Achieving MBSE Benefits amidst Multiple Government Program Office System of System Challenges

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LCS Mission Modules Systems Engineering & Integration

Agenda/Objective

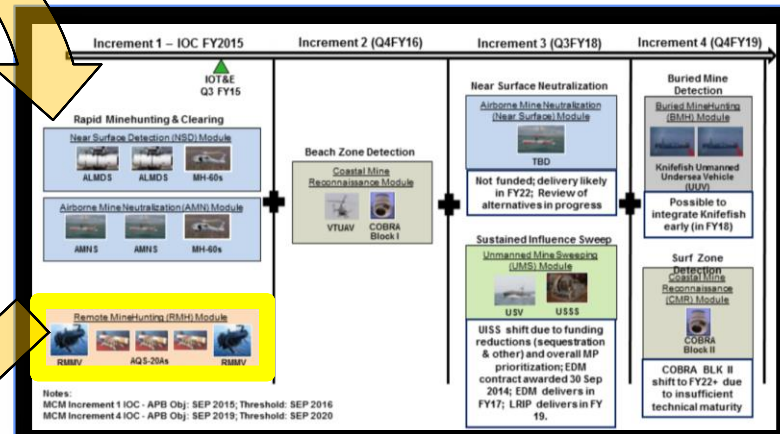
- LCS Mission Module Challenges
- Submarine and LCS synergy
- Come as you are benefit/challenge
- LCS Model based SoS SE&I approach summary
- Interface model SoS analysis schema
- Data concordance analysis capabilities
- Model benefits
- Conclusion

LCS Mission Modules Challenge:
Sheer Complexity

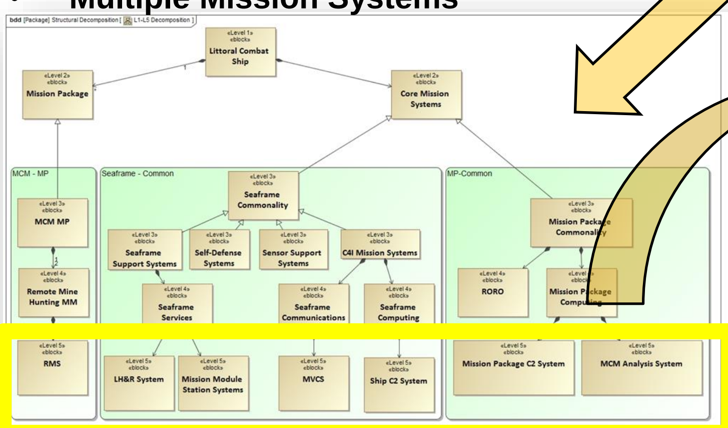
LCS Mission Modules
Systems Engineering & Integration

LCS Mission Capabilities
- **Multiple Mission Packages**

Mine Countermeasures Mission Package
- **Multiple Mission Modules & Multiple Increments**



Remote Minehunting Mission Module
- **Multiple Mission Systems**



RMH Mission Systems
- **Multiple Development Organizations**

System	PM	OEM
RMS	PMS 420	LM
Ships LH&R	PMS 501	LM (FRE), GD (IND)
Mission Bay Stations	PMS 501	LM (FRE), GD (IND)
MVCS	PMS 420	NSWC-PCD
Ship C2	IWS-8	LM (FRE), GD (IND)
Mission Package C2	PMS 420	NSWC-PCD
MCM Analysis	PMS 495	SAIC, NSWC-PCD

LCS mission modules have both system- and organizational-complexity which results in formidable integration challenges

LCS MP Model Based SoS SE Analysis

History & Submarine Reuse

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Systems Engineering & Integration

2000 2005 2010 2015

Submarine SoS SE & I (SWFTS/NPES SE&I) : Thought Leader, Steve Lose

- **Big System**: Multiple PEOs and program offices, 4 ship classes, 4 Million lines of SW code, 65 cabinets
- **Complex interfaces:** 30 subsystems, 2800 interface requirements, 25 OEMs
- **Fast Update Pace:** Yearly alternating capability / technology updates

State of practice

Point to Point IRS Documents → **Centrally managed interface requirements** → **MDA Prototype** → **Model based Systems Engineering (MBSE)** . . .

Reuse

SoS MBSE Methodology

LCS Mission Module SoS SE & I, Thought Leader, George Saroch

- **Big System:** 12 Mission modules, 2 class variants
- **Complex interfaces**: 25 subsystems in RMH MM alone
- **Fast Update Pace:** 4 planned increments / RTI updates

Come as you are → **Remote Minehunting MBSE SoS Pilot**

Gaps

MP Common interface Products

MVCS | MPOE | MPCE | MP ICD

SoS Tasking Details

PMS 420 sponsored SoS LCS Interface Model Pilot

- Interface MBSE model development – Significant Submarine Reuse
- RMH Mission Module Interface Requirements Generation
- Multiple RMH MBSE-enabled issues identified

Interface Model

RMH Mission Module SE Analysis

Significant Submarine Methodology and Tool benefits to LCS

LCS Mission Modules Challenge:
Come-As-You-Are Reuse

"Come as you are" attribute	Result
Capability is already developed and tested on another platform, theoretically being reused for "Pennies on the dollar"	Generally, core capability IS available on the cheap, but integration with the platform and adjacent systems quickly eats into the savings
Interface requirements are individually developed and tested by each "come-as-you-are" mission system developer	Key interface functions are designed out of sync and while initial individual system development costs are less, SoS integration costs can be very high
Mission level operational specifications are not reflected coherently in the interface requirements	Each system has gaps and inconsistent requirements relative to the mission level specs, and as a result, mission level performance is unpredictable and KPPs are often not met

The "come-as-you-are" (low-cost-capability) benefit does not have to come at a high platform integration cost → _A better approach is needed_

SoS MBSE Integration Methodology

MBSE Interface Model Architecture / Process

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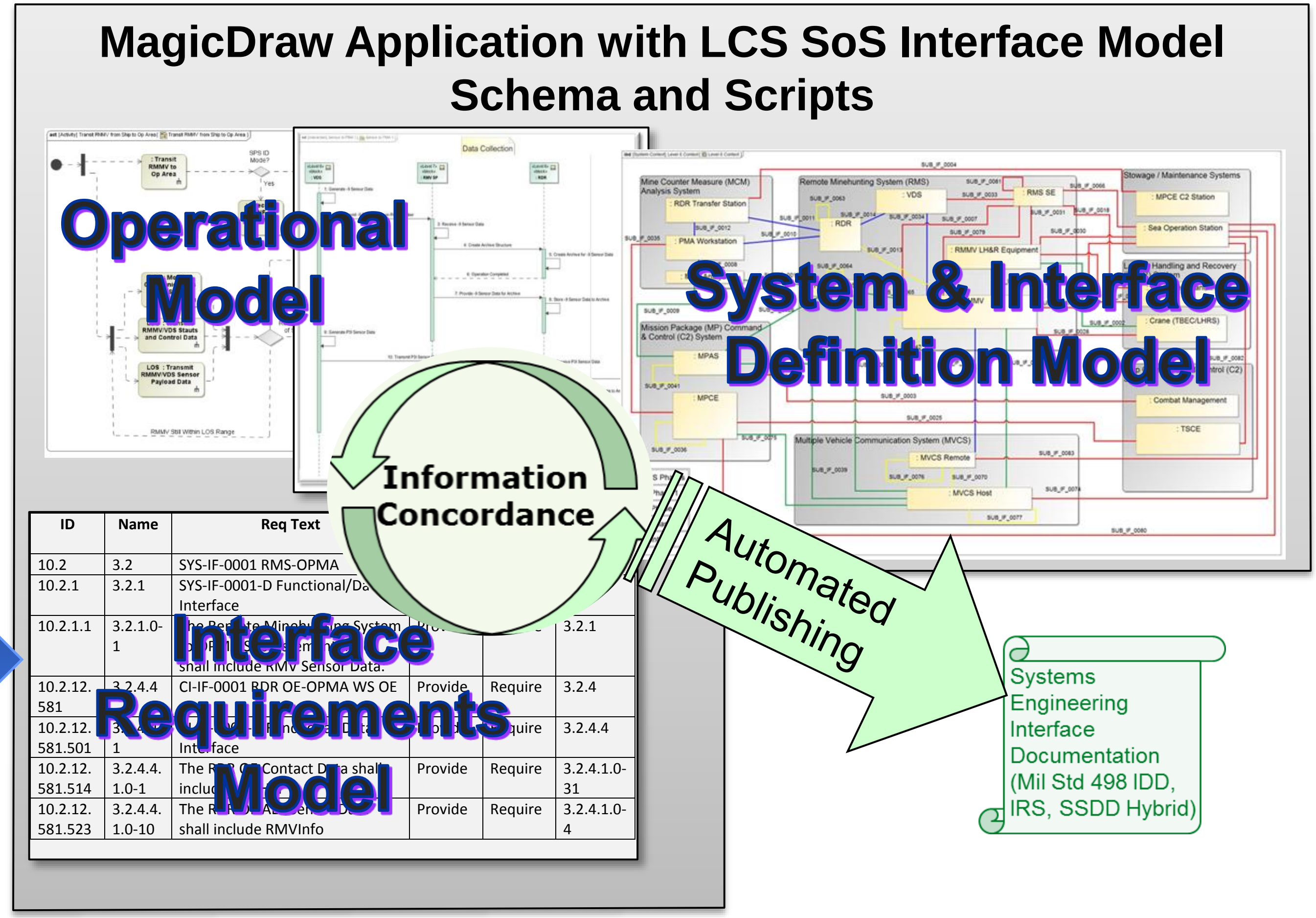
Interface Working Group

Mission System Stakeholders

System Engineer / Modeler

Mission System Stakeholders



- Stakeholder developed requirements
- Structured entry into model
- Jointly reviewed model products

SoS MBSE Integration Methodology starts with a collaborative framework to develop solid interface requirements and ends with SoS thinking amongst all participants

PMS 420 MBSE Landscape

SE Hierarchy / Engineering Model Overview

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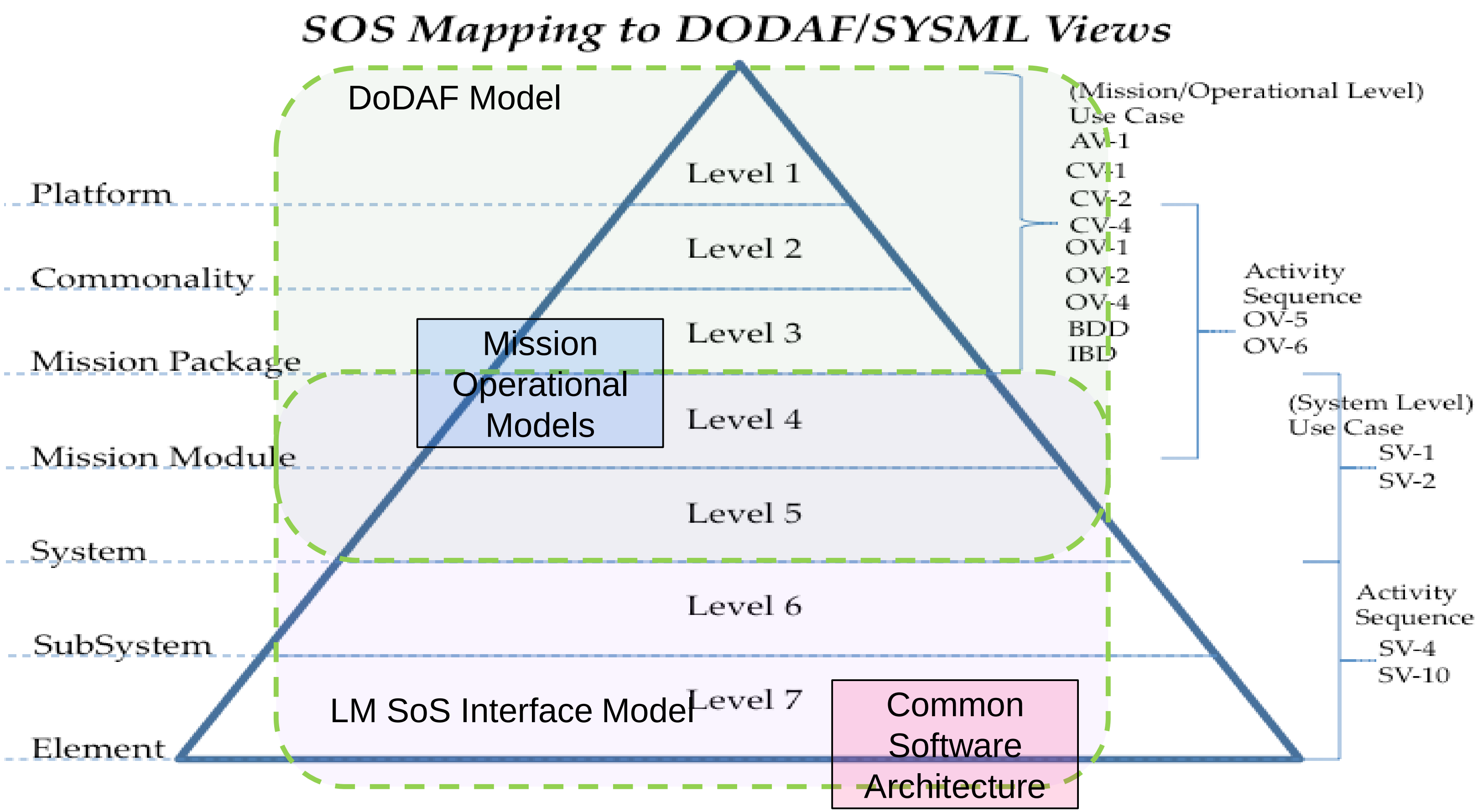

SoS MBSE Interface Model manages the complex system information in a structured manner

LCS SoS Interface Model

Multiple Level (Nested) Interface Definitions

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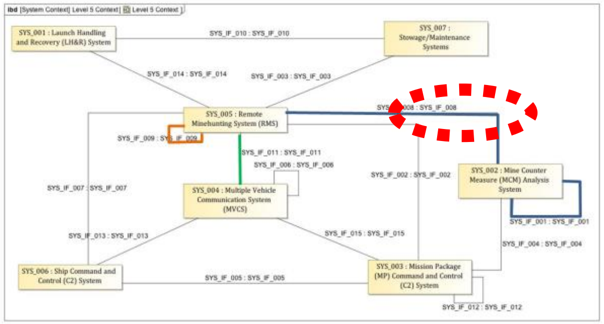
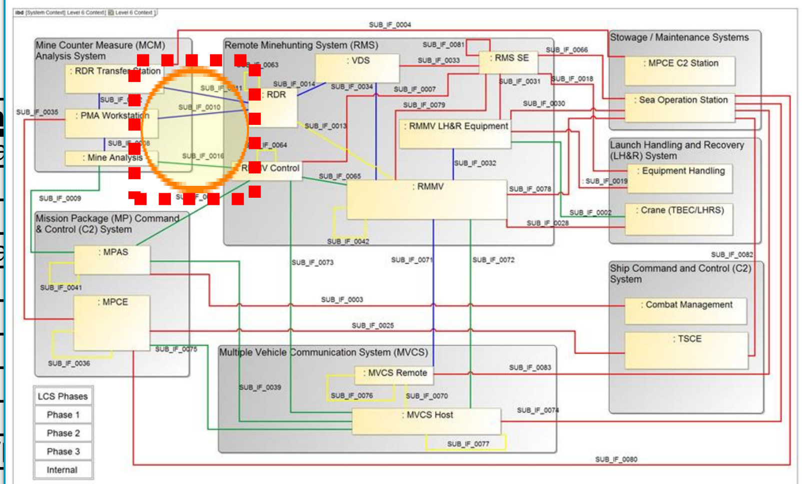
Level 5 (System)



		nd Poin
		ICM Ana
		MS
		MS
		ICM Ana
		IP C2
		MVCS
SYS_IF_007	Ship C2	RMS
SYS_IF_008	MCM Analysis	RMS
SYS_IF_009	RMS	RMS
SYS_IF_010	LH&R	Stowage/
SYS_IF_011	RMS	MVCS
SYS_IF_012	MP C2	MP C2
SYS_IF_013	MVCS	Ship C2
SYS_IF_014	LH&R	RMS
SYS_IF_015	MVCS	MP C2

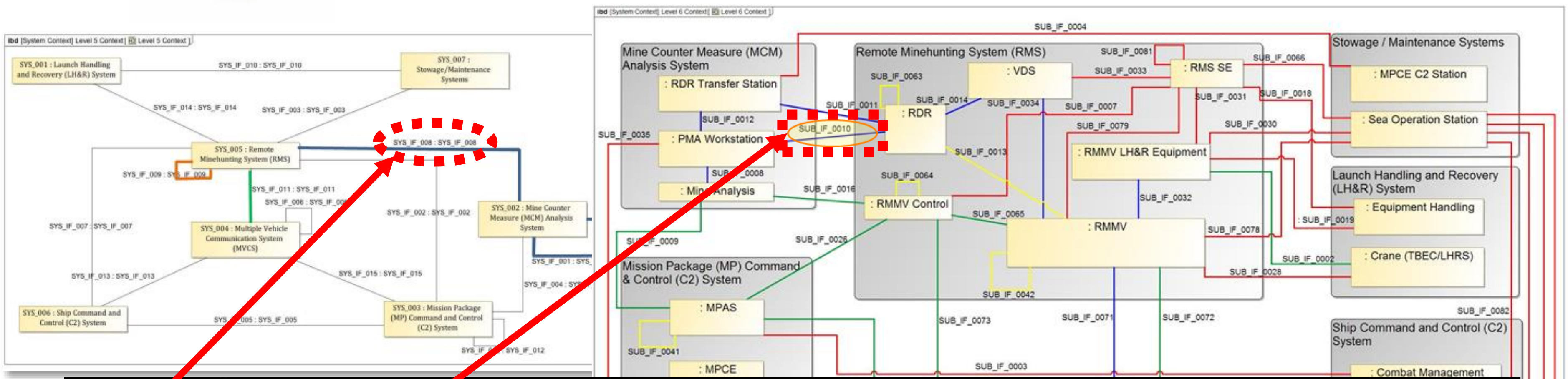
Level 6 (Subsystem)



		End Point #2
		MPCE
		RMMV LH&R Equipment Interface
		Combat Management
		MPAS
		Combat Management
		Off-Board Communications
		RMMV Interface
		PMA Workstation
		MPAS
		PMA Workstation Subsystem
		RDR Transfer Station Subsystem
		RDR Transfer Station Subsystem
		RDR Subsystem
		VDS Subsystem
		RMMV Control
		Off-Board Communications
		MVCS Host Infrastructure
		MVCS Remote Infrastructure Subsystem
		TSCE
		RMMV Control
		MPAS
		RMMV Interface
		Mission Bay
		RMMV LH&R Equipment Interface
	ace	RMS SE
		RMMV LH&R Equipment Interface
		VDS
		VDS Subsystem
		MPCE
		MPCE
SUB_IF_0037	RDR Transfer Station	MPCE
SUB_IF_0039	MPAS	MVCS Host Infrastructure
SUB_IF_0041	MPAS	MPAS
SUB_IF_0042	RMMV Interface	RMMV Interface
SUB_IF_0044	Cabinets	TSCE
SUB_IF_0049	PMA Workstation	MPAS
SUB_IF_0050	MVCS Host Radio	MVCS Host Infrastructure
SUB_IF_0051	MVCS Host Antenna	MVCS Host Radio
SUB_IF_0052	MVCS Remote Radio	MVCS Remote Infrastructure
SUB_IF_0053	MVCS Remote Antenna	MVCS Remote Radio
SUB_IF_0054	MVCS Host Antenna	MVCS Remote Antenna
SUB_IF_0055	MVCS Remote Radio Subsystem	RMMV Interface
SUB_IF_0056	Common Console	RMMV Control
SUB_IF_0057	MPCE	RMMV Control
SUB_IF_0058	MVCS Host Infrastructure	RMMV Control
SUB_IF_0060	TSCE	RMMV Interface
SUB_IF_0061	MVCS Host Radio	RMMV Interface
SUB_IF_0063	RDR Subsystem	RDR Subsystem
SUB_IF_0064	RMMV Control	RMMV Control
SUB_IF_0065	RMMV Interface	RMMV Control
SUB_IF_0066	Mission Bay	RMS SE
SUB_IF_0067	RMS SE	MPCE

Structured and Regimented Nesting of Architecture and Interface Decomposition

Synchronized Interface/Requirements Decomposition Example



ID	Requirement Text	Realized by	Used by
SYS 8.8	**The MCM Analysis to RMS System interface shall support the transfer of sensor data from a yy hour mission in zz minutes or less (threshold), x minutes or less (objective). (1.5)**	Mine Analysis System	RMS
SUB 10.5	The RDR to PMA Workstation interface shall support a minimum data transfer rate of1 Gbit/s (threshold), 10 Gbit/s (objective) for each storage media.	PMA Workstation	RDR
CI 1.6	*The PMA Workstation OE - RDR OE data transfer ports shall be implemented using the Gigabit Ethernet standard (threshold), or the 10 Gigabit Ethernet standard (objective).*	*PMA Workstation OE*	*RDR OE*

Model Schema synchronizes and structures the decomposition of architecture, interfaces, and Interface Requirements

LCS SoS MBSE End to End Analysis

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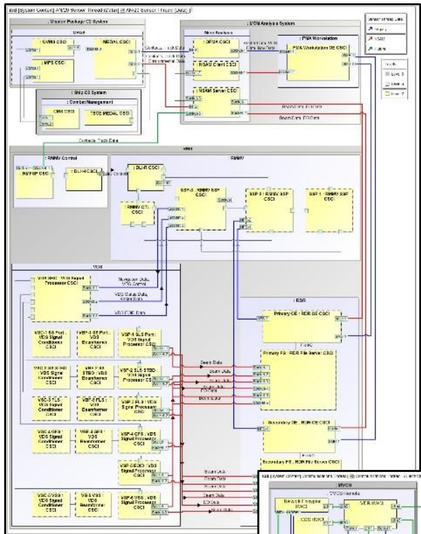
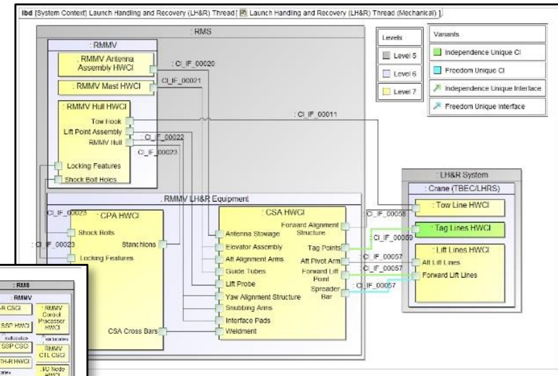
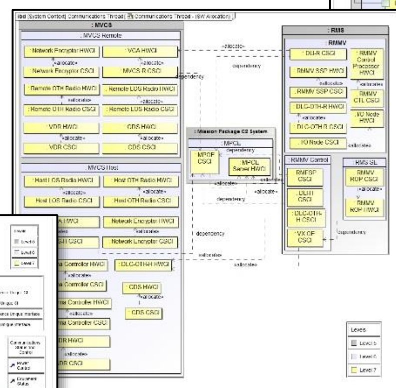
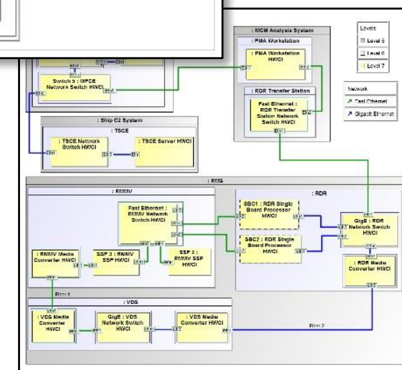


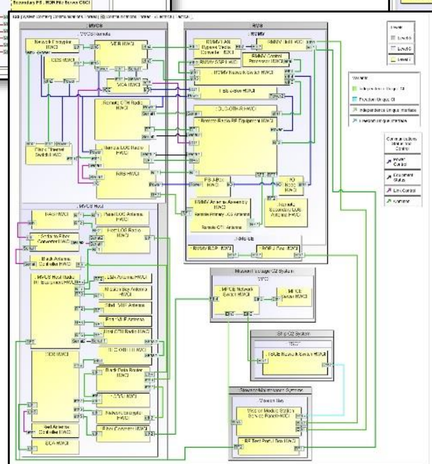
Data Thread View
- CSCI only
- End to End data flow
- Process to process message Flow



Mechanical Thread View
- HWCI Only
- Touch Points
- Complex mechanical Interactions







Electrical Thread View
- HWCI Only
- ANSI and custom interfaces

Software Allocation View
- CSCI Only
- SW Hosting
- Basis to manage OS Environment

Network View
- HWCI Only
- Network Topology
- Network standards
- Throughput “choke point” analysis

Interface model provides an end-to-end viewpoint in the data, electrical and mechanical domains to engage the appropriate SME discipline.

MP ICD Content:
Operational Analysis Artifacts

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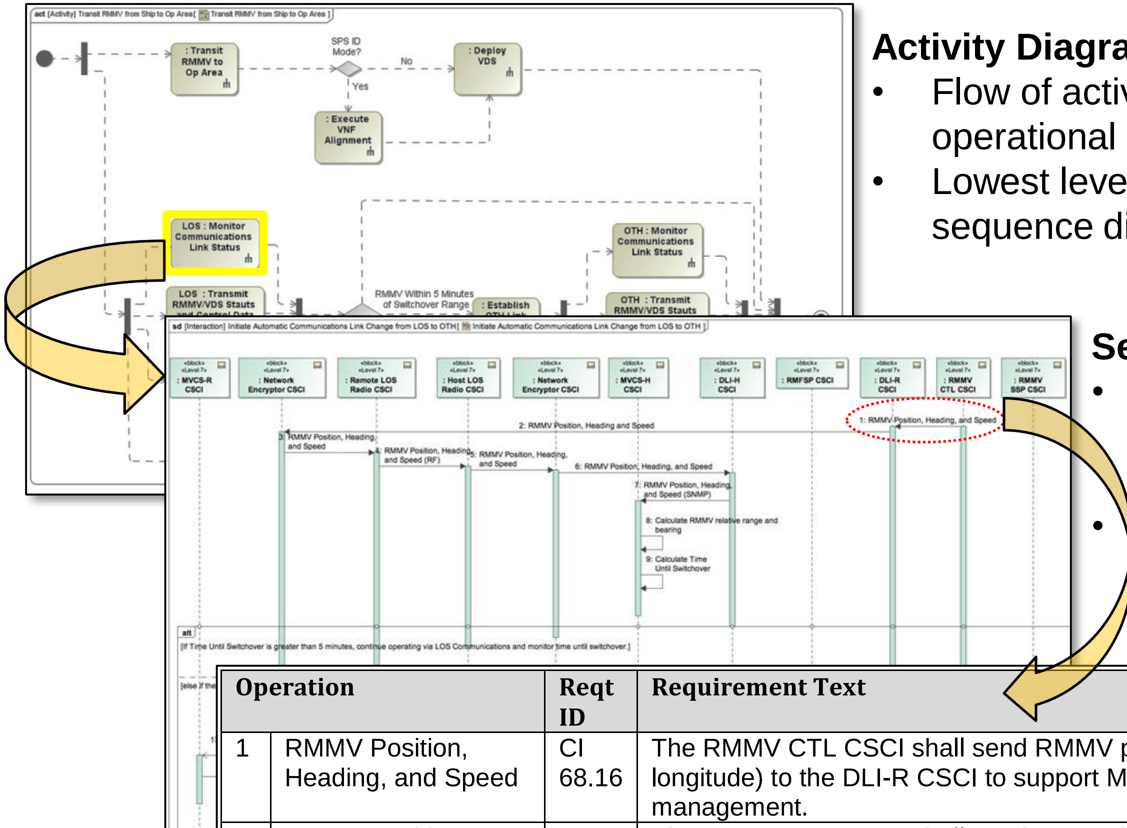

Activity Diagrams

- Flow of activities for decomposing operational information
- Lowest level activity becomes sequence diagram

Sequence Diagrams

- Provides means to ensure operations between subsystems are covered by requirements
- Provides baseline for additional operational analysis

	Operation	Reqt ID	Requirement Text
1	RMMV Position, Heading, and Speed	CI 68.16	The RMMV CTL CSCI shall send RMMV position (latitu longitude) to the DLI-R CSCI to support MVCS automat management.
1	RMMV Position, Heading, and Speed	CI 68.17	The RMMV CTL CSCI shall send RMMV heading to the CSCI to support MVCS automatic link management.
1	RMMV Position, Heading, and Speed	CI 68.18	The RMMV CTL CSCI shall send RMMV speed to the D CSCI to support MVCS automatic link management.

Linked Interface Requirements

- Thread function integrity in requirements baseline
- Objective test checklist

SoS MBSE Interface model provides a solid foundation to ensure operational architecture to interface requirements integrity

System of Systems
Thread Integration Maturity

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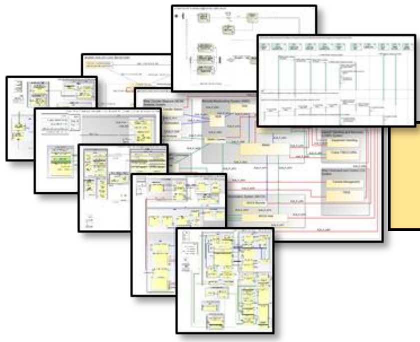
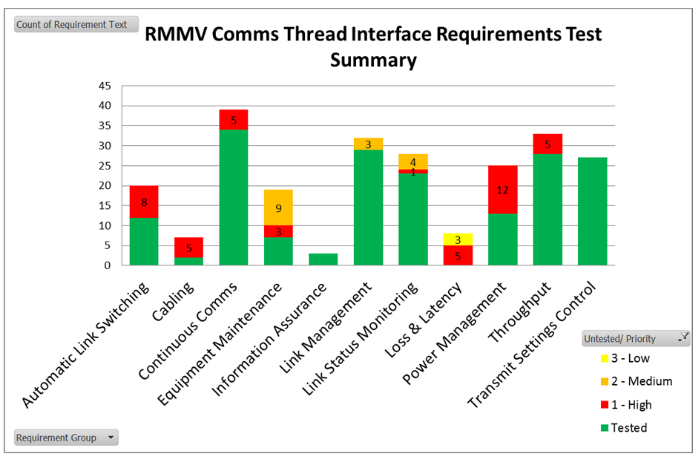
Operational/System Architecture and Interface Requirements



Requirement Text	Realized By	Used By	Thread Function	Ver Method	Pri	LM Test	NSWC Test	Planned Test
The RMMV Control Subsystem and MVCS Host Subsystem shall exchange vehicle navigation data to support MVCS automatic link management.	RMMV Control	MVCS Host	Automatic Link Switching	Test	1 - High	No	No	None
Once the RMMV power has been turned off, the RMMV Subsystem shall alert the MVCS Remote Subsystem and provide [redacted] seconds for a graceful shutdown of MVCS Remote processing equipment.	RMMV	MVCS Remote	Power Management	Test	2 - Med	Yes	No	Yes
The RMMV/MVCS Host subsystem interface shall provide a minimum data link throughput of [redacted] Mbits/second per vehicle for transmission of data from the RMMV to the LCS in LOS communications mode.	RMMV	MVCS Host	Throughput	Test	1 - High	No	Yes	Yes

Enhanced Interface RVM

- Interface requirements with Verification method and Priority
- Test conduct survey from constituent subsystems
- Mission Module thread functional test case organization



Legend:

Tested Requirements

Tested by any of following:
- RMS/LM Val/Ver testing
- MVCS/PCD Throughput testing
- MVCS/PCD SRS testing
- RMS/LM Integration testing

Untested Requirements

High: Requirements failure results in Pri 1 or 2 SPR

Med: Requirements failure results in Pri 3 SPR

Low: Requirements failure results in pri 4 or 5 SPR

SoS Thread Integration Maturity Model

- Mission Module thread functional test case organized
- Compiled survey of prioritized interface requirements test voids

Structured SoS Thread Integration Maturity model provides a means to objectively and thoroughly plan platform integration

MBSE Thread Integration Maturity Support

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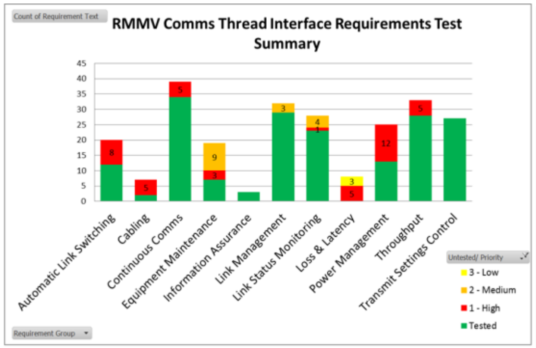
Automated *Thread level* Interface-RVM status



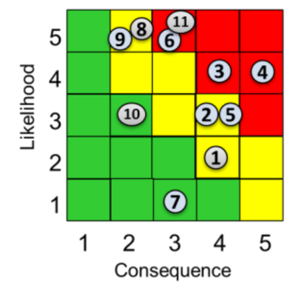
Legend:

Tested Requirements

- **Tested** by any of following:
  - RMS/LM Val/Ver testing
  - MVCS/PCD Throughput testing
  - MVCS/PCD SRS testing
  - RMS/LM Integration testing

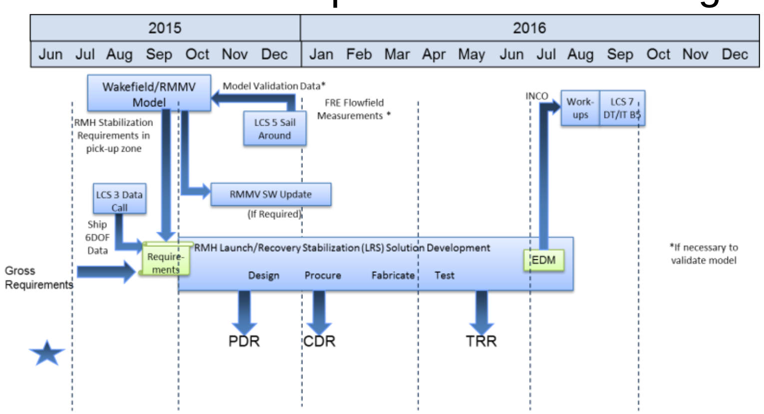
Untested Requirements

- **High:** Requirements failure results in Pri 1 or 2 SPR
- **Med:** Requirements failure results in Pri 3 SPR
- **Low:** Requirements failure results in pri 4 or 5 SPR



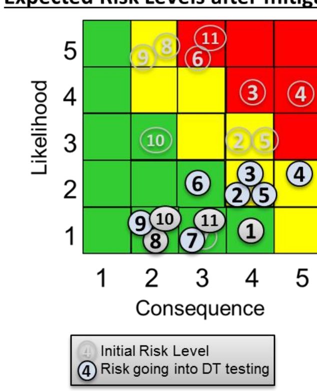
Thread level
Thread
Integration
Maturity

PRE-PLATFORM per thread Risk Mitigation



Predictable per thread Platform Performance

Expected Risk Levels after mitigation



MBSE SoS Thread Integration Maturity → Predictable Platform Performance

LCS SoS MBSE Integration Methodology
RMH Benefit / ROI

SoS MBSE Activity	Approach	Benefit / Result
1. Maximize RMH Q20 Sensor Thread Performance	Defined the RMH sensor thread architecture, end-to-end performance requirements for the Q20-B sensor information movement/processing.	• Technical: Established initial NSAM performance requirements for Q20B sensor • Technical: Developed RMH sensor thread end-to-end architecture to maximize TPM adherance
2. Define RMH MM Orphaned Hardware	Developed PMS 420/403 "Orphan MOA" which adjudicated technical (spec) and programmatic ($$) ownership with 420/501/503/495 for 41 configuration items	• Cost/Schedule: Avoided cost and schedule churn 41 tactically required configuration items • Defined full set of capability required to transition the RMH MM to production
3. Mitigate RMH Comms (RMS / MVCS) Interface Risk	Generated MVCS/RMS interface requirements verification matrix (I-RVM) identifying 62 high-priority interface requirements which had not been adequately tested.	• Cost/Schedule: Drove RMS/MVCS integration problems to be found and fixed much earlier in the lifecycle • Risk Mgt: Provided objective information manage IOT&E integration risk
4. Mitigated RMH on FRE interface risk	Developed performance-requirements based approach to buy-down RMH on FRE risk well ahead of on-platform timeframe	• Risk Mgt: Mitigation plans developed for 4 high priority and 5 medium priority MCM on FRE risks • Risk Mgt: Options developed for wake flow-field analysis to benefit multiple UxV L&R • Risk Mgt: Options developed for seaframe information exchange risk

Model and Methodology investment recouped .. And counting

SoS MBSE ROI Foundation

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PARM #1 / System #1

Spec Development → System(s) Development → Individual Interface Testing → Install

Fix Cost[1] = 5x

PARM #2 / System #2

Spec Development → System(s) Development → Individual Interface Testing → Install

Fix Cost[1] = 5x

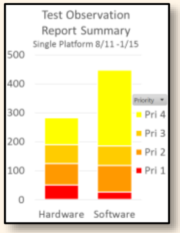
"Come-As-You-Are" Approach

- Interface Specs Generated by each PARM
- Very few interface problems solved early
- Most interface problems solved on-platform (8x)
- Cost, Schedule, Performance unpredictable

Platform / System Test

Fix Cost[1] = 20x

→ TORs / SPRs



Joint Interface Requirement Development → MBSE Interface RVM & Test → TORs / SPRs

Fix Cost[1] = 5x

SE&I IPT: Untested Interface Requirements Focus Areas

SE&I IPT: Interface Requirements Adjudication

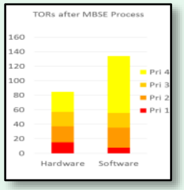
Systems Engineering Interface Documentation (Mil Std 498 IDD, IRS, SSDD Hybrid)

Fix Cost[1] = 1x

Platform / System Test

Fix Cost[1] = 20x

→ TORs / SPRs



SoS MBSE Integration Methodology

- IPT-generated Interface Requirements
- More Interface problems solved early
- More predictable platform tests
  - Fewer "new" problems
- Significant cost reduction
- Improved Schedule, Technical Performance

Note[1] : Source:NIST Planning report 02-3, The Economic Impacts of Inadequate Infrastructure for Software Testing, May 2002.
D. Galin, Software Quality Assurance: From Theory to Implementation, Pearson/Addison-Wesley (2004) B.W. Boehm, Software Engineering Economics, Prentice Hall (1981)

SoS MBSE Integration Methodology enables Rapid Capability Insertion

LCS SoS MBSE Integration Methodology

Conclusion / Takeaway

LCS Mission Modules
Systems Engineering & Integration

- Enables the “come-as-you-are” approach to be rapidly acquiring capability from other Navy programs
- Has been proven with the RMH MM pilot to avoid costs and manage risks at the mission module / platform integration level
- Scales to multiple mission modules and multiple platforms
- Enables all stakeholders to manage their own systems and their own role in mission module / platform integration to cohesively satisfy the LCS fleet and sponsor

The Glue for the LCS MP Engineering Enterprise