System of Systems (SoS) Systems Engineering in Acquisition Program Planning

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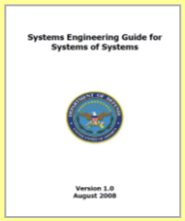
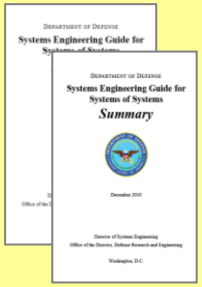
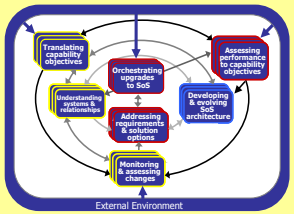
Background and Purpose

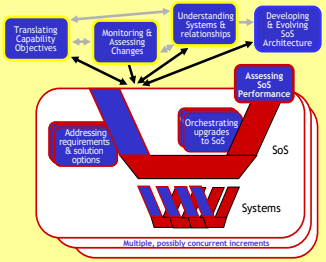
- **DoD has recognized the criticality of ensuring that acquisition programs consider impacts of operational and systems context**
  - Significant program issues have resulted from inadequate attention to key program interdependencies
  - Critical to address SoS context in system requirements and design and effectively work with external systems to address system interdependencies
  - 2011 SE Plan outline and guidance included specific attention to program dependencies and management of external relationships
- **Purpose of this presentation is to discuss experience to date and the way ahead**
  - Present the results of 'SoS reviews' of SE plans and other acquisition documents for a set of Major Defense Acquisition Programs
  - Discuss the results and way ahead

Foundations

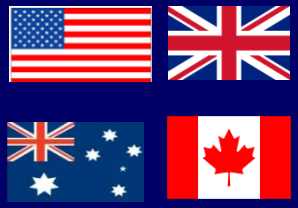


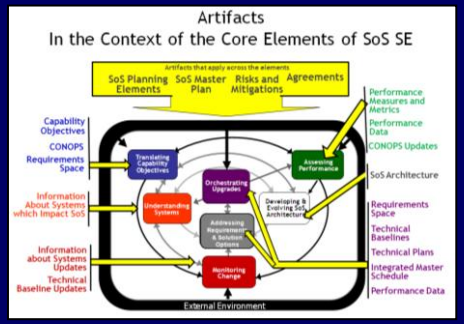


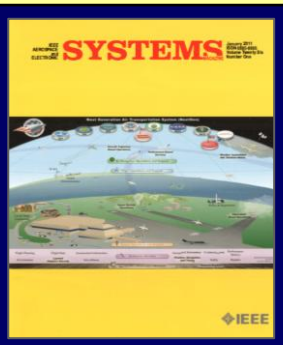




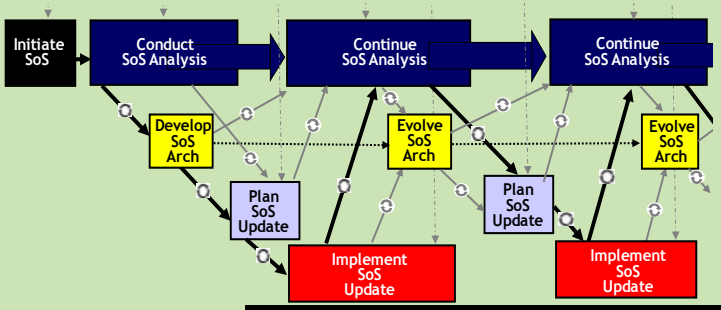
SoS SE Guide with supporting materials prepared with US Army as part of cooperative activity







SoS SE Artifacts
Developed as part of an international SoS SE project under The Technical Cooperation Program (TTCP)



Implementers View
Representation that corresponds with incremental development approaches that are the norm for SoS capability evolution

Applying Understanding of SoS SE to SoS Considerations for Acquisition Programs

http://www.acq.osd.mil/se/initiatives/init_sos-se.html

SoS Considerations in the Systems Engineering Plan (SEP)

SEP Outline - 20 April 2011

1. Introduction – Purpose and Update Plan
2. Program Technical Requirements
   - 2.1. Architectures and Interface Control
   - 2.2. Technical Certifications
3. Engineering Resources and Management
   - 3.1. Technical Schedule and Schedule Risk Assessment
   - 3.2. Engineering Resources and Cost/Schedule Reporting
   - 3.3. Engineering and Integration Risk Management
   - 3.4. Technical Organization
   - 3.5. Relationships with External Technical Organizations
   - 3.6. Technical Performance Measures and Metrics
4. Technical Activities and Products
   - 4.1. Results of Previous Phase SE Activities
   - 4.2. Planned SE Activities for the Next Phase
   - 4.3. Requirements Development and Change Process
   - 4.4. Technical Reviews
   - 4.5. Configuration and Change Management Process
   - 4.6. Design Considerations
   - 4.7. Engineering Tools

Additions to SEP to recognize important role of SoS in systems acquisition

- **SoS context for system acquisition**
  - Identify dependencies and context impacts on system requirements
- **SoS Related Risks**
  - Identify, assess and manage risks related to dependencies
- **Management of dependencies**
  - Develop relationships with external organizations
- **Technical plans address SoS considerations**
  - Organize and plan to address SoS concerns

http://www.acq.osd.mil/se/pg/guidance.html

SoS in Program Technical Requirements

2. Program Technical Requirements

2.1. Architectures and Interface Control – List the architecture products that will be developed, to include system level physical and software architectures…

- A system physical architecture diagram (delineating physical interfaces), if available.
- A system functional architecture diagram (delineating functional interfaces), if available.
- How software architecture priorities will be developed and documented.
- How architecture products are related to requirements definition.
- How engineering and architecture activities are linked.

Expectations: Programs whose system has external interfaces need to have dependencies (i.e., hierarchy) clearly defined. This should include interface control specifications, which should be confirmed early on and placed under strict configuration control. Compatibility with other interfacing systems and common architectures should be maintained throughout the development/design process.

SYSTEMS ENGINEERING PLAN (SEP)
Version 1.0, 04/20/2011, page 7

- **Place system into SoS architectural context**
  - Identify external interfaces and dependencies
  - Show how these are linked to requirements
  - Identify interfaces and MOAs with the relevant organizations
  - Provides basis for both management and technical planning for SoS related system considerations

Relationships With External Organizations (1 of 2)

3.5. Relationships with External Technical Organizations – What processes or methods will be used to document, facilitate, and manage interaction among SE team(s), external-to-program government organizations (e.g., FoS/SoS and contractor(s)/ competing contractor(s)) on technical tasks, activities, and responsibilities (e.g., requirements, technical baselines, and technical reviews) down to and including subcontractors.

- **Responsible Organization and Authority** - Identify the organization responsible for coordinating SE and integration efforts associated with the FoS/SoS and its authority to reallocate resources (funding and manpower)
- **Management** – Summarize how FoS/SoS interfaces will be managed to include:
  - Resolution of issues that cross PM, PEO, and Component lines;
  - Interface Control Documents (ICDs) and any interface control WGs (ICWGs);
  - Memorandums-of-Agreement (MOAs);
  - "Triggers" that require a FoS/SoS member to inform the others if there is a cost, schedule, or performance deviation;
  - Planned linkage between hardware and software upgrade programs within the FoS/SoS;
  - Any required Government Furnished Equipment/Property/Government Furnished Information (GFE/GFP/GFI) (e.g., test ranges, integration laboratories, and special equipment).
- **Schedule** - Include a schedule (optional) which shows FoS/SoS dependencies such as alignment of technical reviews, major milestones, test phases, GFE/GFP/GFI, etc.

SYSTEMS ENGINEERING PLAN (SEP)
Version 1.0, 04/20/2011, page 18

Addresses program approach to management of dependencies

Relationships With External Organizations (2 of 2)

Expectations: Programs should:

- *Recognize the importance of managing both the internal program schedule while maintaining synchronization with external programs' schedules.*
- *Develop MOAs with interfacing organizations that include:*
  - *Tripwires and notification to FoS/SoS members of any significant (nominally > 10%) variance in cost, schedule, or performance;*
  - *Mechanisms for FoS/SoS members to comment on any proposed interface changes; and*
  - *Fast-track issue identification and resolution process.*
- *Develop a synchronized program schedule with interfacing programs schedules to provide insight into the potential impact of interfacing program schedule changes to include milestones, technical reviews, test periods.*
- *Inform Component and OSD staffs so they better understand synchronizing funding and aligning priorities with external programs.*

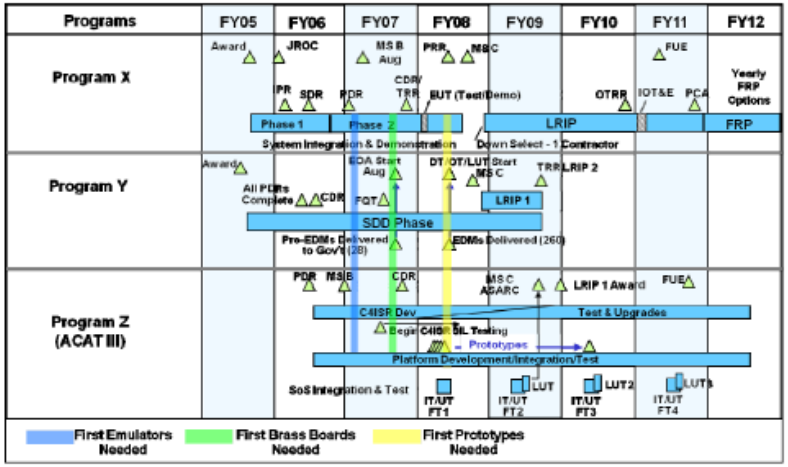


Figure 3.5-1 System-of-Systems Schedule (optional) (sample)
Note: Include an as-of date – time sensitive figure

- **Includes clear identification of**
  - Responsibilities & resources
  - Technical documentation (ICDs)
  - Technical management of issues and planned upgrades
  - Schedules

SYSTEMS ENGINEERING PLAN (SEP)
Version 1.0, 04/20/2011, page 17-18

The Data

- **47 Major Defense Acquisition Programs (MDAPs)**
  - 21% in Material Solutions Analysis (MSA) Phase
  - 51% in Technology Development (TD) Phase
  - 28% in Engineering and Manufacturing Development (EMD) Phase
- **All produced one or more plans (SEP, TDS or AS) from September 2011 – June 2012**
  - 70% (33) programs – SE Plan (SEP)
  - 45% (21) programs – Acquisition or Tech Development Strategy
  - 21% (10) programs – Both
- **Reviews were conducted of the plans for each program**
  - Included informal, formal and final plans
  - Assess extent and nature of SoS issues or risks identified in review of program plans

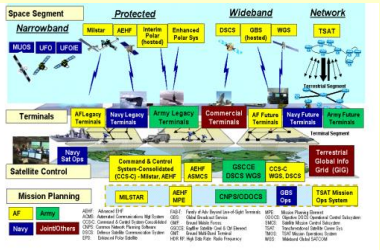
Issue Areas

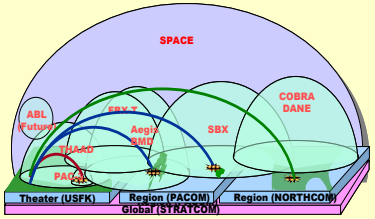
- **Issues were identified in 3 areas**
  - **Context** - Programs are asked (SEP Section 2.1):
    - To present the larger architecture for their systems
    - To identify the interfaces and external dependencies for their acquisition program
  - **Management** of external relationships - Programs are asked to:
    - Provide MOAs with external organizations (Section 2.1)
    - Present (SEP Section 3.5) plans for working with these organizations to address dependencies
  - **Technical** approach to SoS considerations - Programs address
    - SoS requirements in their plans for (Section 4) 'Technical Activities and Products" for the system as whole and in their identification and mitigation of risks (Section 3.3)

- **Critical issues identified in plans were addressed in revisions**
- **Too early to tell if addressing SoS in plans leads to improved program performance**

Results from the Perspective of What Is Being 'Acquired'

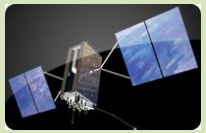
'SoS'





An SoS, a suite of systems which together support a user capability or an integrating SoS element

'Platforms'



A warfighting platform (e.g. air or ground vehicle)

'Systems'

A weapons, sensor, communications or information system

Current Major Defense Acquisition Programs (MDAPs) include some acquisitions which address systems, some which address platforms, others which address missions, or some combination

Systems, Platforms and SoS

- **Data includes programs acquiring systems, platforms and SoS**

System (21)	Platform (18)	System of Systems (8)
AF Integrated Personnel and Pay System (AF-IPPS)	Abrams ECP	Advanced Extremely High Frequency (AEHF)
Air and Missile Defense Radar (AMDR)	Amphibious Combat Vehicle (ACV)	Army Integrated Air and Missile Defense (AIAMD)
B2 Defensive Management System (DMS) Mod Prog	Apache Block 3	DCGS-A
CANES	Armored Multi-Purpose Vehicle (AMPV)	Enhanced Polar System (EPS)
Chemical Demil-Assembled Chemical Weapons Alt (ACWA)	B2 EHF & SATCOM 1	Integrated Electronic Health Record (iEHR)
Defense Enterprise Accounting And Management System	B61 Life Extension Program - Tailkit Assembly	Joint Space Center (JSpOC) Mission System (JMS)
eProcurement (eProc)	Bradley ECP	Littoral Combat Ship (LCS) Mission Module (MM)
Excalibur	Combat Rescue Helicopter (CRH)	Space Fence
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)	F-22 Increment 3.2B	
GPS Next Generation Operational Control System (OCX)	F-35 Lightning	
GPS-MGUE	Fleet Replenishment Tanker (T-AO(X)	
Integrated Personnel and Pay System - Army (IPPS-A)	GCV	
Integrated Strategic Planning and Analysis Network (ISPAN)	Joint Light Tactical Vehicle (JLTV)	
Joint Personnel Identification V2 (JPIv2) System	LCS Seaframe	
Joint Precision Approach and Landing System (JPALS)	MQ-4C Triton Broad Area Maritime Surveillance (BAMS	
Logisitics Modernization Program (LMP)	MQ-9 Unmanned Aircraft System (UAS)	
Next Generation Enterprise Network (NGEN) Increment 1	P-8A Poseidon Increment 3	
Next Generation Jammer (NGJ)	Paladin Integration Management (PIM)	
Ship to Shore Connector (SSC)		
Three-Dimensional Expeditionary Long-Range Radar (3DELRR)		

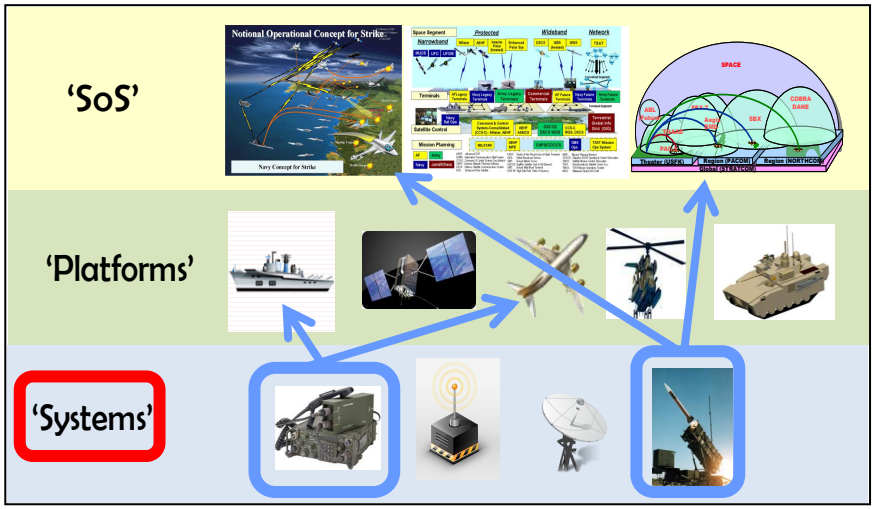
Acquiring Platforms, Systems or SoS

	Total	Document Reviewed		Issues			
		SEP	Other	None	Context	Mgt	Tech
SoS	8	100%	75%	13%	38%	50%	75%
		8	6	1	3	4	6
Platform	18	56%	50%	44%	28%	44%	44%
		10	9	8	5	8	8
System	21	76%	43%	33%	43%	52%	48%
		16	9	7	9	11	10
Total	47	72%	45%	32%	36%	49%	51%
		34	21	15	17	23	24

- **Identified issues for program types and issue areas**
  - Platform programs seem to be doing the best at addressing SoS considerations; for 44% of the programs there were no SoS issues identified in the reviews
  - On the other hand, programs classified as SoS had the most issue; only 13% with no SoS issues identified in the reviews

…More interesting than the numbers are the specific types of issues which tend to face platforms, systems and SoS

Systems



Potential SoS risks:

- Technical, schedule, performance, or funding disconnects between systems and the platforms or SoS
  - System doesn't 'fit' on platform or adequately support SoS capability
  - No funding or plan for integration
  - System is not delivered in time for the platform or other elements of SoS

- **Issues**
  - **Missing information** on context and management
    - Architecture and dependencies
    - Plans for working with external organizations, including MOAs
  - **Internally focused** and don't address external considerations in
    - Technical organization
    - Technical processes
    - Risks
    - Schedule

SoS Issues in system program plans span the spectrum (context, management and technical) and are also found in platforms and SoS

Issues for Systems

Issue Area	%*	Description of Issues
Context	33%	Did not provide the information or it was at such a **high level** it was not useful Pointed to other documents for the information but did not present the **implications** for system requirements or SE approach Despite the interfaces shown in architecture and other diagrams, indicated in the text they had **no dependencies**
Mgmt	52%	Missing **MOA**s Inadequate discussion of **roles and responsibilities**. Inadequate management approach to relationships with **external** organizations No planning for impacts of future, **planned** upgrades
Technical	48%	**Technical organization** is entirely internally focused and does not include participation of eternal organizations **Technical processes** do not address working with external organizations, including • Obtaining, integrating, and installing the GFE throughout development and fielding • Managing external interfaces **Schedule** does not include interactions with external organizations or dependencies Do not address **risks** related to configuration management of the external interfaces

* % of 'system' programs where issue of this type was identified in one or more plans

Platforms

Potential risks:

- Technical, schedule, performance, or funding disconnects between platform and the system or the SoS
  - System doesn't 'fit' on platform
  - No funding or plan for integration
  - System is not delivered in time for the platform
  - Delivered product may not effectively support the capability that motivated its development (data exchange, compatible functionality, etc.)

- **Issues**
  - Failure to identify dependencies and SWAP-C* issues **early**
    - Impact on requirements and early planning
  - **Inadequate management approach**
    - GFE roles and responsibilities
    - External system integration
  - Lack of **technical processes** for
    - GFE integration, risk and schedule
    - Addressing SWAP-C technical issues

Platform program issues focus integration of systems developed independently from the platform, particularly addressing SWAP-C considerations

* Size, Weight, Power, and Cooling

Issues for Platforms

Issue Area	%*	Description of Issues
Context	40%	Failed to identify and address inherent risk with independent developments, particularly the **systems which are intended to support the platform** being acquired Did not recognize **SWAP-C dependencies** early in the acquisition so they can be addressed in requirements and development approach
Mgmt	50%	Lack of defined roles and responsibilities associated with **GFE** throughout development and fielding An inadequate approach to managing **external system integration** planning and implementation
Technical	70%	A lack of technical processes for **managing, scheduling and integrating GFE** • Government lead systems integrator is not well defined • Do not address risks associated with interdependency with GFE providers • Schedule does not consider GFE program interdependencies and hence no indication of Interdependency risks and mitigation Inadequate attention to **technical issues associated with platform SWAP-C** considerations

* % of 'system' programs where issue of this type was identified in one or more plans

SoS

Potential Risks

- Conflict between SoS decisions and constituent system decisions can lead to disconnects between the systems and the SoS
- May be difficult to get closure on current acquisition milestone reviews because of risk of the SoS dependencies on systems decisions not considered in current milestone criteria
- Design of the SoS component does not adequately address SoS capability needs
- Integration into/with constituent systems is not adequately planned of funded across the SoS

Issues

- Limited exposure of **complexity of the dependencies**
  - And the impact on program
- Unclear **roles and responsibilities** with constituent systems
  - Reflected in issues related to organization, processes, agreements across systems
- Lack of technical attention to
  - Integration risks
  - Schedule coordination
  - Interface testing
  - Cross cutting TPMs

SoS program issues center on the complexities of an acquisition dependent on multiple independent players

Issues for SoS

Issue Area	%*	Description of Issues
Context	29%	Did not address the **complexity** of the SoS including the relationships among the programs involved well enough to provide the basis for the plans for the **coordinated developments** involved in the acquisition program
Mgt	47%	Poorly defined **roles and responsibilities** of the key players, particularly the constituent systems and their relationship to the acquisition program Lack **MOAs** or other documents describing roles and responsibilities Approach to **organizational coordination** is unclear Cost management is decentralized and no mechanism for **monitoring cost** issues across the SoS
Technical	47%	Failure to identify and address **integration risk** Insufficient attention to **interface testing** Technical **analysis considerations for constituent systems** is lacking Technical Performance Measures (**TPMs**) not explicitly shown for the SoS as well as the constituent systems **Technical strategy** of distributed development without adequate integration and prototyping has high technical risk not addressed by the program

* % of 'system' programs where issue of this type was identified in one or more plans

Programs by Acquisition Phase

Data includes programs at different acquisition phases

Materiel Solution Analysis (MSA)	Technology Development (TD)	Engineering, Manufacturing, and Development (EMD)
Amphibious Combat Vehicle (ACV)	B2 Defensive Management System (DMS) Mod Prog	Integrated Electronic Health Record (iEHR)
Fleet Replenishment Tanker (T-AO(X)	Next Generation Jammer (NGJ)	Advanced Extremely High Frequency (AEHF)
GCV	Three-Dimensional Expeditionary Long-Range Radar (3DELRR)	Air and Missile Defense Radar (AMDR)
Armored Multi-Purpose Vehicle (AMPV)	GPS-MGUE	Enhanced Polar System (EPS)
B61 Life Extension Program - Tailkit Assembly	AF Integrated Personnel and Pay System (AF-IPPS)	Joint Space Center (JSpOC) Mission System (JMS)
Bradley ECP	Combat Rescue Helicopter (CRH)	Paladin Integration Management (PIM)
ChemDemilitarization-Assembled Chemical Weapons Alt	Defense Enterprise Accounting And Management System	Space Fence
F-22 Increment 3.2B	Excalibur	GPS Next Generation Operational Control System (OCX)
F-35 Lightning	Integrated Strategic Planning and Analysis Network (ISPAN)	Littoral Combat Ship (LCS) Mission Module (MM)
Joint Light Tactical Vehicle (JLTV)	Joint Personnel Identification V2 (JPIv2) System	Army Integrated Air and Missile Defense (AIAMD)
P-8A Poseidon Increment 3	Joint Precision Approach and Landing System (JPALS)	DCGS-A
LCS Seaframe	Ship to Shore Connector (SSC)	
Abrams ECP	Logisitics Modernization Program (LMP)	
B2 EHF & SATCOM 1	eProcurement (eProc)	
MQ-4C Triton Broad Area Maritime Surveillance UAS	Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)	
MQ-9 Unmanned Aircraft System (UAS)	Integrated Personnel and Pay System - Army (IPPS-A)	
Apache Block 3	Next Generation Enterprise Network (NGEN) Increment 1	
	CANES	

Acquisition Phase

Were there differences for programs at different stages of acquisition?

Phase	Total	Issues			
		No SoS Issues	Context	Mgt	Tech
MSA	10	20%	50%	50%	80%
		2	5	5	8
TD	24	25%	21%	50%	42%
		6	5	12	10
EMD	13	38%	54%	46%	38%
		5	7	6	5
Total	47	30%	36%	49%	51%
		14	17	23	24

- **Later in cycle**
  - Fewer SoS issues identified in plans
    - 20-25% plans had no issues at MSA/TD
    - 38% had no issues at EMD
  - Fewer technical issues in plans
    - 80% plans had technical issues at MSA
    - ~40% of plans at TD/EMD

Observations

- **SoS considerations are risk drivers in all program types**
  - All systems deploy as part of a **mission context** which may impact system requirements, design etc. This context must be considered from the start.
    - Need to share information across systems is common and well recognized
  - In some cases, system effectiveness depends on **external system dependencies** (e.g. precision sensor feeds for new precision weapons)
    - Each program is responsible to develop a way to address these dependencies
    - If recognized and tracked on a case by case basis, risks can be identified and addressed
  - Independent development of **platforms and the systems which they host** (and depend upon) is a common source of SoS issues
    - Recent problems have highlighted this type of SoS issue and heightened effort of programs to address this in their plans
  - **SoS programs** face a particularly broad set of management and coordination issues
    - Overlapping management and technical authorities make developing an effective approach difficult to plan and implement
    - Complexities of adapting current systems to meet new objectives particularly when systems continue to support current users pose particular challenges and risks

Additional Observations (2 of 2)

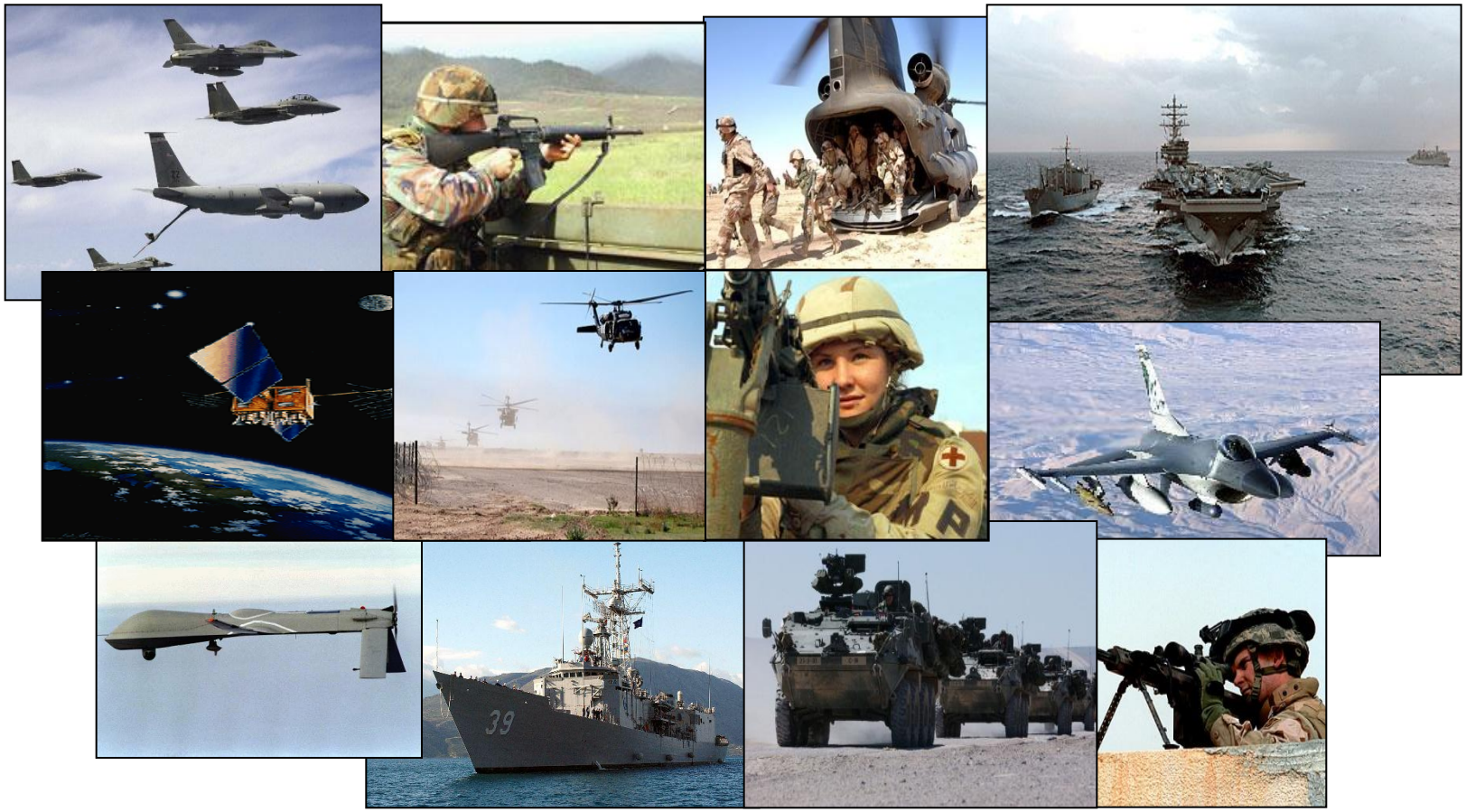
- **SoS considerations are a new element in plans, so many of the issues may be due to a lack of understanding of expectations**
  - Programs have been responsive to correcting deficiencies in revisions
- **Even when interdependencies are identified, tendency is to wait and address these later in a system acquisition**
  - One of many considerations facing a program
  - Outside of program control so may get less attention until they become a problem
- **SoS considerations can pose difficult issues without well understood or clearly demonstrated approaches**
  - Can account for high level descriptions of approach to address SoS dependencies

Summary and Conclusions

- **Acquisition programs are now addressing SoS considerations in the SE plans**
  - Important because SE Plans reflect PM priorities
- **SE Plans for programs of all types have SoS issues**
  - Systems program have general issues across the board, issues which are also observed in platform and SoS programs
  - Platform programs issues focus on GFE integration, particularly SWAP-C
  - SoS program issues center on the complexities of an acquisition dependent on multiple independent players
- **Programs later in acquisition seem to have somewhat fewer SoS issues with their plans**
  - However, early risk identification is important; focus area for MS A SEP
- **Reviews reveal areas for increased reinforcement by leadership**
  - Services and Agencies, DAU, functional leadership can assist in proper planning
- **Heightens need to identify effective approaches and share these across the acquisition and SE community**
- **And we do see these issues become problems that impact program success**

QUESTIONS?

Systems Engineering: Critical to Program Success



Innovation, Speed, and Agility

http://www.acq.osd.mil/se