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The Modular SoS Paradigm

An Availability Paradox?

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Introduction

This Presentation will discuss :

- Modularity: what it is, Pros and Cons, how it is used on LCS
- Overview of extended systems
  - What's the concern
- Discuss Availability definitions: A_m, A_o, Mission Availability A_{om} alternative definition
- Discuss a strategy to address and manage the Availability Design of Modular SoS systems

Modular Systems Design

- Design Of Highly Modular Systems Is Expected To Quicken Development, Expand Mission Functionality And Reduce Cost
  - Complex SoS Architectures Have Multiple Levels Of Modularity
- Functional And Physical Modularity Coupled With Standard Software & Hardware Interfaces Enable New And Complex Functionality To Be Quickly Configured
  - Open Systems Design Approaches And Use Of COTS Enable Extended Systems Adaptation, Integration And Functional Growth
- Benefits Abound, But Challenges Remain, Good System Engineering Practices Are Vital To Realizing Open System/Modularity Benefits
- The Larger The System The More Challenging The Operational Availability - More Things To Fail – Longer Sequential Fault Trees

Modular Design, COTS, and Open System Concepts Enable Functional Expansion Across SoS, but care must be taken to achieve operational available to be of use to the Warfighter

Modularity Benefits

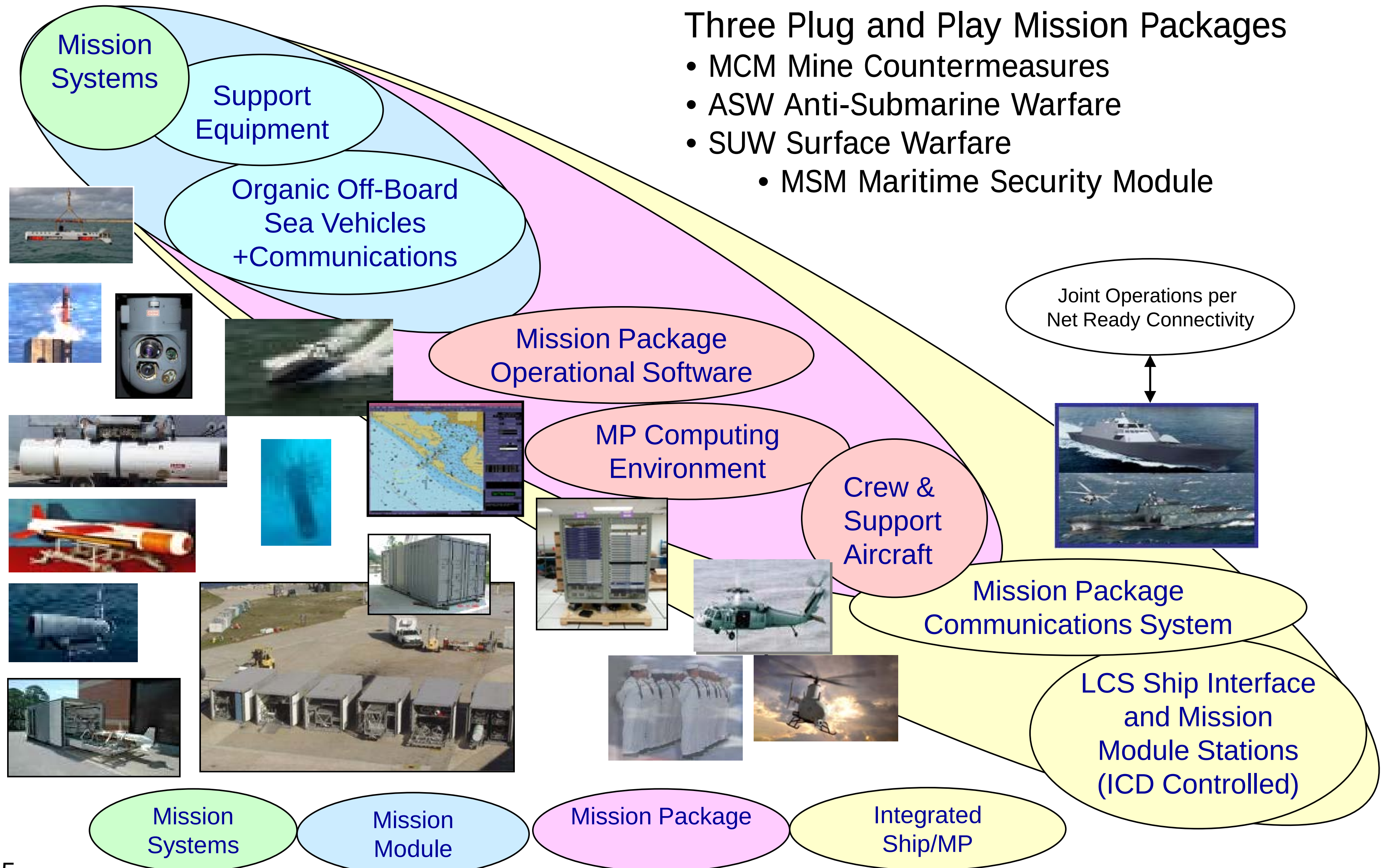
- Functional Modularity and Standard Software/Hardware Interfaces are all around us:
  - Cable and Satellite TV, cell, digital telephones
  - PC Plug and Play Hardware and Software, Networked gaming, Internet Cams, NetMeeting, WEBEX, Memory sticks, Portable hard drives, etc
- Open Systems Tools
  - SOA, XML, Java Wrappers, IP (data sharing), CORBA, P&S, Discovery
  - Plug and Play OS approach, simplified expansion of Functionality
  - Swap and Reuse of common modules built to common interface standards
  - Net Ready interconnectivity and functionality (SOA, SAS)
- LCS Modular Mission Systems Goals and Objectives
    - Plug and play sensors and I/O devices (e.g.: Modular 30mm Gun)
    - Plug and play mission software and hardware
    - Fast reconfiguration of functional and mission capabilities
    - Unmanned platforms, IP Multi-Vehicle Communications Network
    - Plug and Play Ship and Command Infrastructure

Open Systems Techniques and Mission Modularity Benefits Are Real

The LCS Levels of Modularity

Three Plug and Play Mission Packages

- MCM Mine Countermeasures
- ASW Anti-Submarine Warfare
- SUW Surface Warfare
    - MSM Maritime Security Module



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SoS Modularity challenges

- Complex functionality can be quickly configured but extended systems have sustainability challenges, e.g.:
  - Internet applications subject to: overload, environmental disturbance, virus downtime, variable quality of service
  - Satellite communications exhibit environmental outages, and long term degradation, lack of physical security
- Availability issues require attention
  - The inherent reliability employing modular off-board systems is lower due to increased number or elements in the Reliability Block Diagram.
  - Additional Off-board deployed systems difficulties arises due to increase handling e.g. cyclic mission cycle, shipboard storage, shore refit/storage
- Redundancy or mission system diversity counters sustainability challenges
  - High availability operational requirements and real time system functions require derived Ao allocations and quality of service that support the operational need
  - Alternative mission equipment or CONOPS can help achieve mission availability

RMA and Fault Tolerance Design and Analysis are Essential Tools for SoS Modular Design

Generalized Implementation Characteristics For Classes Of Platforms

Characteristics of Implementation and System Integration	Fixed in-place Hardwired, Dedicated On-board systems	Manned Deployable Vehicles flexible/fixed Payload Stores Variations	Un-Manned Deployable Vehicles flexible/fixed Payload Stores Variations	Family of Modular Off -Board Systems with flexible P/L Station
Example systems:	DDG-1000, E2C, HUON Mine hunter, BAMS	e.g. F-35, F22 , B2, etc	e.g. Global-Hawk, Predator, etc	e.g. CVN/F with A/C, LCS with USV, VTUAV, UUV, SSUV, Helios
Complexity	high	high	high	high
Set-up before use: initialization	minimal	medium	medium	extensive
Pre-test, Pre-flight	automatic computer driven	automatic computer driven, some physical installation and verification	automatic computer driven, some physical installation and verification	extensive hands-on
Intrinsic Composition of Mission Equipment	Fixed Systems, stand alone systems	Fixed systems with Home base (ship or ground control)	Fixed systems with Home base (ship or ground control)	Off-Board systems linked to a Home base (ship or ground control)
Deployed external system, types	Minimal Deployed Systems other than: rockets, missiles, munitions, towed sonar	Payload stores, EMC decoys, refueling	Payload stores, EMC decoys, refueling	OOVs, payload Sensor Systems, munitions appendages, towed systems
Number of Make-Break Physical Interconnects Prior to Use	few	more	more	Many
Electrical connectors	Payload stores	<5/Station	<5/Station	Many
Required Software load and initializations, per mission (Steady State)	few, initialization and mission plans	few, initialization and mission plans	Focused mission plans	Software reconfiguration often
Data links	many interfaces, HI connectivity	flexible, HI-Medium connectivity	flexible, HI-Medium connectivity	Sea to Sea connectivity challenged
Communication Bandwidth	High	Hi - Moderate	Moderate	Moderate
Comparative Availability (Public sources)	.9 to .95	0.85 to .98 (Autonomic Logistics (AL))	0.85-.9	.8 to 0.85

Modularity Paradigm Challenges

Modularity Challenges That Require Attention

- The mission string is inherently less reliable because we increase the # of serial components in the mission/operational function
- Extended Unmanned systems set up time and potential for damage is increased because of the increased handling, and the deploy and recovery environment and handling systems design
- Infrastructure Over-head can be over whelming in the particular adaptation of modular P&P design approach (weight, extra services, handling operations, S/W & H/W overhead)
- Deployment of remote systems have security challenges (physical and data related)

**SoS Extends The Systems Reach,
But They Also Extend The Environmental Considerations And Exposure of Systems To Adversarial Threats**

Availability KPP

- Availability consists of two components;
  - Materiel and Operational Availability
    - A_m Materiel Availability is a readiness factor of all the systems required to execute a mission
    - Operational Availability (A_o) as based on MTBF, MTTR, MLDT
- These components provide availability from a fleet-wide perspective and operational unit/mission percentages respectively
- Mission Availability is a system characteristic that allocates A_{om} among the system End-to-End mission string as required for operations during deployment (CONOPS driven approach)

Functional expansion to multiple platforms such as unmanned vehicles or satellites requires focus on operational availability of the mission strings

Materiel Availability (A_m)

- Materiel Availability (A_m) provides the average percentage of time that the entire population of systems is materially capable for operational use during a specified period.
  - This can be expressed mathematically as the number of operational end items/total population.
  - Includes those temporarily in a non-operational status once placed into service (such as for depot-level maintenance). The total life cycle timeframe, from placement into operational service through the planned end of service life, must be included.

$$A_m = \frac{\text{Number of End Items Operational}}{\text{Total Population of End Items}}$$

At the equipment level we find insight for top level decision makers; what's impacting operations?

Materiel Availability (A_m)

- Am challenges in a SoS
  - Operational use during a specified period
  - Operational use may use a small percentage of the mission suite depending on the mission, e.g. for MCM; Mapping, identification, clearing.
  - Operational environment may call for a a smaller or larger subset of equipment to be used in a deployment
- Am indicates if the full package is ready for operational use
  - Gives little in the indication if systems in the package can support the deployment reliably
- Resilient/Persistent Technical Requirements Example
  - MCM Package Materiel Availability; Threshold: 0.64, Objective: 0.712
  - MPCE Materiel Availability Threshold: 0.90 Objective: 0.95

What's impacting operations could be biased

Classic Availability (A_o)

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT}$$

***MTBF**: Mean Time Between Failure*

***MTTR**: Mean Time to Repair*

***MLDT**: Mean Logistics Delay Time*

$$*MLDT = MAdmDT + MOADT + MSRT$$

***MSRT** : Mean Supply Response Time (index of system supportability)*
***MOADT** : Mean Outside Assistance Delay Time (index of system supportability)*
***MAdmDT** : Mean Administrative Delay Time (index of system supportability)*

***Mean Logistics Delay Time (MLDT)**
Operational Availability Handbook
OPNAVINST 3000.12A

At the box level we find insight for the hardware/software/reliability designers and engineers

A_m, A_o, Mission A_{om}, Comparisons

- **Am calculation for MCM mission, A_m =17/24 = 0.71**

Mission Package	Total # ships	Ship Am	# Ships Available	Deploy Duration (months)	Duration MP Embarked (months)	Total # MP	MP# Operating	MP# Maint	MP# RFI	MP Am
MCM	55	0.64	35	18	9	24	14	4	3	0.7

- **A_o = Classic Serial-Parallel String Solution**
  - **Yields System A_o = 0.95**
- **Mission A_{om} = 0.75 (average for CONOPS A)**
  - **Mission Availability avg. (Aom) = 19Days/(35-9)Days = 0.75**

Mission A_{om} provides operational assessment needed to cope, plan and improve critical elements in order to support demanding performance and operationally sustainable SoS

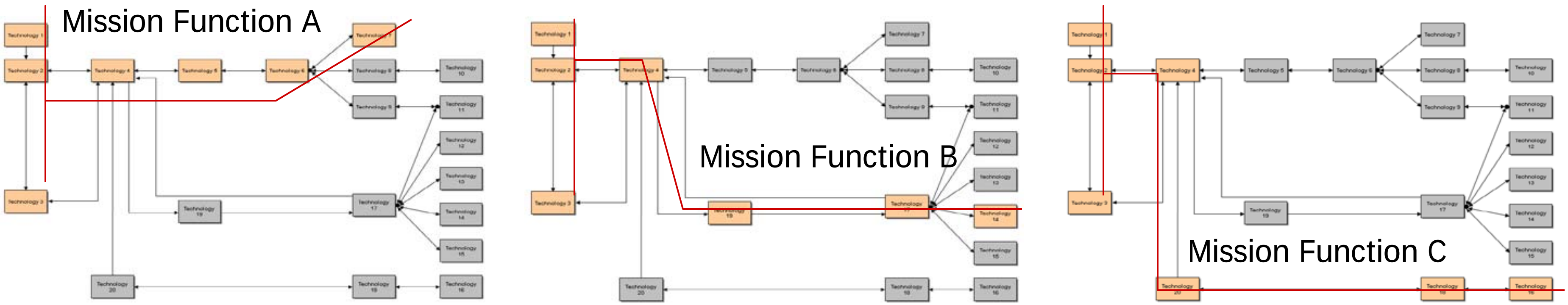
Mission Operational Availability (A_{om})

- Determining the optimum value for Mission Operational Availability requires a comprehensive analysis of the system and its planned use as identified in the CONOPS, including the planned operating environment, operating tempo, reliability alternatives, maintenance approaches, and supply chain solutions.
- Defining the SoS that will contribute to the mission will vary the Aom
  - Statistical combination of CONOPS and a blending the contributions of the equipment will identify the critical components and provide insight into which require shorter MTTR and MLD and higher MTBF

$$A_{om} = \text{System operational/Time Allocated for Mission}$$

Through mission string analysis we gain mission operational performance and sustainment insight linked to CONOPS

Mission Operational Availability “String” Analysis*



- Operational strings were analyzed to identify the components required to execute independent mission functions of the system
- An assessment of the string to achieve a Mission A_{om} contribution is made
- Common components (nodes) which form a critical function in more than one mission function are identified, operational time is calculated for each mission it touches over the deployment cycle
- Allocation of the Mission A_{om} forms an A_o requirement at the component (LRU) level

Complex systems often offer numerous options for conducting operations, but critical and commonly used/shared components must be available

* Notional Data Applied

MCM Mission String Analysis (CONOPS A Deployment)*

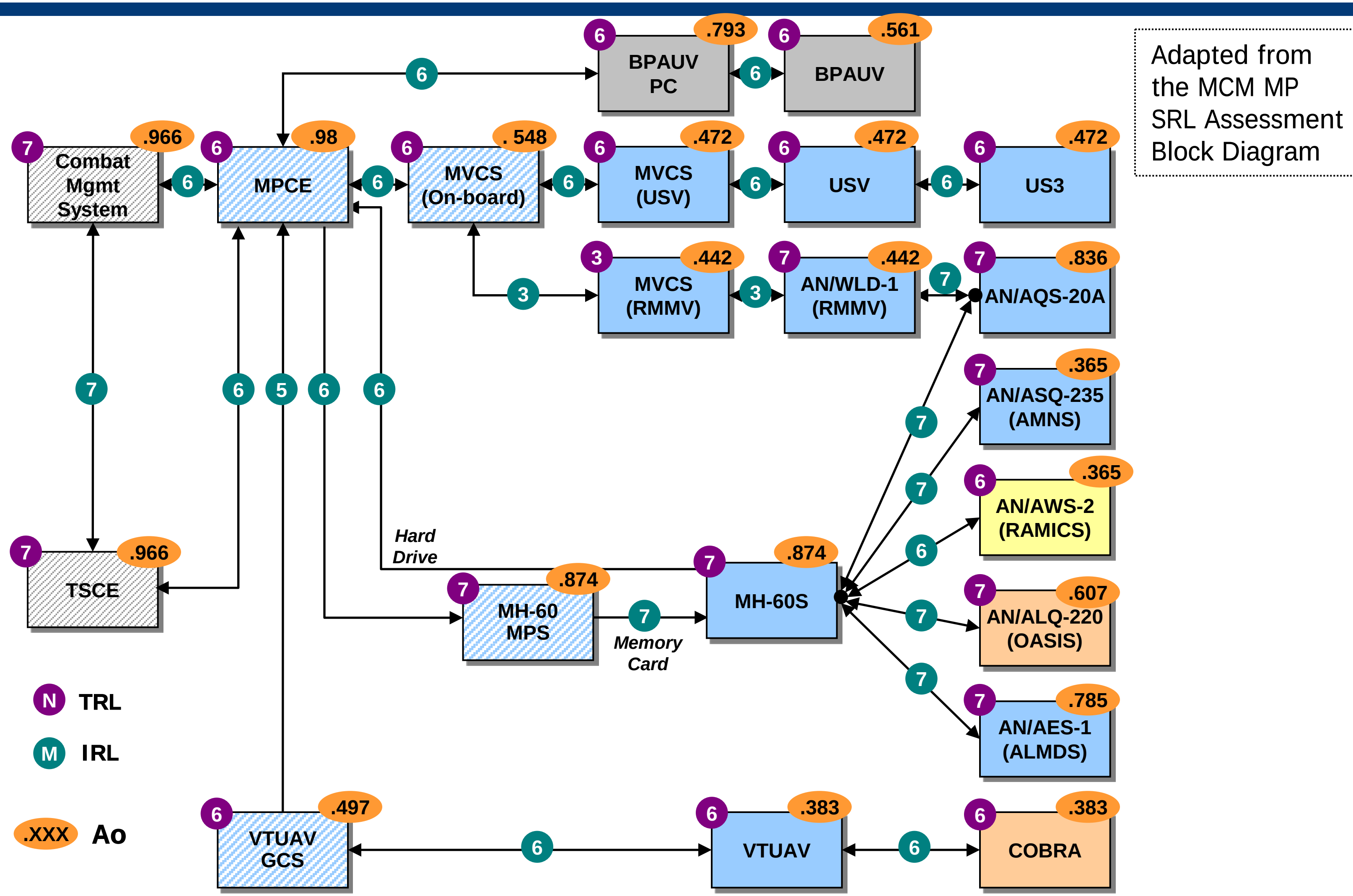
*** Notional Data Applied** Mission	Hunt Bottom & Volume Mines Deep Water to VSW		Hunt Near Surface & Floating Mines	Neutralize Bottom & Bottom Mines	Neutralize Near-SurfaceFloating Mines	Sweeping Mines		Detect Beach Zone Minefields	Clandestine Battlespace Preparation	Hunt Mines in VSW	Hunt Mines in SZ	Neutralize Mines in VSW	Neutralize Mines in SZ	Post data Analysis
Alternative CONOPS	Prime	BU				Prime	BU							
CMS (Includes Ship Up & Capable)	X	X	X	X	X	X	X	X	X	X	X	X	X	
TSCE	X	X	X	X	X	X	X	X	X	X	X	X	X	
MPCE	X	X	X	X	X	X	X		X					X
MVCS on board	X													
VTUAV GCS								X						
VTUAV								X						
COBRA								X						
MH-60		X	X	X	X		X			X	X	X	X	
MH-60 MPS		X	X	X	X		X			X	X	X	X	
AN/AES-1 (ALMDS)			X											X
AN/ALQ-220 (OASIS)							X							
AN/AWS-2 (RAMICS)					X									
AN/ASQ-235 (AMNS)				X										
AN/AQS-20A	X	X												X
AN/WLD-1 (RMMV)	X													
MVCS (on RMMV)	X													
US3						X								
USV						X								
MVCS (USV)						X								
BPAUV									X					
BPAUV PC									X					X
Mission Time* (example values, real values are classified)	20.93	40.00	35.00	12.00	12.00	25.00	50.00	14.00	40.00	X	X	X	X	70.00
Ship Deployment duration	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Explosive Ordnance Disposal (EOD) or Naval Special Clearance Team (NSCT) not provided by MP										X	X	X	X	

Mission Availability avg. (A_{om}) = 19Days/26Days = 0.75

Modular Diversity of the MCM suite enables options to mission execution

A_{om} is calculated as average of min/max mission operational

SoS (CONOPS A Deployment)*: MCM Mission Architecture Availability Allocation of A_o from A_{om}



Extrapolate A_{om}=0.75 from 26 day to 18 month DD yields system A_o=0.95

* Notional Data Applied

Improving Modularity Benefits Realized Through

- Developing RMA performance expectations for these systems, based on mission analysis (completion time) and type of systems employed
- Using RBD's as a method for helping to pick technology insertion by looking at the impact across a mission area.
  - Allows resource focus on changes that increase number of mission systems or availability of the systems (which means better reliability, better maintainability, lower LDT). Increase number of mission systems or availability of the systems (which infers higher reliability, better maintainability, lower LDT).
- Designs should have as much BIT as possible, maybe even LAN based debug capabilities, (minimize handling to test RFU).
- Approaches to automatically verify interconnects should be used.
- Specifications should consider reparability in the modular sense, easy to find - quick to replace.
- If Crew size limitations are dictated, operations and maintenance approach should be simplified and standardized
- Incorporating prognostics technology which provides early prediction of expected failures via monitoring key component parameters and failure prediction algorithms (lower LDT)
- Alternative test and repair concepts; e.g. MSC support ship (lower LDT).

The Modular SoS Paradigm Summary

For a SoS Mission Availability Requires Continuous Risk Mitigation

- For SoS Allocate A_o based on Mission Operational Need and analysis, established MTBF may not meet the requirements
  - Identify the mission strings
  - ID Critical system nodes and connectivity points
  - Allocate Availability Goals
  - Define CONOPS alternatives that can achieve the mission timeline
  - Plan Availability Evolution (Technology Insertion or Obsolescence Opportunities)
  - Include any safety issues that could also drive A_o
- Balance modularity with fixed systems
  - Understand the development status of the systems
    - Weight new systems with SRL status
  - Collect data and project expectations against allocations
  - Harden the fixed systems but balance with cost benefit analysis
- Trade reliability improvement options with Program Cost and include RMA in the system roadmap to evolve A_o over the program LC
  - MTBF - design improvement, proper handling,
  - MTTR - modular construction, automated test equipment, Online MM,
  - MLDT - just-in-time spares, built in redundancy, prognostics