NDIA 18th Annual Systems Engineering Conference

BUILT FOR TODAY.

DESIGNED FOR TOMORROW.

18085 - Putting Engineering Back into Systems Engineering

10/28/2015

Bill Miller
(908) 759-7110
wmiller@innovativedecisions.com

Frank Salvatore
(973) 634-2957
frank.salvatore@engilitycorp.com

IDI Innovative Decisions, Inc.

ENGILITY Your Mission. Our Commitment.

Abstract

- The Department of Defense has long recognized systems engineering in partnership with program management as necessary to successfully execute programs. Back in the 1950's programs like the Semi-Automatic Ground Environment (SAGE), Atlas, Titan, the Air Force Ballistic Missile program, and the Navy Polaris programs relied on Systems Engineering to achieve their objectives. One of the main promises systems engineering brought to these programs was to help them with making decisions, to help with technical communications across functional and organizational boundaries, to provide a steady "Aim point" for the program with a set of well-defined, feasible, verifiable, understood and managed set of requirements. We still need to do this but it seems we have lost our way. While there has been a steady rise in the application of systems engineering on programs there is still a need to do more. Even with a steady trend toward model based systems engineering and greater emphasis on specialty engineering disciplines and working as an IPT, it is still not enough to accomplish the Systems Engineering required. Is this really an issue, perception, or perhaps an excuse? Is there something that Systems Engineers are not doing, are not being asked to do, aren't capable of doing, are doing wrong? Has there been a loss of Engineering knowledge skills and abilities? What is causing this situation and what could be done to help raise awareness and to improve the practice and application of systems engineering on projects.
- This presentation will explore these questions and more. It will identify the "Engineering" elements of Systems Engineering, explain what they mean, why they are important and when they should be performed. Finally we will share some tips and tricks that could put the "Engineering" back into Systems Engineering.

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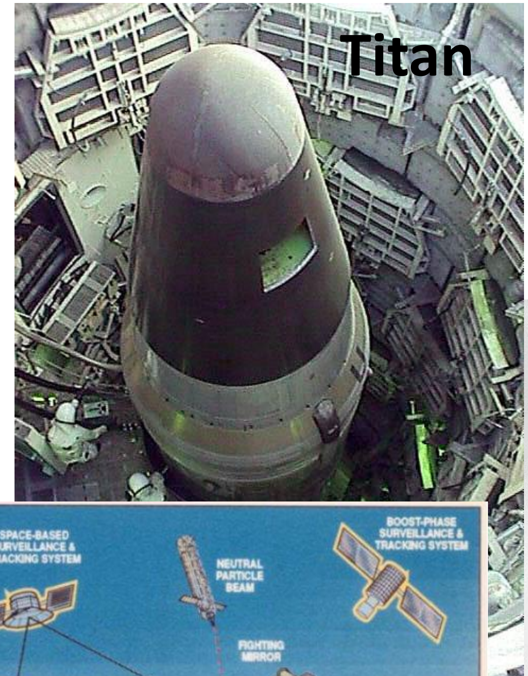
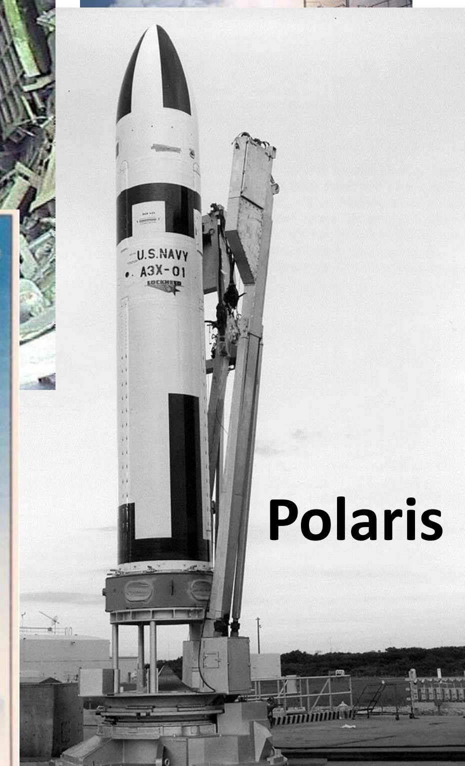
Programs that relied on Systems Engineering to achieve their objectives





Systems Engineering Contribution:

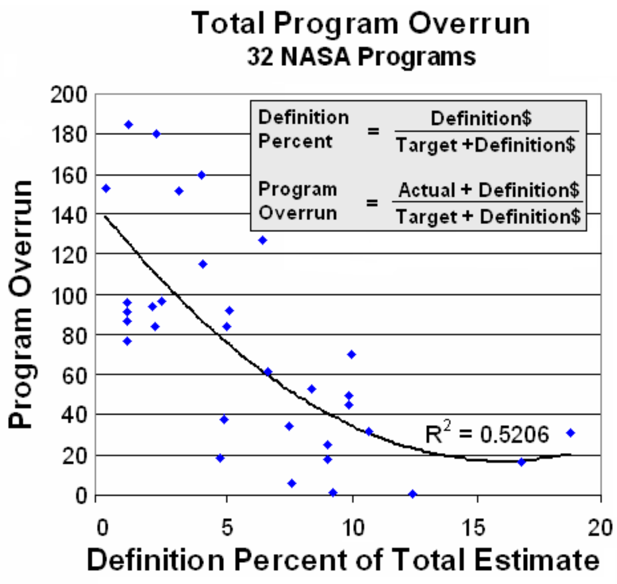
- Decision Making
- Communicate
- Feasible Requirements

Thesis (n): *an unproved statement put forward as a premise in an argument*

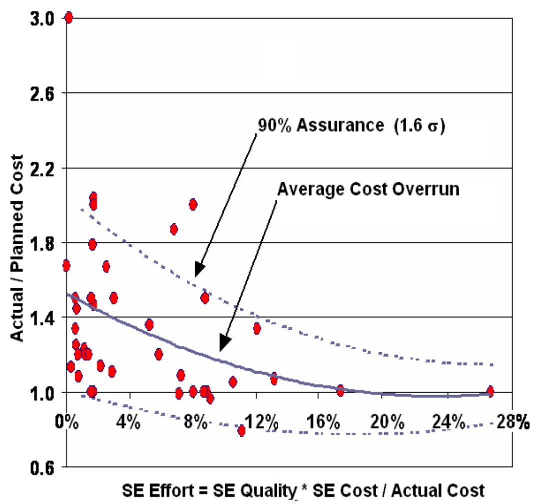
- Has there been a degradation of systems analysis skills to the detriment of the standing of the discipline?
- Has systems engineering become much more about process than outcomes?
- Is it just another engineering discipline rather than the integrating discipline of the parts of the system and the system in its context?

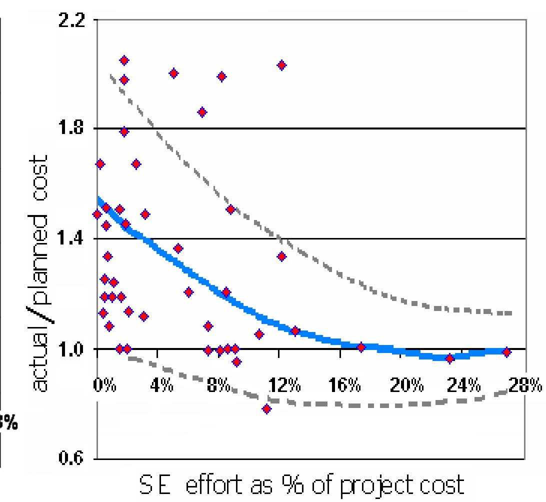
We know the sweet spot for effective systems engineering effort on programs

NASA Programs[1]



Value of SE[2] (SEI/NDIA Study)





[1] Gruhl, 1992
[2] Honour, 2004

SE Effectiveness Studies

The numbers of systems engineers needed, appear to be right sized @ 10-20%

United States Government Accountability Office

GAO

Report to the Committee on Armed Services, U.S. Senate

September 2011

WEAPONS ACQUISITION REFORM

Actions Needed to Address Systems Engineering and Developmental Testing Challenges

U.S. Government Accountability Office GAO 90 YEARS 1921-2011 ACCOUNTABILITY ★ INTEGRITY ★ RELIABILITY

GAO-11-806

The following table shows the baseline, goal, and current number of civilian and military personnel performing systems engineering and test and evaluation activities for each of the services at the end of fiscal year 2010, as well as the percentage of the growth goal target achieved.

Table 3: Actual and Planned Military Service Systems Engineering and Test and Evaluation Career Field Growth

	Baseline[a]	Growth goal by the end of fiscal year 2015[b]	Current workforce as of September 30, 2010	Percentage of growth goal target achieved as of September 30, 2010
Systems engineering career field				
Air Force	6,380	7,059	7,575	107%
Army	10,615	12,076	10,938	91%
Navy	17,961	20,870	19,012	91%
Totals	**34,956**	**40,005**	**37,525**	**94%**
Test and evaluation career field				
Air Force	2,622	2,566	2,840	111%
Army	2,135	2,297	2,211	96%
Navy	2,652	2,829	2,977	105%
Totals	**7,409**	**7,692**	**8,028**	**104%**

Estimate 200K+ SEs in aerospace & defense across government and industry

Then what's the problem?

NDIA
NATIONAL DEFENSE INDUSTRIAL ASSOCIATION
STRENGTH THROUGH INDUSTRY & TECHNOLOGY

National Defense Industrial Association
Systems Engineering Division
Top Systems Engineering Issues
In
Department of Defense and Defense Industry

July 2010

Final 9a-7/15/10

Background

The Director, Systems Engineering, Office of the Under Secretary of Defense, Acquisition Technology & Logistics, DDR&E, who serves as the primary OSD interface to the NDIA Systems Engineering Division, agreed in early December 2009 that the Division should update the Top 5 Issues in Systems Engineering (SE) report that was issued initially in 2003 and updated in 2006. The issues related to our defense industry are complex, affecting both the industry participants as well as the government participants.

A Task Group was formed, inputs were solicited in advance, and a reconciliation meeting with about 18 members was held on March 17th and 18th, 2010. Although scores of separate issues were identified, the group found that the bulk of these actually fell into five major issue categories. The detailed results, including the status of the previous 2006 SE issues, are described below.

Status of Activities against the Top Systems Engineering Issues for 2006

#	2006 Issue	2010 Status
1	Key systems engineering practices known to be effective are not consistently applied across all phases of the program life cycle.	• Institutionalization of practices has shown value when adopted but adoption tends to be spotty • Determination of proficiency in applying practices appears to be problematic
2	Insufficient systems engineering is applied early in the program life cycle, compromising the foundation for initial requirements and architecture development.	• Improving by necessity in complex systems • Policy updates (5000.2, competitive prototyping and earlier decisions) imply SE engagement, but are not explicit
3	Requirements are not always well-managed, including the effective translation from capability statements into executable requirements to achieve successful acquisition programs.	• WSARA requirements for independent estimates are an improvement • Variability in approaches to requirements definition, validation and consolidation continue

Congressional Research Service

The Army's Ground Combat Vehicle (GCV) Program: Background and Issues for Congress

Andrew Feickert
Specialist in Military Ground Forces

January 2, 2013

GAO

United States Government Accountability Office
Report to Congressional Committees

DEFENSE ACQUISITIONS

Assessments of Selected Weapon Programs

GAO-09-362T Cites Lack of Disciplined Systems Engineering

"… managers rely heavily on assumptions about system requirements, technology, and design maturity, which are consistently too optimistic. These gaps are largely the result of a lack of a <u>disciplined systems engineering analysis</u> prior to beginning system development …

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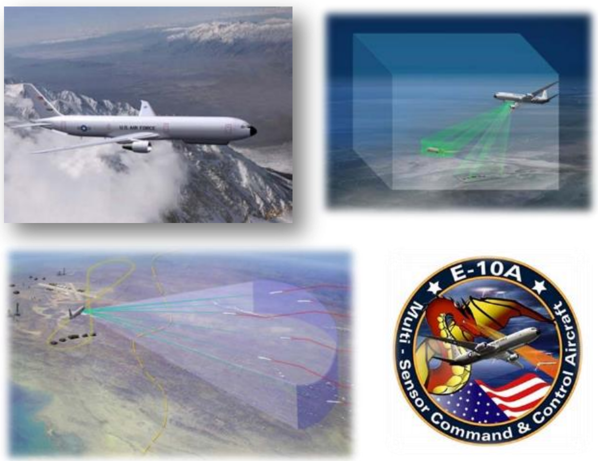
NDIA SE Findings 2010

- Increasingly urgent demands of the warfighter are requiring effective capabilities to be fielded more rapidly than the conventional acquisition processes and development methodologies allow.
- The quantity and quality of Systems Engineering expertise is insufficient to meet the demands of the government and defense industry
- Systems engineering practices known to be effective are not consistently applied or properly resourced to enable early system definition
- Technical decision makers do not have the right information & insight at the right time to support informed & proactive decision making to ensure effective & efficient program planning, management & execution.
- The development of systems with a full level of integrity (all technical aspects considered) is longer and more expensive over the entire lifecycle as the technical solution is iterated and reworked in later stages of the development.

AFIT SE Case Studies

E-10A MC2A
SYSTEMS ENGINEERING
CASE STUDY

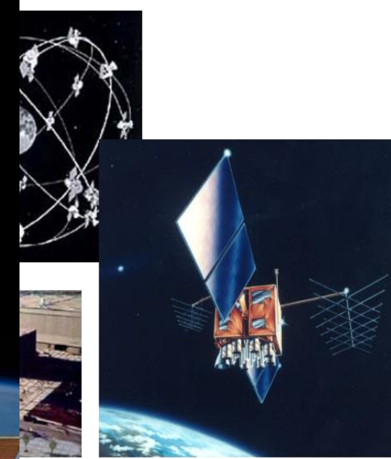
WILLIAM ALBERY, Ph.D.



Air Force Center for Systems Engineering (AFIT/SY)
Air Force Institute of Technology
2950 Hobson Way, Wright-Patterson AFB OH 45433-7765

GLOBAL POSITIONING SYSTEM
SYSTEMS ENGINEERING
CASE STUDY

4 October 2007



er for Systems Engineering (AFIT/SY)

International Space Station
Systems Engineering Case Study

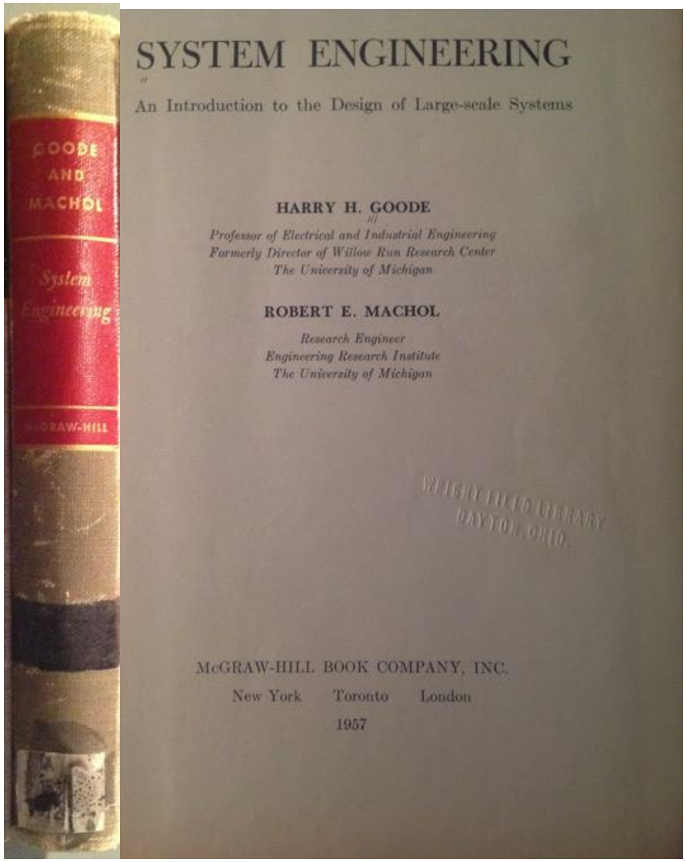
Dr. Bill Stockman
Joe Boyle
Dr. John Bacon

What are we doing wrong or not doing?

- There is a perception that the Systems Engineer is only on a project to do documentation & requirements management.
  - We are doing the documentation (Spec Writers)
  - We may only be managing the requirements ("DOORS Jockeys")
  - We may be managing the risk
- Our Emphasis is largely on process, requirements management and documentation

Who is accountable for the Feasibility of the requirements as a set.

Back in time when systems engineering was much more about engineering



Goode and Machol 1957

1. Introduction
2. Probability – The Basic Tool of Exterior System Design
3. Exterior System Design
4. Computers – The Basic Tool of Interior System Design
5. Interior System Design
    1. Inputs
    2. Classification of Systems
    3. The Single Thread
    4. High Traffic
    5. Competition
    6. Some Principles of System Design
6. Epilogue

Our current Systems Engineering Process doesn't provide us with the analytics needed.

11

Characteristics of Good Requirements

Attributes of Individual Requirement

1. **Unambiguous** – every requirement has only one interpretation
2. **Understandable** – the interpretation of each requirement is clear
3. **Correct** – a requirement the system is in fact required to do
4. **Concise** – no unnecessary information is included in the requirement
5. **Traced** – each requirement is traced to some document or statement of the stakeholders
6. **Traceable** – each derived requirement must be traceable to an originating requirement via some unique name or number
7. **Design independent** – each requirement does not specify a particular solution or a portion of a particular solution
8. **Verifiable** – a finite, cost-effective process has been defined to check that the requirement has been attained

Attributes of the Set of Requirements

9. **Unique** – requirement(s) is (are) not overlapping or redundant with other requirements
10. **Complete** – (a) everything the system is required to do throughout the system's life cycle is included, (b) responses to all possible (realizable) inputs throughout the system's life cycle are defined **[including unintended inputs and undesired outputs]**, (c) the document is defined clearly and self-contained, and (d) there are no to be defined (TBD) or to be reviewed (TBR) statements; completeness is a desired property but cannot be proven at the time of requirements development, or perhaps ever
11. **Consistent** – (a) internal, no two subsets of requirements conflict and (b) external, no subset of requirements conflicts with external documents from which the requirements are traced
12. **Comparable** – the relative priority of the requirements is included
13. **Modifiable** – changes to the requirements can be made easily, consistently (free of redundancy) and completely
14. **Attainable** – solutions exist within performance, cost and schedule constraints

Adapted from Buede 2000 and 2009

Complete Requirements Include Appropriate Responses to Unintended Inputs and Undesired Outputs

Illustrative Examples: Where does the system break?

	Inputs		Outputs	
	Intended	**Unintended**	**Desired**	**Undesired**
Signal	Pulse shape, data rate, signal to noise ratio	Electrical noise	Data rate, accuracy	Error rate, false alarm rate
Electrical	Nominal voltage	Surge voltages and timing	Voltage, current, frequency stability	Electromagnetic interference, electric shock
Mechanical	Activation force	Shock and vibration	Movement, resistance	Acoustic noise levels
Environmental	Normal temperature range	Temperature and humidity extremes	Particle density, air flow	Heat, effluents

System analytics and decision analysis throughout the system life cycle

Development Phase	Examples of Analysis and Decisions in Systems Engineering
Conceptual design	▪ Should a conceptual design effort be undertaken? ▪ Which system concept (or mixture of technologies) should be the basis of the design? ▪ Which technology for a given subsystem should be chosen? ▪ What existing hardware and software can be used? ▪ Is the envisioned concept technically feasible, based on cost, schedule and performance requirements? ▪ Should additional research be conducted before a decision is made?
Preliminary design	▪ Should a preliminary design effort be undertaken? ▪ Which specific physical architecture should be chosen from several alternatives? ▪ To which physical resource should a particular function be allocated? ▪ Should a prototype be developed? If so, to what level of reality? ▪ How should validation and acceptance testing be structured?
Full-scale design	▪ Should a full-scale deign effort be undertaken? ▪ Which configuration items should be bought instead of manufactured? ▪ Which detailed design should be chosen for a specific component given that one or more performance requirements are critical?
Integration and qualification	▪ What is the most cost-effective schedule for implementation activities? ▪ What issues should be tested? ▪ What equipment, people, facilities should be used to test each issue? ▪ What models of the system should be developed or adapted to enhance the effectiveness of integration? ▪ How much testing should be devoted to each issue? ▪ What adaptive (fallback testing in case of a failure) testing should be planned for each issue?
Product refinement	▪ Should a product improvement be introduced at this time? ▪ Which technologies should be the basis of the product improvement? ▪ What redesign is best to meet some clearly defined deficiency in the system? ▪ How should the refinement of existing systems be implemented given schedule, performance and cost criteria?

DOD calls this Early SE

Are Systems Engineers doing this work?

Adapted from Buede 2009

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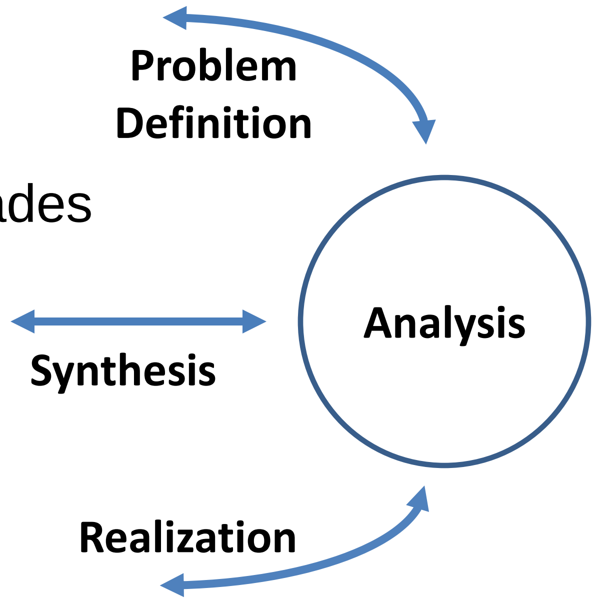
Some Engineering Elements of Systems Engineering

- Requirements
  - Cause and Effect Relationships (causal loop, qfd) Qualitative.
  - Key Performance Parameters need to be modeled
  - Characterizing Interface Performance
  - Requirements Validation.
- Architecture
  - Concept Selection and Architecture Trades
  - Allocation of functions to components
  - Coupling/Cohesion
  - Logical Behavior Description
  - Reliability Strategy
  - SWAP requirements analysis
- Build and Assurance
  - Minimize surprises during manufacturing, integration and test.
- ….



Proper Analytics need to be performed …… integrating disciplines

What can we do to move forward?

- Raise awareness

- Improve the practice effectiveness and competence
  - We need to learn Systems Engineering in the context of a Domain in Order to teach analytical skills.
  - Our current Systems Engineering Process doesn’t provide us with the analytics needed
  - Maybe we need Patterns, Models,…
  - Do we need Licensed Systems Engineers?
  - …..

The systems engineer in action

Apply Foundational Skills & Awareness on Projects

Increase Foundational Skills & Awareness

Lead & Communicate

Review & Improve

Systems Thinking Mastery

and know when to go deep.

<u>Systems Competency</u>
Requirements, Architecture, Behavior, Systems Analysis, etc…

with a broad base of knowledge…

<u>Foundational Engineering Skills Familiarity</u>
Modeling & Simulation, Probability & Statistics / Statics & Dynamics / Electrical Theory / Computing , Mathematics, Chemistry, Physics etc…

that are respected by the IPT…

<u>Awareness</u>
<u>Domains:</u> Engineering (Elec, Mech, Mfg, ilities, etc.) System Type / Class, User, Industry, Technologies (Sensors (RADAR, IR, etc..), etc…
<u>Infrastructure:</u> Process (Acquisition, IPT Roles and Responsibilities), Tools, Standards, Flow, Planning, Management, Leadership, etc..

You need the right type of people…

It ain't just requirements management!

- Systems engineers as engineers
  Live the system and its context:
  – Requirements, structure, behavior, analytics
  – Performance envelopes and sensitivities
  – Systems & decision analysis, especially *fast approximations*
  – On the lookout for emergent behaviors & characteristics
- Systems engineers as "linguists" … more than just communication
  Speak, understand, translate and balance:
  – "Conscious" of the stakeholders, especially users and customers
  – Program, project and product management
  – Civil, mechanical, electrical, industrial, nuclear, software, …*ilities*
  – Operations research
  – Production/manufacturing, operations, maintenance, logistics, retirement/disposal
  – Marketing
- And yes, process, documentation, and requirements management

Foundational engineering skills also including systems thinking, modeling, stochastic and competitive/comparative/gaming