Air Force Institute of Technology

NDIA Systems Engineering Conference

System of Systems Challenges and Solutions: Case Study Insights

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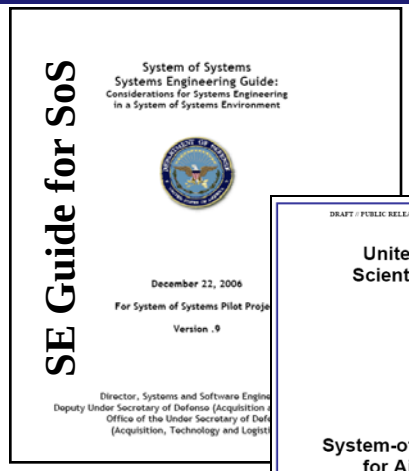
System of Systems

Cliché? Buzz word?

Any characteristics in an SoS different than a system?

Is the engineering effort in an SOS different than traditional Systems Engineering?

Welcome to the debate.



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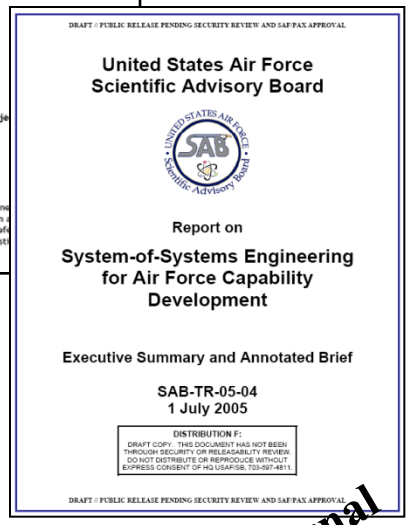
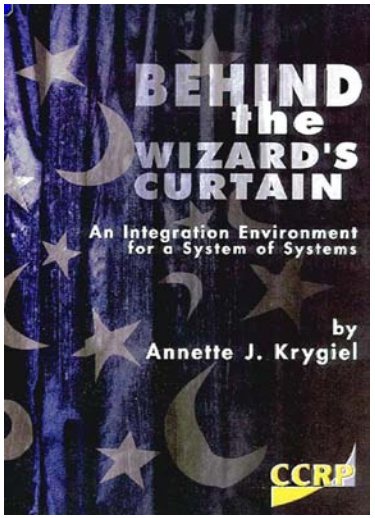




IEEE Systems Journal

SoS Eng Conferences

SoS Track at NDIA

Disclaimer/ Acknowledgements

The views expressed in this presentation are those of the authors and do not reflect the official policy or position of the Air Force Institute of Technology, the United States Air Force, the Department of Defense or the United States Government.

As a professor, I am obligated to put this disclaimer on everything

Thanks to the many interviewed (Gov't, FFRDC, SETA, primes) and to many students

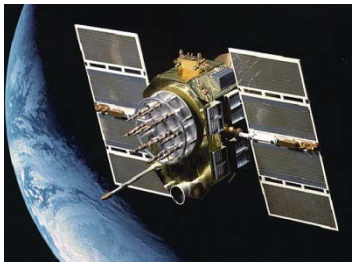
Major Katosic	Major Nance	Major Barker
Major Yates	Major Bode	Major Couluris
Major Ferko	Major Gunn	Major Sheesley
Major Cohee	Major Turner	

Agenda

- System-of-Systems Challenges
  - Definition
  - Characteristics
  - Challenges and Example Cases
- Implementation Strategies/ Solution Considerations
  - Engineering the SoS
  - Architecture and Patterns
  - Interface Management
  - Test and Evaluation
  - Agile Development
- Summary

Systems Engineering Case Studies*

C-5 Galaxy



GPS

A-10

F-111

Hubble Space Telescope

JASSM

TBMCS (Theater Battle Management Core Systems)

B-2 Spirit

Peacekeeper

In work / In plan

-International Space Station
-Global Hawk
- KC-135 trainer
- T-6A, E-10
- MH-53J/M Helicopter

Classified cases

2007, 08, 09

*** Unclassified cases available for download http://www.afit.edu/cse**

SoS Definition

A SoS is defined as a set or arrangement of systems that results from independent systems integrated into a larger system that delivers unique capabilities.

-- Defense Acquisition Guide

- Maier (1998) highlights two characteristics that distinguish the SoS from very large complex monolithic systems:
  - 1. **Operational Independence**
  - 2. **Managerial Independence**

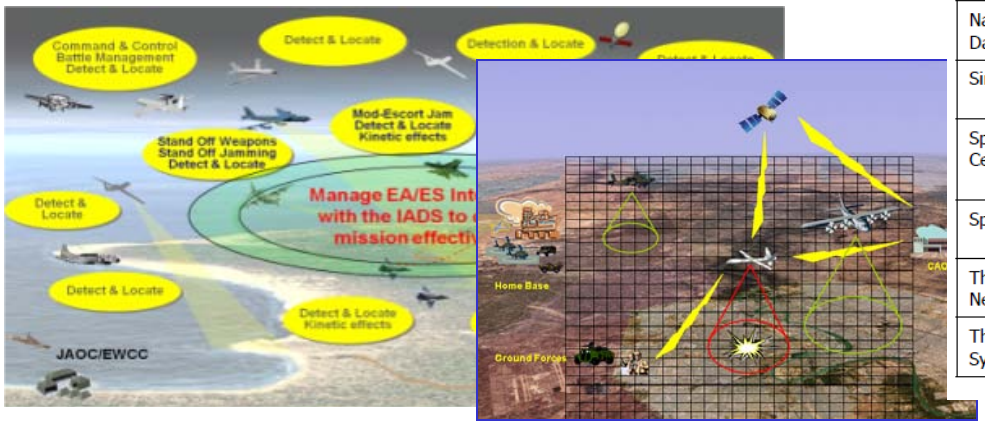
- Maier (1996) and others originally stated others characteristics
  - 3. **Evolutionary Development**.
  - 4. **Emergent Behavior:**
  - 5. **Geographic Distribution:**

Lots of DoD SoS Examples

- Space Community
  - …"single, fully integrated, multi-INT architecture"
  - …"Community-wide architecture" …"ground architecture"
  - …"overhead enterprise architecture"
- C4ISR Community
  - Small Clusters of Systems (U2 – Datalink – DCGS)
  - Air Force Constellation Net
  - Air Force Research Lab's Layered Sensing concept
  - Airborne Electronic Attack (AEA) SoS Architecture

Name	Acronym	Owner
Army Battle Command System	ABCS	Army
Air Operations Center	AOC	Air Force
Ballistic Missile Defense System	BMDS	Joint
USCG Command & Control Convergence	C2 Convergence	Coast Guard
Common Aviation Command & Control System	CAC2S	Marine Corps
Distributed Common Ground Station	DCGS-AF	Air Force
DoD Intelligence Information System	DoDIIS	Intel
Future Combat Systems	FCS	Army
Ground Combat Systems	GCS	Army
Military Satellite Communications	MILSATCOM	Joint
Naval Integrated Fire Control – Counter Air	NIFC-CA	Navy

Name	Acro
Naval Surface Warfare Center Dahlgren Division	NSWC
Single Integrated Air Picture	SIAP
Space and Missile Systems Center	SMC
Space Radar	SR
Theater Joint Tactical Networks	TJTN
Theater Medical Information Systems – Joint	TMIP



* From DoD SoS Engineering Guide v1.0

SoS Challenges

Interface Management

SoS Performance

SoS capabilities

LEADERSHIP

Competing Operational Demands (LDHD)

INTEGRATION FUNDING

Schedules

Test and Evaluation

Complexity

Stakeholders

Requirements Management

Control

Boundaries

STANDARDS

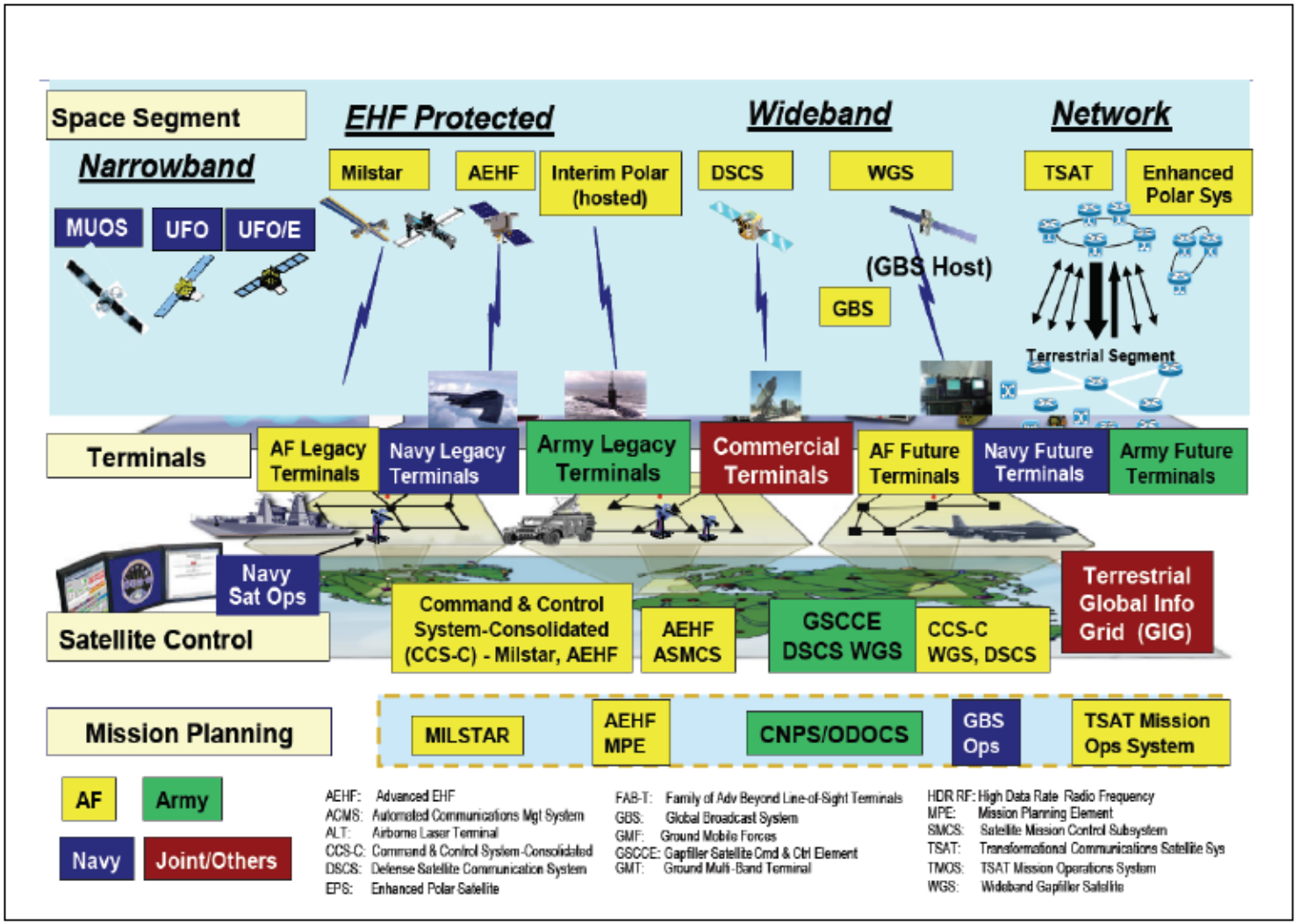
Interfaces

Legacy Issues

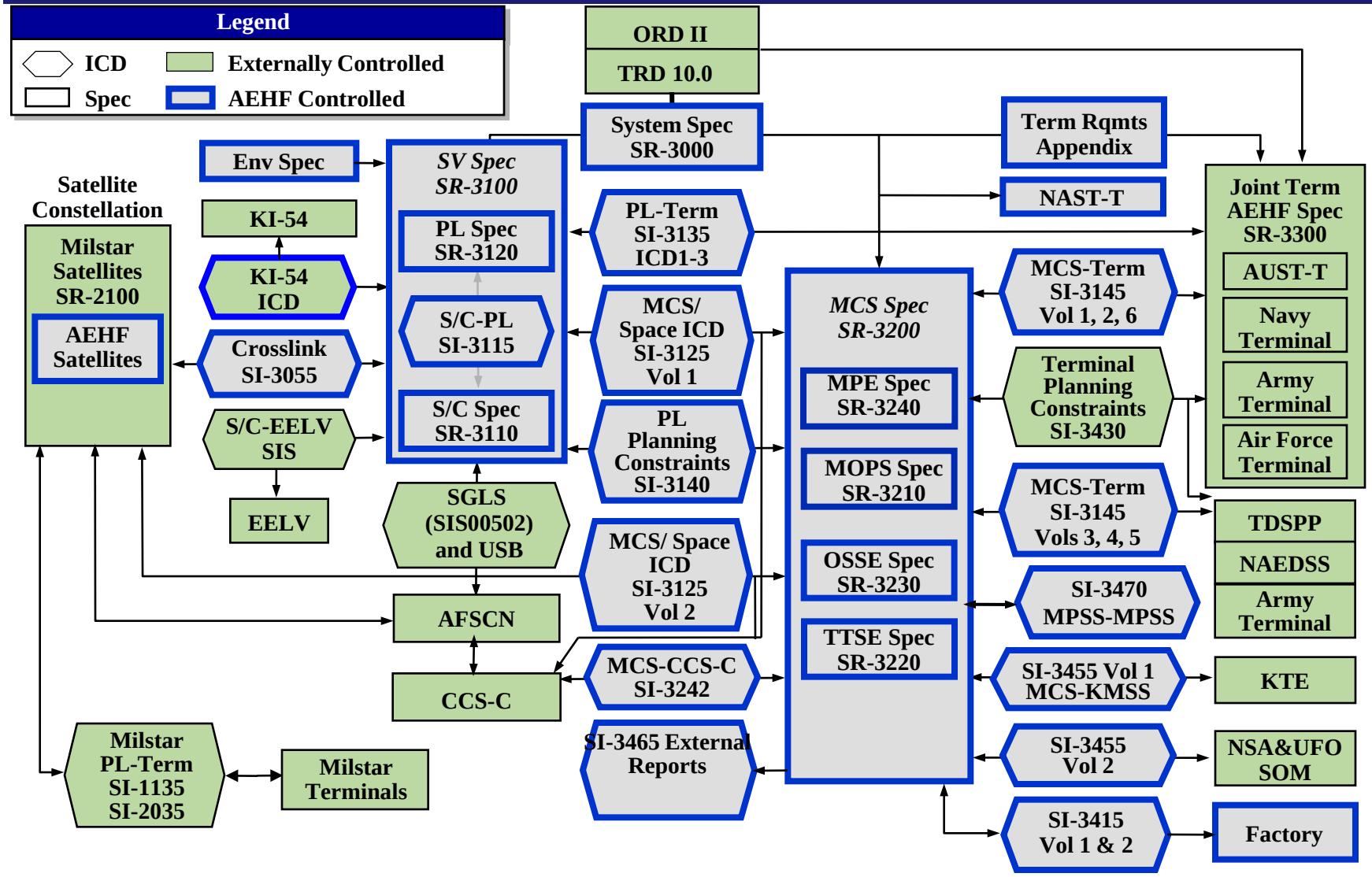
Survey Item	Percent
Leadership	75%
Requirements Communication	75
Standards	71
Funding	68
Knowledge Skills and Abilities	54
Aligning System Interdependencies	50
End to End Mission Threads	46
Configuration Management	39
Changing Environmental Demands	32
Information Access	32
Organizational Alignment	29
Commitment	25
Understanding Scope	25
Deconflicting Schedules	25
Doctrine	21
Interdisciplinary Teams	21
Conflict Negotiation	21

Let's focus on a few…

MILSATCOM (AEHF) Interface Management Case

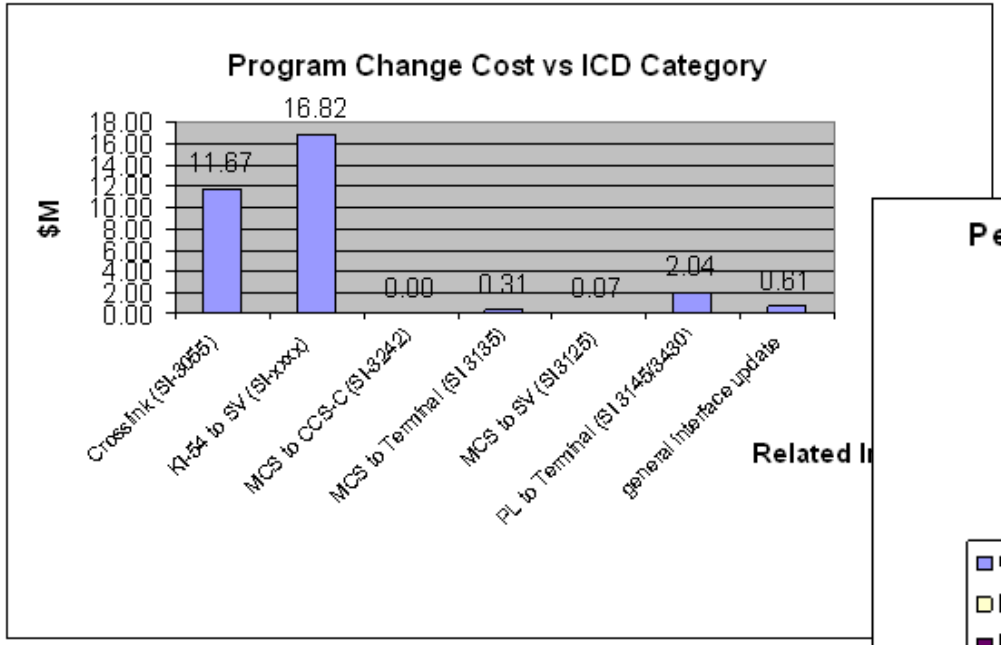


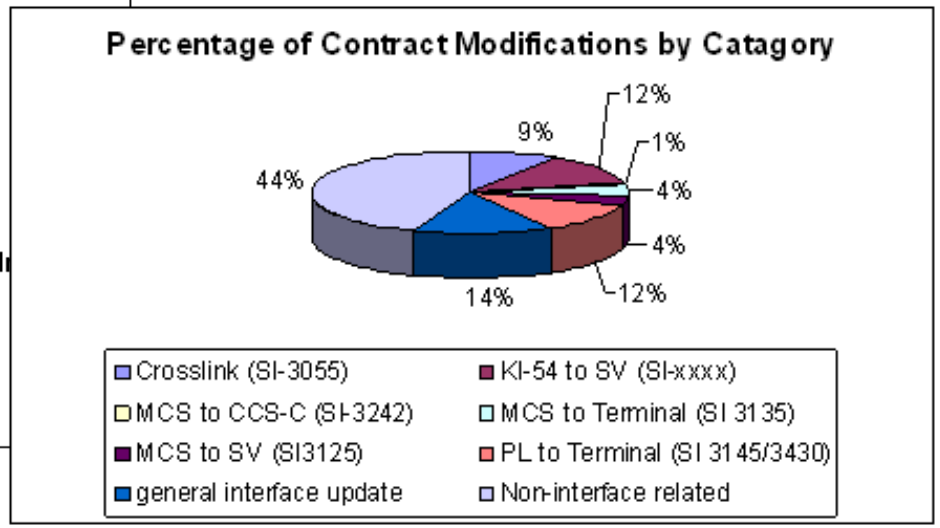
Interface landscape



Cost of Interface Management

In a 3 year period, 56% of baseline modifications were ICD-related
$31.5M of $71.2M (44%) of contract modifications were ICD-related

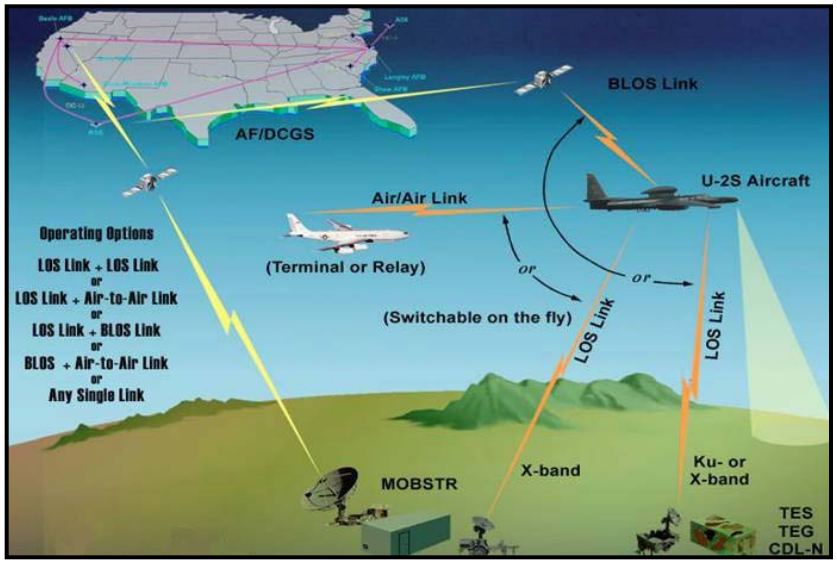




Case Observation

- **Cost and Effort of SoS Integration**

U-2 SoS T&E case



U-2S aircraft

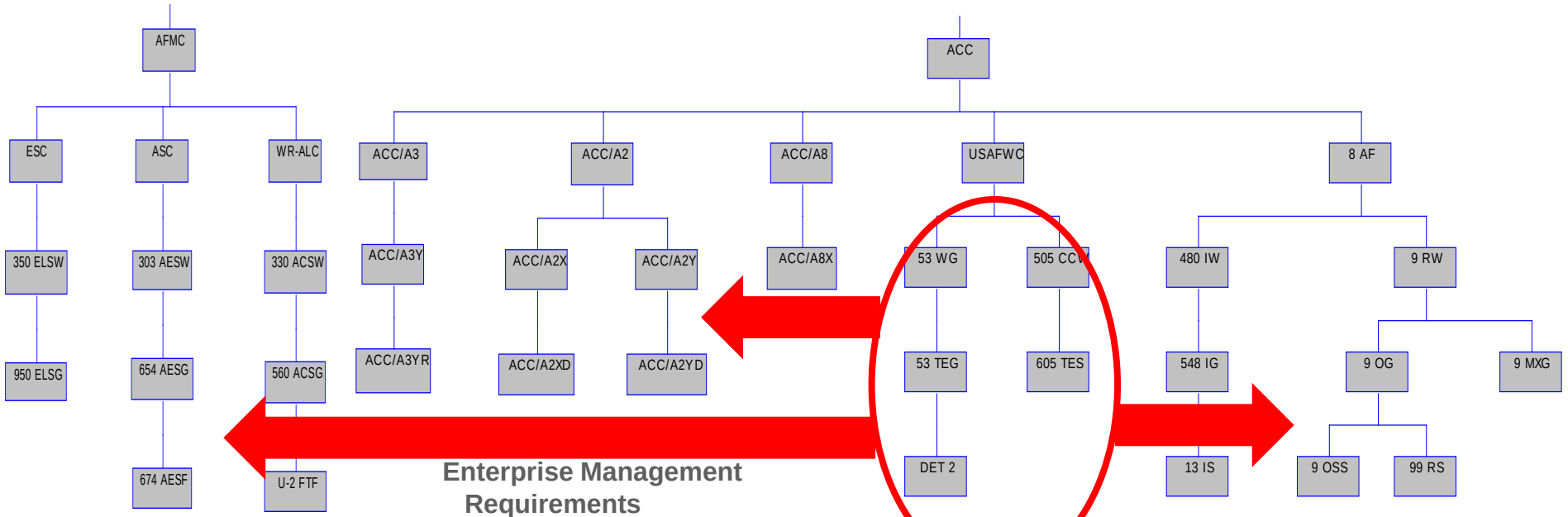
Upgraded SYERS-2A
--multispectral (EO/IR) sensor

Dual Data Link 2 (LOS/ BLOS)

Distributed Common Ground Station

- **Operational concern:**
  - **Test events being planned without full coordination**
  - **T&E plans not fully validated**
  - **Missing opportunities to "piggy-back" test objectives**
- **Examined Force Development Evaluation T&E Process**

U-2 SoS T&E case



C2 Sustainment (O&M)
Aircraft Sustainment (O&M)
C2 System Program Management
New Acquisition and Modernization
Aircraft System Program Management
New Acquisition and Modernization
Flight Test Facility

Test Objective: "Verify new SYERS-2A sensor end-to-end operations and to demonstrate full airborne/ground segment functionality with DLL2 in available configurations and operational representative architectures"

SoS T&E case

- **Case Observations**
  - **SoS Integration is NOT Built Into the Process**
  - **"Seamless" Seams Among Interdependent Systems still Real**
  - **Ability to Define the "Ends" Disappearing**
  - **Program Priorities Dominate**

DoD T&E Summit, 2004, Dr. Glenn Lamartin

- *Increasing complexity and interdependencies of systems*
- *Exponential growth in interfaces (network participants)*
- *Increased requirements for T&E (Evolutionary Acquisition)*

Network Centric Warfare, 1996, Alberts, Garstka and Stein

"Testing systems will become far more complex since the focus will not be on the performance of individual systems by on the performance of the federation of systems"

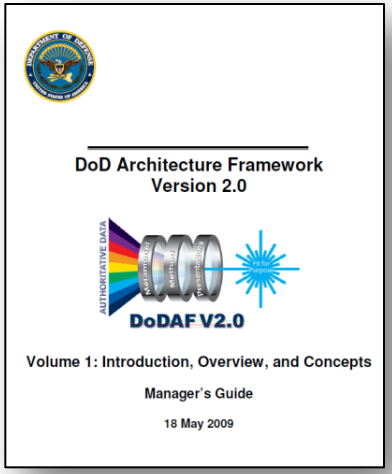
SoS Emerging Solutions

- **Importance of Architecture across the SoS**
  - **Focus on interfaces**
  - **Architectural Pattern**
- **Acknowledging the different roles for SoS**
  - **SoS Integration and T&E Lessons Learned**
  - **Systems engineering versus SoS Engineering/ Architecting**
- **Address acquisition management issues**
  - **Agile development methodologies**
  - **Appropriate contracting strategies**

Solution - Architecture

Emphasize Operational, Systems Engineering

- Top-down Architecting and Architecture frameworks (DoDAF, Zachman, TOGAF, FEAF, etc)
- Bottom-up system integration for new CONOPS and Capabilities
- Early Architecture Evaluation/ Analysis
- Define, organize and communicate interfaces

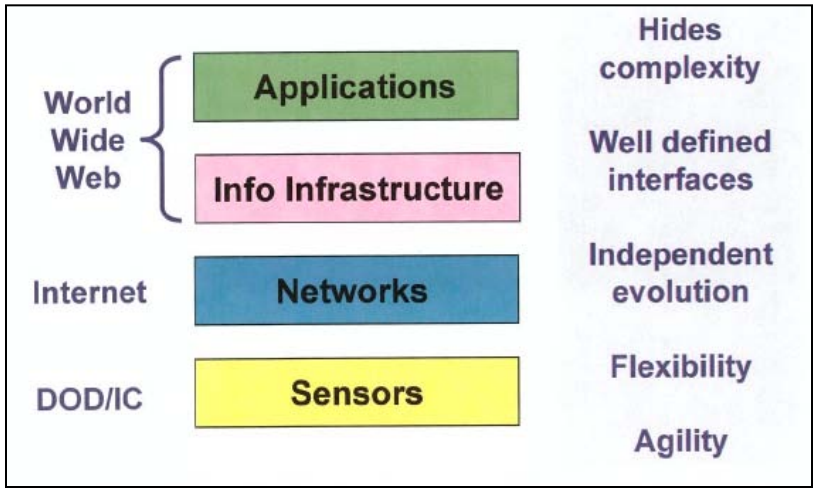


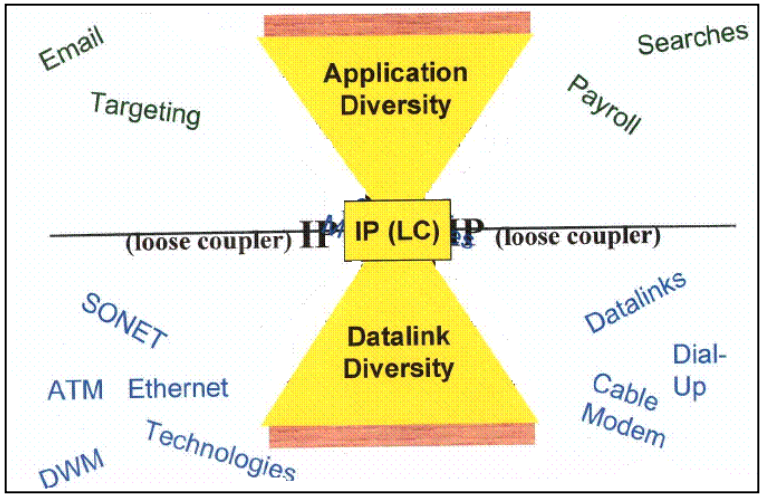
"The greatest leverage in system architecting is at the interfaces … the greatest dangers are also at the interfaces!"

— Mark W. Maier and Eberhardt Rechtin,
***The Art of Systems Architecting*, CRC Press, 2002**

Solution-Architectural Patterns

- **Architect interfaces at all levels of abstraction for agility, adaptability (evolution) and growth**
  - **Layers and "Bowtie" architectural pattern for SoS agility***
  - **SAB concept of "convergence protocol"****

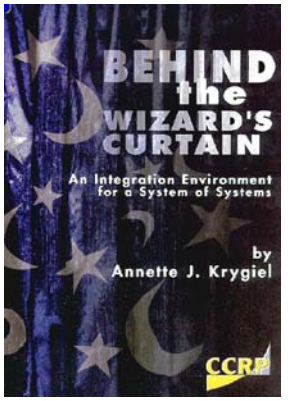


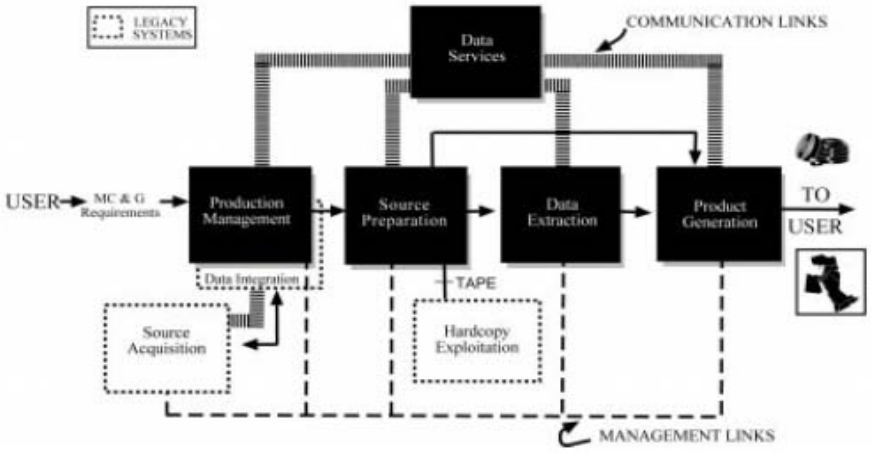


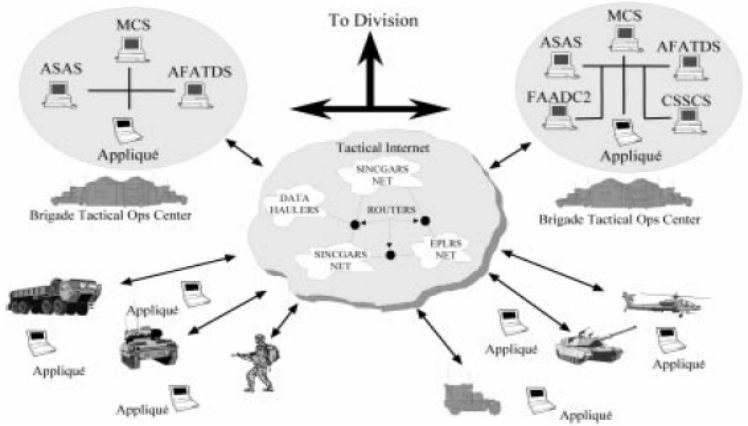
*** Rich Bryne, MITRE, from 2008 NRO Systems Engineering Conference**
**** Scientific Advisory Board 2004,**

Solution SoS Integration/ T&E

- **Annette Krygiel's "Behind the Wizard's Curtain"**
- **SoS Integration (mid 1990s) for**
  - **Digital Mapping Agency**
    - Digital production
  - **Army Task Force XXI**
    - Digital battlefield







Solution - SoS Integration/T&E

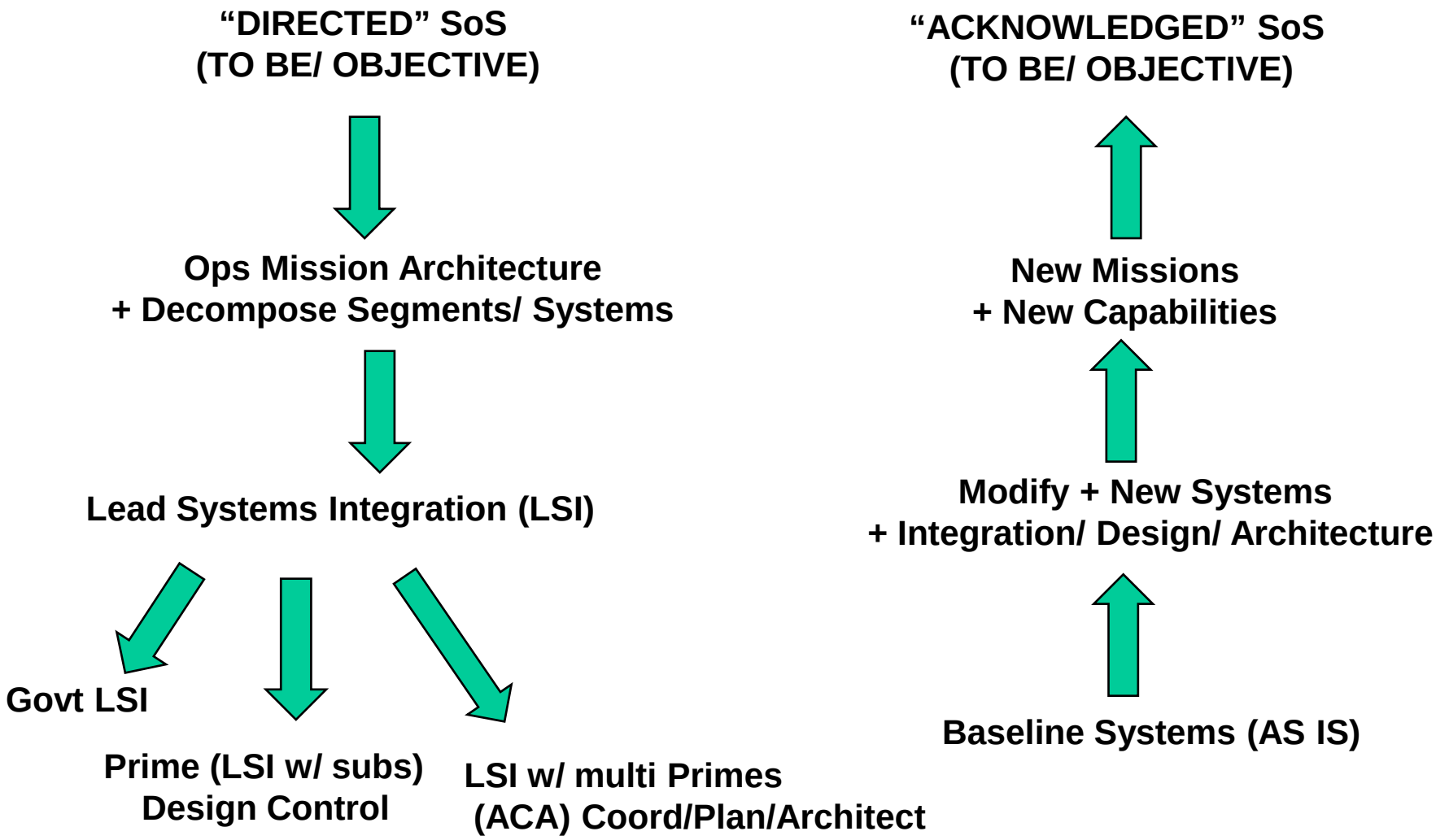
1. Key Activities need to preceed SoS integration
   - Architecture and architecture compliance, system test
2. Robust Testing strategy. Early, incremental and iterative integration
   - Build a little--test a little
3. Plan for substantial difficulties, significant time and resources
4. One site facilitates integration and test of SoS components
5. Address the leadership of the SoS integration
6. Prototyping the SoS provides early insight to ops requirements
   - Test with Operators

Solution - Engineering for SoS*

1. Translating SoS Capability Objectives into High-Level SoS Requirements over Time
2. Understanding the Constituent Systems and Their Relationships over Time
3. Assessing Extent to Which SoS Performance Meets Capability Objectives over Time
4. Developing, Evolving and Maintaining an Architecture for the SoS
5. Monitoring and Assessing Potential Risk and Opportunities on SoS Performance
6. Addressing SoS Requirements and Solution Options
7. Orchestrating Upgrades to SoS

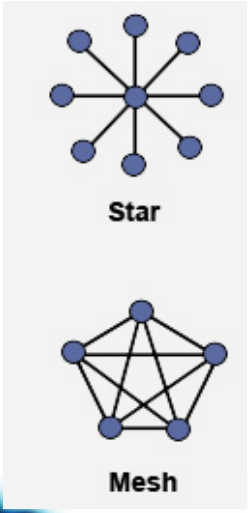
* From DoD SoS Engineering Guide v1.0

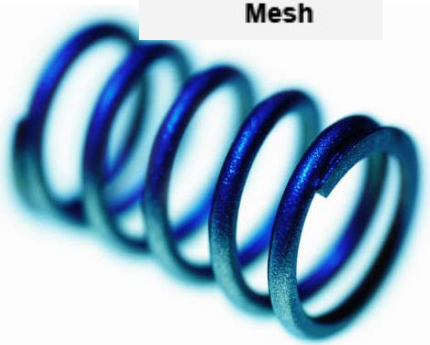
Engineering an SoS
Two SoS extremes



Need for Agile/ Adaptability

- **Changing Requirements across the SOS**
  - **Add/ Subtract/ Move (phasing)**
  - **Clarify/ Definition of Requirements based on Ops feedback**
- **Changing Schedule across the SOS**
  - **Move work requirements (phasing)**
  - **Deployment to sites/ Ops tempo**
- **Changing Interfaces**
  - **Add new interfaces, Changing/ Clarify Definition**





One PM suggested the need for “Flexpoints”

Solution – Acq Implications

- **Organizational (People)**
  - Experience with SoS Strategies
  - Experience with Agile development methodology
  - Familiarity (or connection) with the Domain (system type)
  - Attitudes – collaborative, communicative

- **Development Method**
  - Spiral or Iterative Lifecycle
  - Scrum software practices
  - Ability to handle CHANGE

Conclusion

- SoS Lessons can be learned from system, enterprise and SoS case studies
- DoD policy and guidelines now reflect the changing IT landscape of system of systems
  - Leaders have predicted this changing landscape will directly impact engineering activities
- Requirements & Acquisition community must address
  - Growing program interdependencies
  - Greater numbers of potential changes across the SoS
  - The ability to operational test (and resource those tests)
  - Organization aspects to best handle SoS challenges