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System of Systems Engineering Pilot
Quality Function Deployment Analysis

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Introduction

- SoS Systems Engineering project addressing LCS ASW Integration & Mission Capability Evolution

- Pilot project conducted by ASW Systems Engineering Team (ASSET) chaired by PEO-IWS5 SE

- Application of ASN/RDA CHSENG Naval SoS SE Guidelines

- Employed Quality Function Deployment (QFD) for SoS capability evaluation

LCS ASW SoS Pilot Project

- Proliferation of quiet diesel submarines creates a growing ASW challenge
- ASW inherently a "system-of-systems" enterprise:
  - Platforms
  - Sensors
  - Weapons
  - Command, Control & Communications
- Littoral Combat Ship (LCS) a "transformational" concept:
  - Agile platform
  - Reconfigurable mission packages
  - Extensive use of unmanned vehicles & off-board sensors
  - Spiral development
- Pilot project objectives
  - Address needed ASW capability
  - Apply ASN/RDA SoS SE guidelines
    - Including QFD
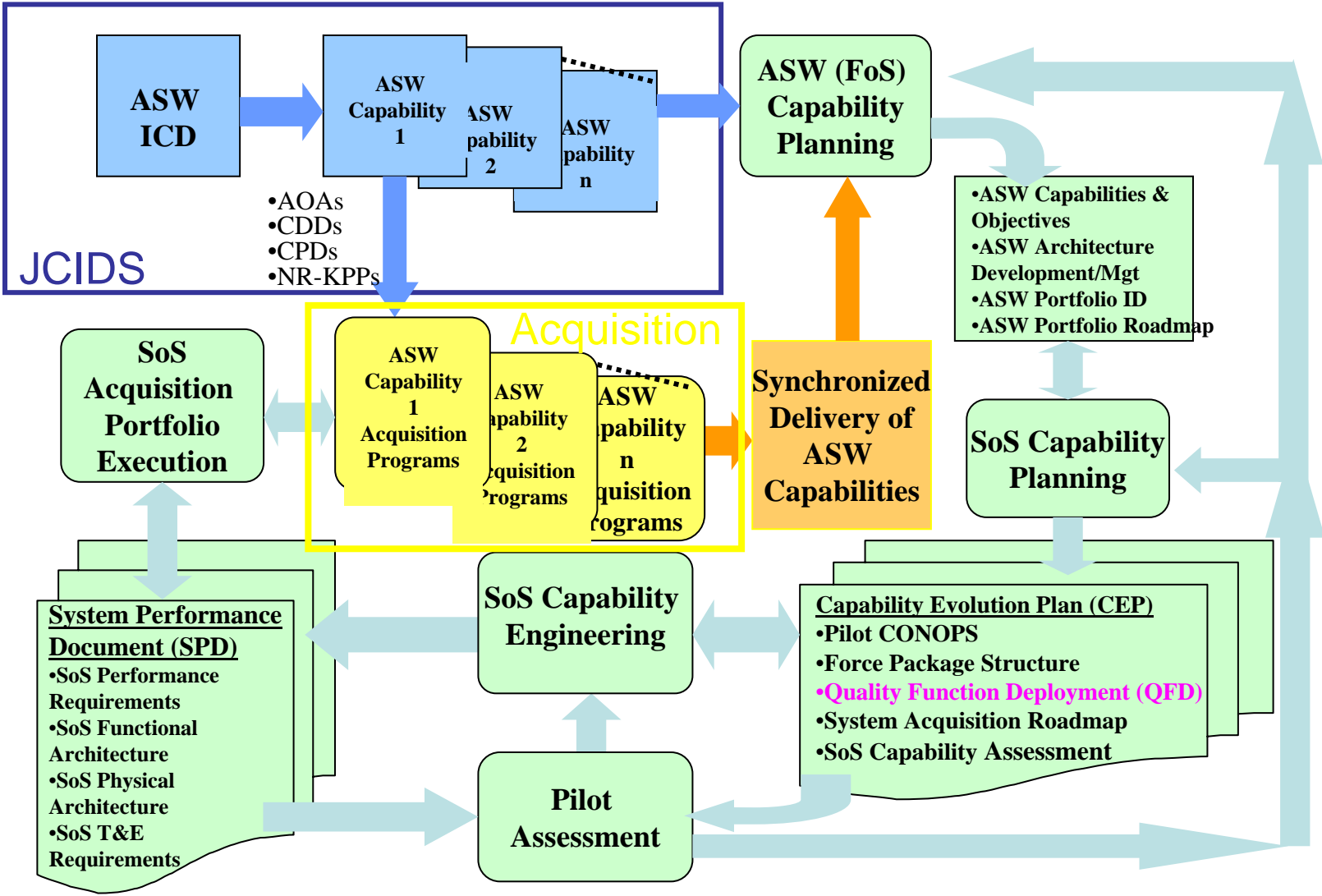 - Show "value added" in SoS acquisition
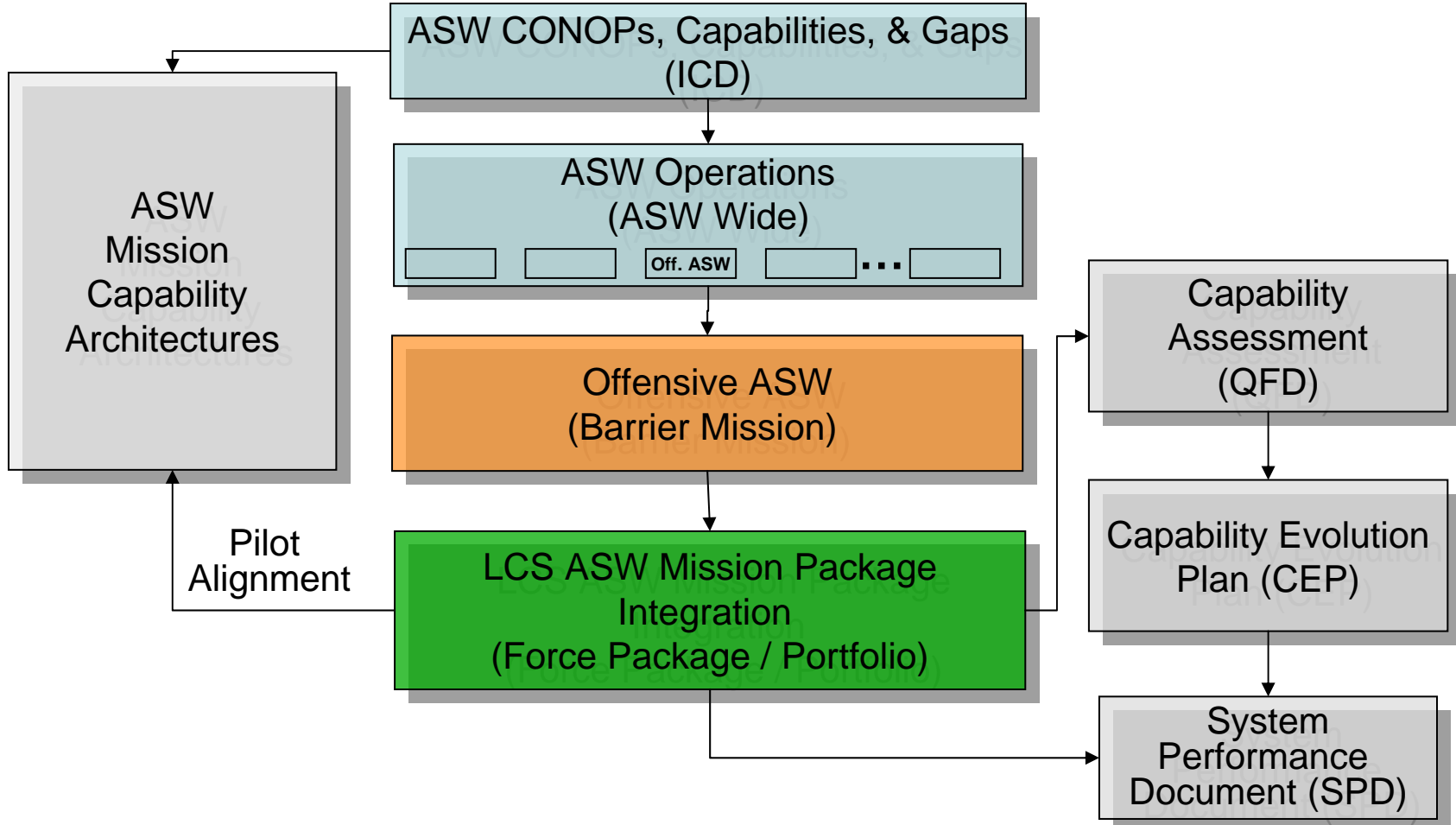
Quiet Diesel Submarine Threat

LCS Platform Concepts
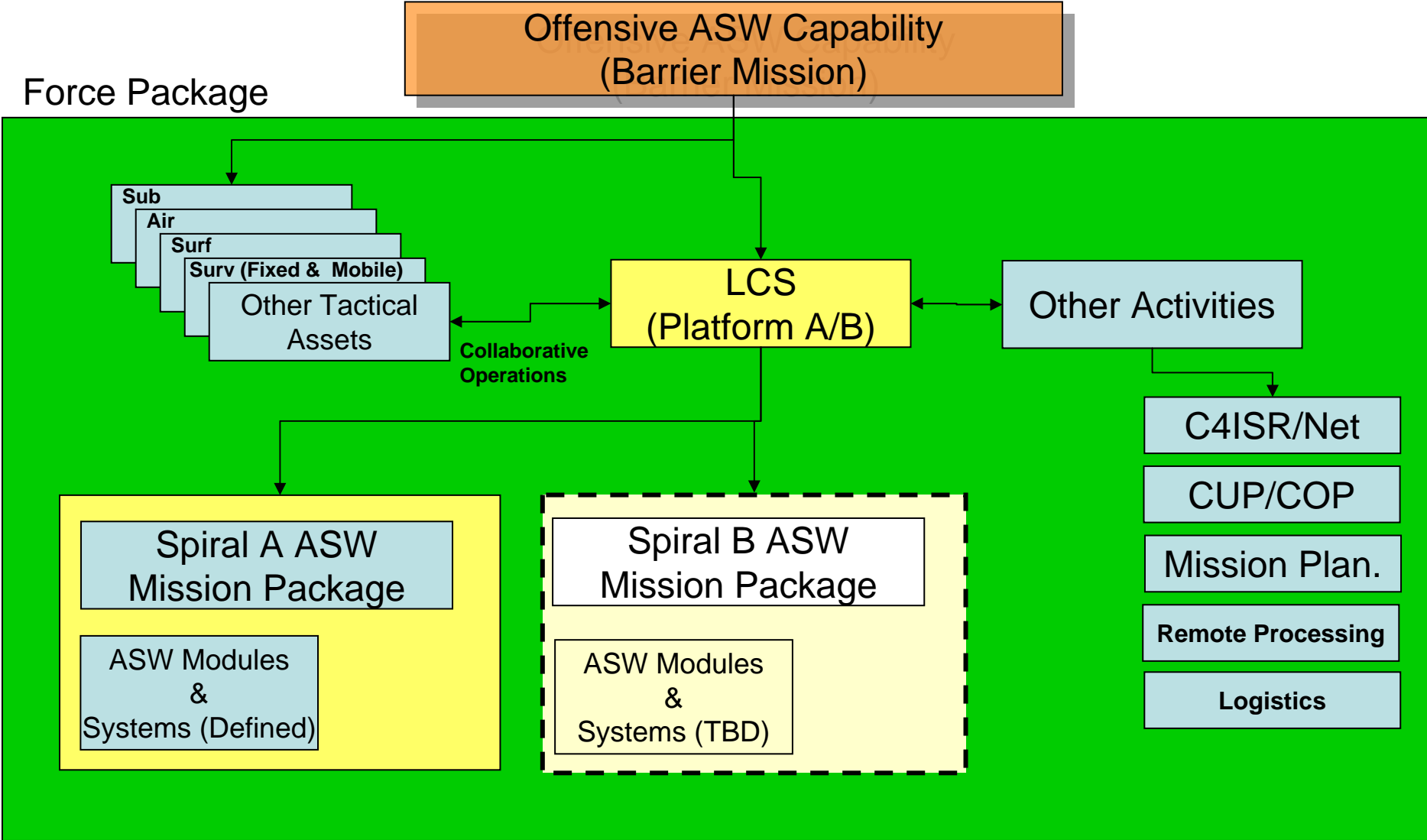
ASW System of Systems Engineering Process

JCIDS

- ASW ICD
- ASW Capability 1
- ASW Capability 2
- ASW Capability n

- •AOAs
- •CDDs
- •CPDs
- •NR-KPPs

Acquisition

- ASW Capability 1 Acquisition Programs
- ASW Capability 2 Acquisition Programs
- ASW Capability n Acquisition Programs

ASW (FoS) Capability Planning

- •ASW Capabilities & Objectives
- •ASW Architecture Development/Mgt
- •ASW Portfolio ID
- •ASW Portfolio Roadmap

Synchronized Delivery of ASW Capabilities

SoS Capability Planning

SoS Acquisition Portfolio Execution

SoS Capability Engineering

System Performance Document (SPD)
- •SoS Performance Requirements
- •SoS Functional Architecture
- •SoS Physical Architecture
- •SoS T&E Requirements

Pilot Assessment

Capability Evolution Plan (CEP)
- •Pilot CONOPS
- •Force Package Structure
- •Quality Function Deployment (QFD)
- •System Acquisition Roadmap
- •SoS Capability Assessment

Connotes SoS SE Steps

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LCS ASW Mission Context

ASW CONOPs, Capabilities, & Gaps (ICD)

ASW Operations (ASW Wide)

Off. ASW

ASW Mission Capability Architectures

Offensive ASW (Barrier Mission)

Capability Assessment (QFD)

Pilot Alignment

LCS ASW Mission Package Integration (Force Package / Portfolio)

Capability Evolution Plan (CEP)

System Performance Document (SPD)

SoS SE Elements

LCS Pilot Project Portfolio

Offensive ASW Capability (Barrier Mission)

Force Package

Sub
Air
Surf
Surv (Fixed & Mobile)

Other Tactical Assets

Collaborative Operations

LCS (Platform A/B)

Other Activities

C4ISR/Net

CUP/COP

Mission Plan.

Remote Processing

Logistics

Spiral A ASW Mission Package

ASW Modules & Systems (Defined)

Spiral B ASW Mission Package

ASW Modules & Systems (TBD)

QFD Matrices for Capability-Based Planning

Commercial/DoD
QFD Examples

Naval SoS SE Guidebook QFD Process
(and DODAF Relationships)

CAPABILITY ALIGNMENT ASSESSMENT

INTEROPERABILITY ASSESSMENT

CAPABILITY PERFORMANCE ASSESSMENT

FUNCTIONAL ALLOCATION ASSESSMENT

LCS Pilot Matrix 2

LCS Pilot Matrix 1

Label	Box	SV
8a	System KPPs	
6a	Systems, Applications & Personnel	SV-7
4	Platform/ Facility Nodes	SV-3, 10c
8b	Interop. KPPs	
3a	Force Package Structure	SV-2
	System Interfaces, MMI	SV-7
2	Mission Threads	SV-1
7a	Information Exchange	SV-6
1	Capability MOEs	OV-5
5a	Operational Activities/ Tasks	OV-3
	Capability Objectives	AV-1
3b	Mission Threads	OV-6c
8c	System MOPs	SV-7'
6b	Systems, Applications & Personnel	SV-5b, 10c
5b	Functional Processes	
	Operational Activities/ Tasks	SV-5a
7b	System Interfaces, MMI	SV-6
	Functional Data Flow	
6c	Functional Processes	SV-4a

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Pilot QFD Matrices & Workshop

Mission &
SoS Systems
MCA

Operational &
Engineering Metrics
(ICD, CDD, Other)

Matrix 1

Matrix 2

Operational Stages and Activities	SoS Functions & Systems
	Operational Priority and Functional & System Importance
	Importance Score
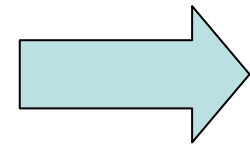
Critical Functions

SoS System Functions & Systems	SoS Capability Metrics
	Functional Capability Assessment
	Capability Score

Workshop Day 1

Workshop Day 2

- 2-Day Workshop
- ~30 Subject Matter Experts (SME)
- Divided into four teams
- Operational, technical, engineering expertise
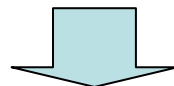
SoS Capability
"Gaps"
(CEP Focus)

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Matrix 1 (partial)
Operational Activity & System Functions

Step 1: Allocation of 1000 points across stages and activities

LCS Pilot SoS System and Functions

Step 2: Score in terms of criticality of function to operational activity (scale: 9-6-3-1, 0)

Function Importance

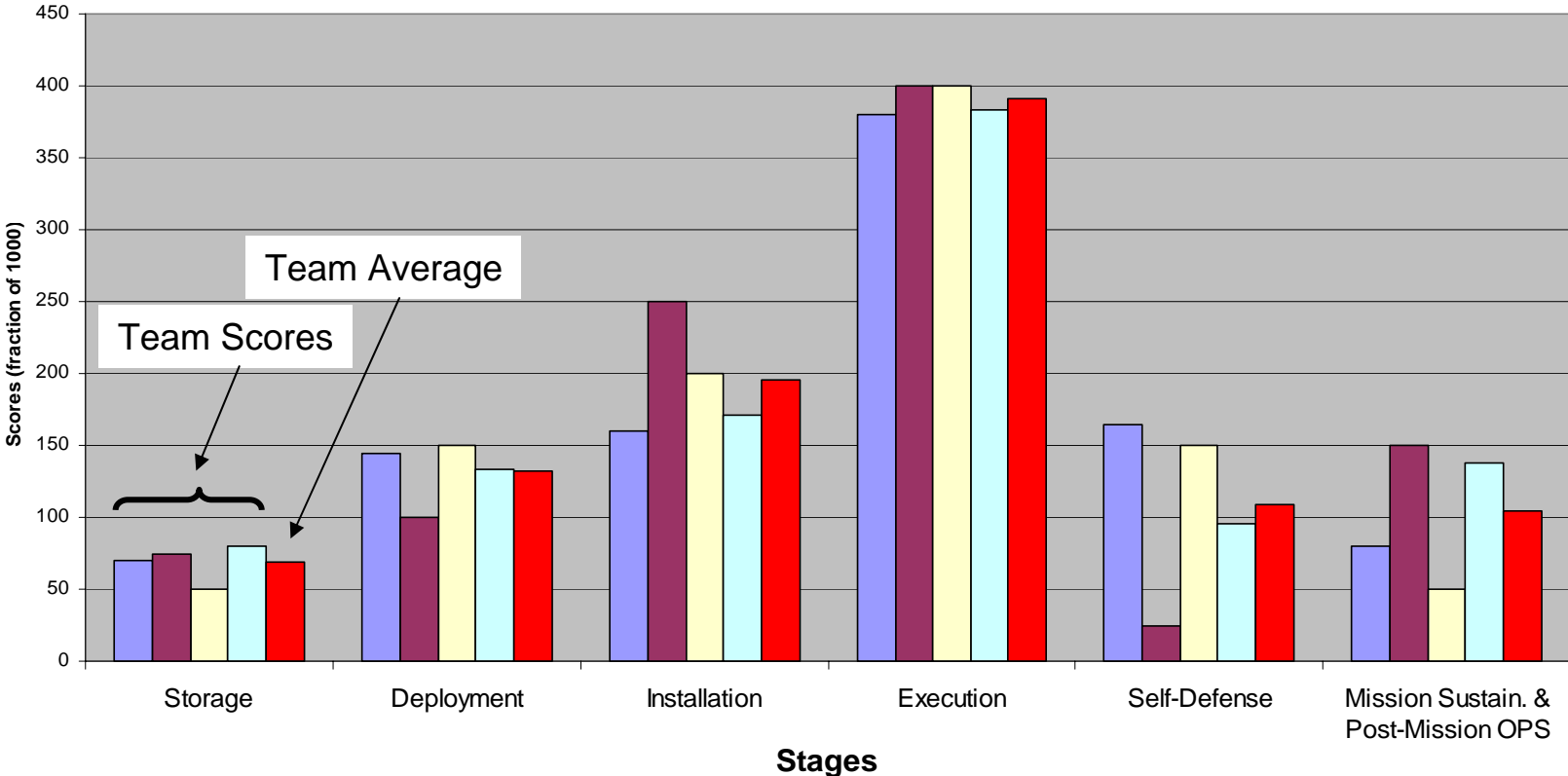| Operational Stage	Stage Score	ID	Activity	Stage Score Allocations	Functions:	Flight operations	Communicate	Sensor Processing	Navigation	Deploy	Sense	Localize	Onboard Processing	Deploy	Sense	Localize	Onboard Processing	Communicate	DCL	Deploy / Placement	Search	Acquire Target	Kill
A. Storage	0	A.1	Retrieve MP from Stowage																				
		A.2	Module configuration and checkout																				
		A.3	Transport																				
		A.4	Onload modules and mission crew																				
B. Deployment	0	B.1	Assign Mission																				
		B.2	Plan ASW mission																				
		B.3	Underway and Transit																				
		B.4	Arrive at assigned operating area																				
		B.5	Establish theater tactical communications (OPCON and TACON)																				
		B.6	Coordinate with other assets																				
C. Installation	0	C.1	Arrive OPAREA																				
		C.2	Characterize/measure area environment																				
		C.3	Mission/Sensor employment planning																				
		C.4	Final vehicle/sensor reconfiguration and checkout																				
		C.5	Launch vehicles/OOV's																				
		C.6	Check operability																				
		C.7	Return to patrol station																				
		C.8	Operate and monitor OOV's																				

Platform / Vehicle — 1.1.1 Helicopter

System: 1.1.1.1 Helo (SH-60B, MH-60R) | 1.1.1.2 ALFS (Dipping Sonar) (MH60R Only) | 1.1.1.3 Sonobuoy (Family) | 1.1.1.4 MAD, Radar, EO (Helo Dependent) | 1.1.1.5 Weapons (Mk46, MK54)

IDs: F1.1.1.1.1, F1.1.1.1.2, F1.1.1.1.3, F1.1.1.1.4, F1.1.1.2.1, F1.1.1.2.2, F1.1.1.2.3, F1.1.1.2.4, F1.1.1.3.1, F1.1.1.3.2, F1.1.1.3.3, F1.1.1.3.4, F1.1.1.3.5, F1.1.1.4.1, F1.1.1.5.1, F1.1.1.5.2, F1.1.1.5.3, F1.1.1.5.4

Metric Score: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Step 3: Compute overall Importance Score

Importance score = Σ (Activity value X criticality value per cell)

Additional Matrix Rows & Columns

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Stage Score Allocations (Matrix 1)

Matrix 1 (Day 1)

Operational Stages and Activities	SoS Functions & Systems
	Operational Priority and Functional & System Importance
	Importance Score

Team prioritization of operational the six stages
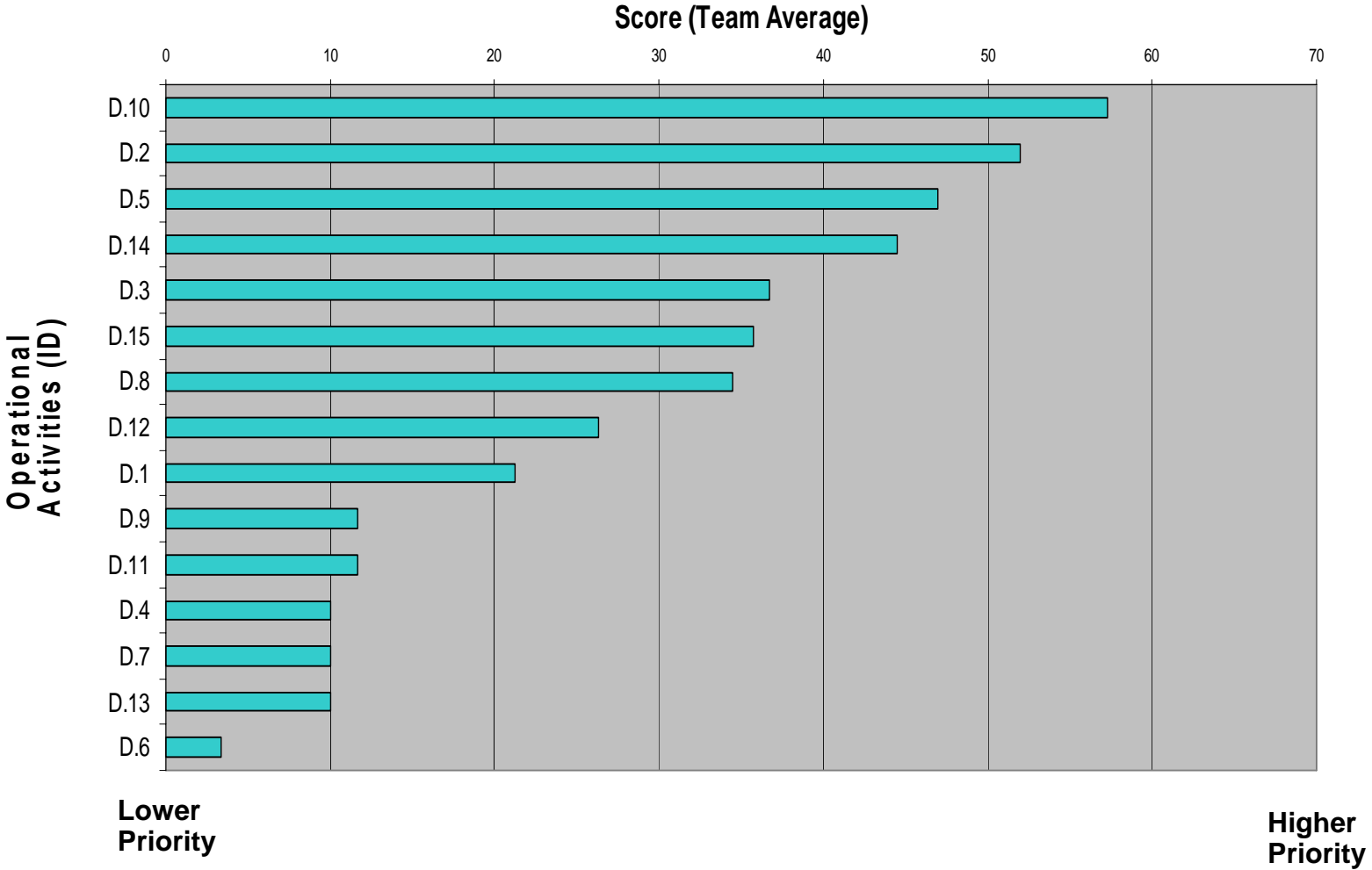(Allocation of 1000 points)

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Operational Activity Priority – *Execution Stage*
Rank Ordered Team Averages

(Allocation of points assigned to Execution Stage)

Matrix 1 (Day 1)

Operational Stages and Activities	SoS Functions & Systems
	Operational Priority and Functional & System Importance
	Importance Score

Score (Team Average)

Operational Activities (ID)

D.10, D.2, D.5, D.14, D.3, D.15, D.8, D.12, D.1, D.9, D.11, D.4, D.7, D.13, D.6

Lower Priority

Higher Priority

Matrix 1 (Day 1)

Operational Stages and Activities	SoS Functions & Systems
	Operational Priority and Functional & System Importance
	Importance Score

Function Importance (Execution Stage/Matrix 1)
## Team Score Averages (Ranked)

Importance = ΣActivity Score X Rated Functional Criticality

Top Rated Functions
(Importance > 1000)

Importance Score

System Functions (ID)

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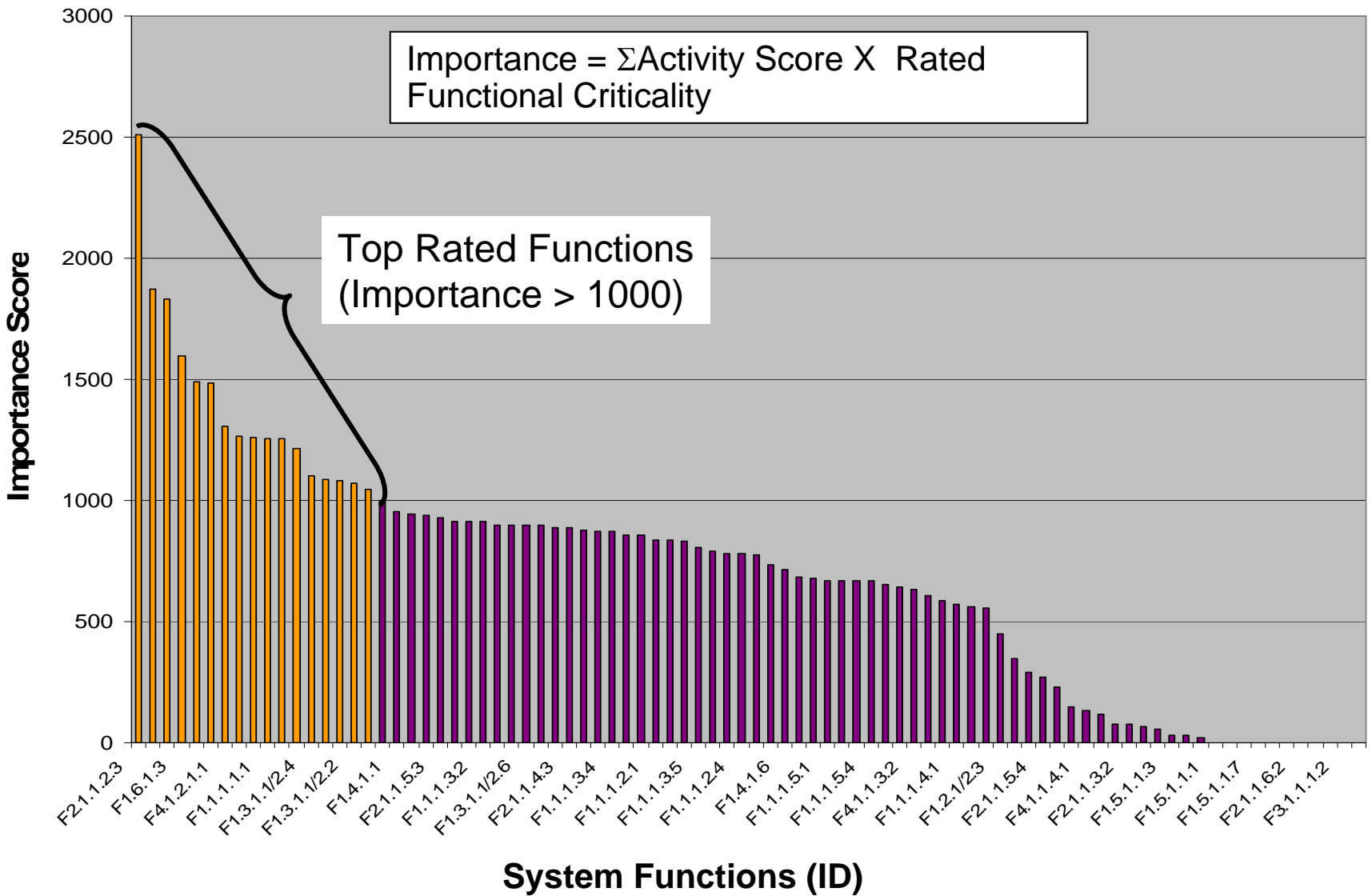
System Importance (Matrix 1)
Execution Stage
Ranked Team Averages

Matrix 1 (Day 1)

Operational Stages and Activities	SoS Functions & Systems
	Operational Priority and Functional & System Importance
	Importance Score
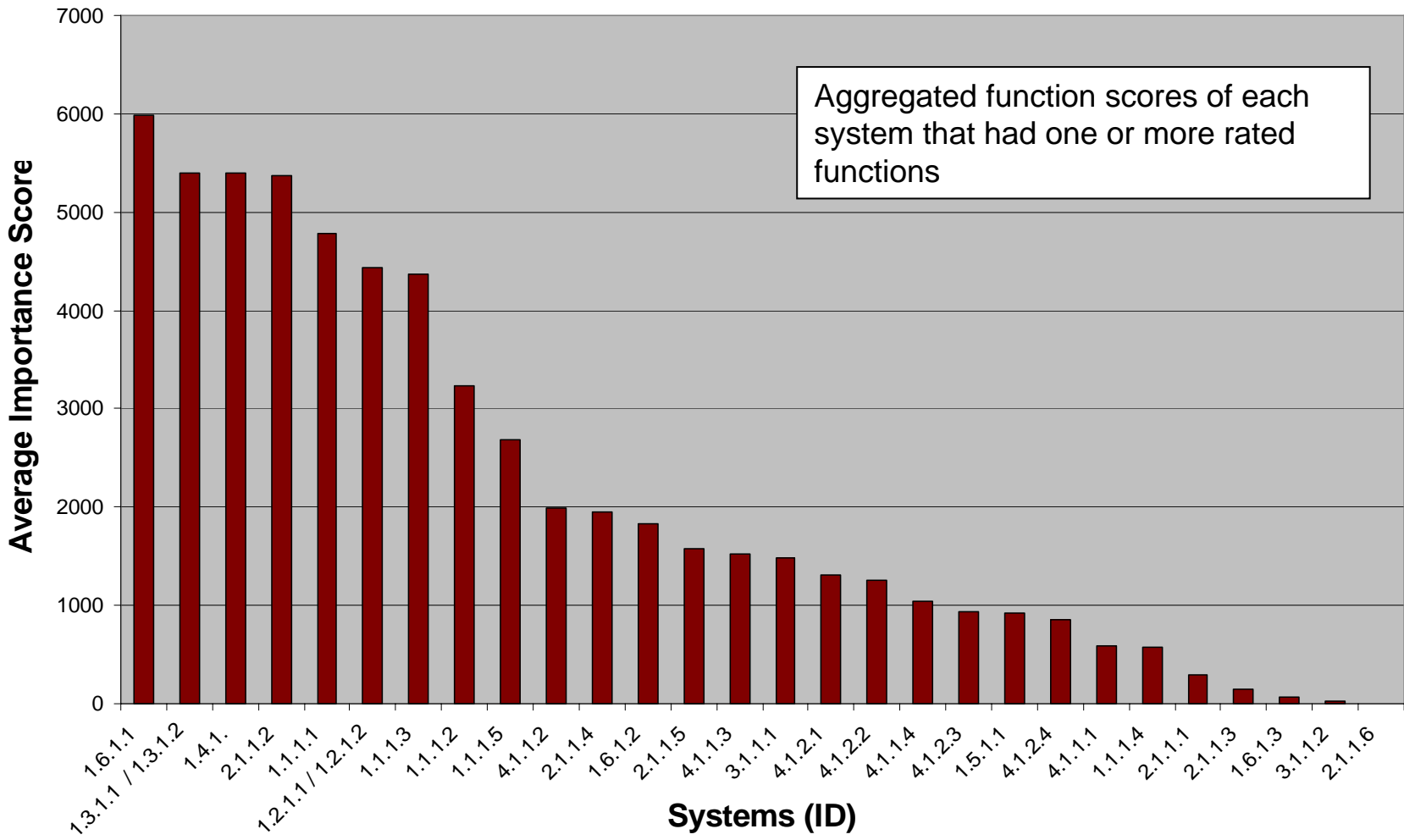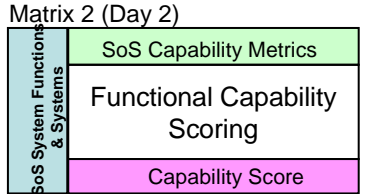
Matrix 2 (partial)
System/Functions vs Capability

Matrix 2 (Day 2)

SoS System Functions & Systems	SoS Capability Metrics
	Functional Capability Scoring
	Capability Score

Step 1: Address higher important functions and systems from Matrix 1

Capability Metrics (by Category)

System and Functions (from Matrix 1)

System Capability Score

Overall Capability Score

Step 2: Score in terms of capability (fully capable to significantly incapable)

Global Metric			M1.1 ASW Search					M1.2 Kill Chain Metrics					
ID	M1.1.1	M1.1.2	M1.1.3	M1.1.4	M1.1.5	M1.1.6	M1.2.1	M1.2.2	M1.2.3	M1.2.4	M1.2.5	M1.2.6
Metric	Search Rate/Coverage	Detect/Class	Track	False Contact Rate	LCS Mission Sustainment (days)	Area Environmental Understanding	Redetect & Class	Localize	Engage	Kill	Asset Availability/Responsiveness	Weapon Availability

| Functional Component	Platform / Vehicle	System	ID	Functions:	Metric Score (from Matrix #1)
1.1 Aviation Mission Module	1.1.1 Helicopter	1.1.1.1 Helo (SH-60B, MH-60R)	F1.1.1.1.1	Flight operations	0
			F1.1.1.1.2	Communicate	0
			F1.1.1.1.3	Sensor Processing	0
			F1.1.1.1.4	Navigation	0
		1.1.1.2 ALFS (Dipping Sonar) (MH60R Only)	F1.1.1.2.1	Deploy	0
			F1.1.1.2.2	Sense	0
			F1.1.1.2.3	Localize	0
			F1.1.1.2.4	Onboard Processing	0
		1.1.1.3 Sonobuoy (Family)	F1.1.1.3.1	Deploy	0
			F1.1.1.3.2	Sense	0
			F1.1.1.3.3	Localize	0
			F1.1.1.3.4	Onboard Processing	0
			F1.1.1.3.5	Communicate	0
		1.1.1.4 MAD, Radar, EO (Helo Dependent)	F1.1.1.4.1	Detect/Classify/Localize	0
		1.1.1.5 Weapons (Mk46, MK54)	F1.1.1.5.1	Deploy / Placement	0
			F1.1.1.5.2	Search	0
			F1.1.1.5.3	Acquire Target	0
			F1.1.1.5.4	Kill	0
1.2 Mid-Frequency Bistatic Mission module	1.2.1 RMV(2)	1.2.1.1 RTA / 1.2.1.2 RTAS	F1.2.1/2.1	Operate & Control	0
			F1.2.1/2.2	Sense	0
			F1.2.1/2.3	Localize / Track	0
			F1.2.1/2.4	Communicate	0
			F1.2.1/2.5	Onboard Processing	0
			F1.2.1/2.6	Navigate	0
1.3 LF Bistatic Mission Module	1.3.1/ 1.4.1 USV(2)	1.3.1.1 UTAS / 1.3.1.2 MSOBS	F1.3.1.1/2.1	Operate & Control	0
			F1.3.1.1/2.2	Sense	0
			F1.3.1.1/2.3	Localize / Track	0
			F1.3.1.1/2.4	Communicate	0
			F1.3.1.1/2.5	Status / Diagnostics	0
			F1.3.1.1/2.6	Navigate	0
1.4 Mid-Frequency Monostatic Mission Module		1.4.1. UDS	F1.4.1.1	Operate & Control	0
			F1.4.1.2	Sense	0
			F1.4.1.3	Localize / track	0
			F1.4.1.4	Communicate	0
			F1.4.1.5	Navigate	0
			F1.4.1.6	Onboard Processing	0
			Score		0 0 0 0 0 0 0 0 0 0 0 0

Step 3: Compile overall capability scores

Score = Σ (system function score X adequacy rating value per cell)

Additional Matrix Rows & Columns

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Capability Scores
(Execution Stage)

Matrix 2 (Day 2)

SoS System Functions & Systems	SoS Capability Metrics
	Functional Capability Scoring
	Capability Score
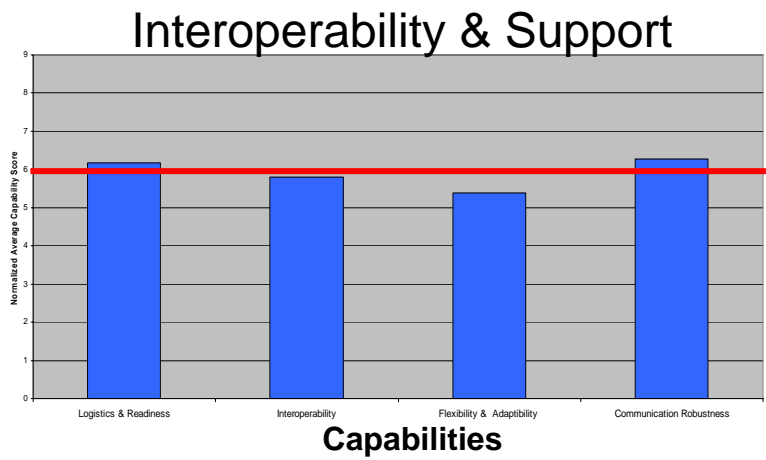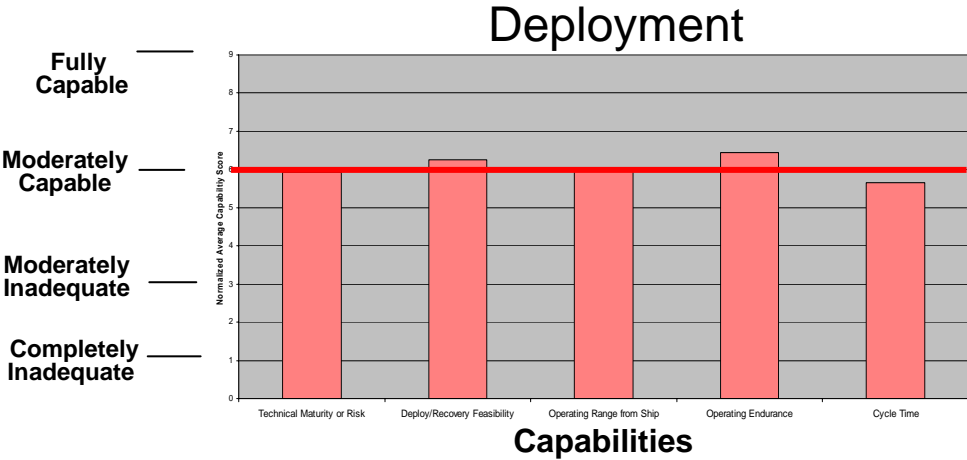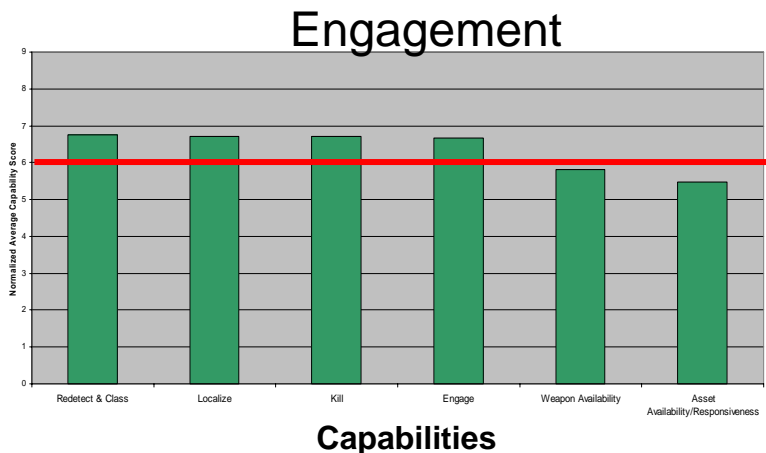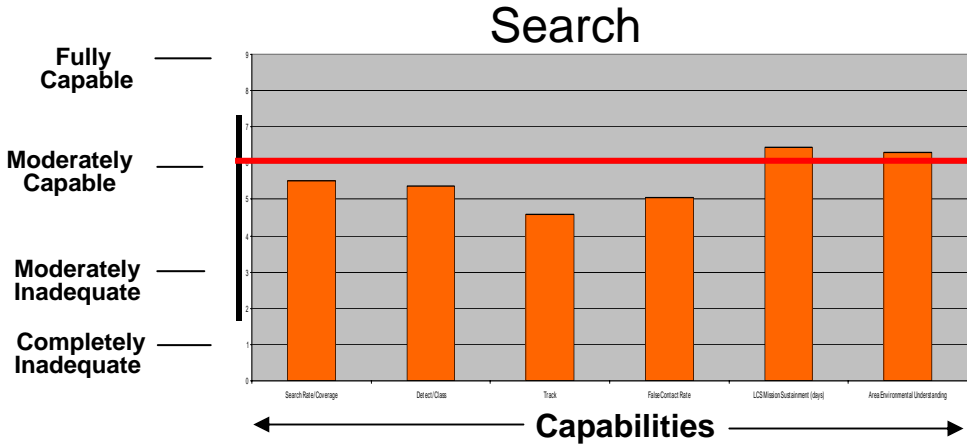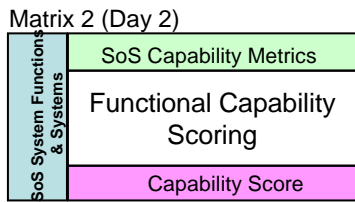
Score < 6 considered a Capability "gap"

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System Capability vs. Importance
(Results of Matrix 1 & 2)
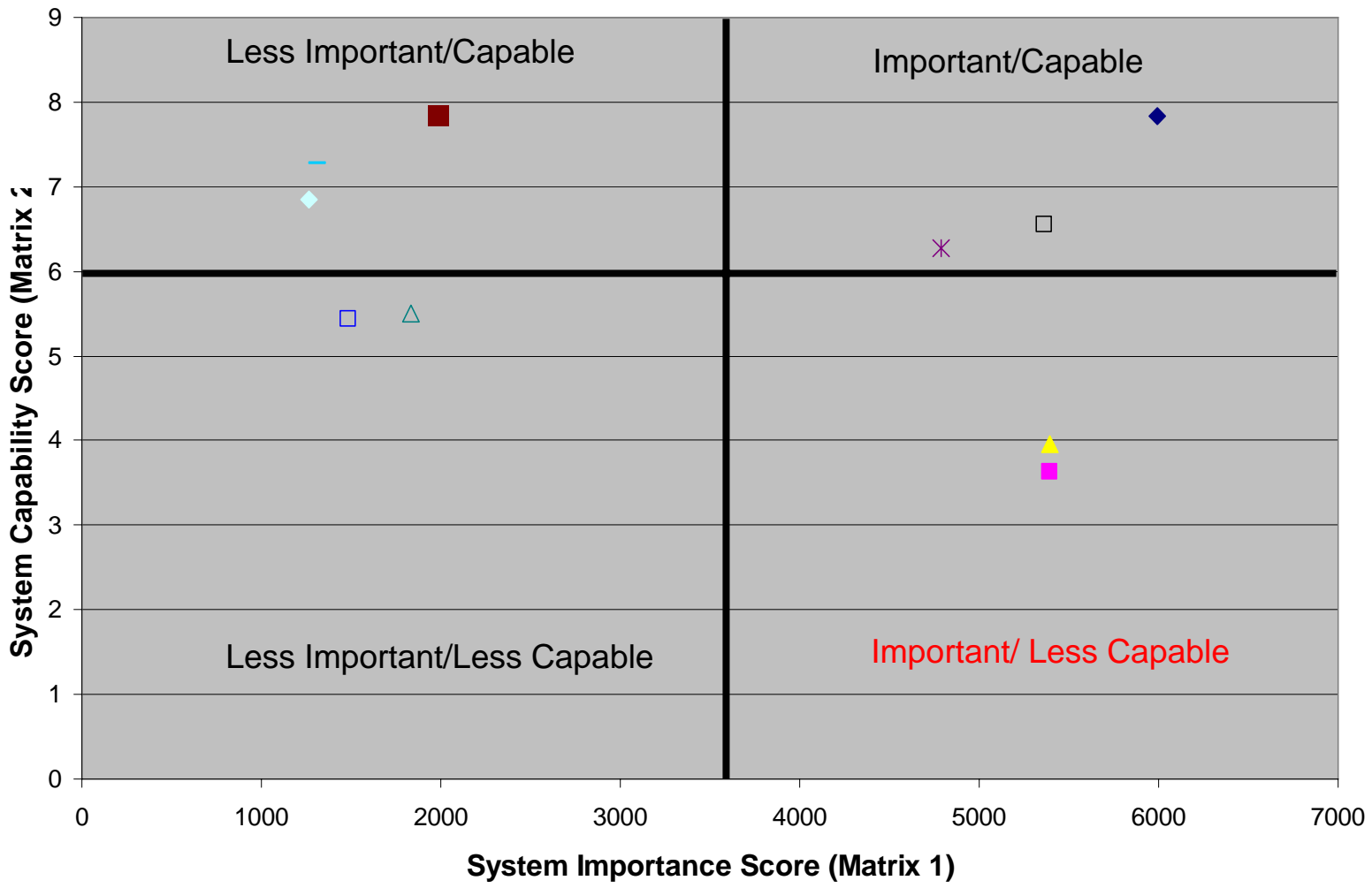
(Based on Execution Stage evaluation)

QFD Workshop Comments

- Carefully constructed matrices critical to success

- Manageable matrix size (dimensions)

- A two-day workshop was insufficient

- Dividing participants into four smaller working groups worked well.

- Need clear Concept of Operations and mission threads (ideally an approved set of architectures)

- Description and performance information regarding the systems being rated needed on site

- An experienced QFD workshop facilitator if not facility recommended

Summary

- LCS ASW Integration Pilot project has been a good example of SoS SE process
  - Portfolio of systems
  - Application of the ASN/RDA SoS SE Guidelines

- The QFD process was adapted from the SoS SE Guide and other QFD applications and was effective in identifying functional priorities and capability gaps across a complex SoS portfolio.

- QFD matrices must be customized to assess the operational, functional, and physical aspects of the Force Package.

- The matrices map to or expand upon the DOD Architecture Framework and thereby are a further use of the architecture products

- The process followed is considered useful, applicable, and adaptable to other SoS capability evolution scenarios.

Backups

LCS Operational Stages and Activities (Matrix 1)

Activity

Storage
Module configuration and checkout
Transport
Onload modules and mission crew

Deployment:
Plan ASW mission
Underway and Transit
Arrive at assigned operating area
Establish theater tactical communications (OPCON and TACON)
Coordinate with other assets

Installation
Characterize/measure area environment
Mission/Sensor employment planning
Final vehicle/sensor reconfiguration and checkout
Launch vehicles/OOV's
Check operability
Return to patrol station
Operate and monitor OOV's

Activity

Execution
Conduct area search
Detect and classify contacts
Resolve possible false contacts
Report detections to Sqn and ASWC
Localize, track and monitor threat submarines
Target reported to sqn and ASWC
Prosecution assets proceed to target
Prosecution assets redetects, classifies and localizes target
Prosecution assets request and receives attack authorization
Prosection assets launches weapon
Attack assessment
Reattack if required
Prosecution assets return to LCs or patrol station
Handoff/receive targets with other assets
Maintain tactical Picture

Activity

Self-Defense
Threat /Weapons DCL
Evade

Mission Sustainment & Post-Mission OPS
Refurbish and Redeploy OOV's
LCS proceeds to sensor station
Final recovery of OOV's
Conducts turnover with relieving LCS
Onboard stowage
Transit to port (or ship replenishment sight)
Off-load
Refurbishment
Stowage

*Ref: LCS ASW Mission Package Overview, PMS 420

**Ref: LCS Operational Assessment Scenario, SPA and other sources

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LCS ASW SoS Pilot
System and Functions (Matrix 1 & 2)

1. OOV/Sensors

1.1.1 Helicopter																		
1.1.1.1 Helo (SH-60B, MH-60R)				1.1.1.2 ALFS (Dipping Sonar) (MH60R Only)				1.1.1.3 Sonobuoy (Family)					1.1.1.4 MAD, Radar, EO (Helo Dependent)	1.1.1.5 Weapons (Mk46, MK54)			
F1.1.1.1.1	F1.1.1.1.2	F1.1.1.1.3	F1.1.1.1.4	F1.1.1.2.1	F1.1.1.2.2	F1.1.1.2.3	F1.1.1.2.4	F1.1.1.3.1	F1.1.1.3.2	F1.1.1.3.3	F1.1.1.3.4	F1.1.1.3.5	F1.1.1.4.1	F1.1.1.5.1	F1.1.1.5.2	F1.1.1.5.3	F1.1.1.5.4
Flight operations	Communicate	Sensor Processing	Navigation	Deploy	Sense	Localize	Onboard Processing	Deploy	Sense	Localize	Onboard Processing	Communicate	DCL	Deploy / Placement	Search	Acquire Target	Kill

1.2 Mid-Frequency Bistatic Mission module						1.3 LF Bistatic Mission Module						1.4 Mid-Frequency Monostatic Mission Module						1.5 UAV Mission Module							1.6 Mission Package Support						
1.2.1 RMV(2)						1.3.1/ 1.4.1 USV(2)												1.5.1 VTUAV							1.6.1 MPSE/COMMS/Storage						
1.2.1.1 RTA / 1.2.1.2 RTAS						1.3.1.1 UTAS / 1.3.1.2 MSOBS						1.4.1. UDS						1.5.1.1 VTUAV Payload							1.6.1.1 MPCE					1.6.1.2 OOV COMMS	1.6.1.3 Storage
F1.2.1/2.1	F1.2.1/2.2	F1.2.1/2.3	F1.2.1/2.4	F1.2.1/2.5	F1.2.1/2.6	F1.3.1.1/2.1	F1.3.1.1/2.2	F1.3.1.1/2.3	F1.3.1.1/2.4	F1.3.1.1/2.5	F1.3.1.1/2.6	F1.4.1.1	F1.4.1.2	F1.4.1.3	F1.4.1.4	F1.4.1.5	F1.4.1.6	F1.5.1.1	F1.5.1.2	F1.5.1.3	F1.5.1.4	F1.5.1.5	F1.5.1.6	F1.5.1.7	F1.6.1.1	F1.6.1.2	F1.6.1.3	F1.6.1.4	F1.6.1.5	F1.6.1.2.1	F1.6.1.3.1
Operate & Control	Sense	Localize / Track	Communicate	Onboard Processing	Navigate	Operate & Control	Sense	Localize / Track	Communicate	Status / Diagnostics	Navigate	Operate & Control	Sense	Localize / track	Communicate	Navigate	Onboard Processing	Operate & Control	Communicate/ Relay	Sense	Classify	Localize	Attack?	BDA	Data Fusion & Contact Management	CAUSS	Display	Mission Planning	Sonar Operations	Control & Data Links	Weapons, HAZMAT, CPG

2. Host Platform

2.1.1.1 Crew	2.1.1.2 Communications (Various Radios & Nets))			2.1.1.3 MS Handling Systems		2.1.1.4 Mission Package Support Equipment					2.1.1.5 Command & Control				2.1.1.6 Ship Defense			
F2.1.1.1.1	F2.1.1.2.1	F2.1.1.2.2	F2.1.1.2.3	F2.1.1.2.4	F2.1.1.3.1	F2.1.1.3.2	F2.1.1.4.1	F2.1.1.4.2	F2.1.1.4.3	F2.1.1.4.4	F2.1.1.4.5	F2.1.1.5.1	F2.1.1.5.2	F2.1.1.5.3	F2.1.1.5.4	F2.1.1.6.1	F2.1.1.6.2	F2.1.1.6.3	F2.1.1.6.4
Ship Operations	Ship-Ship	Ship-to-Shore	Ship to Off-Board Systems	Ship to Force ASW Assets	MM Deploy Crew	Deploy/Recover MM	MP Control	Data Processing	Display	Mission Planning	Test MP	Mission Planning	Env. Data Gathering	Coordination	Common Processing	Weapon DCL	Counter	Evade	Mission recovery

(Note: header row above has 20 F-codes spanning the same columns.)

3.1 Maintenance and Storage

3.1.1 MP Shore/IMA/Depot

3.1.1.1 MP Shore/IMA			3.1.1.2 Depot & OEM
F3.1.1.1.1	F3.1.1.1.2	F3.1.1.1.3	F3.1.1.2.1
Train MP personnel	Store & Maintain Equip	Transport MP Equipment	Accept & Refurb Equip

4. Theater Assets

4.1.1 CSG/ESG Platforms								4.1.2 Other Assets			
4.1.1.1 Network (GIG/ForceNet)	4.1.1.2 ASW Command & Control		4.1.1.3 Common Picture		4.1.1.4 Mission Planning			4.1.2.1 P8 A, P3-C	4.1.2.2 Force Helo's	4.1.2.3 Other ASW Assets	4.1.2.4 Theater ISR
F41.1.1.1	F4.1.1.2.1	F4.1.1.2.2	F4.1.1.3.1	F4.1.1.3.2	F4.1.1.4.1	F4.1.1.4.2	F4.1.1.4.3	F4.1.2.1.1	F4.1.2.2.1	F4.1.2.3.1	F4.1.2.4.1
Communications	ASWC	TASW	Common Tactical Picture	Common Operational Picture	Area assignment	Sensor employment	Mutual Interfeerence	Cooperative ASW	Cooperative ASW	Cooperative ASW	Cueing

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Capability Performance Metrics
(Matrix #2)

M1.1 ASW Search						M1.2 Kill Chain Metrics					
M1.1.1	M1.1.2	M1.1.3	M1.1.4	M1.1.5	M1.1.6	M1.2.1	M1.2.2	M1.2.3	M1.2.4	M1.2.5	M1.2.6
Search Rate/Coverage	Detect/Class	Track	False Contact Rate	LCS Mission Sustainment (days)	Area Environmental Understanding	Redetect & Class	Localize	Engage	Kill	Asset Availability/Responsiveness	Weapon Availability

M2 System Employment Metrics					M3 SOS Metrics			
M2.1	M2.2	M2.3	M2.4	M2.5	M3.1	M3.2	M3.3	M3.4
Deploy/Recovery Feasibility	Operating Endurance	Cycle Time	Operating Range from Ship	Technical Maturity or Risk	Communication Robustness	Interoperability	Flexibility & Adaptibility	Logistics & Readiness