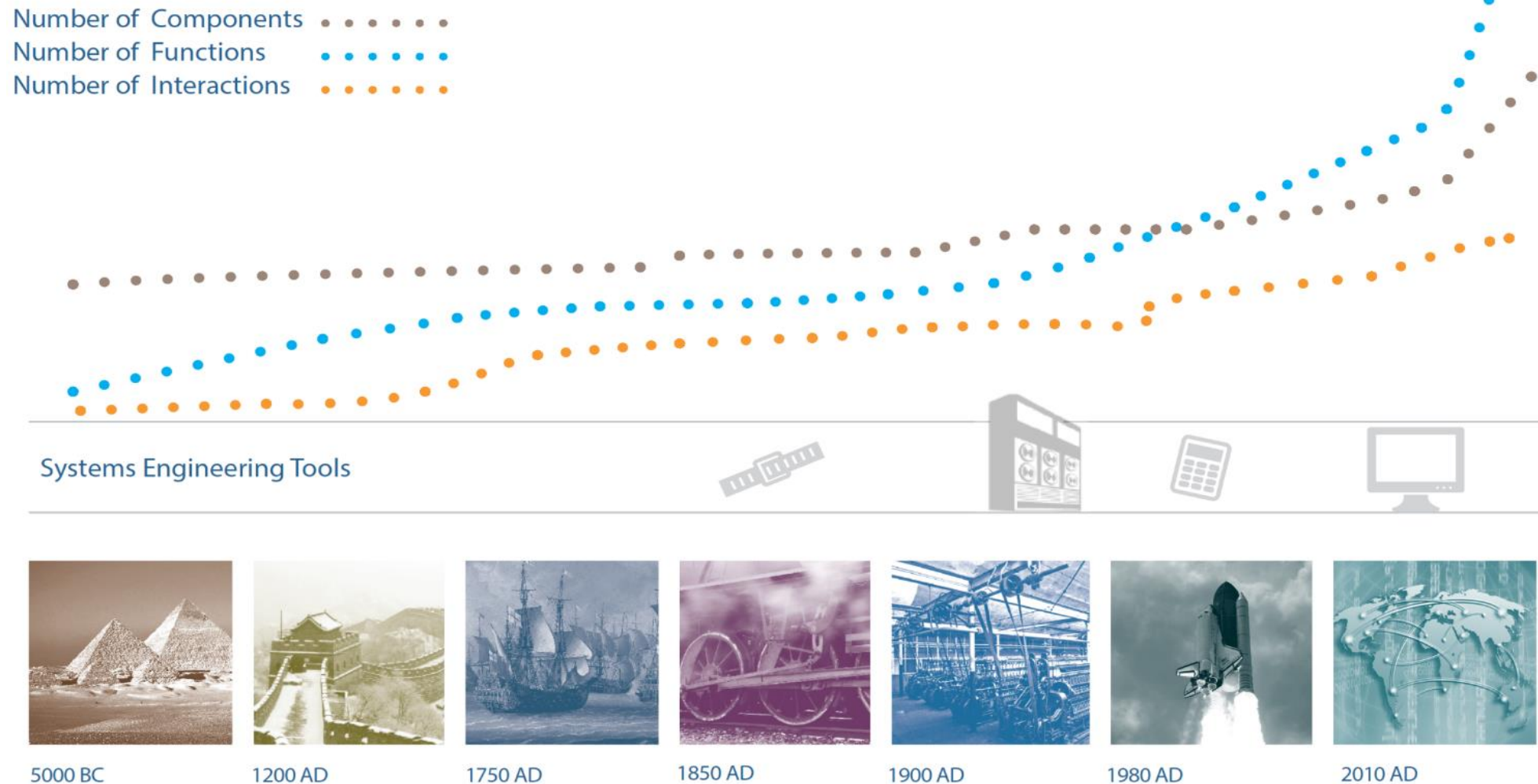
3

Knowledge and investment are lost at project life cycle phase boundaries . . . increasing development cost and risk of late discovery of design problems

6

Most major disasters such as Challenger and Columbia have resulted from failure to recognize and deal with risks. The Columbia Accident Investigation Board determined that the preferred approach is an “independent technical authority”.

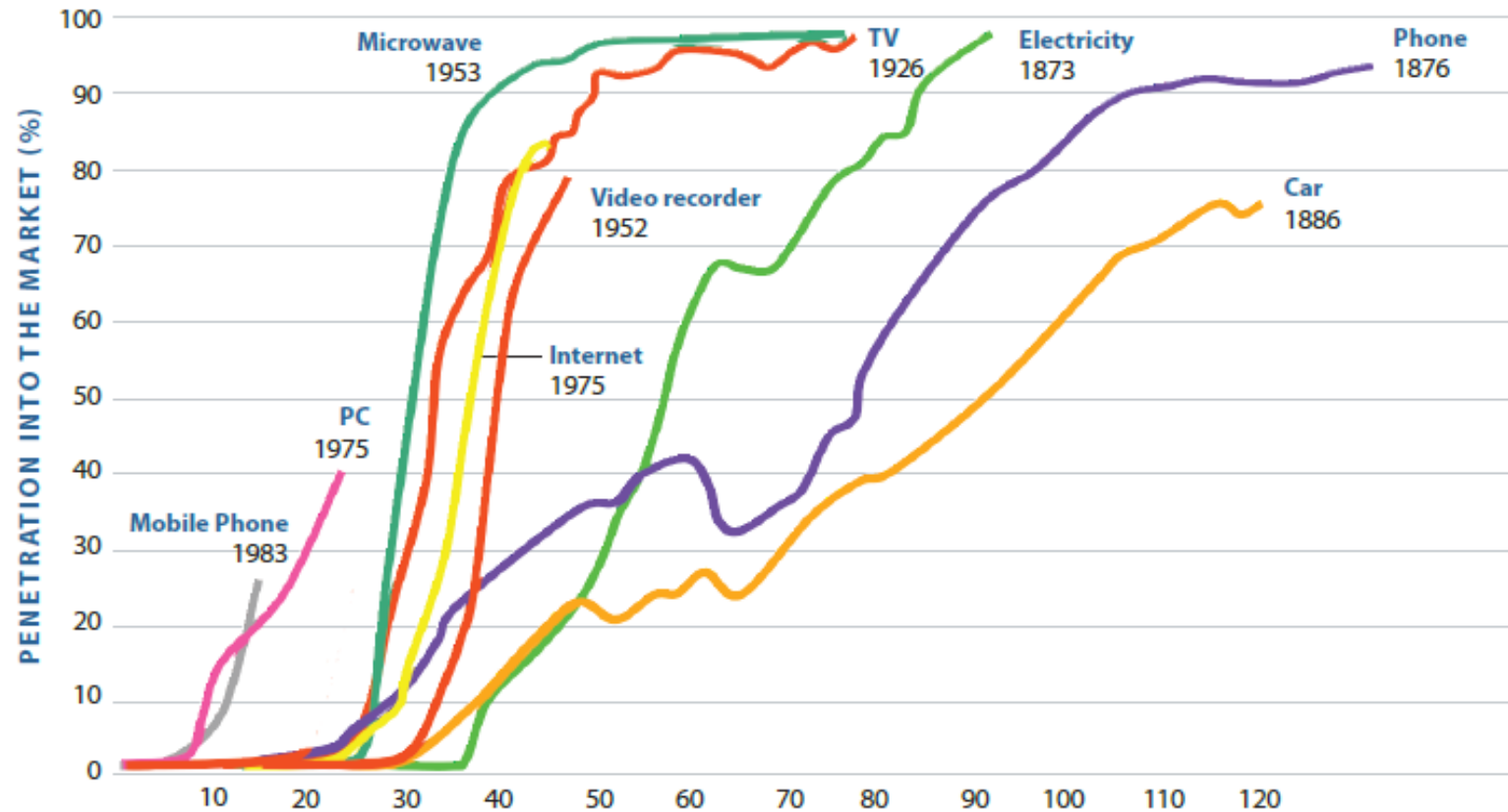
# Trend: Increasing Complexity of Systems



# Trend: Increasing Rate of Technology Adoption

NEW TECHNOLOGIES  
CHANGE OUR DAILY  
LIFE AT AN EVER  
INCREASING RATE

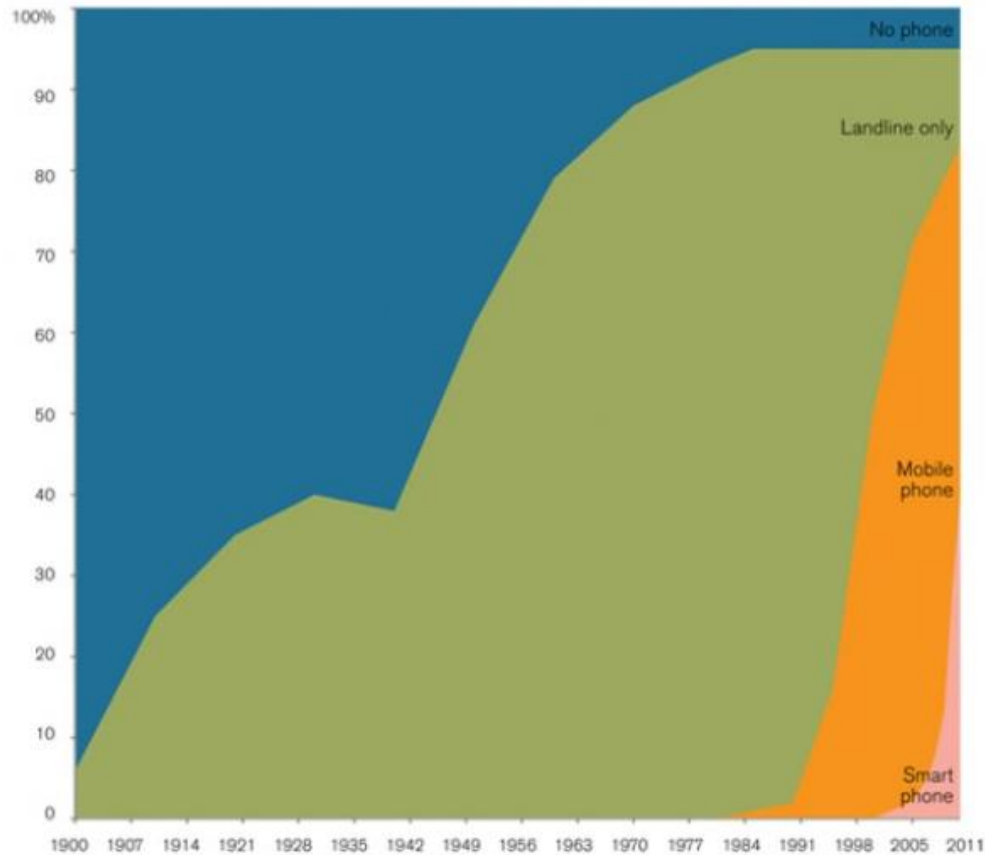
Source: Forbes magazine



“With technology infusion rates increasing, the pressure of time to market will also increase, yet customers will be expecting improved product functionality, aesthetics, operability, and overall value. ”

# Example: Smart Phone Adoption

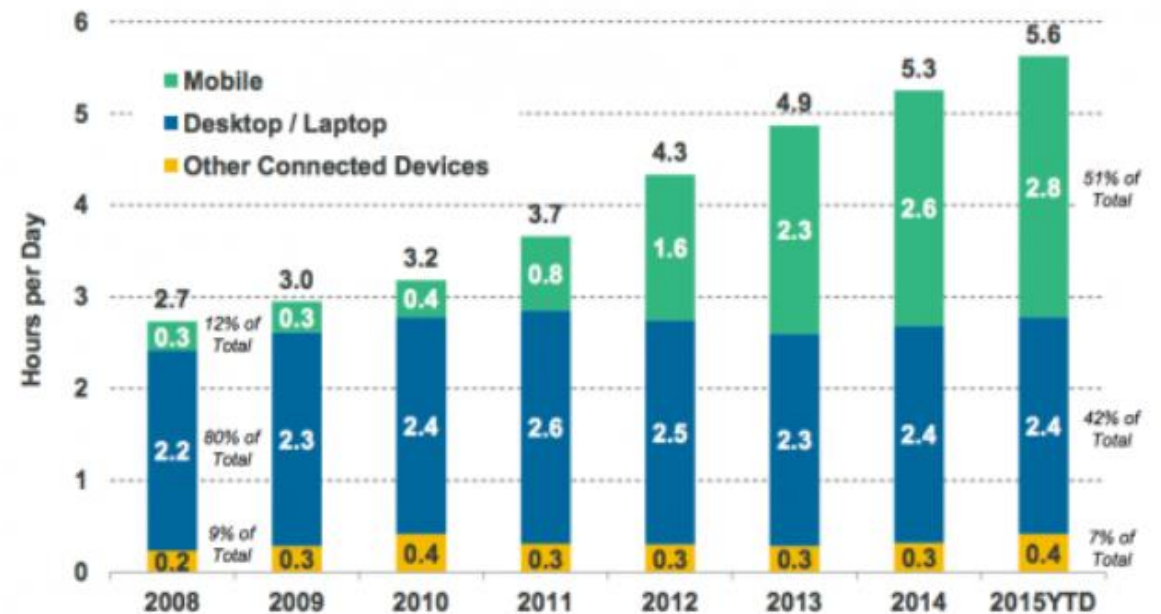
From No Telephone to Smart Phones  
U.S. households by type of phone, 1900–2011



Sources: Forrester, Knowledge Networks, New York Times, Nielsen, Pew, U.S. Census.  
"No phone" numbers derived by subtraction.

Internet Usage (Engagement) Growth Solid  
+11% Y/Y = Mobile @ 3 Hours / Day per User vs. <1 Five Years Ago, USA

Time Spent per Adult User per Day with Digital Media, USA,  
2008 – 2015YTD



Source: eMarketer 9/14 (2008-2010), eMarketer 4/15 (2011-2015). Note: Other connected devices include OTT and game consoles. Mobile includes smartphone and tablet. Usage includes both home and work. Ages 18+; time spent with each medium includes all time spent with that medium, regardless of multitasking.

Jun 28, 2017

Source: [KPCB mobile technology trends](#) by Mary Meeker

Smart Phone is the most quickly adopted consumer technology in history



# Example: Recent technology adoption with increasing complexity

## Autonomy / AI

- Embedding into many of our systems
- Driverless cars
  - Uber - Pittsburgh
  - Google – Palo Alto
- Deliveries
  - [Amazon](#)
  - Budweiser – Otto - [Video](#)
- [Hotels](#) ([CNN](#))
- [Google DeepMind](#)
- Advanced Robotics ([Sophia](#))
- DoD
  - Autonomous Learning Systems
  - Human-machine Collaborative Decision Making
  - Assisted Human Operations
  - Advanced Manned-Unmanned System Operations

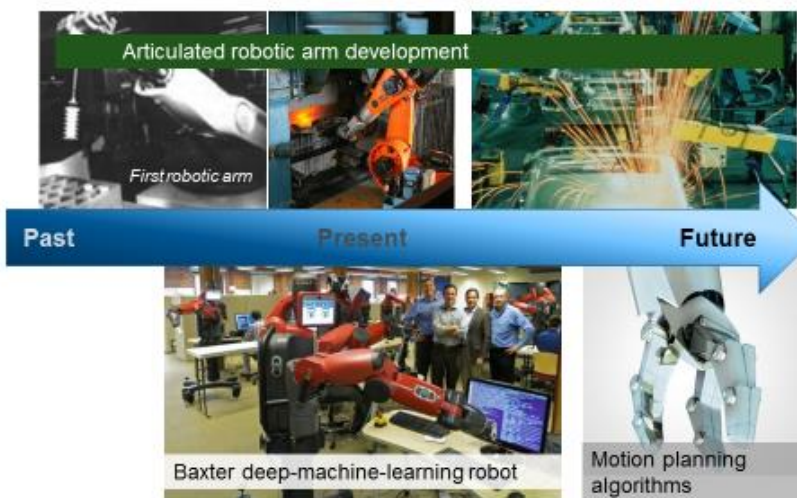


Credit: Steve Jurvetson, 2012.



# Effects of Autonomy

## Autonomous systems improve productivity



Software Engineering Institute | Carnegie Mellon University

© 2017 Carnegie Mellon University

(DISTRIBUTION STATEMENT A) This material has been approved for public release and unlimited distribution.

12

## They can operate continuously



Software Engineering Institute | Carnegie Mellon University

© 2017 Carnegie Mellon University

(DISTRIBUTION STATEMENT A) This material has been approved for public release and unlimited distribution.

13

## They increase information sharing



Software Engineering Institute | Carnegie Mellon University

© 2017 Carnegie Mellon University

(DISTRIBUTION STATEMENT A) This material has been approved for public release and unlimited distribution.

14

## They can process tremendous volumes of data



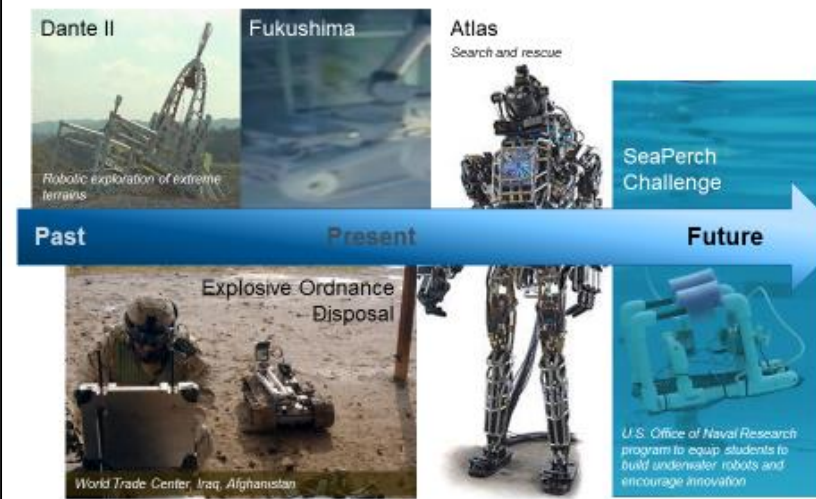
Software Engineering Institute | Carnegie Mellon University

© 2017 Carnegie Mellon University

(DISTRIBUTION STATEMENT A) This material has been approved for public release and unlimited distribution.

15

## They will work where we cannot safely go



Software Engineering Institute | Carnegie Mellon University

© 2017 Carnegie Mellon University

(DISTRIBUTION STATEMENT A) This material has been approved for public release and unlimited distribution.

16

# Effects of Autonomy - 2

## Effects of Autonomy



Source: Paul Nielsen, "Systems Engineering and Autonomy: Opportunities and Challenges", Keynote Presentation at INCOSE Symposium, July 2017 – used with permission

However, autonomy creates other issues

- Emergent behavior
- Continuous change
- Human/machine interfaces
- How to do V&V
- Trust
- Attack vulnerabilities
- Unemployment
- Unintended changes to other businesses
- Ethics
- Issues from new interfaces
- Information overload

## Are we ready to deal with these new issues?



# But Do We Know How to Manage AI?

**Disruption certainly. Deep AI is the real risk, though, not automation.**

*Musk on Automation versus AI*

— **Elon Musk (@elonmusk)** **June 9, 2017**

Disruption may cause us discomfort, but it's not a threat in and of itself. However, Musk and others do see the potential for deep AI to be world-shattering, at least for humans.

Futurism, June 2017

Computers are going to take over from humans, no question. If we build these devices to take care of everything for us, eventually they'll think faster than us and **they'll get rid of the slow humans to run companies more efficiently.**"  
(Steve Wozniak)

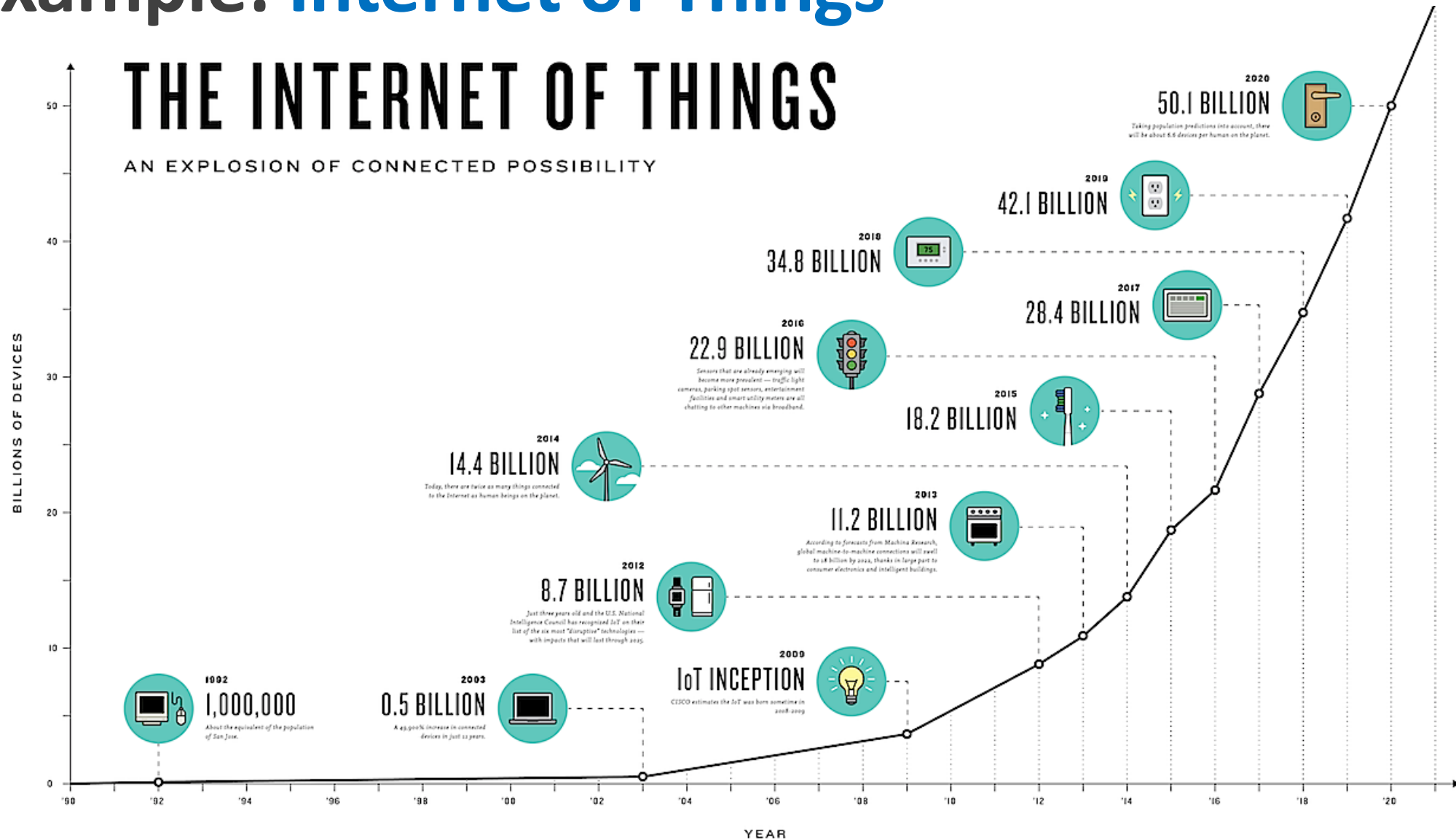
...perhaps most disturbing, scientists working with Google's DeepMind AI tested whether or not AI are more prone to cooperation or competition — and found that it can go either way

...

Futurism, June 2017

The development of full artificial intelligence could **spell the end of the human race.**"  
(Stephen Hawking)

# Example: Internet of Things



# Other technology trends in systems

Brain-Machine Interface Systems

Intelligent Systems, Intelligent Sensing, and Intelligent Learning in Systems

Digital Engineering / Digital Twins

Cognitive Computing

Applied Artificial Intelligence - Cognitive Assistants and Human Augmentation

Interactive and Wearable Computing and Devices

Cyber physical systems


Biometrics, Bio-mechatronics, and Bio-robotics

Augmented Reality / Virtual Reality


Big Data and Data Analytics

Cyber Resilient Systems

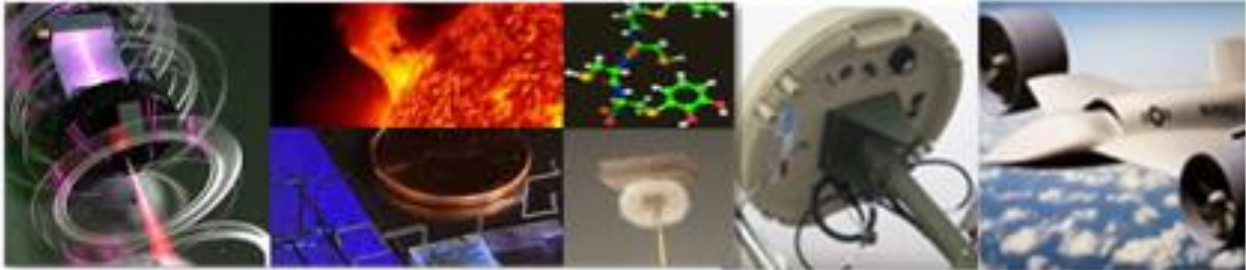
...



## Key Research & Development Investment Areas



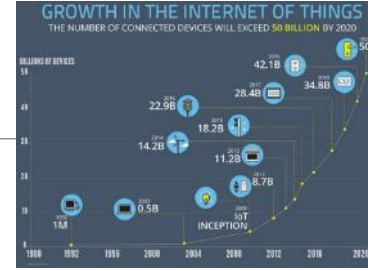
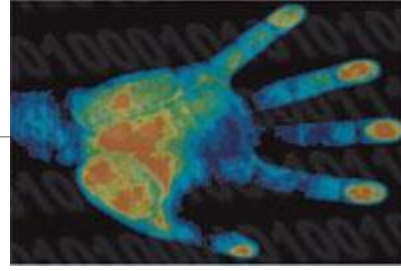
- **Autonomy & Robotics**
- **Artificial Intelligence / Man-Machine Interface**
- **Electronic Warfare / Cyber**
- **Future of Computing**
- **Microelectronics**
- **Novel Engineered Materials**
- **Hypersonics**
- **Precision Sensing: Time, Space, Gravity, Electromagnetism**
- **Directed Energy**
- **Emerging Biosciences**
- **Manufacturing**
- **Understanding Human and Social Behavior**



SAE 2017  
8/30/2017 Page 3Distribution Statement A - Approved for public release by DCPSR. Case # 17-G-0187 applies. Distribution is unlimited.

# Evolution is Needed

- Evolve our systems



- Evolve our systems engineering approaches (processes, methods, tools, perspectives, ...)

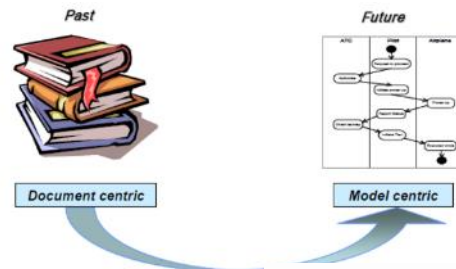
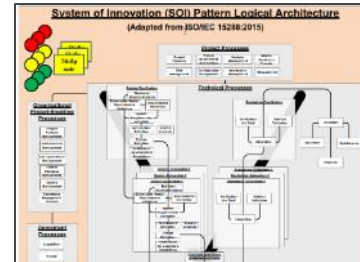
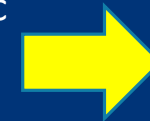


Figure from INCOSE Systems Engineering Vision 202

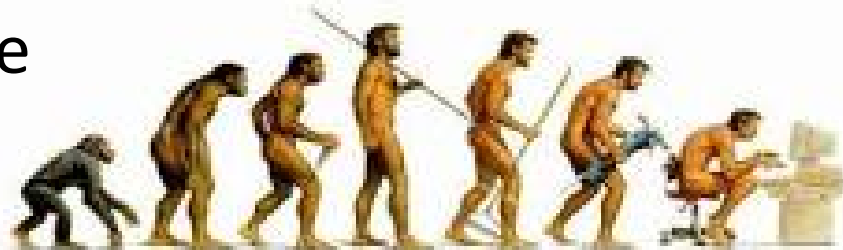


Deterministic  
Linear  
Predictable



Non-deterministic  
Evolutionary  
Stochastic

- Evolve our people

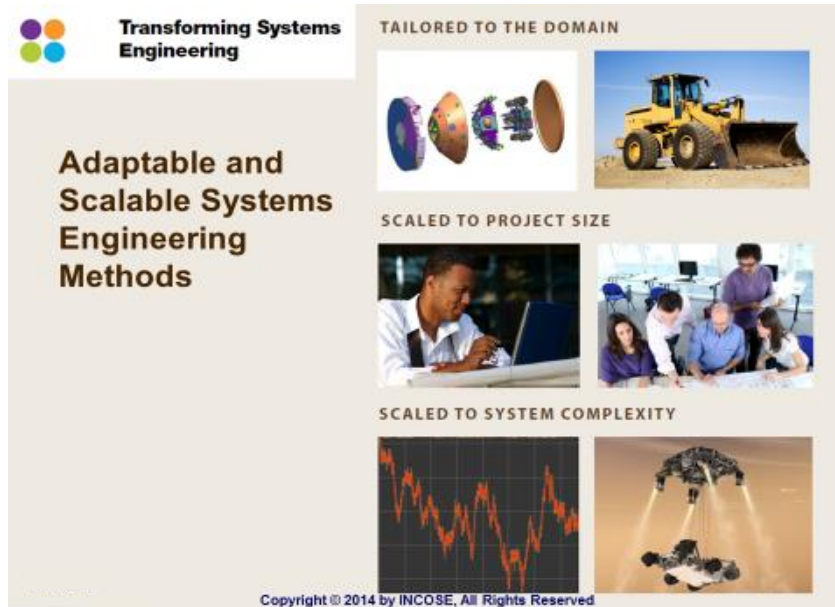


Alphabytesoup.wordpress.com

“When the rate of external change exceeds the rate of internal change, the end of your business is in sight.” [Jack Welch]



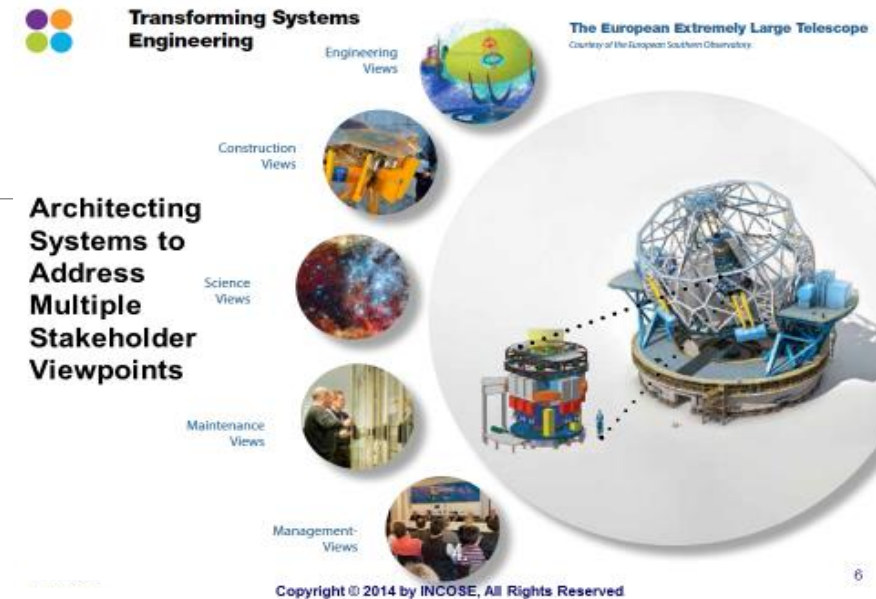
# INCOSE Focus on Evolving the Discipline



Systems Engineering needs to evolve practices to address:

- Faster pace of change
- Increasing complexity
- Affordable solutions
- Agile, adaptable, and resilient solutions
- Challenges of tomorrow

Move SE to a cohesive discipline



- Need to place emphasis on transforming our SE practices
  - Model Based Systems Engineering / Digital Systems Models
  - System of Systems / Complex Systems
  - Agile Systems Engineering
  - Product Line Engineering
  - Composable Architectures and Designs
  - Resilient and Adaptable Systems
  - ...



# Overview of SE Vision 2025 and the Need for Change

*Are we ready for the Future?*



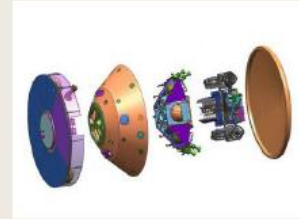
# SE Vision 2025



Note: Chapter and Domain versions of the Vision are being developed (e.g., Dutch Chapter and Automotive)

18 December 2018

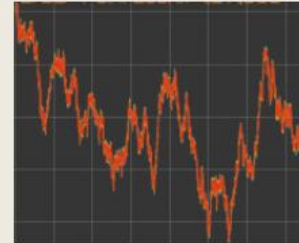
## TAILORED TO THE DOMAIN



## SCALED TO PROJECT SIZE



## SCALED TO SYSTEM COMPLEXITY



## THE PATH FORWARD

### EVOLVING THE VISION THROUGH COLLABORATION

Establish  
Grand  
Challenges

Establish  
Research  
Roadmap

Establish  
Standards  
Roadmap

Establish  
Education  
and Training  
Roadmap

Evolve the  
SEBoK to en-  
compass new  
application  
domains

Engage  
industry,  
government,  
and academic  
leaders

ASSESSING  
THE CURRENT  
STATE

DEVELOPING  
DETAILED  
ROADMAPS

EXECUTING  
FOR  
ACHIEVEMENT



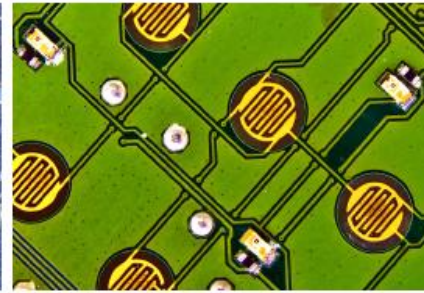
# Vision Objectives

The purpose of the Vision 2025 is to *Inspire and guide* the direction of systems engineering across diverse stakeholder communities, which include:

- Engineering Executives
- Policy Makers
- Academics & Researchers
- Practitioners
- Tool Vendors

This vision will continue to evolve based on stakeholder inputs and on-going collaborations with professional societies.

\* Used with permission of SAE International. This license explicitly does not extend to any use of the "A WORLD IN MOTION" mark on or in conjunction with any STEM-related products or services that INCOSE provides or may provide in the future.



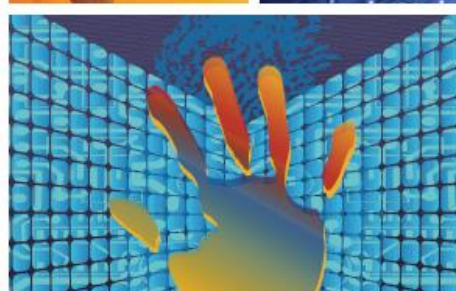
Promote SE research and organizational investment



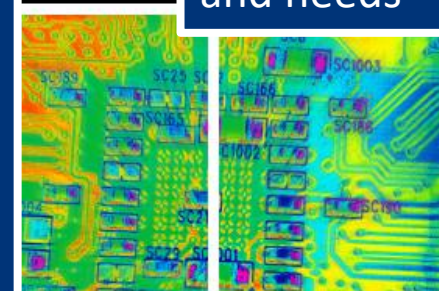
Align SE initiatives, including SE research, SE standards, methods, tools, and curriculum



Identify SE capabilities to support future challenges and needs



Broaden the base of practitioners across industry domains



# SE Vision Systems Engineering Imperatives

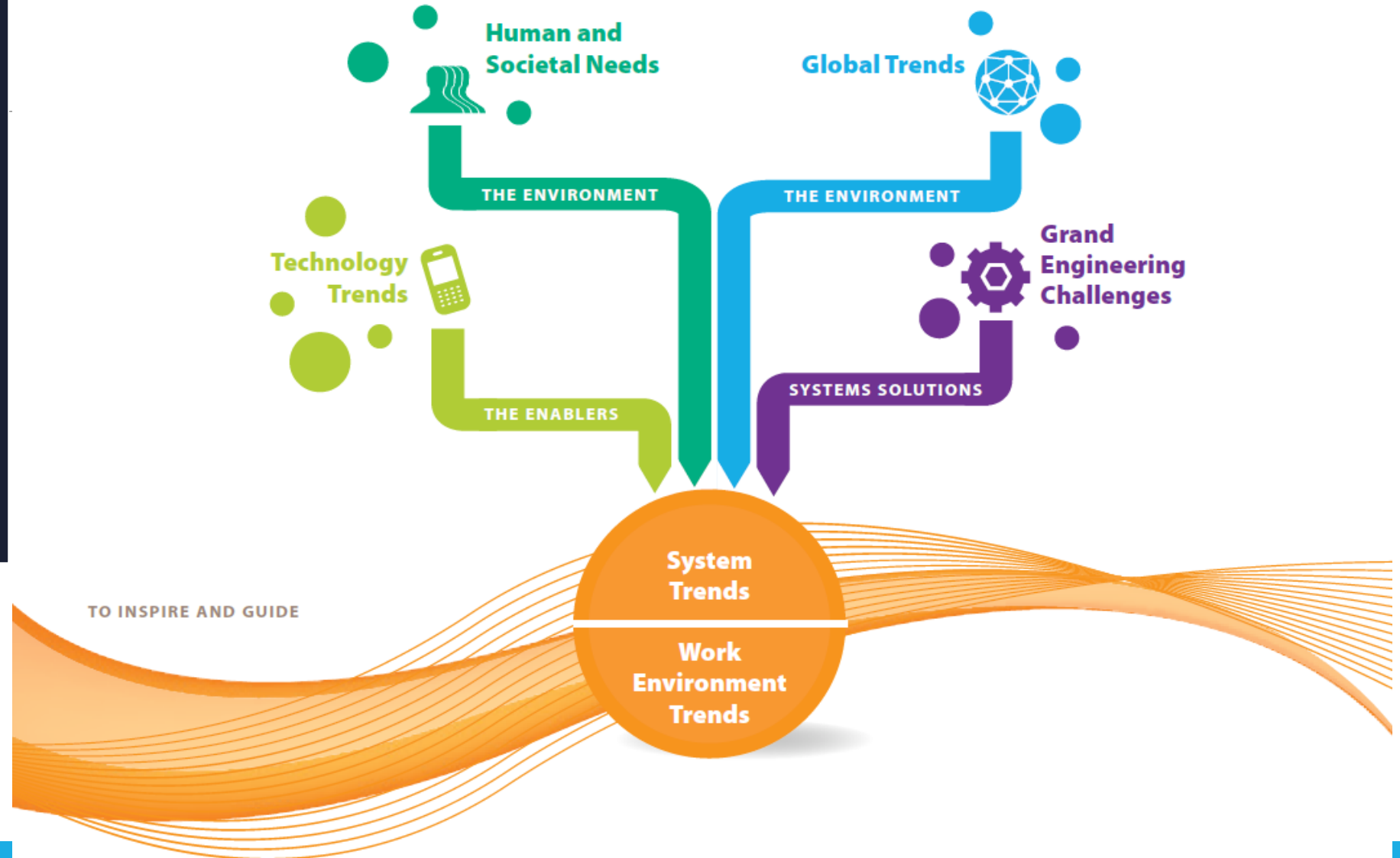
- Expanding the APPLICATION of systems engineering across industry domains.
- Embracing and learning from the diversity of systems engineering APPROACHES.
- Applying systems engineering to help shape policy related to SOCIAL AND NATURAL SYSTEMS.
- Expanding the THEORETICAL foundation for systems engineering.
- Advancing the TOOLS and METHODS to address complexity.
- Enhancing EDUCATION and TRAINING to grow a SYSTEMS ENGINEERING WORKFORCE that meets the increasing demand.



# Global Context of SE

Global trends:

- Increasing stress on natural resources
- Increasing globalization
- Environmental changes
- Increasing population growth and urbanization
- Increasingly interdependent economies



# Today's Global Challenges

Food and Shelter

Clean water

Health environment

Access to healthcare

Transportation and mobility

Economic security & equity

Security and safety

Access to info, communications, education



The diagram illustrates the Systems Engineering Body of Knowledge (SEBoK) as a central hub connected to five domains. The central hub is a blue cloud shape labeled "Systems Engineering Body of Knowledge". Below this cloud is a stack of books representing the SEBoK content. The five domains are represented by colored squares with images and labels:

- Biomedical** (Pink square): Image of a circuit board.
- Transportation** (Blue square): Image of a high-speed train.
- Consumer Products** (Green square): Image of a hand holding a smartphone.
- Automotive** (Orange square): Image of a car chassis.
- Energy** (Yellow square): Image of a glowing lightbulb.



# Transforming Systems Engineering

## Leveraging Technology for SE Tools

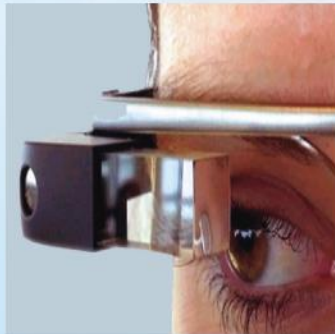
Cloud-based  
high performance  
computing  
supports high  
fidelity system  
simulations



Advanced search  
query, and ana-  
lytical methods  
support reasoning  
about systems



Immersive  
technologies  
support data  
visualization

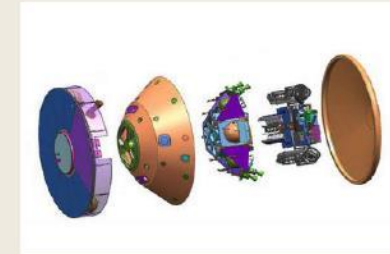


Net-enabled  
tools support  
collaboration



## Tailoring and Scaling Practices for Best Value

### TAILORED TO THE DOMAIN

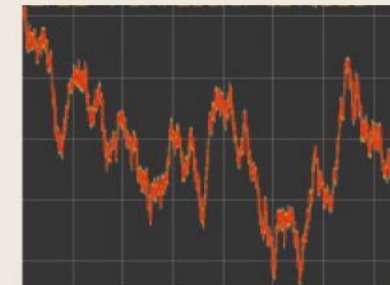


Value  
Driven  
Practices for  
Developing  
Systems in  
2025 and  
Beyond

### SCALED TO PROJECT SIZE



### SCALED TO SYSTEM COMPLEXITY

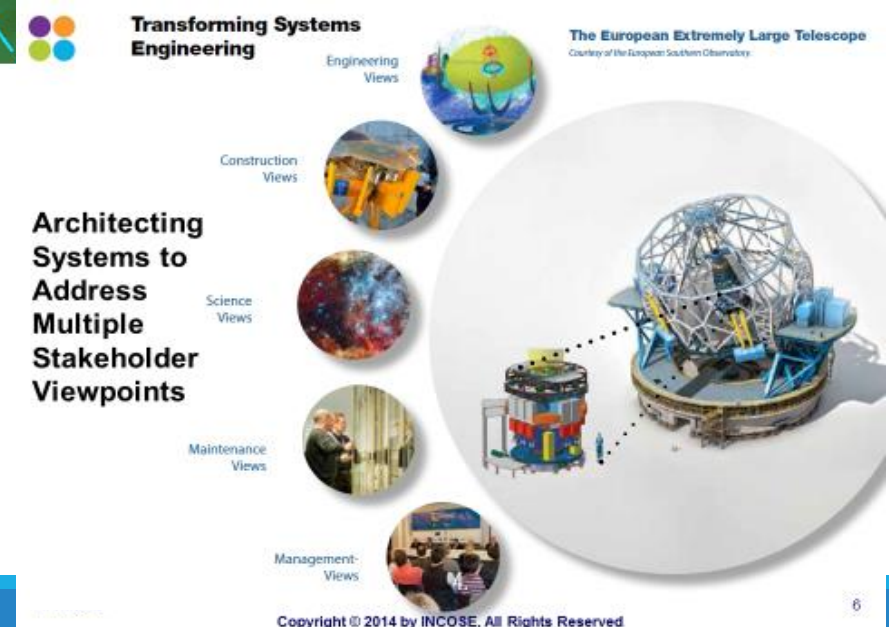


# Transforming Practices

Collaborative Engineering  
Complex System Understanding  
System of Systems Engineering  
System Architecting for multiple viewpoints  
Composable Design  
Design for Resilience  
Design for Security – system integrity  
Decision Support  
Virtual Engineering and MBSE – part of the digital revolution  
Change of process implementation to address technology & application  
Tailoring and scaling practices for value



Source: SE Vision 2025.  
Copyright © 2014 by INCOSE.  
All rights reserved.



# What Does SE Look Like in This Environment? (1)

Dynamic, non-deterministic, evolutionary

- Emergent Behavior is common
- Capabilities continue to evolve
- Learns and adapts to new needs

Cybersecurity and assurance need to be integral, not “bolt-on”

- Integrity, Availability, and Confidentiality (resistance to access)

New approaches to V&V

- Current methods are inadequate for testing systems that learn and adapt
- Behavior changes as data and models are changed by system
- V&V needed throughout life cycle – especially when state changes

# What Does SE Look Like in This Environment? (2)

## Ongoing modeling and simulation challenges

- Robust modeling and simulation capabilities are needed, but ...
- How is M&S kept current and controlled when system learns and adapts?

## Ongoing operational changes

- Less human dependent, changing Rules of Engagement and Concept of Operations
- Changes to training and mission/business parameters

## Changes required for a literate workforce

- Much greater man-machine interface, and machine may have the leading role
- Need for skilled personnel at all lifecycle phases
- Adaptable workforce, as roles will change more quickly - get past culture change issues

# What Does SE Look Like in This Environment? (3)

Technology will  
continue to  
influence

- But at potential faster rates ...
- “Tech watch” programs are necessary, but not sufficient

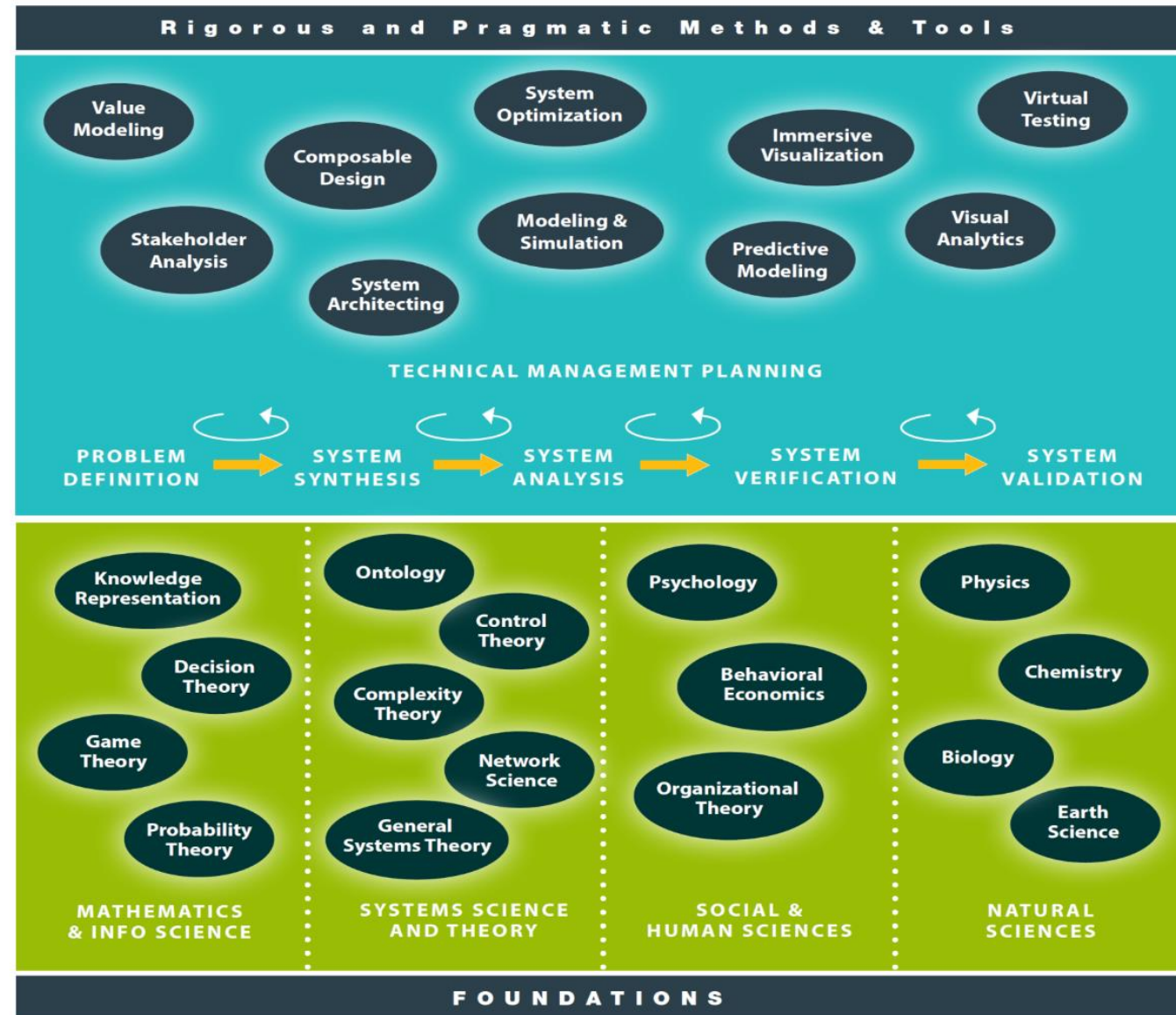
Governance may  
present issues

- Different “ownership” of the interacting systems (System of Systems issue)
- Control of the learning and changing system
- Management of the changing operational areas
- Preventing unintended use or consequences



# Systems Engineering Foundations

## SHORING UP THE THEORETICAL FOUNDATION OF SYSTEMS ENGINEERING



# Essential Systems Engineering Competencies





# Back-up Charts

---

# SE Vision 2025 Copyright (for extracts from the Vision)

Copyright ©2014 by INCOSE, subject to the following restrictions:

INCOSE use: Permission to reproduce this document and to prepare derivative works from this document for INCOSE use is granted provided this copyright notice is included with all reproductions and derivative works.

External Use: This document may be shared or distributed to non-INCOSE third parties.

Requests for permission to reproduce this document in whole are granted provided it is not altered in any way.

Extracts for use in other works are permitted provided this copyright notice and INCOSE attribution are included with all reproductions; and, all uses including derivative works and commercial use, acquire additional permission for use of images unless indicated as a public image in the General Domain.

Requests for permission to prepare derivative works of this document or any for commercial use will be denied unless covered by other formal agreements with INCOSE.

Contact INCOSE Administration Office, 7670 Opportunity Rd., Suite 220, San Diego, CA 92111-2222, USA.

Service marks: The following service marks and registered marks are used in this document:

