Day 1 Introduction to workshop topic

Abstract: Systems Engineering Cultural Transformation

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A systems engineering culture is an umbrella of shared values and behaviors that transcends the individual cultures of teams, departments, and disciplines—rooted in the appreciation of overarching system concepts and system relationships. Engineering is an ancient discipline, but systems engineering has a history of only a few decades. The primary benefits of systems engineering have been stated as the ability to control complexity, improve communication, and prevent defects. Systems engineering and particularly model-based systems engineering, is often touted as the approach to ensure high reliability from systems that are at the same time becoming more auto-mated, adaptable, agile, and interoperable. These systems tend to also become more complex system-of-system solutions.

If systems engineering is the approach to control this explosion of complexity and assurance of reliability, then why is the transformation to a systems engineering culture so difficult? It has been said that determining the return-on-investment for a transformation to a systems engineering approach is practical-ly impossible to determine. What, then, is the paradigm shift that needs to happen to implement a successful systems engineering culture? What is required for an effective transformation? What impedes the recognition and realization of value here?

This workshop will explore individual and organizational challenges that need to be overcome to effect a transformation toward a successful systems engineering culture.

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.

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Systems Engineering Cultural Transformation

Good morning.

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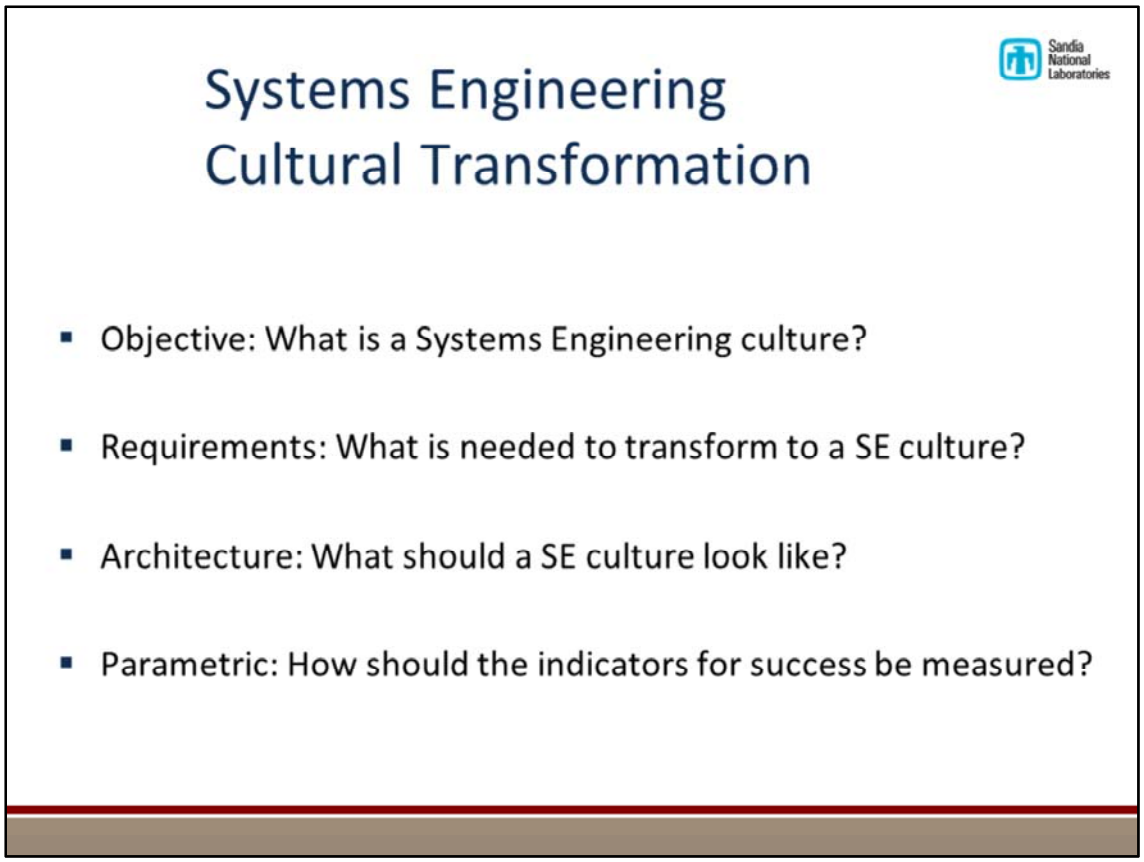
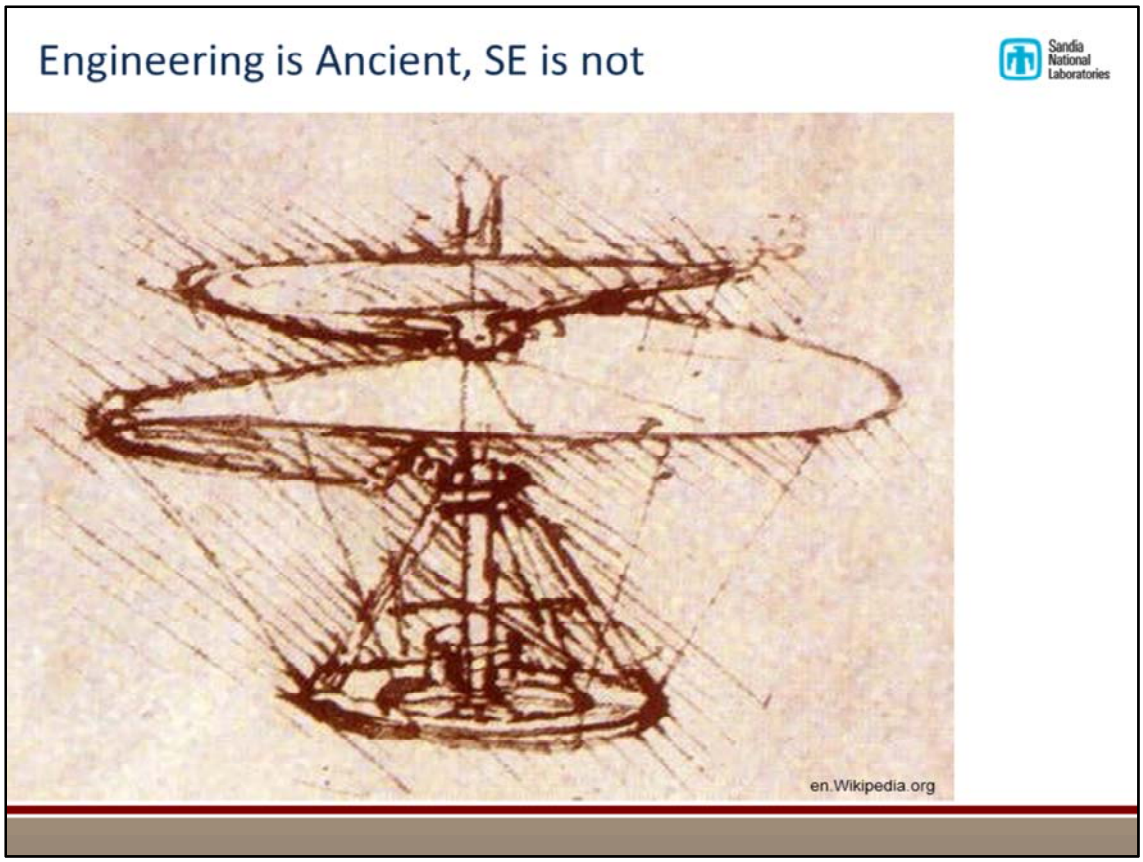


Rick Dove describes a systems engineering culture is an umbrella of shared values and behaviors that transcends the individual cultures of teams, departments, and disciplines—rooted in the appreciation of overarching system concepts and system relationships.

- Let's explore that concept a little further, using basic systems engineering technique.
- Let's start with the objective. What is a Systems Engineering Culture?
- We'll explore the requirements, opportunities and barriers to cultural transformation.
- We'll define the reference architecture for what a systems engineering culture should look like.
- And we'll define the key indicators for success and how to measure them.



Engineering is an ancient craft. However, Systems Engineering is a term that was only coined a few decades ago. Wikipedia traces the history of systems engineering to Bell Telephone Laboratories in the 1940s.[1] The need to identify and manipulate the properties of a system as a whole, which in complex engineering projects may greatly differ from the sum of the parts' properties, motivated various industries, especially those developing systems for the U.S. Military, to apply the discipline.[2]

In 1990, a professional society for systems engineering, the *National Council on Systems Engineering* (NCOSE), was founded by representatives from a number of U.S. corporations and organizations. NCOSE was created to address the need for improvements in systems engineering practices and education. As a result of growing involvement from systems engineers outside of the U.S., the name of the organization was changed to the International Council on Systems Engineering (INCOSE) in 1995.

Image reference: en.Wikipedia.org

Why Systems Engineering? And why a systems engineering culture? Well the benefits speak for themselves. Our systems are growing more complex, and systems engineering controls complexity (for example, there are few systems more complex than an aircraft carrier). Systems engineering improves communication (both within a project, program, or organization, as well as externally). Systems engineering ensures reliability (and as we've all heard, air travel is the safest way to travel). Perhaps most importantly, systems engineering prevents defects and errors (which can be catastrophic in a complex system).

Yet, an old friend of mine, Anonymous, claims that determining the ROI for (model-based) systems engineering is impossible. And perhaps as a result, a systems engineering culture is hard to find.

{image references:

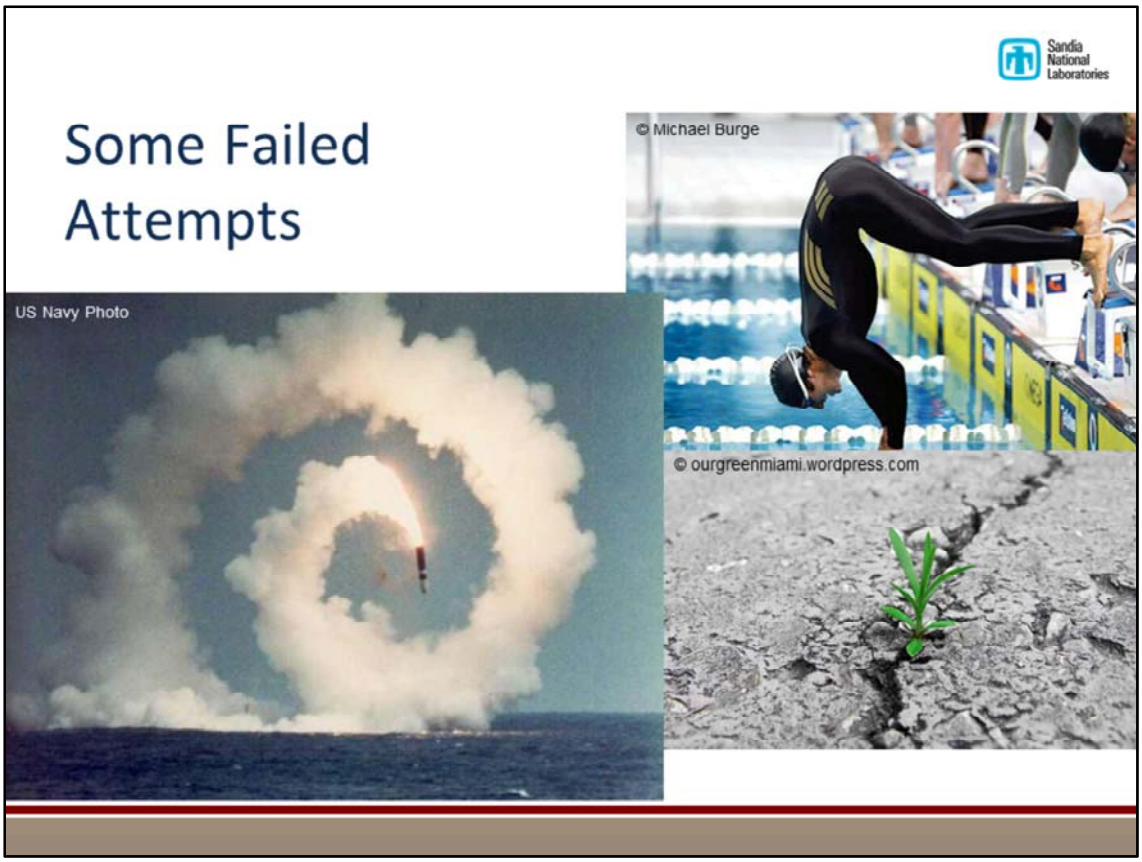
Aircraft carrier (US Navy photo)
Controlled Impact Demonstration (NASA photo)
Satellite Constellation (NASA photo)
A-6 barrier crash landing (US Navy photo)

Customers demand systems that are automated, adaptable, agile, and interoperable – in short – more complex, System-of-Systems solutions. Systems Engineering and Model-based Systems Engineering is touted as the solution approach to achieve these.

If so, why are there not more Systems Engineering cultures? Why is the transformation to a systems engineering culture not obvious?

I conducted a Systematic Literature Review, where we searched through 20,000 documents. Many described success of some kind on a single project, and some on a larger program. None demonstrated that Systems Engineering was ingrained across the enterprise. The best examples in my industry were Lockheed Martin, Boeing, Huntington Ingalls, and JPL. Lockheed Martin has a corporate initiative to implement Systems Engineering (where MBSE is a sub-set of that initiative), with some successes in large programs such as the Orion Human Space Program and the Littoral Combat Ship Program, but they expect it to take 10 more years before SE/MBSE are ingrained into the culture. Boeing has a corporate initiative to implement Systems Engineering (where MBSE is a sub-set of that initiative), with some success in large programs such as the Presidential Aircraft on the defense side, and a significant level of model-based engineering on the commercial side. But the commercial side does not employ a Systems Engineering approach and Boeing makes many other defense related systems, without an integrated systems engineering approach. Huntington Ingalls is developing the Ford-classed CVN-78 Supercarrier using a Model-based Systems Engineering approach. They have a target to develop the entire carrier in digital models by CVN-80. In other words, they are getting there, but not there yet. JPL may have the most advanced systems engineering and MBSE culture, particularly with programs such as the Europa Mission or the 2020Mars Mission, yet even they do not employ systems engineering practices across all programs.

{image references (left to right):
Orion Human Space Program (NASA photo)
Presidential Aircraft-747-8 (copyright: Boeing, Corp.)
CVN-78 Supercarrier (US Navy photo)
Europa Mission (NASA/JPL photo)



If systems engineering is the approach to control this explosion of complexity and assurance of reliability, then why is the transformation to a systems engineering culture so difficult?

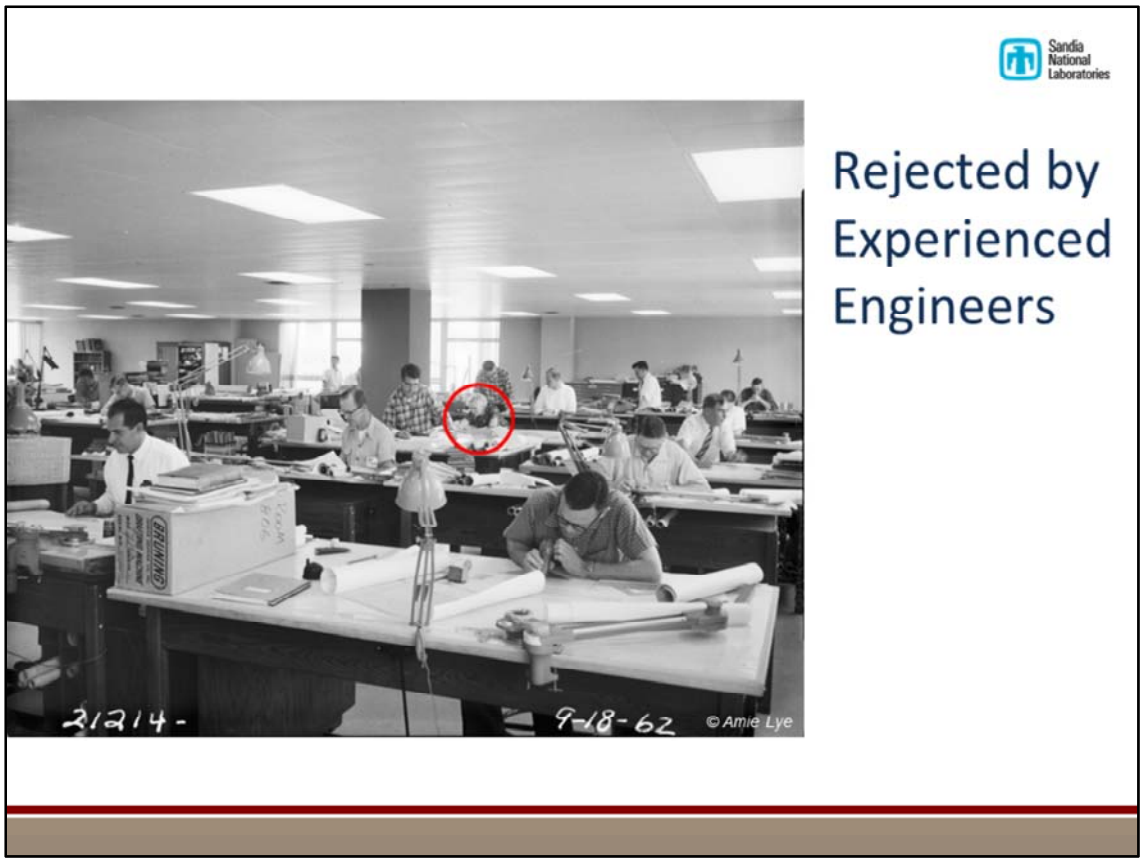
Perhaps the issue is that there have been many ways to fail to implement a Systems Engineering culture.

- Some groups start by attempting to tackle the entire enterprise all at once (a Big Audacious Goal, that is missed) – a personal example: I failed to achieve a large objective once, and was told afterwards that new executive often like to make a name for themselves by taking on a new large project which appear to be a shot for the moon. He then accused me of shooting for Mars!

- Other groups jump the gun, starting a systems engineering transformation before they are ready.

- Some groups never grow beyond their grass roots efforts, running small pilot projects that never manage to convince the enterprise to change.

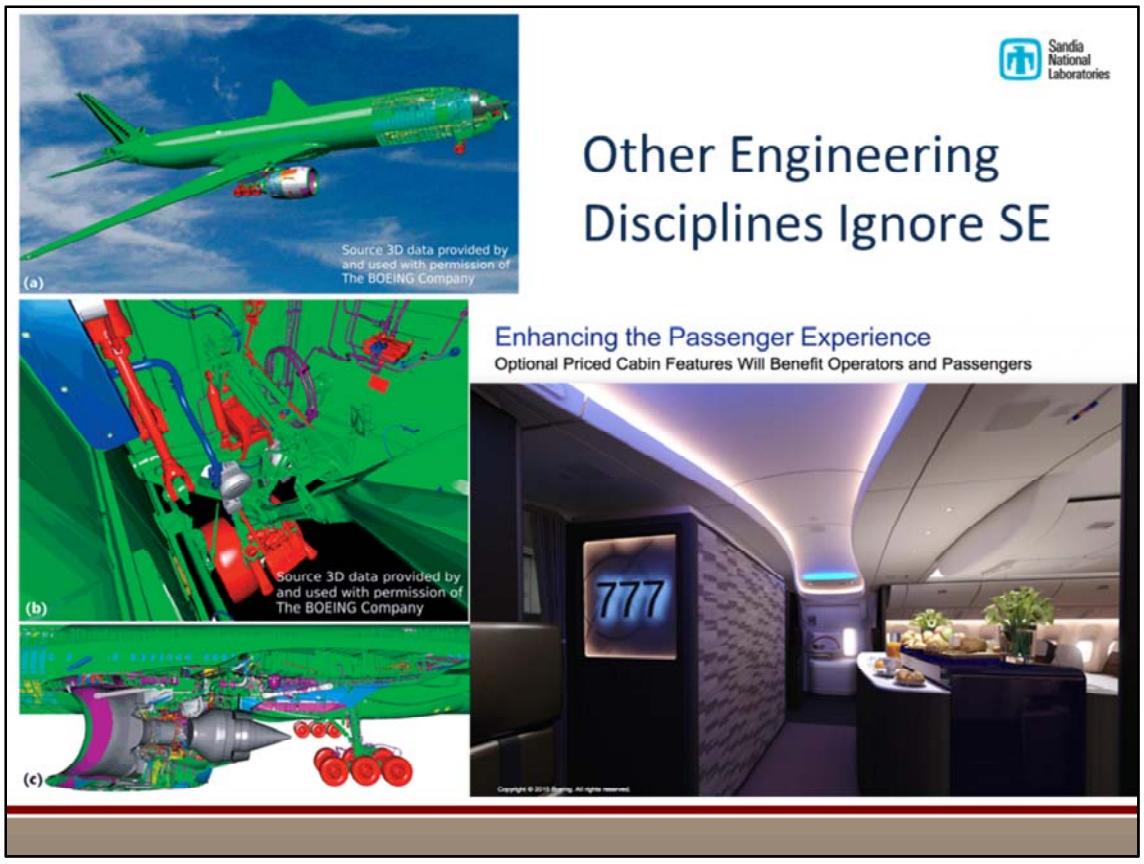
{image references:
BAG (US Navy photo)
False start-jump the gun (copyright: Michael Burge)
Too small-tiny plant in a desert (copyright: https://ourgreenmiami.wordpress.com/page/5/)



Your company may have developed massively complex systems for 50 years or more! Who are you then, a lowly Systems Engineer, to suggest that change is needed? It is often surprising to a Systems Engineer when other engineering disciplines do not support their desire to modernize their processes. However, engineers are like many of us. They get set in their ways, they worry that change will disrupt what they know, perhaps change will put them at a competitive disadvantage, or the old guys are afraid that they might look foolish in the eyes of the new hot engineers.

The best example I could come up with to represent this rejection by experienced engineers is this photo of Amie Lye (can you see her here inside this little red circle? The lone female engineer). In 1962, there were very few female engineers, largely due to rejection by experienced engineers. Happily, we are seeing many more women in engineering today.

Image reference: Treat Me Like An Engineer, Not A Female Engineer, Amie Lye

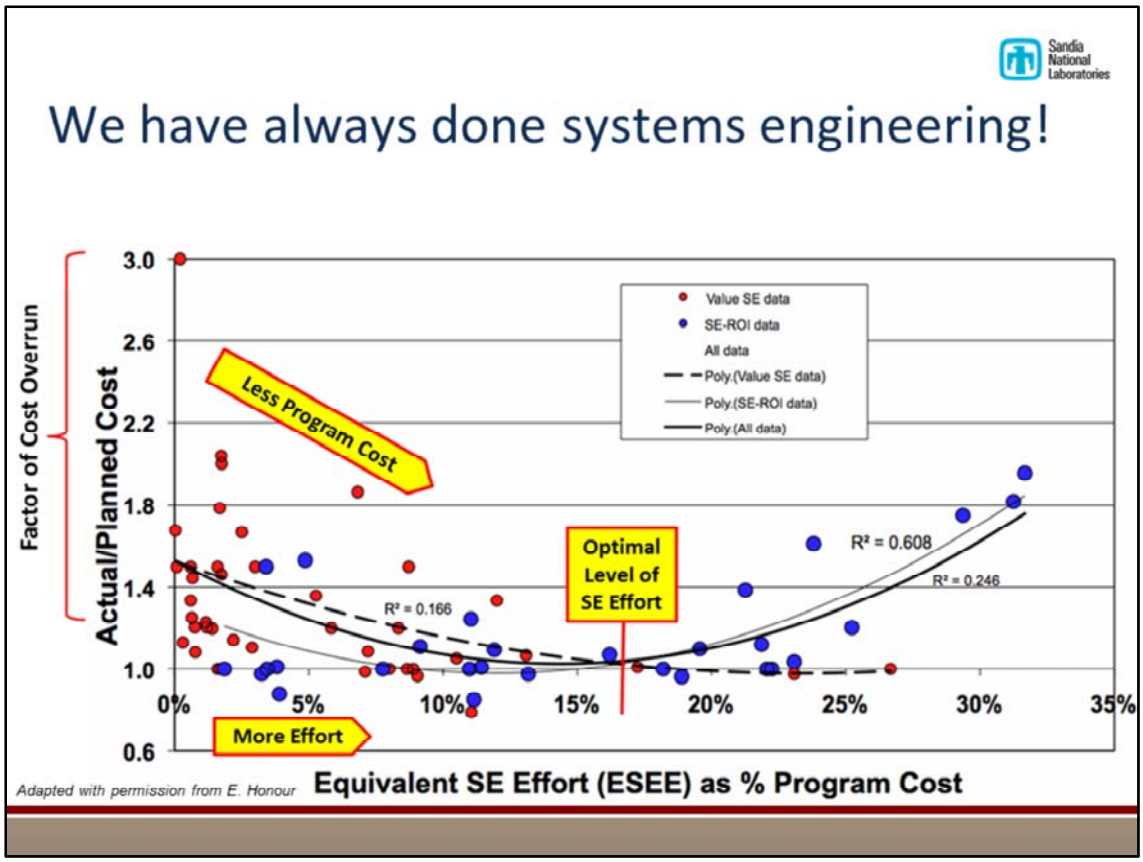


Mechanical and electrical engineering disciplines have been using digital models for well over 25 years. The Boeing Company created of the Boeing 777 in the early 1990s. I was with Boeing when the 777 was rolled out. They were quite proud of their efforts to digitally create 3D spatial models of the entire airplane. I particularly enjoy these mock cabins. I say mock, because I cannot imagine ever being allowed to fly in this kind of comfort.

So, the other engineering disciplines model design, but do they understand why requirements (such as human factors), architecture, or test should be modeled? How do you convince them that requirements, architecture, and test also need to be modeled (or should I say, “engineered”)?

When you ask a mechanical or electrical engineer what systems engineering is about, do they know? Let me guess, they say, “requirements”, am I right? You tell me, is there more to systems engineering than requirements? They don’t even say “requirements management”, do they?

Image reference: The Boeing Company

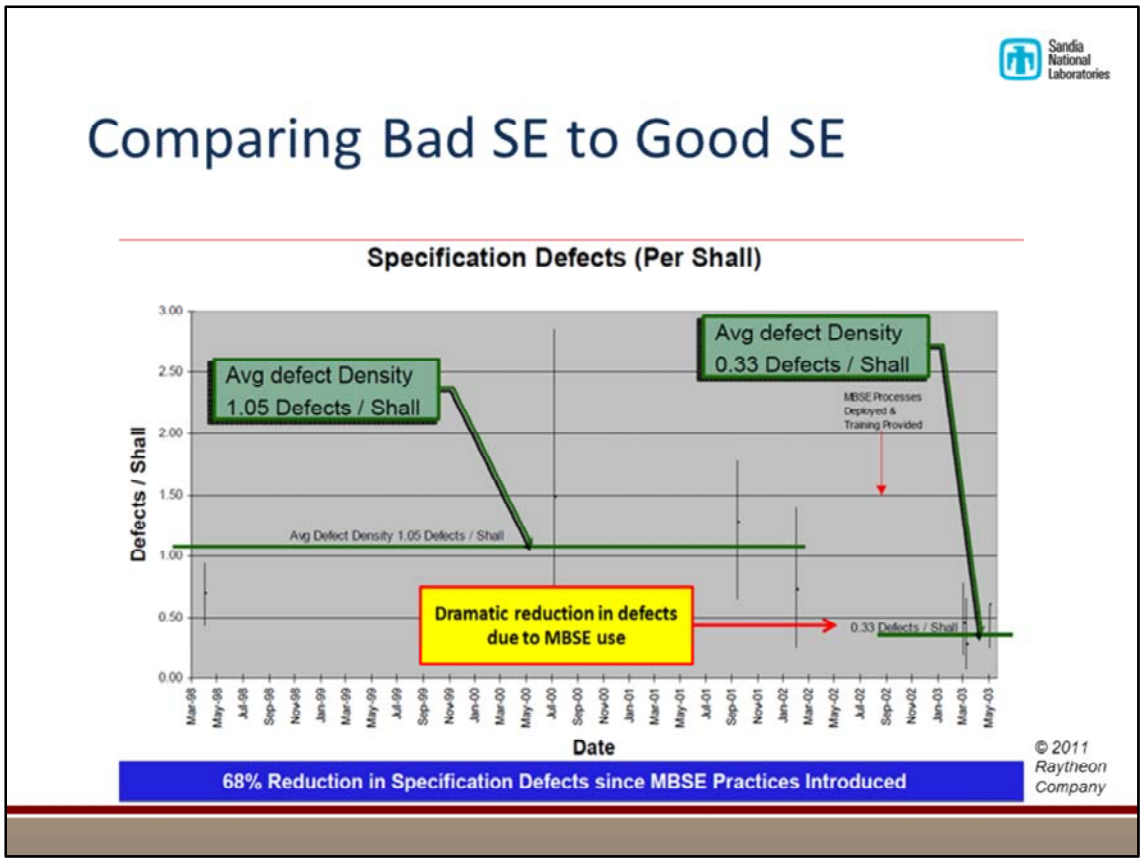


We already established that your firm may have been doing systems engineering for decades. One idea I gained while conducting my research was that systems engineers were not speaking to executives in the language that executives wanted to hear. That is, cost and schedule ROI. However, ROI may not convince a VP when that VP believes that their team has always done good Systems Engineering (for decades), and therefore does not need to change processes or add modeling to their systems engineering efforts?

In 2013, Eric Honour published a study where he compared SE effort against actual cost for NASA projects. He identified that an optimal level of systems engineering effort was between 10% and 18% of total program cost. 1.0 on the y axis represents Planned Cost. Everything above 1.0 is a cost overrun, in order of magnitude. So, 1.4 is a 40% overrun. Notice how many projects are above 1.0. If VP's were so easily swayed by ROI data, they should pay attention to this optimal performance graph. How many of your projects load systems engineering at 15% of total work effort? So, when the prevailing assumption is that we already know all about systems engineering, how do you convince anyone that change is needed?

Image reference:

E.C. Honour, "Systems engineering return on investment," Ph'D thesis, Defence and Systems Institute, School of Electrical and Information Engineering, University of South Australia, 2013.



There is a fair amount of hype regarding the benefits of a model-based systems engineering approach. In my literature review (another shameless plug – you would think I receive royalties), we identified several case studies that showed a marked improvement after they had implemented a model-based systems engineering approach. However, after collaborating further with Eric Honour, the researcher in this area, whom I mentioned in my last slide, we feel (anecdotally) that it is likely that many, if not all, of the DBSE to MBSE comparisons (particularly those that showed a significant improvement) were actually comparing bad systems engineering to good systems engineering. In other words, the improvement was due to implementing good engineering processes, not due to adding modeling or digital tools.

Image reference: *© 2011 Raytheon Company and adapted with permission from S. Saunders*

So, to get us started, here are some ideas that I've gleaned out of several articles on transforming an engineering culture (funny how all of the articles had basically the same ideas):

1. Communicate your objectives – why you want to change the culture - often and to everyone. No one achieves an objective by accident (at least I never have)
2. Do not forget that there are many stakeholders and they should all be included in the process. If not, they will not support the effort.
3. Communicate your objectives – why you want to change the culture – often and to everyone (have I said that already? Well, it is worth repeating)
4. Plan your changes incrementally. Big bang only works in physics
5. Keep in mind that what works in a pilot or prototype may not work at a larger scale, so plan the scaled rollout. No one achieves an objective by accident (at least I never have)
6. Communicate your objectives – why you want to change the culture – often and to everyone (Worth repeating, again)
7. Take on a mentor, empower them, and listen to what they say!
8. Keep leadership engaged – set their expectations and affect them to embrace the changes for the long-term – they are the ones who can/will/should pull the organization toward the goal
9. (And once again,) Communicate your objectives – why you want to change the culture – often and to everyone

So, join me as we explore the individual and organizational challenges that need to be overcome to effect a transformation into a successful Systems Engineering culture.

Systems Engineering Cultural Transformation

Moderator: Ed Carroll

Day-1 Brief Out (as decided Friday, subject to change during Saturday)

Planned Primary Workshop Issues to Explore

- What is culture and how to translate into systems engineering culture
- What is the roadmap to systems engineering culture, and what is the value of it what does it value
- Barriers to Transformation what does systems engineering not cover

Objectives

- What is a system engineering culture?
- What is needed to transform a system engineering culture?
- What should a system engineering culture look like?
- How should the indicators for success be measured?

Systems Engineering Cultural Transformation

Moderator: Ed Carroll

Day 2 Brief Out

What is a system engineering culture?

- Culture=beliefs, values, and behaviors
- Everyone values system engineering for the end variable
- Everyone understands there is a larger relation between product, output, and process
- Everyone accepts the role of the System Engineer
  - Defines the scope and architecture of the system
  - transforms stakeholder requirements into the technical requirements
  - Traces requirements through tests and validation
  - Leads program retrospective
- Involves people, processes, and tools
- SE engineering is most applicable/justified for complex issues

What are Barriers? How to Overcome Them?

- Lack of a definition or vision for Systems Engineering Culture
- Top levels must endorse the use of S.E. and hold accountability
  - SE must be brought in early
  - There must be increased SE effort
  - SE must have authority
- SE culture must appeal to the needs of individuals
- The old guard must be convinced of the benefits of SE
- Overcome perception that the organization is already performing optimally
- Communicate:
  - By example, person-person, systematic study, specific to the audience
- Expect incremental change
- Find an executive champion

What can we learn from others?

- Quality-compared failures
  - Comparative failure analyses
- Security-became urgent
  - Increase of cyber threats
- Safety-lawsuits forced
  - Regulatory compliance
- Software Agile Method-environment enabled change
  - Competition forced change
    - Offshore competition cut cost by 5x
    - Agile Method proved successful against offshore

What should a system engineering culture look like?

- Leadership has ownership and feels accountable
  - Because it is the right/ethical thing to do
  - And by-the-way the customer requires it
- Everyone down the line also believes and feels accountable
  - Because it is the right thing to do
  - By regulation
- Roles, processes, and tools are well communicated to everyone
- Low defect products
- Respect and understanding of all organizational roles and disciplines

How should the indicators for success be measured?

- Surveying the constituency
  - Pre-program
  - Throughout the lifecycle
  - Retrospective
- SE capability maturity
- Defects, costs, Schedule, LOE
- Periodic audit (by secondary team)
  - Independent/past/at phase gates
  - Compliance

What would motivate individuals to broaden their SE knowledge/skillset?

- Recognize that they need help
- They foresee career progression potential
- Regulation
- Make the change easy and less dramatic
- Keep the person feeling needed