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Complex Product Family Modeling for Common Submarine Combat System MBSE

28 September 2010

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Agenda

- What are Complex Product Families (CPF) with High Variability?
- Systems Engineering for CPF: the Traditional Approach
- Model-Based Systems Engineering for the SWFTS Product Family
- Future Research

Product Families

Product Families

- Definition: A Product Family is a group of products derived from a common product platform.
  - Chrysler K-cars, Boeing 747
- Product Families are commonly developed across Lockheed Martin to tailor base product platforms to varying applications
  - Atlas V, F-35, Aegis
- Product Families also emerge through technology evolution
  - F-16, AN/UYQ-70, Atlas

Product Families Enable Effective Reuse of Engineering Investment

Complex Product Families (CPF) Combine

- Major Versions for Different Applications
  - Aegis for Cruisers, Destroyers, Frigates, Corvettes
  - F-35 Versions for Conventional Take-Off, STOVL, Naval Aircraft Carrier Operations
- Variants within Versions
  - Atlas V 401, 402, …, 552, 5H1, 5H2
- Multiple Generations/Baselines
  - Technical Refresh, Capability Enhancements
- Export Considerations

Product Families May Have Many Dimensions of Complexity

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Traditional Systems Engineering Approach to Product Families

Traditional Systems Engineering Approach

1. Document Initial Product Platform
2. Branch Documentation Package for Each Subsequent Family Member
3. Manually Maintain Correlation Between Document Tree Forks – Or Not
4. Manually Trace Bugs, Obsolete Components, etc. Between Family Members – Or Not

Maintaining Complex Product Families Is Labor Intensive and Error Prone

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Model Based Systems Engineering for SWFTS

Product Family Example: SWFTS
Submarine Warfare Federated Tactical System

- A Common Combat System Deployed Across Multiple Fleets
  - USN: Los Angeles (SSN 688), Ohio (SSGN 726), Seawolf (SSN 21), Virginia (SSN 774), Ohio Replacement (SSBN)
  - RAN: Collins (SSG 73)
- Federates Multiple Subsystems from Multiple Program Offices and Vendors
  - Sonar, ESM, Imaging, Tactical Control, Weapons Control, Communications, etc.
- SWFTS Manages Subsystem Interfaces and System I&T

SWFTS Reduces Maintenance and Training Costs while Maximizing Capabilities

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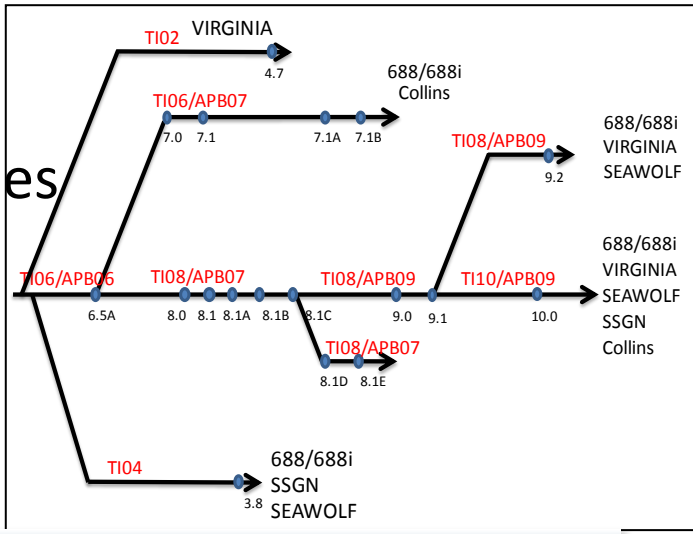
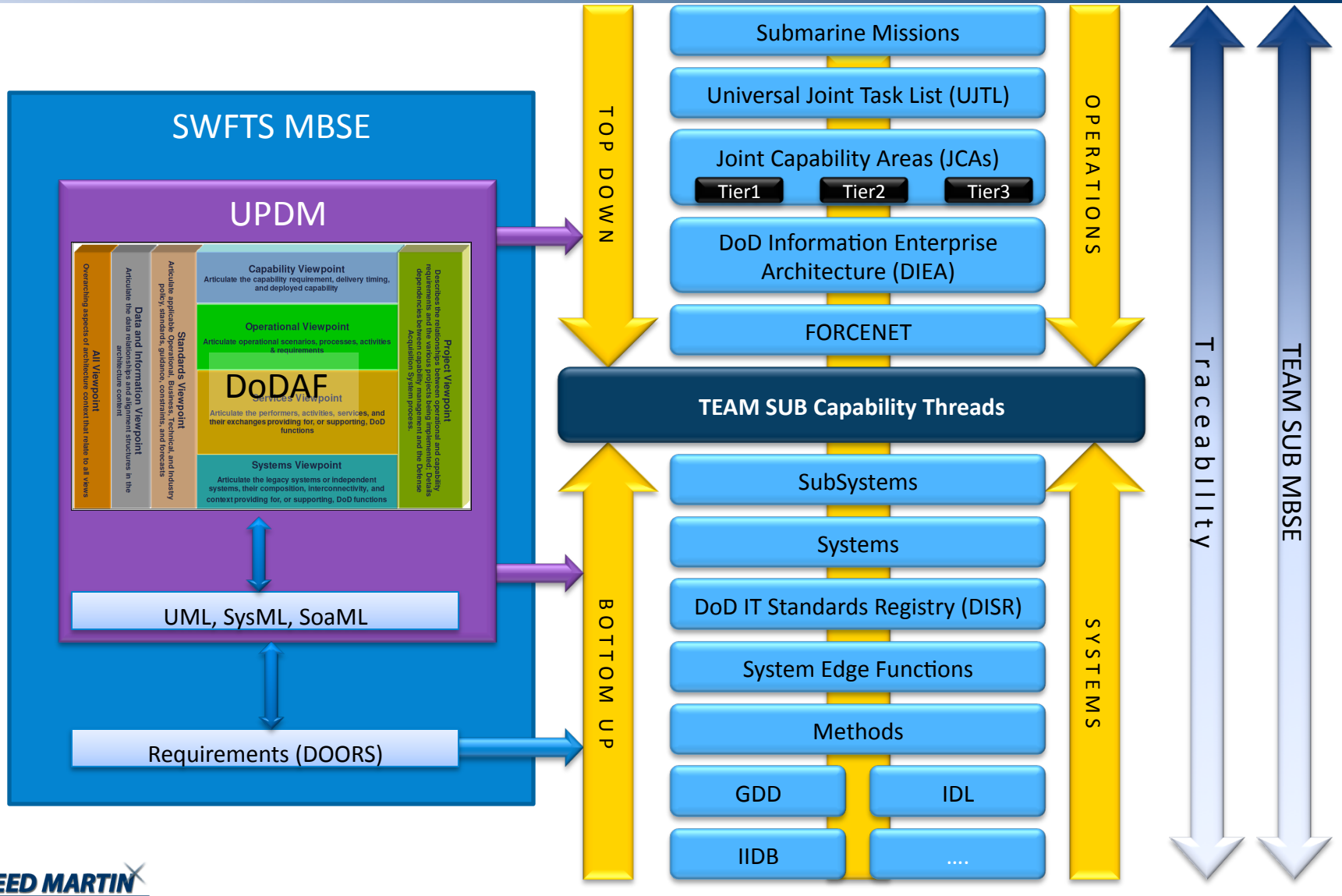
High Variability Between Product Family Members

- Each Class May Have Multiple Flights
  - Los Angeles Flights 1, 2, Improved
  - Ohio SSBN (Trident I, Trident II) and SSGN
  - Virginia Flights 1, 2, 3, 4, …
- Within Flights, Ships May Vary Significantly
  - SSN 23 is 100 feet longer than sister ships
  - TEMPALTs and SHIPALTs for New Sensors, Weapons, etc for At-Sea Testing or Special Operations are Common
- Multiple Deployed and/or Managed Baselines within Flight
  - Annual SWFTS baselines (denoted TInnAPBmm)
  - Subsystems Updated on Varying Cycles
  - Individual Boats Updated on ~4 Year Cycle



Over 21 Dimensions of Variation Must Be Managed in SWFTS

Modeling Approach



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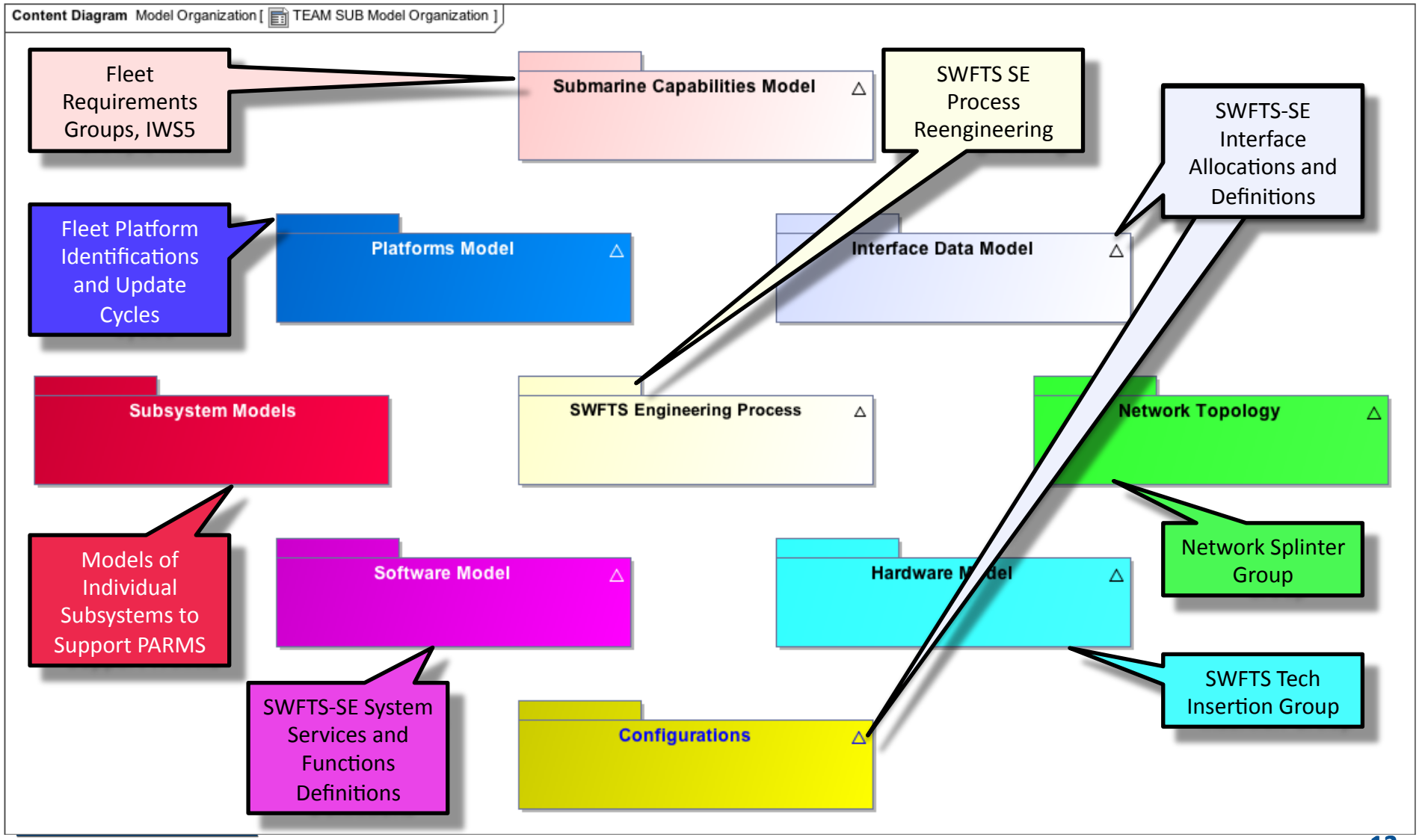
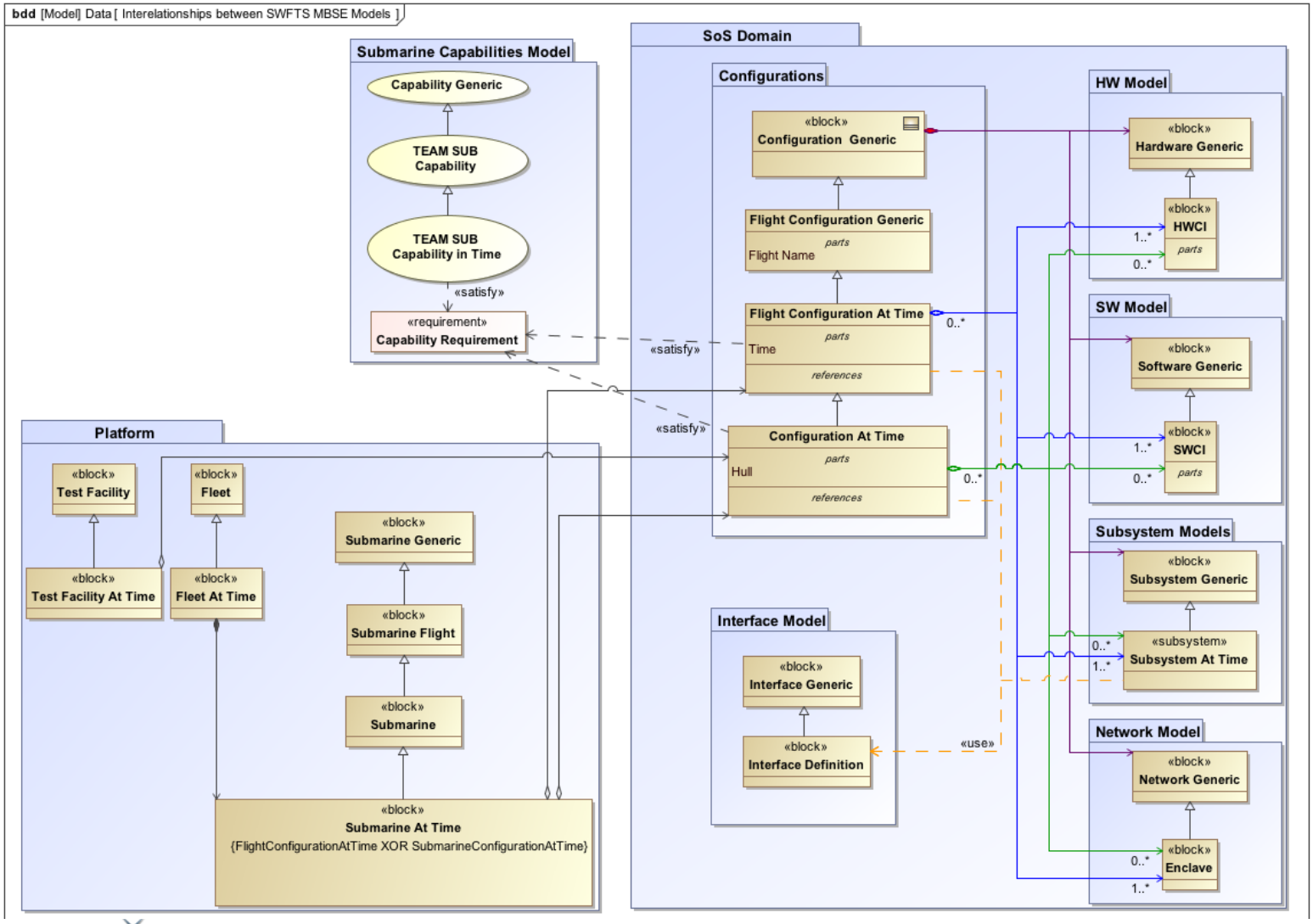
SWFTS Engineering Data Model

- Common Submarine Combat System is Modeled in UML, SysML, and SoaML using UPDM
  - XML Representation Stored in Database
- Supplemental Information Also Stored in Database and in Associated Document Repositories Linked Into Database
- Modeling Tool Profiles and Web Services Built Around Model Repository
  - Enable Engineers in Various IPTs to Access Models Through Task-Specific Interfaces (Spreadsheets, Database Queries, etc)
  - Produce Required Systems Engineering Artifacts as Reports from Model Repository

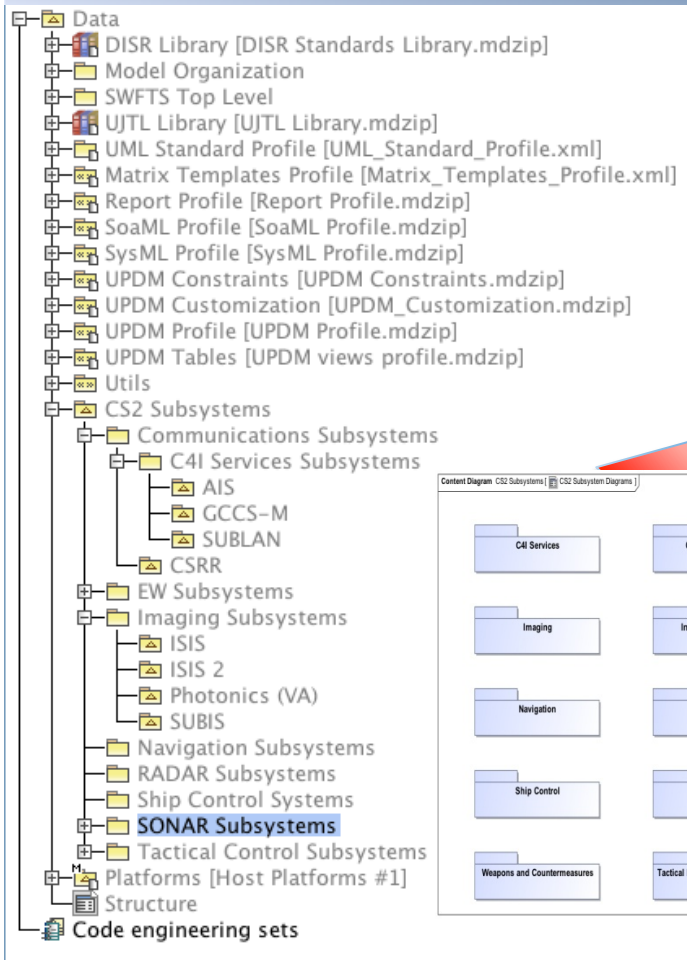
Top Level SWFTS Model Organization

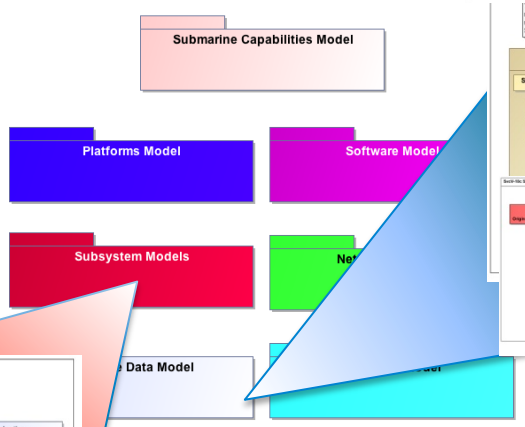


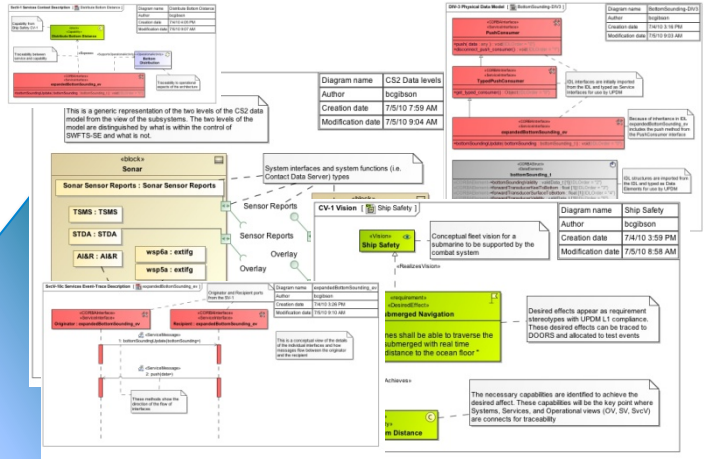
SWFTS' Multiple Interdependent Models

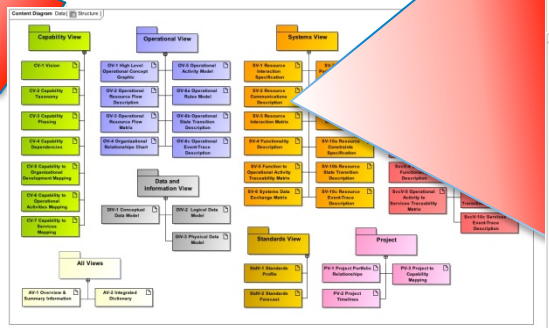


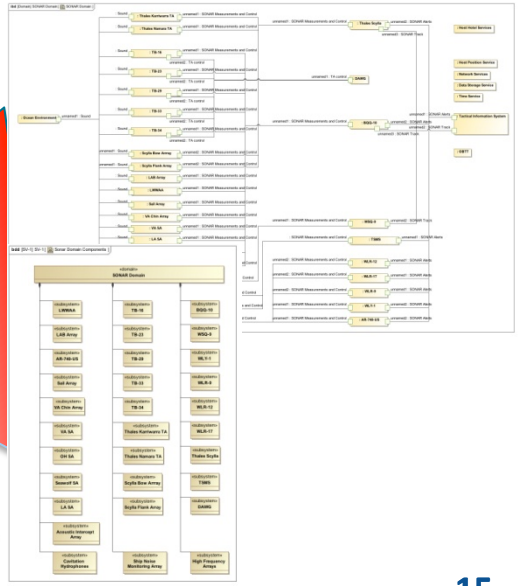
Hierarchy of Models Supporting TEAM SUBMARINE Engineering











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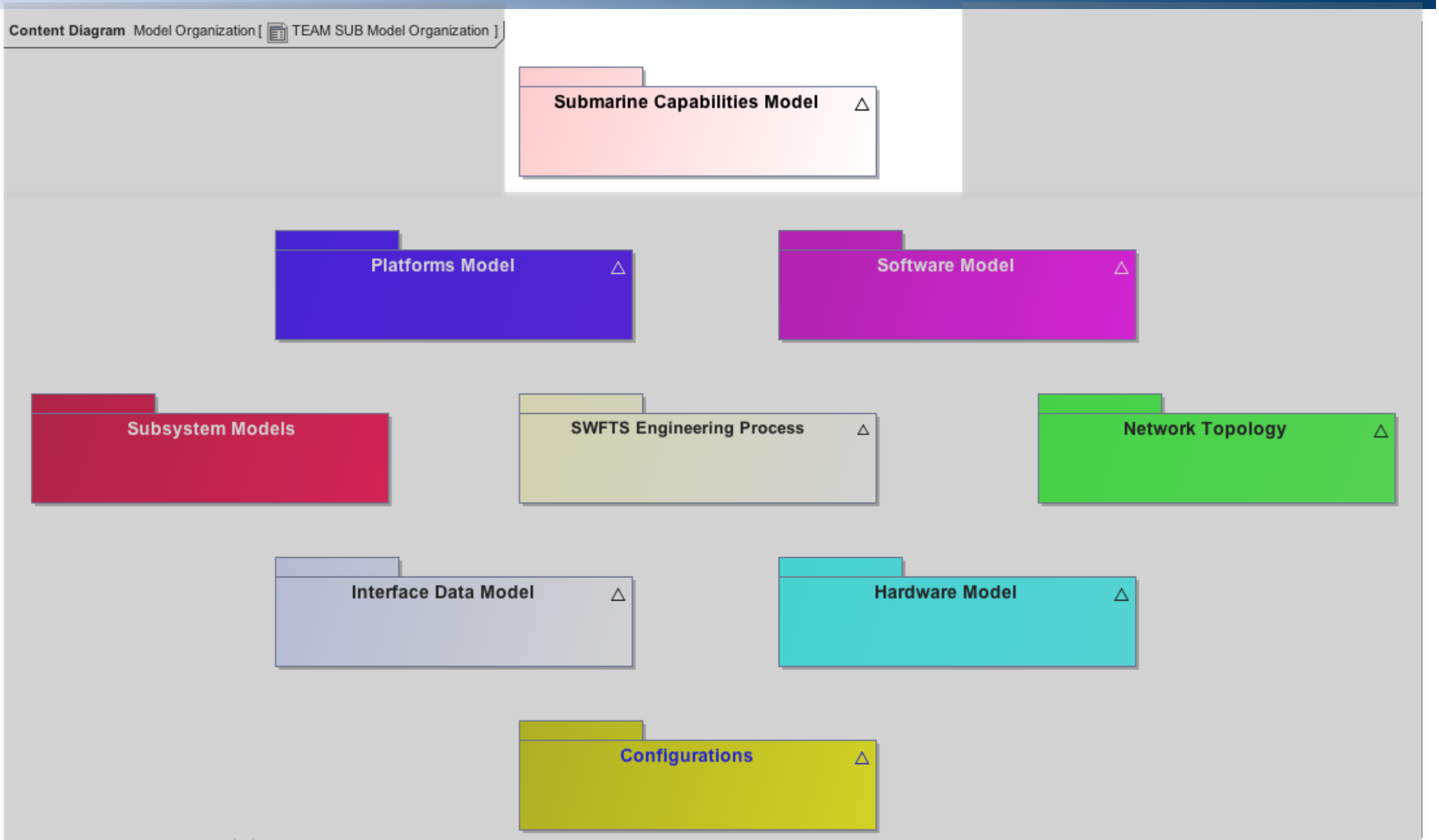
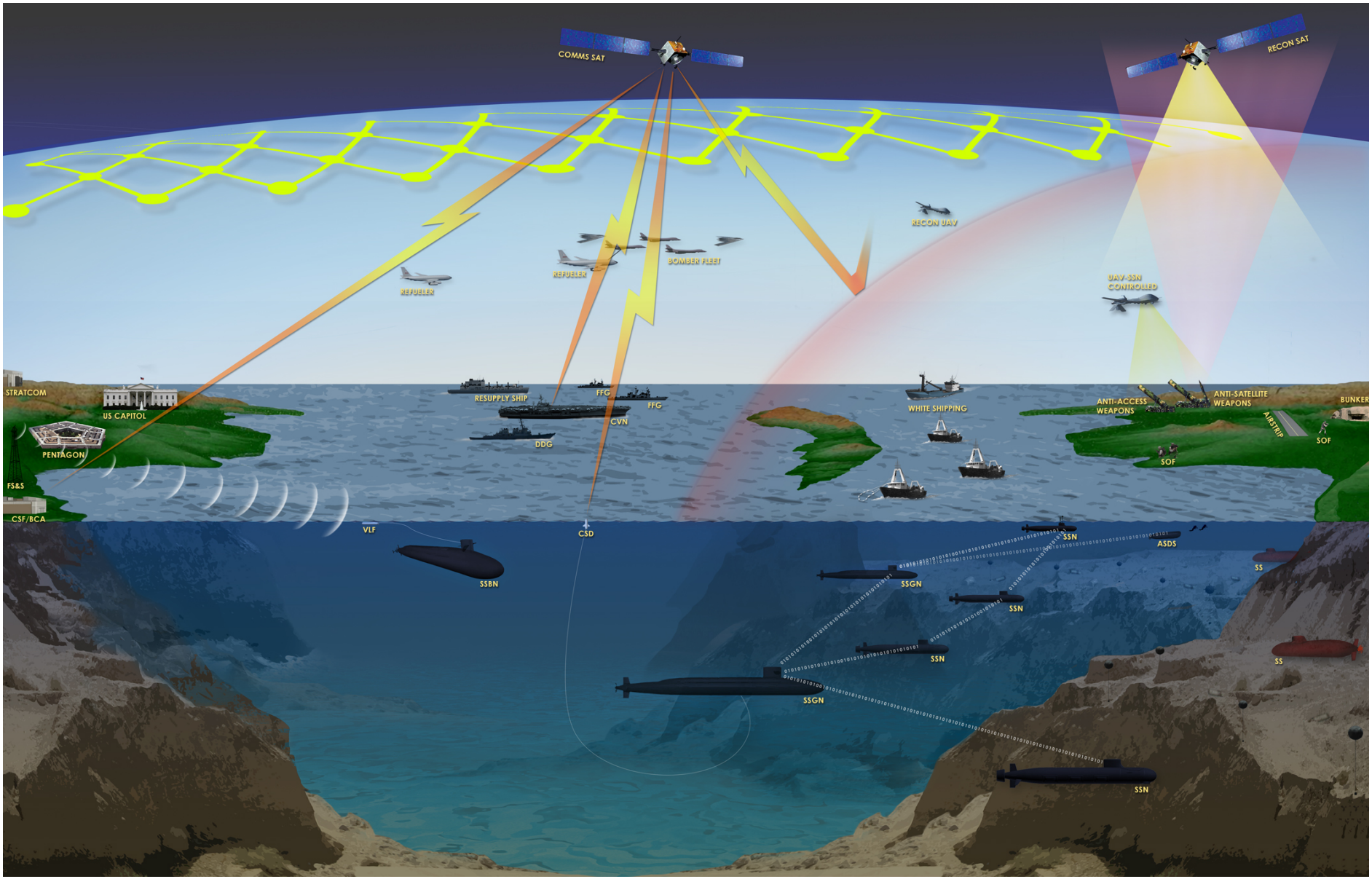
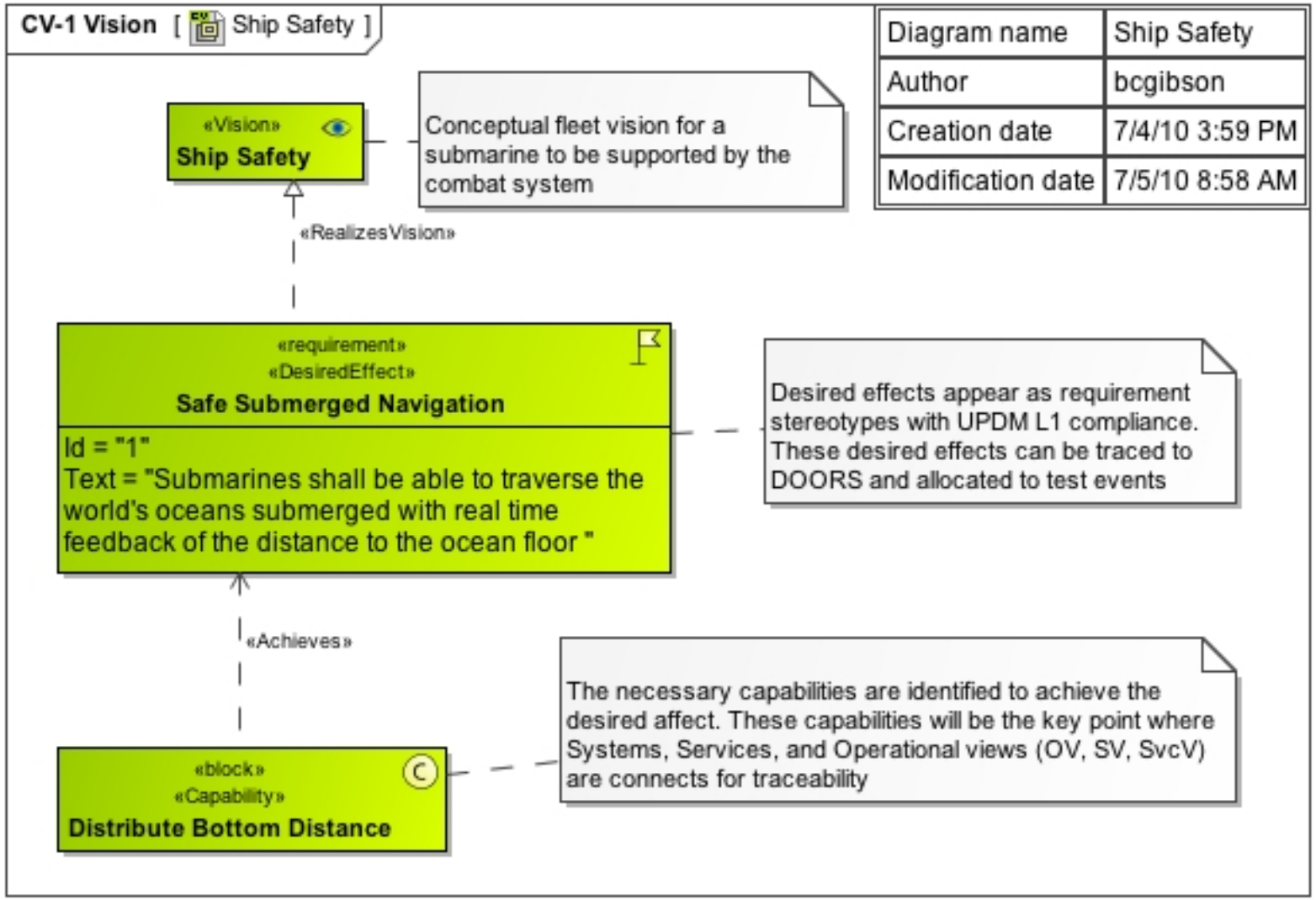
Submarine Capabilities Model



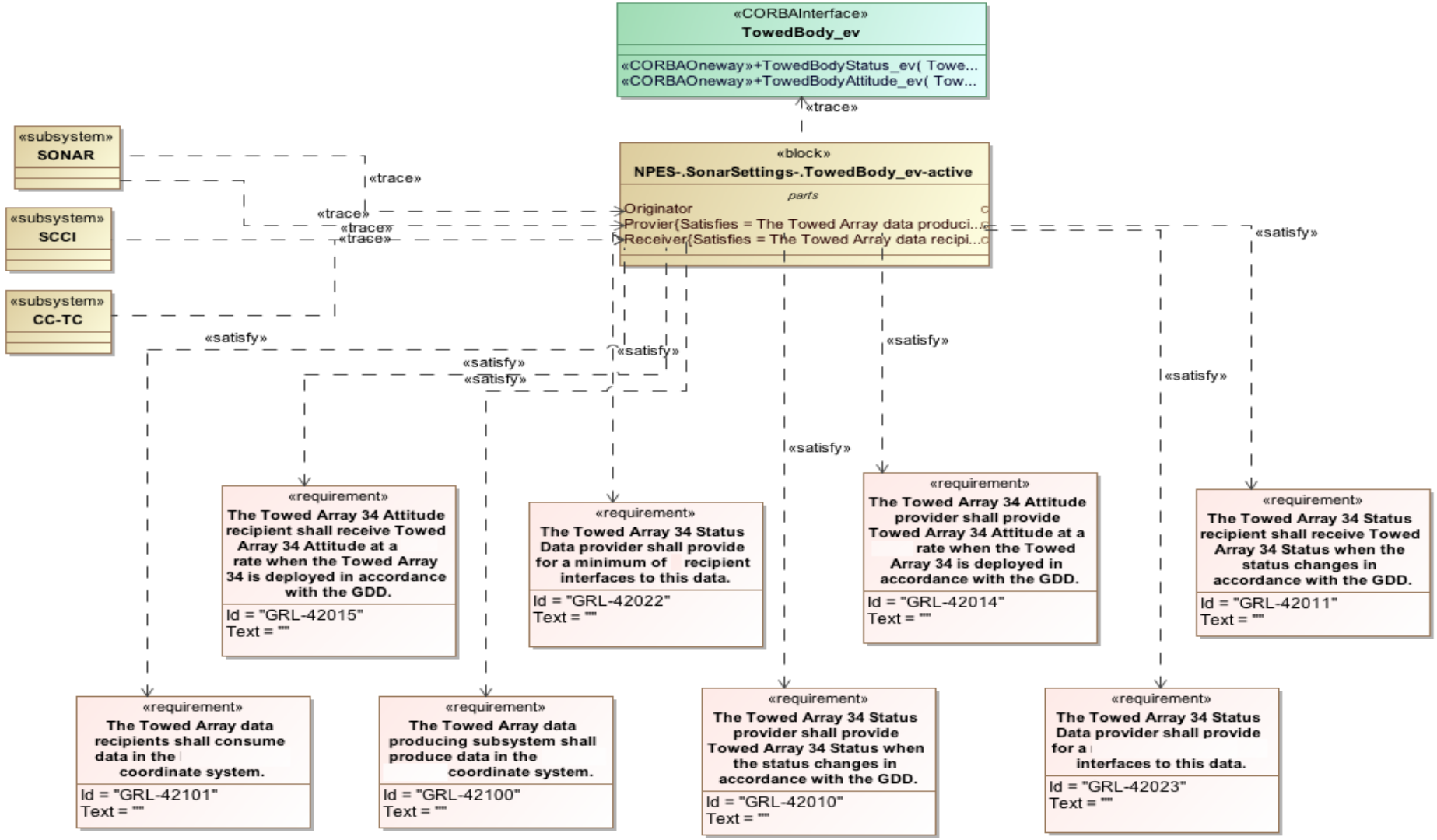
Submarine Capabilities Model
Sample OV-1



Capabilities Decomposition



Requirements Tractability in SWFTS Model



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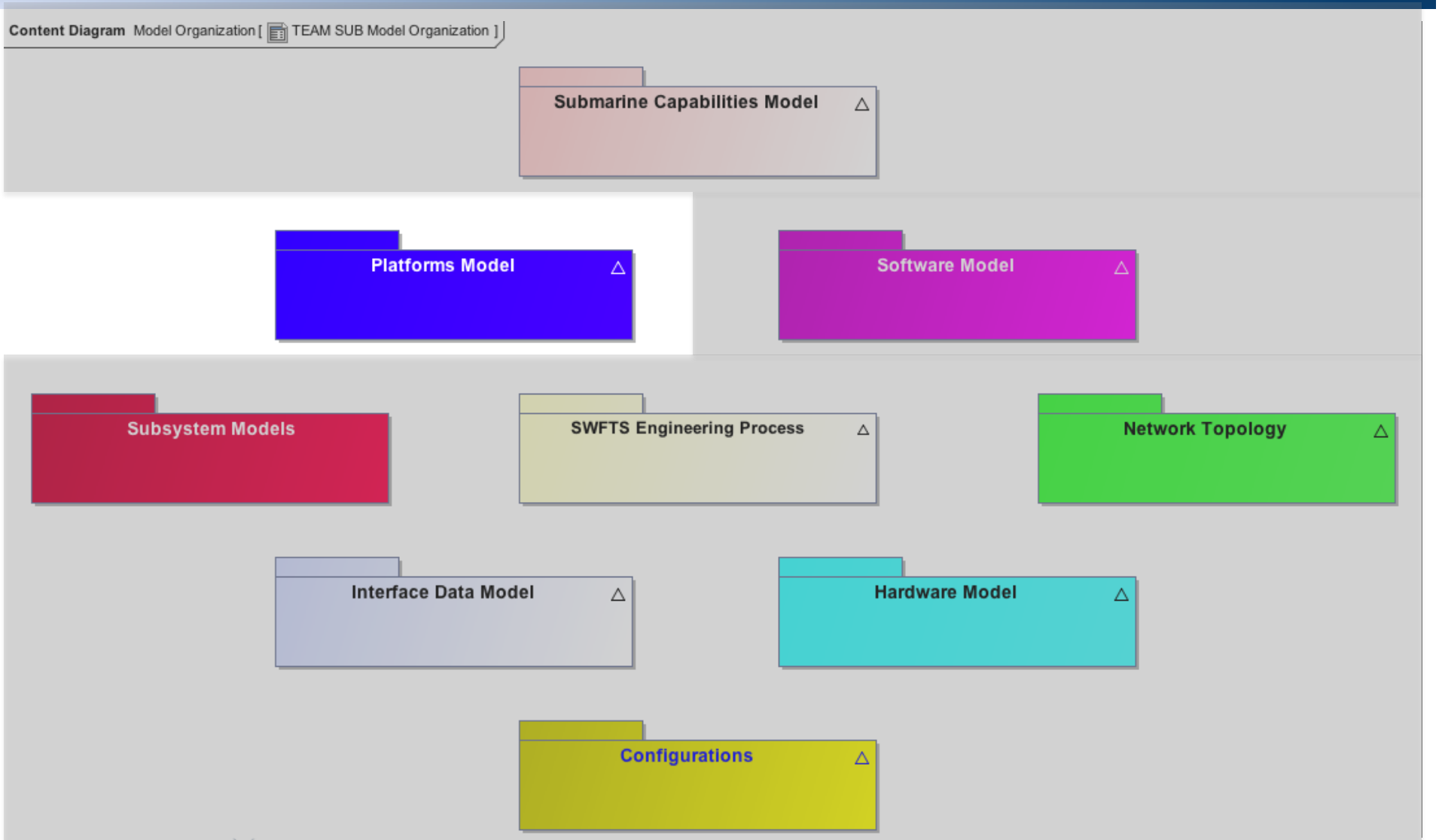
Conceptual Data Model Constructs

•The Conceptual Data Model (CDM) identifies the TEAM SUB data sources and their relationships to CDM constructs to document understanding of the organization's processes from an enterprise perspective leveraging MBSE artifacts

CDM Constructs	Current Source	UPDM/SysML Artifacts
Mission	FRD, ORD, CDD	Capability Views (CV)/Use Cases Operational Views (OV)/Sequence Diagrams
Capability	CONOPS	Capability Views (CV)/Use Cases
Desired Effects	FRD, SIFT, STRG	Capability Views (CV)/Requirements Diagrams
Systems	IPSS, SILC	Systems Views (SV)/Block Diagrams
Services	IIDB, IDL	Services Views (SvcV)/Block Diagrams
Operational Activities	CONOPS, SIFT	Operational Views (OV)/Activity Diagrams
Standards	IPSS, GRL, GDD, DISR, FORCENET, DIEA	Standards Views (Std)/Block Diagrams
System Functions	FRD, P-SPEC	Systems Views (SV)/Sequence & Block Diagrams
Performers	IIDB	Operational View (OV-2)/Block Diagrams
Interfaces	IIDB, SILC	System Views (SV)/Block Diagrams Services Views (SvcV)/Sequence Diagrams

Submarine Platforms Model



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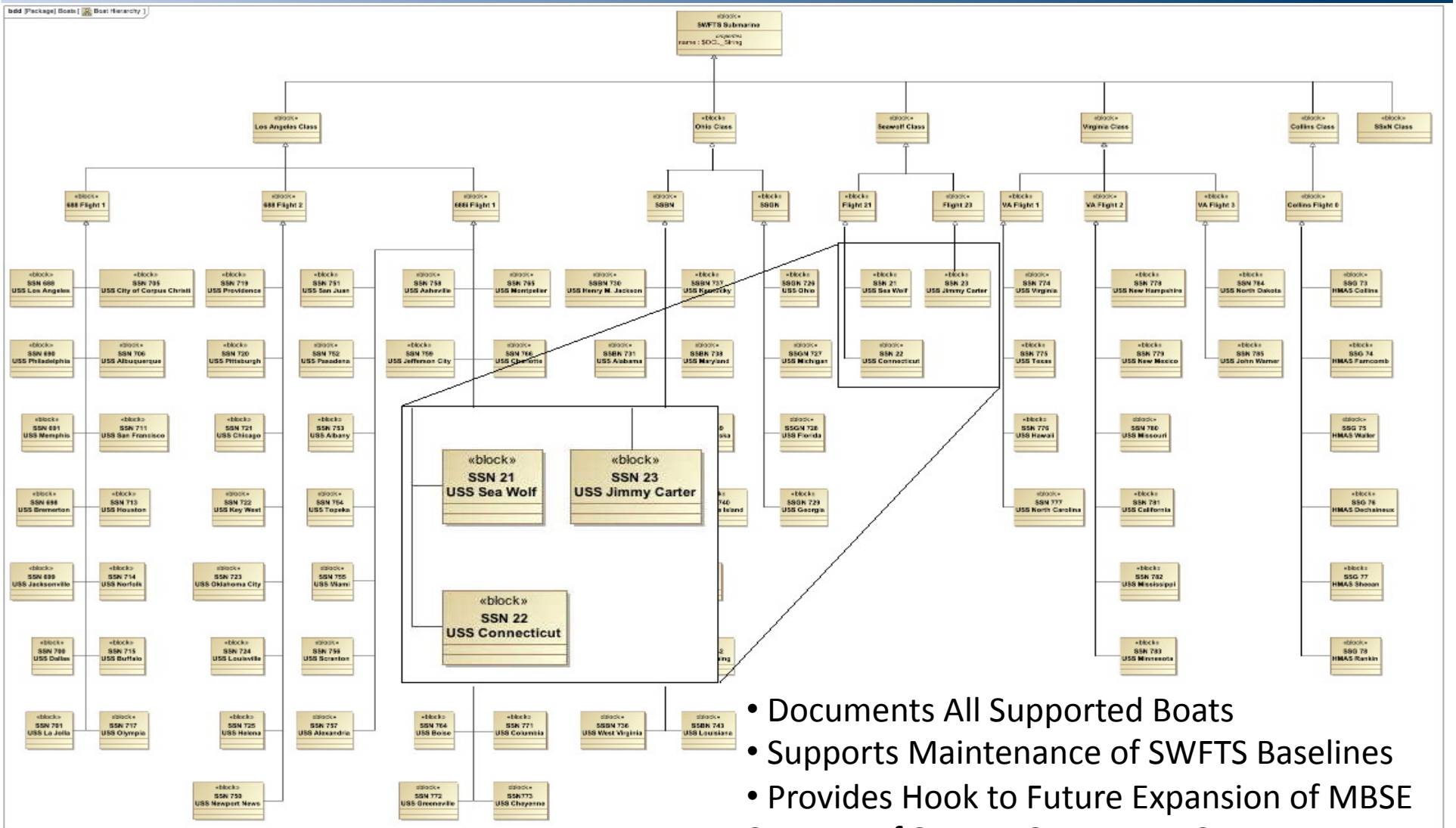
SWFTS Platforms Model



- Documents All Supported Boats
- Supports Maintenance of SWFTS Baselines
- Provides Hook to Future Expansion of MBSE Support of SHIPALTS, TEMPALTS, etc.

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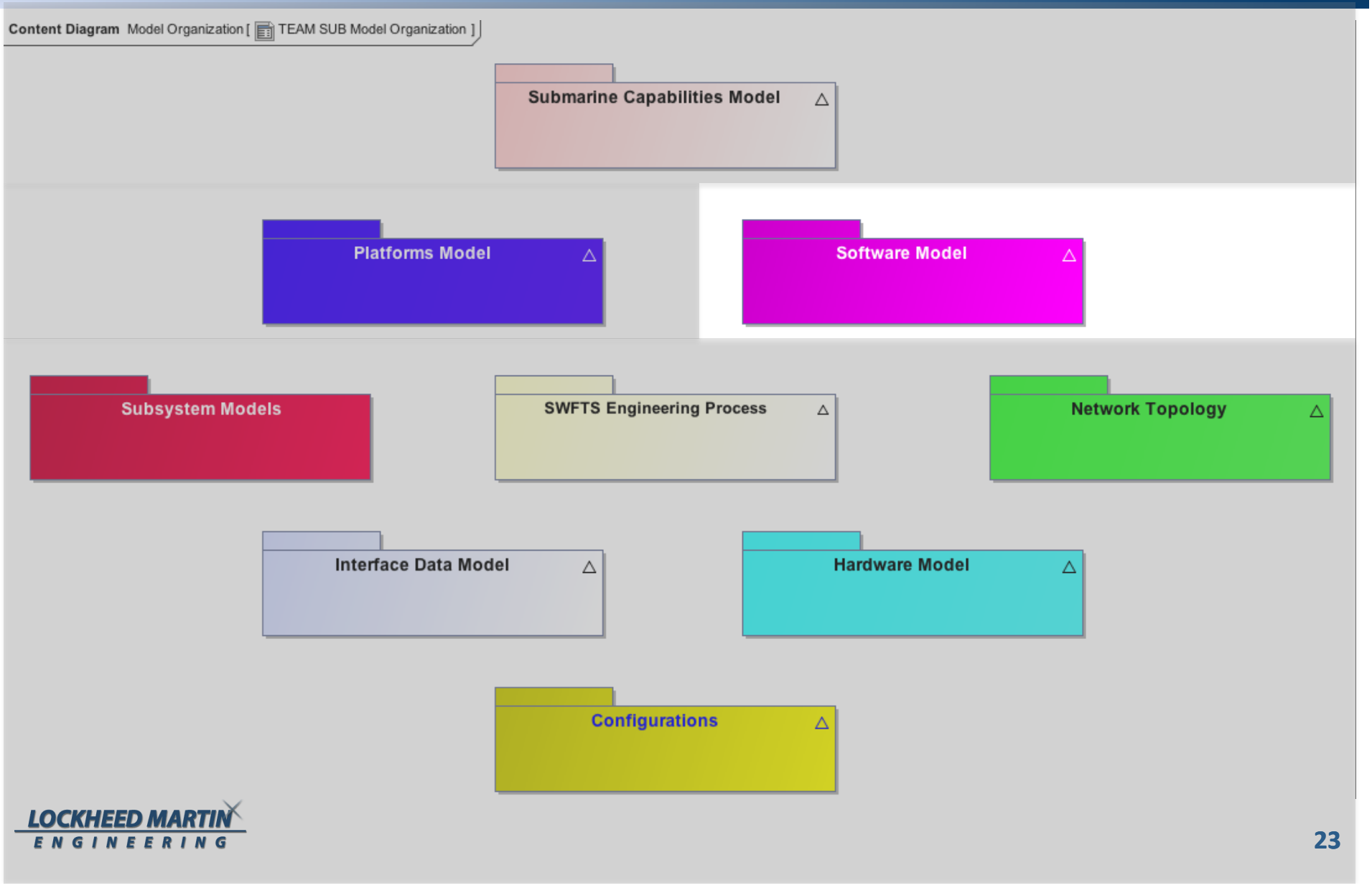
System Functions and Services Model



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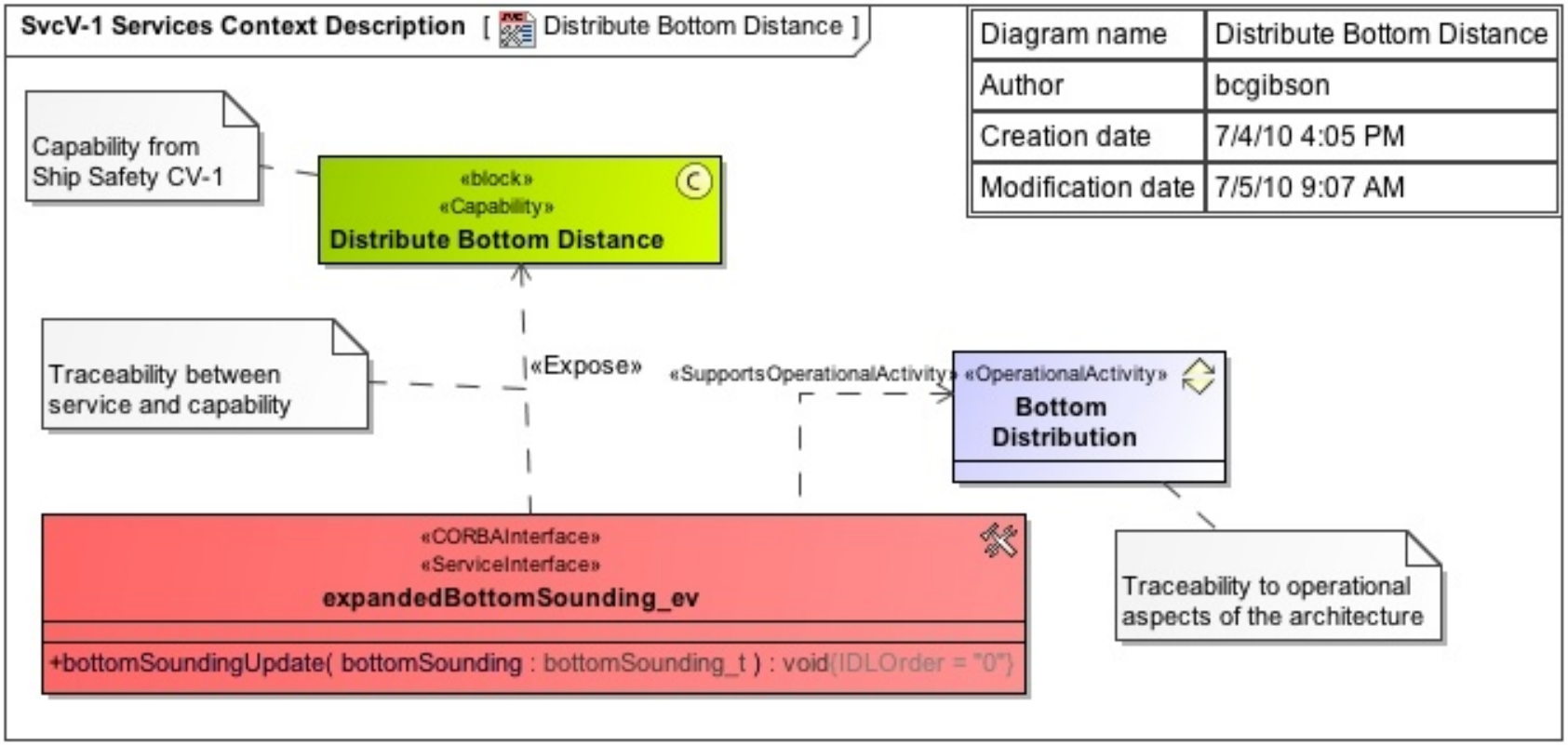
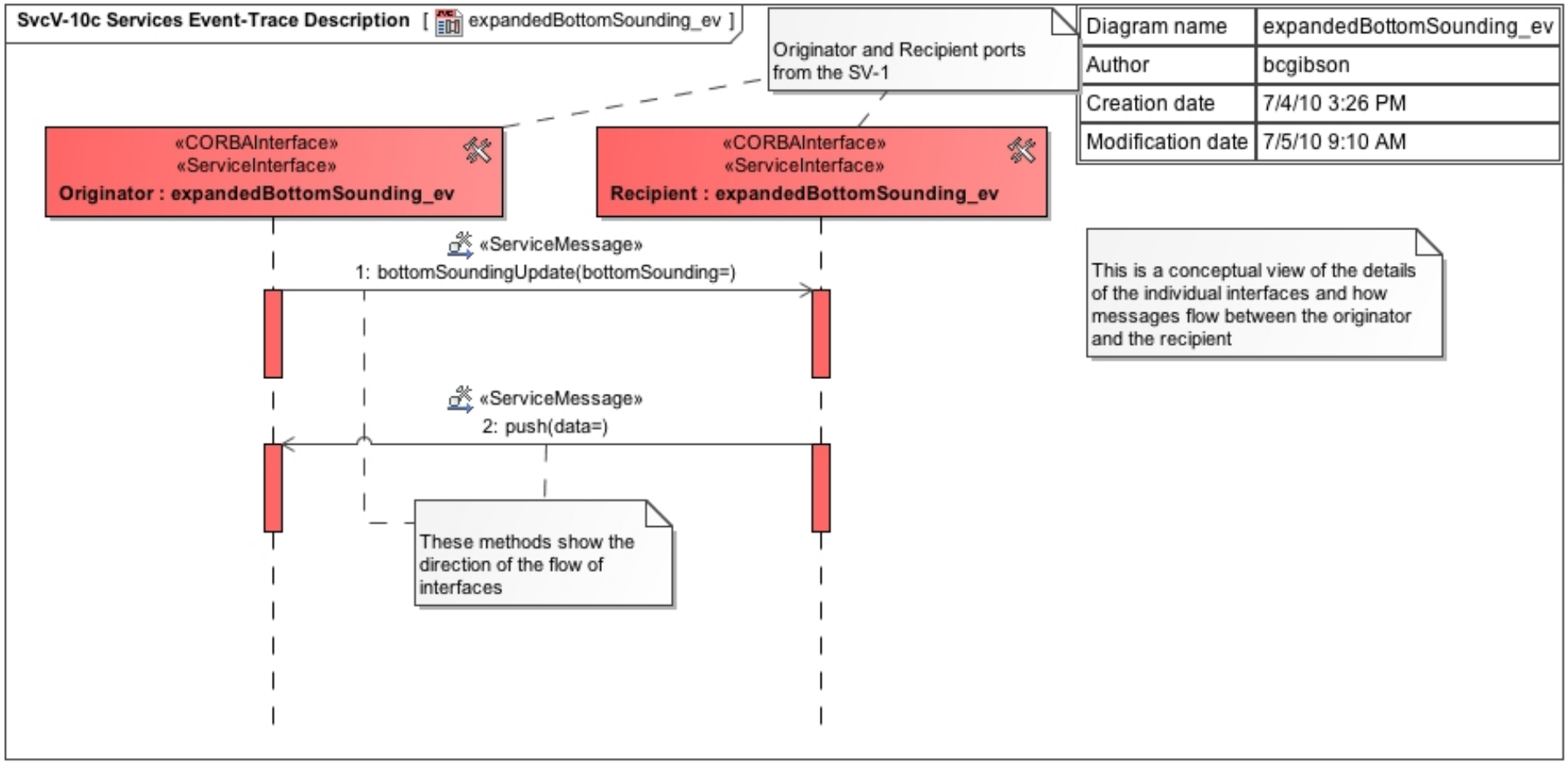
System Functions and Services Model

- Functions and Services that can be traced to system capabilities
  - Functions/Services are allocated to platform subsystems
  - Traced to Operational Activities, Requirements, etc.

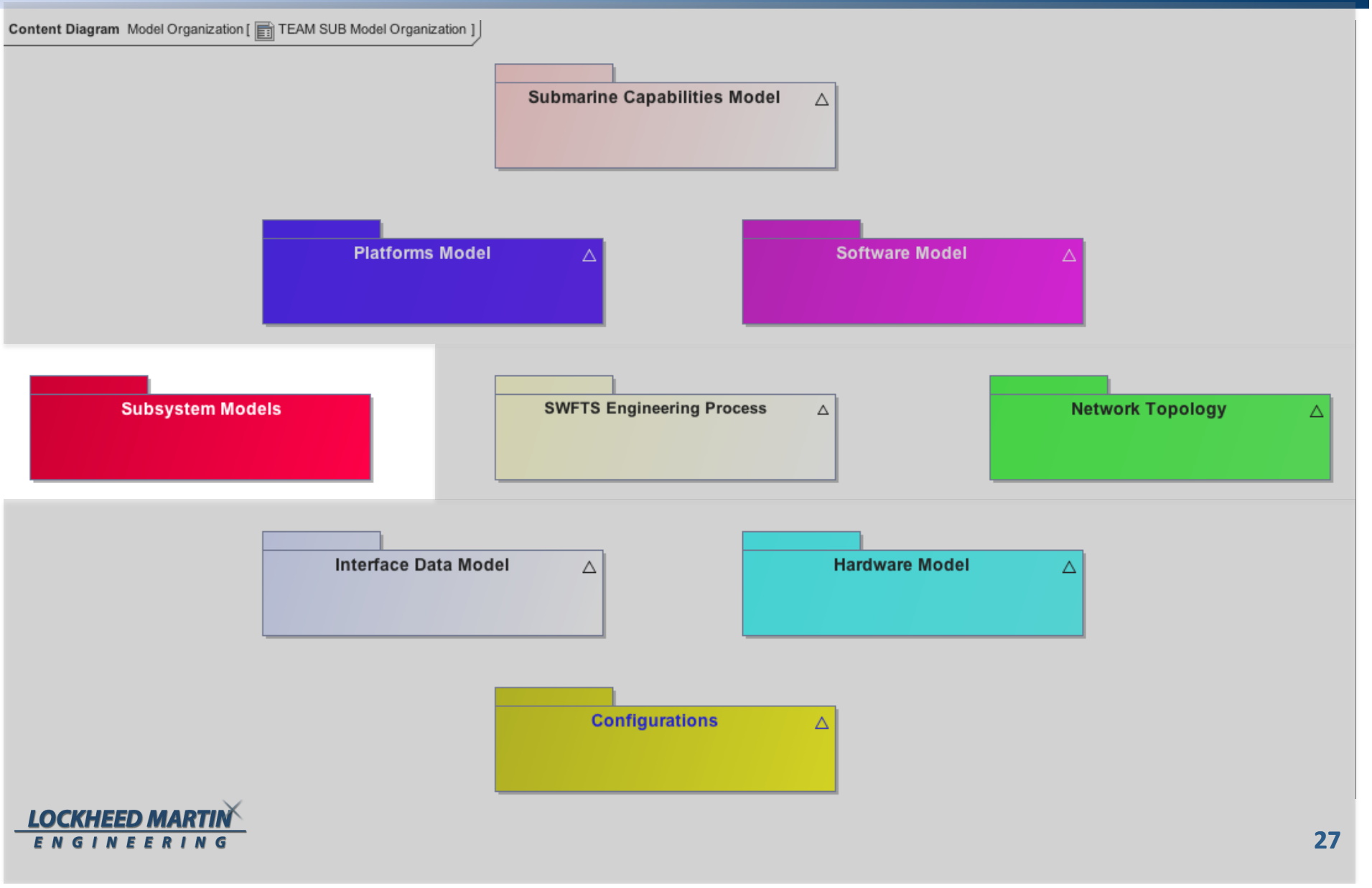
SvcV-1 Service Context



SvcV-10c
Expanded Bottom Sounding Sequence



SWFTS Subsystems Model



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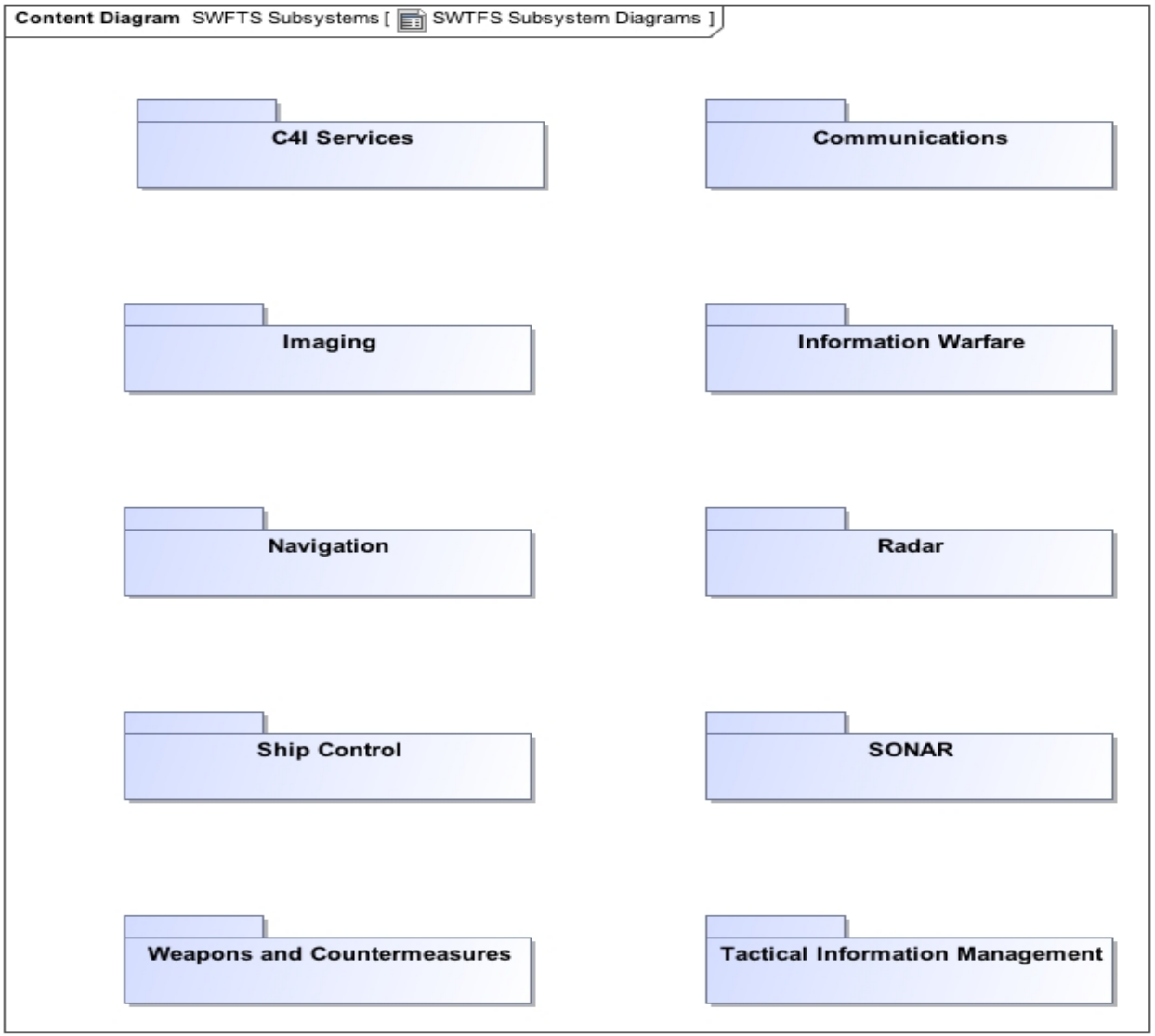
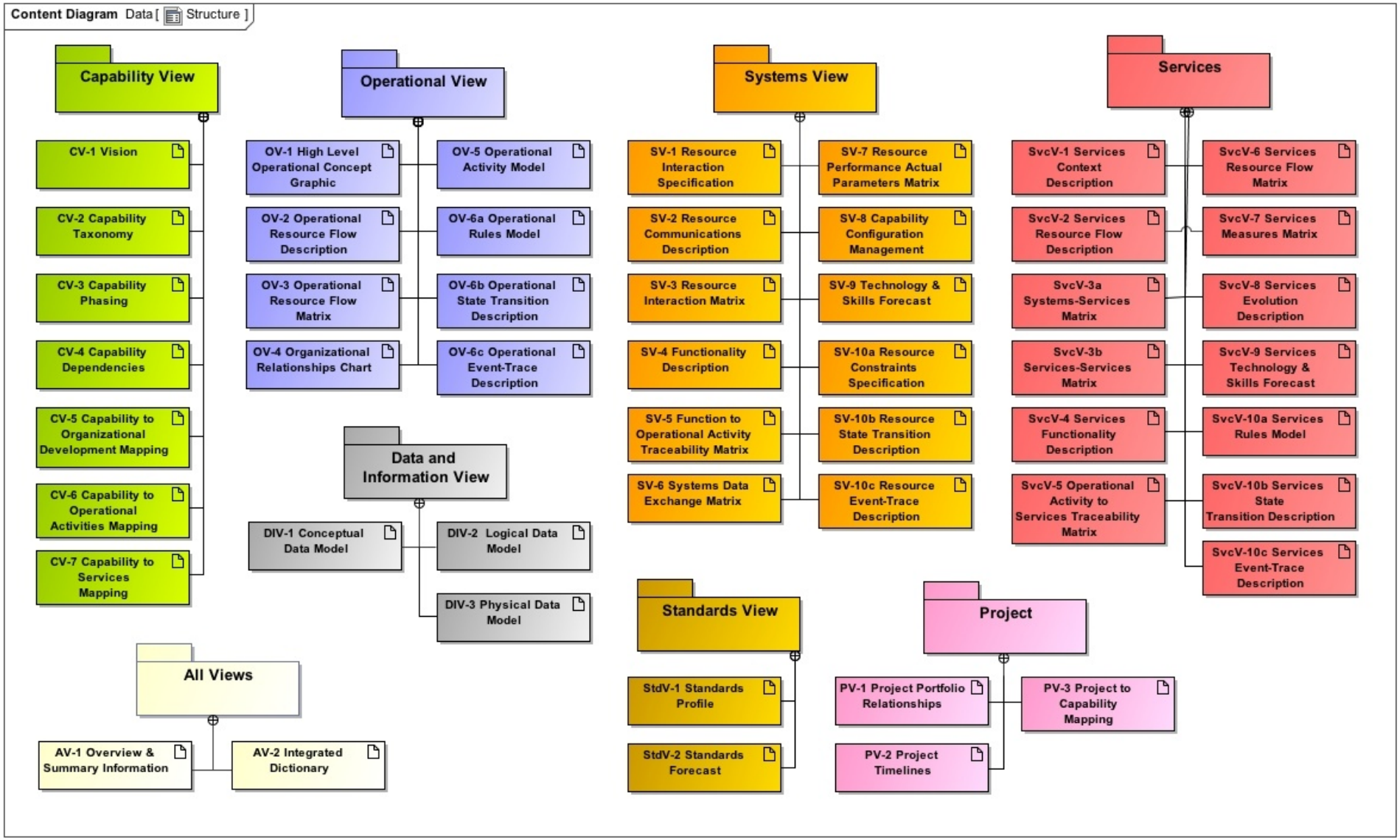
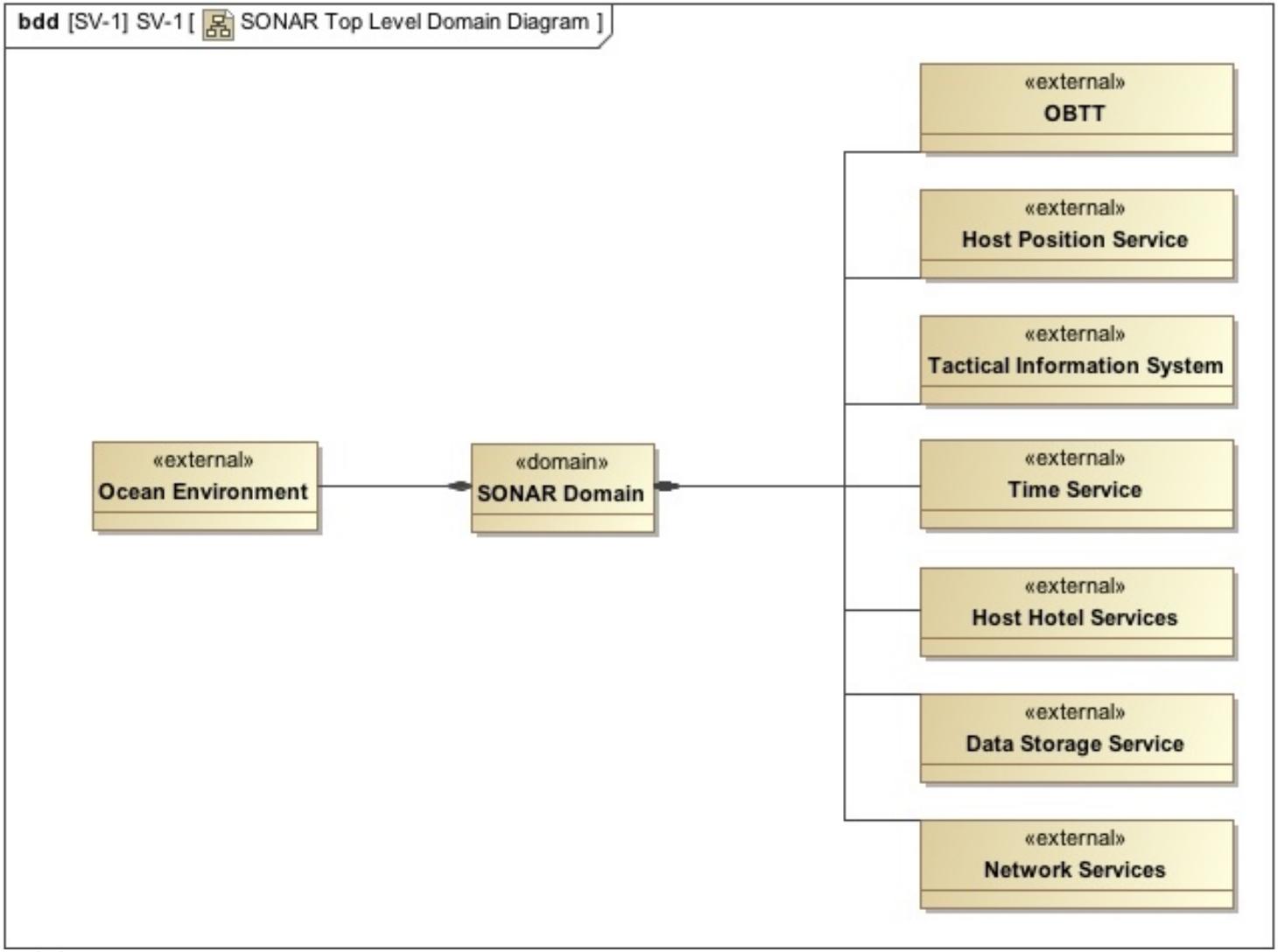
SWFTS Subsystems Models



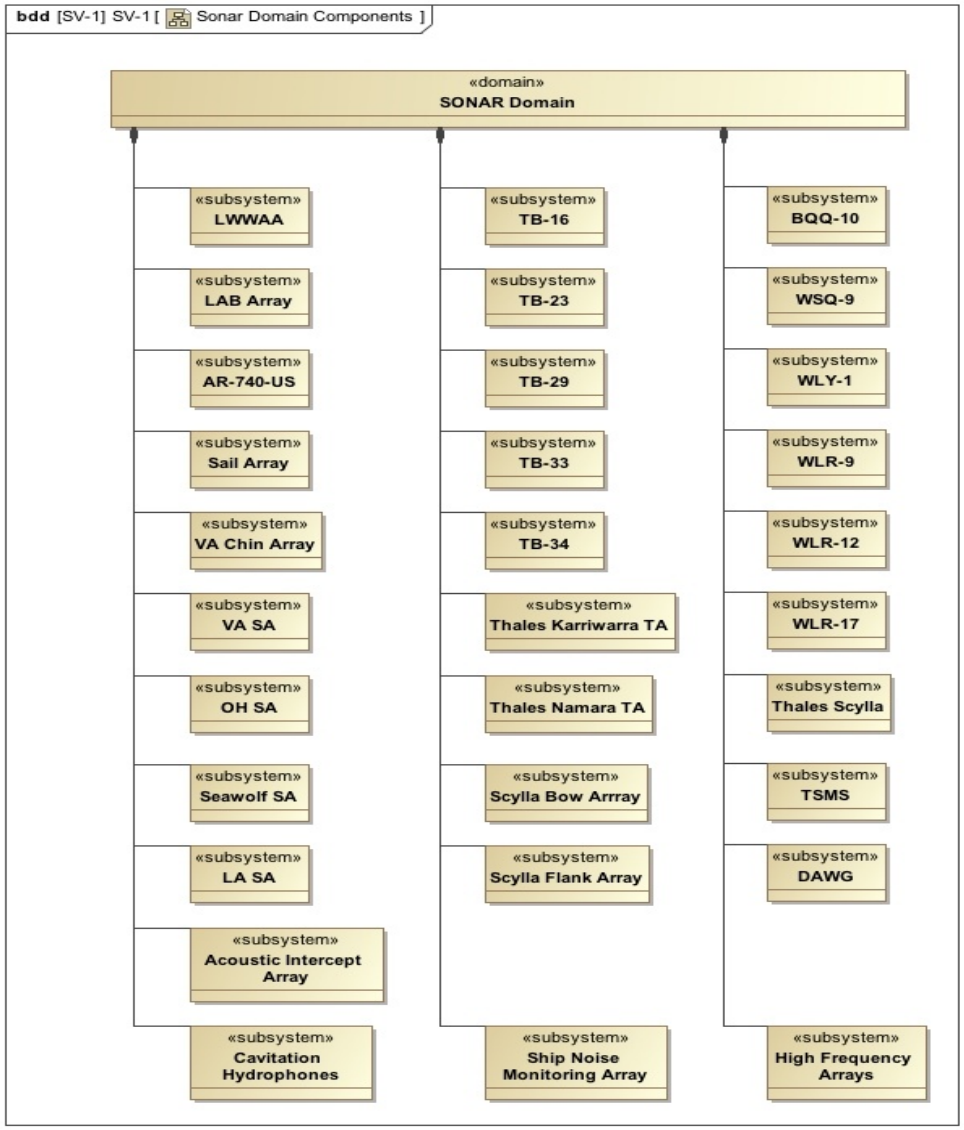
DoDAF 2 for Subsystem Acquisition Support



Subsystem Example – SONAR Domain



Subsystem Example – SONAR Component Hierarchy



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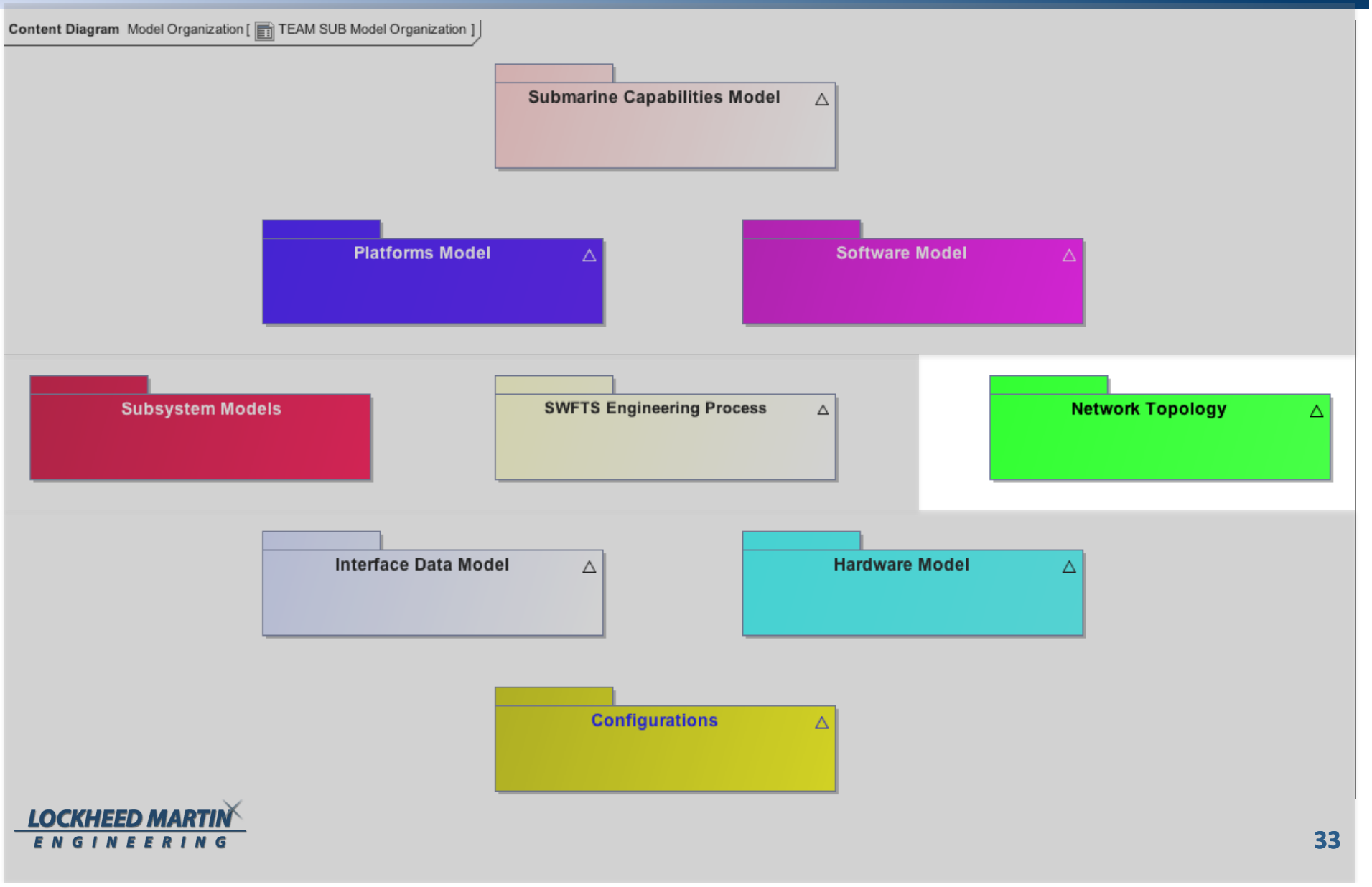
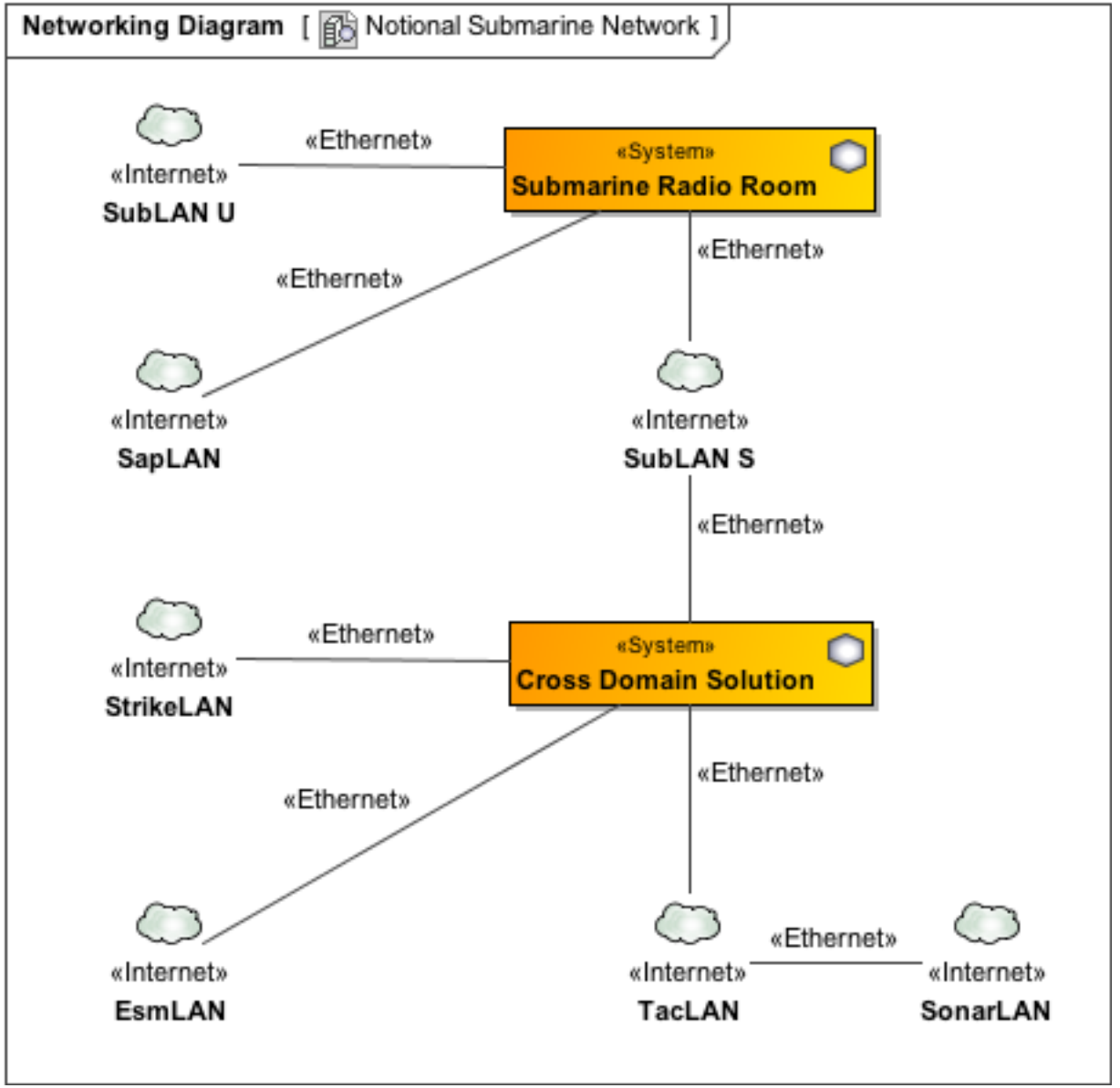
Subsystem Example – SONAR Domain Flow

Network Topology Model



SWFTS Network Topology Model



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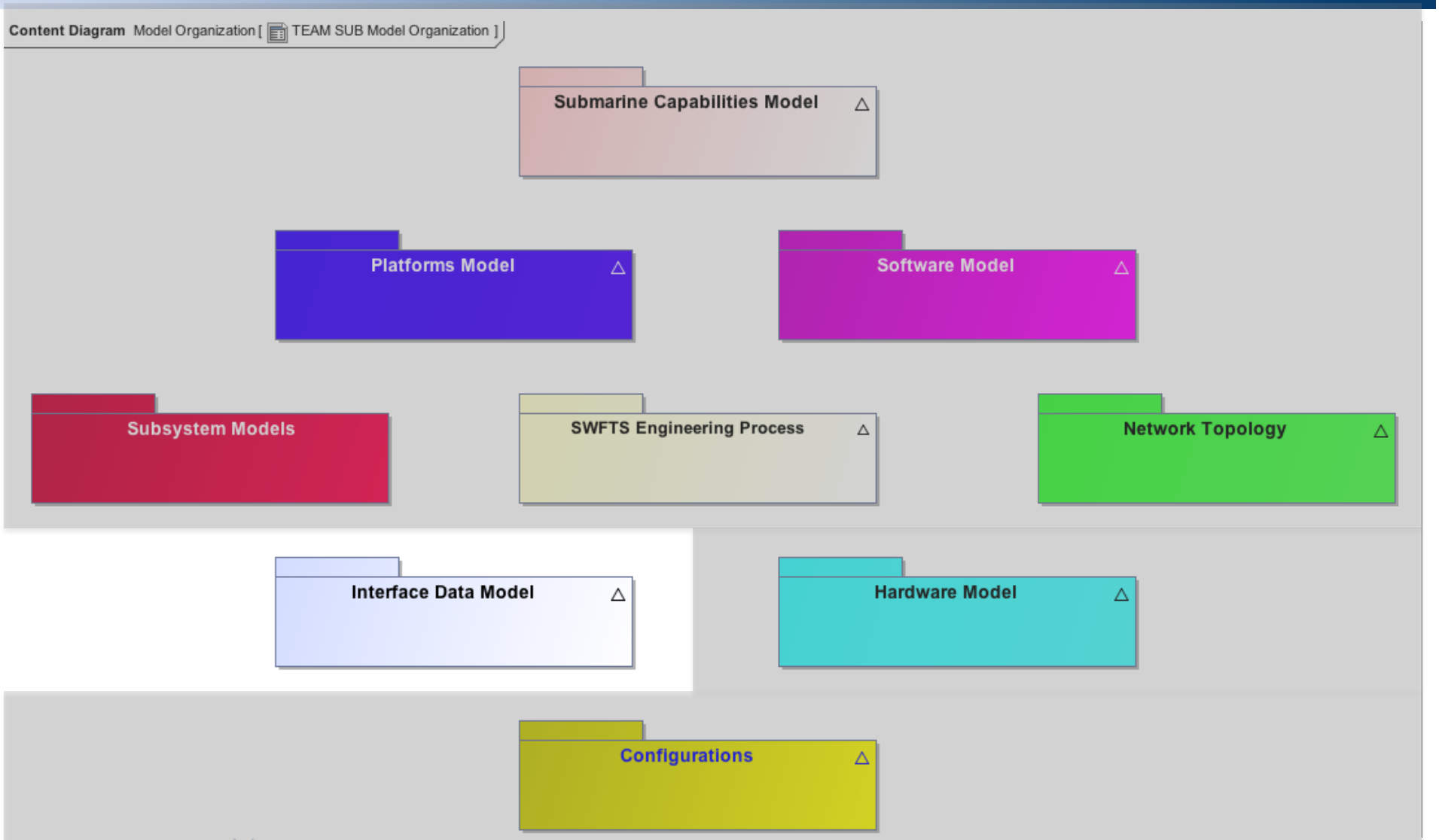
Interface Data Model



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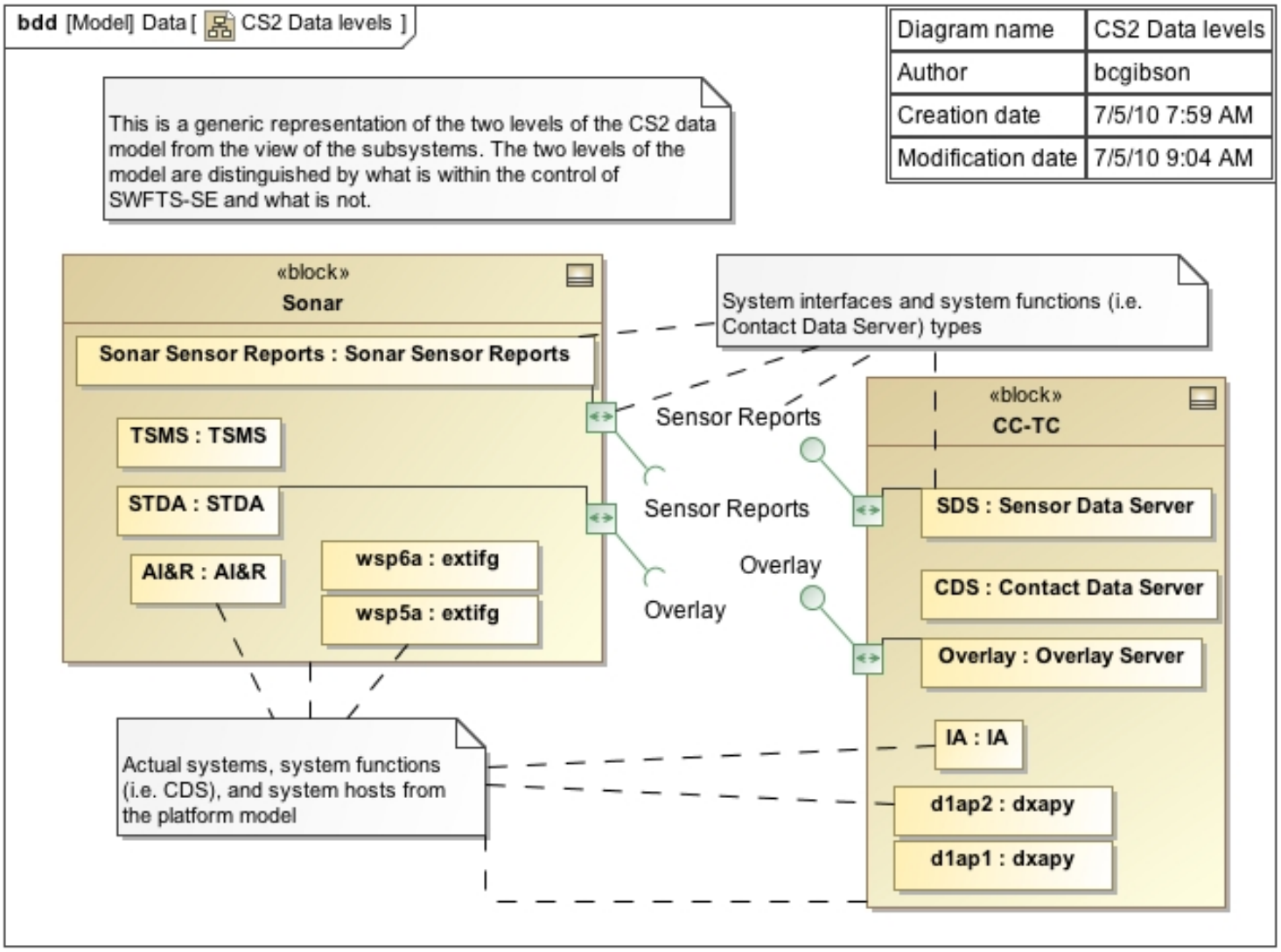
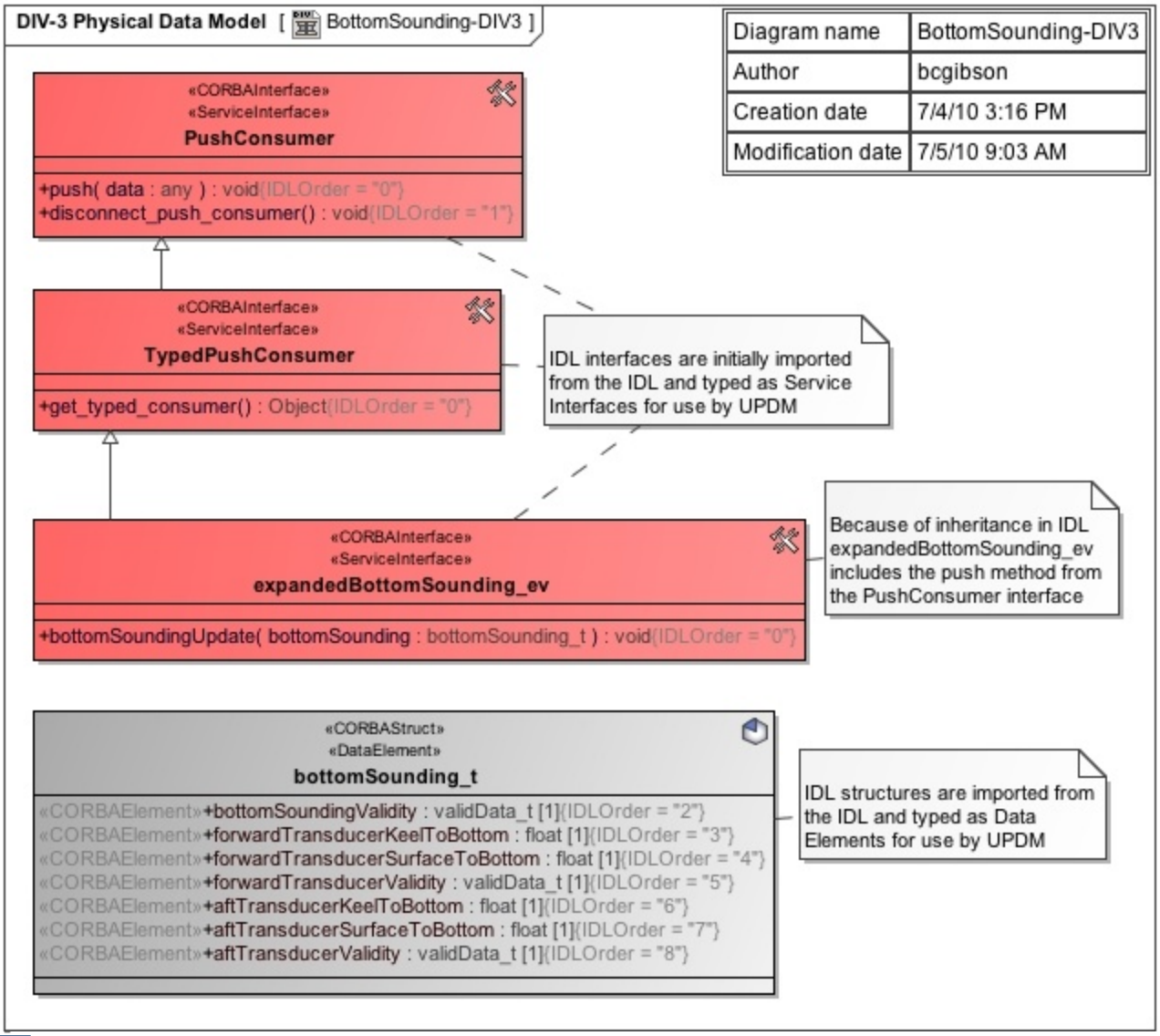
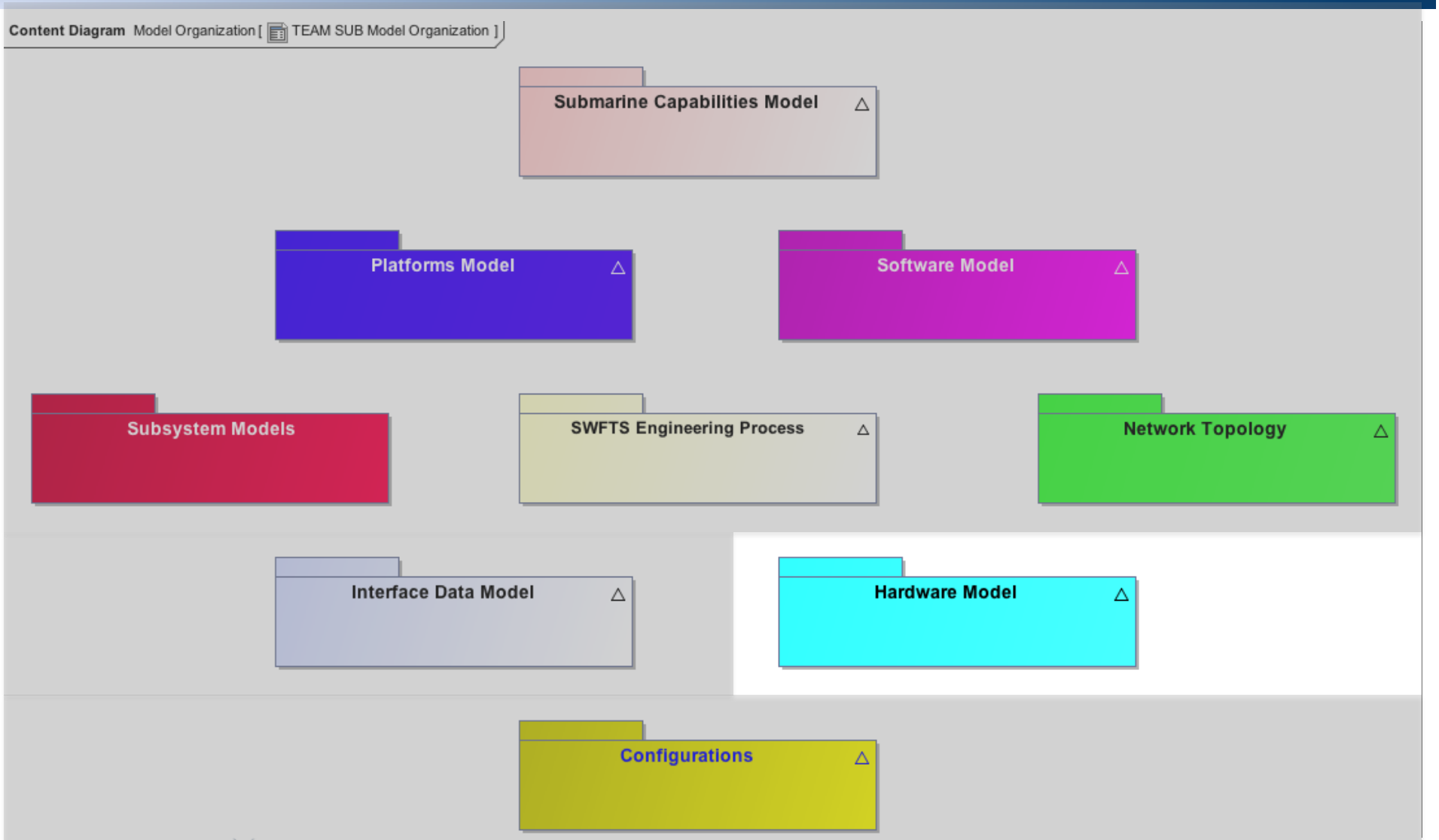
Two Interface Model Levels



SWFTS Interface Data Model



SWFTS Hardware Model



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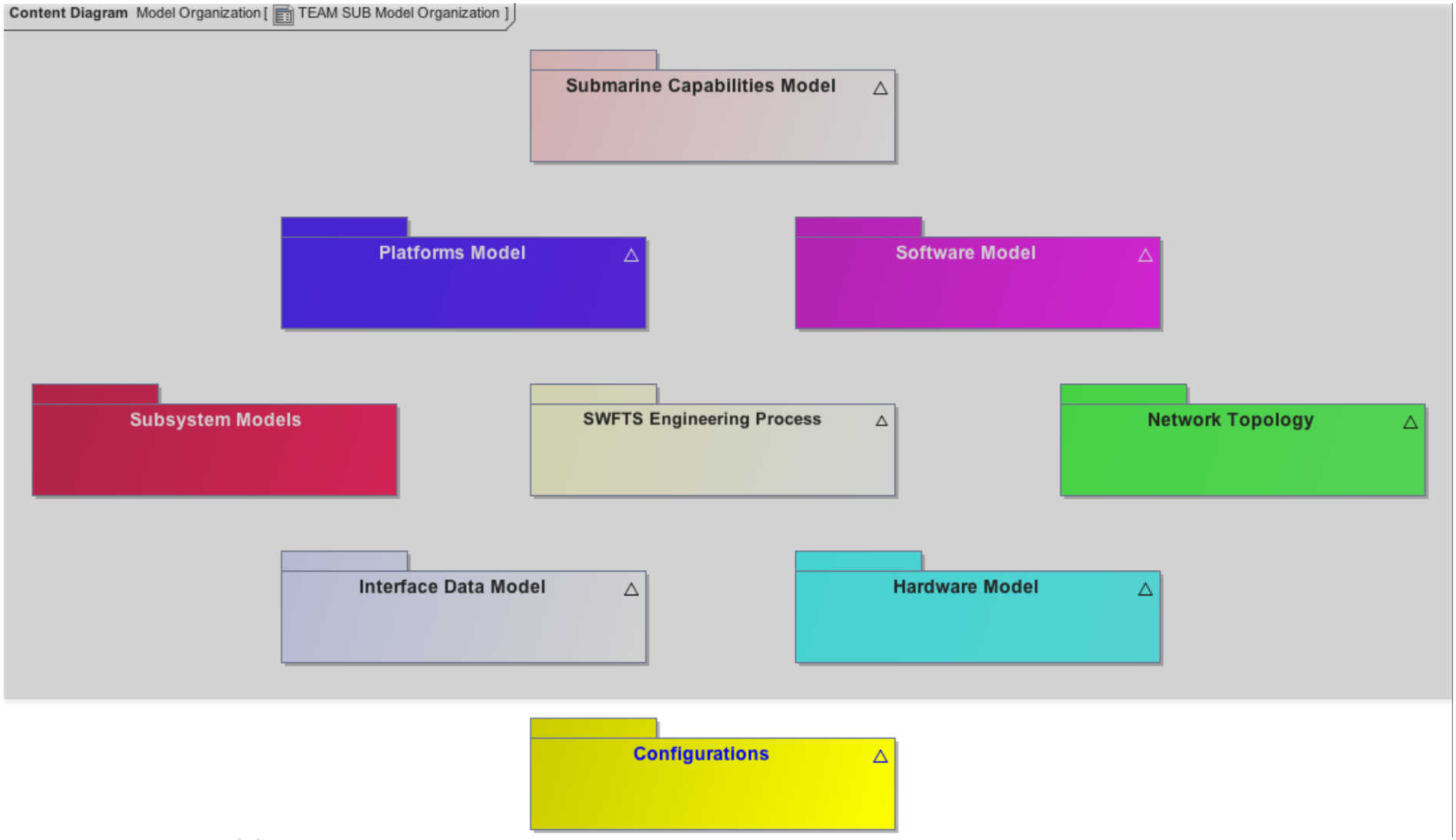
SWFTS Hardware Model

- Pick-list of specific hardware and software options (brand, model, configuration) for a particular TI/APB baseline available to subsystems for implementation
  - 1U, 2U, 4U servers, blades
  - Backbone and edge switches
  - RAID and NAS devices
  - OS (linux distribution, MS Windows version)
  - Middleware (CORBA ORB, etc)
  - Etc.

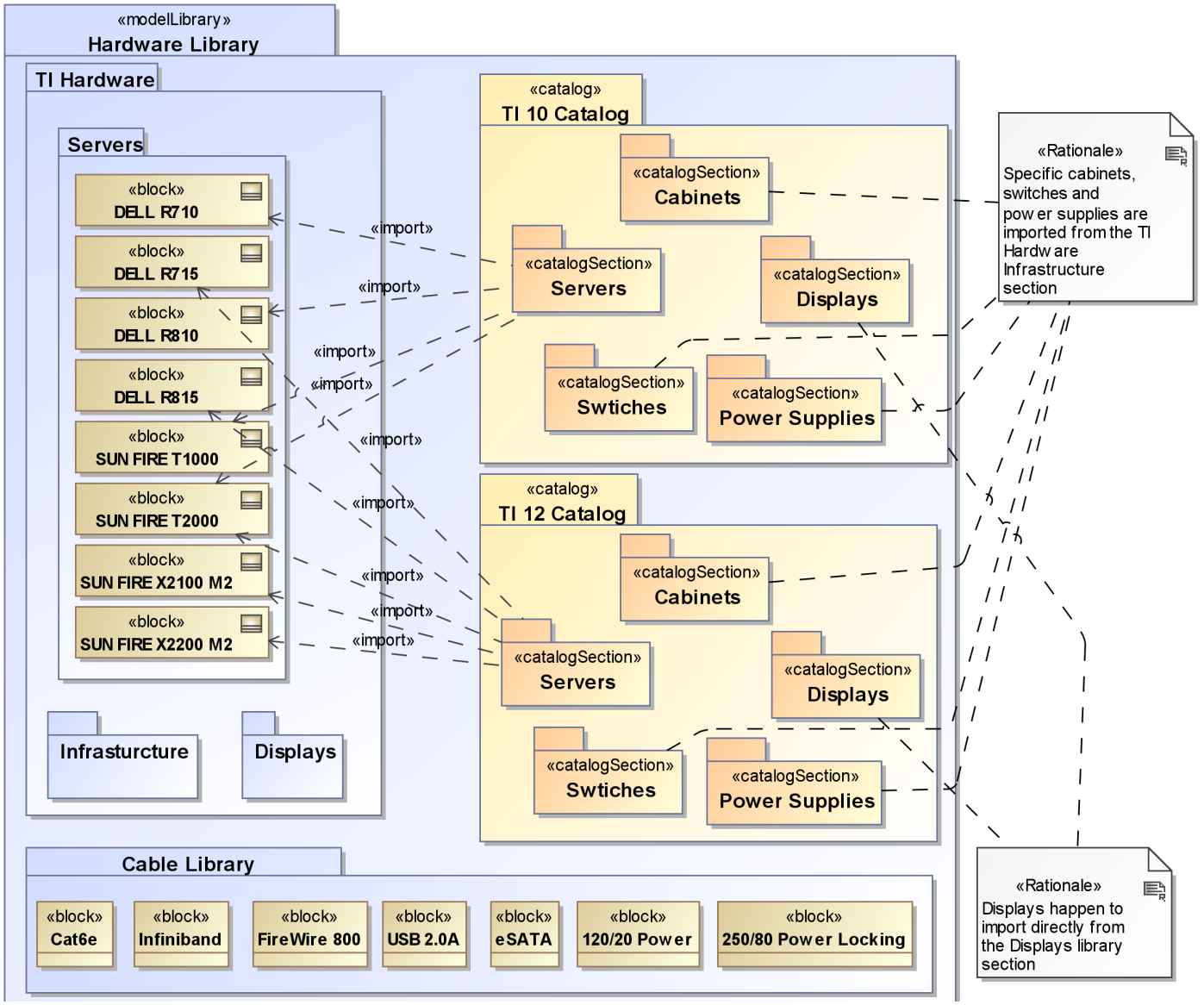
Baseline Configurations Model



Constructing SWFTS Baseline Configurations

- Leveraging collections of components from Subsystems Models, Software Model, Hardware Model, Network Model, and Interface Model, build catalogs for each baseline (TI*nn*, APB*mm*, etc.)
- *<<include>>* items from baseline Catalogs to build Configurations for Classes in the Platform Model
- Subclass Configurations to Flights and Submarines in the Platform Model as required to capture variations

Managing Baseline Variants with Catalogs



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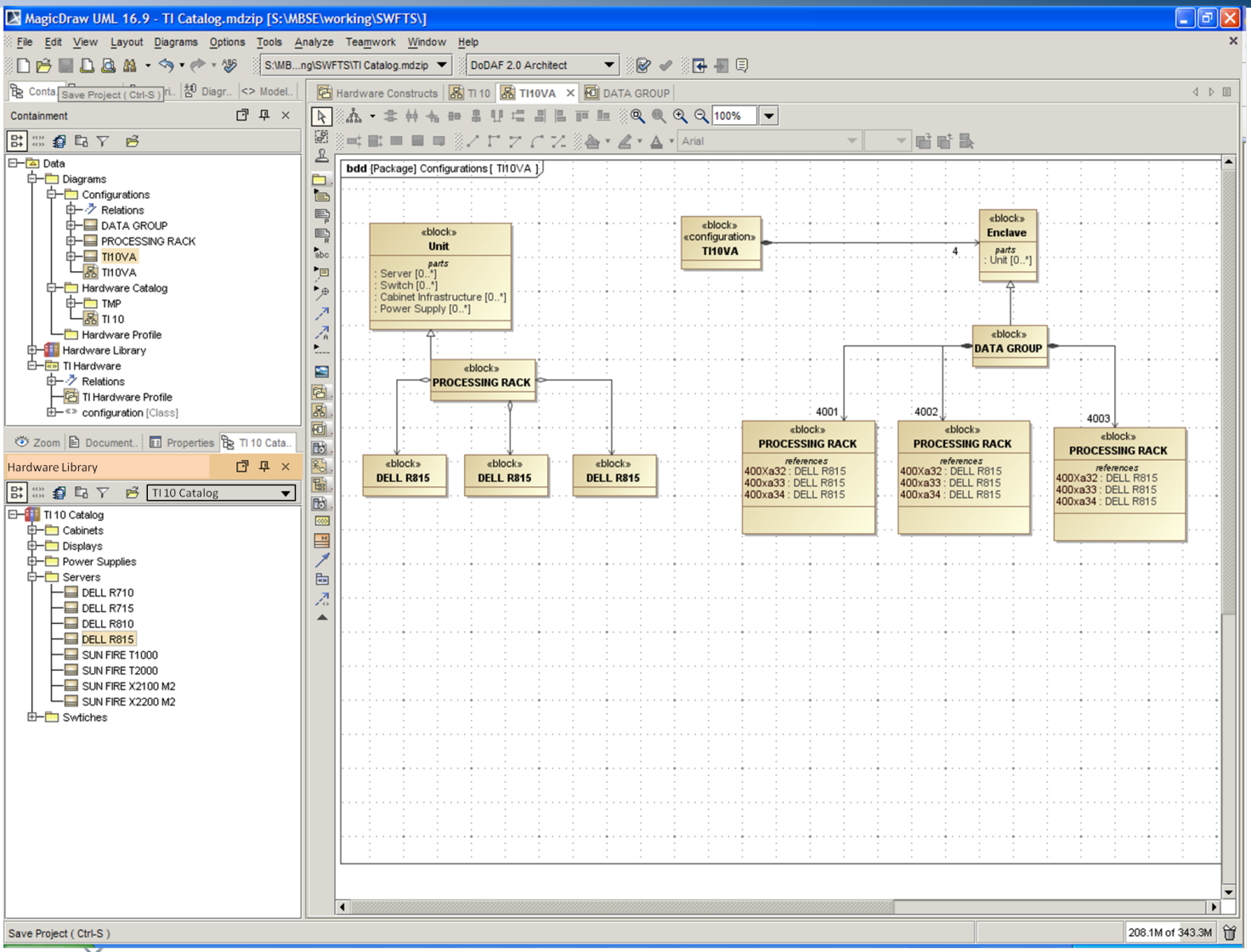
Use Catalogs to Build Baseline Configurations



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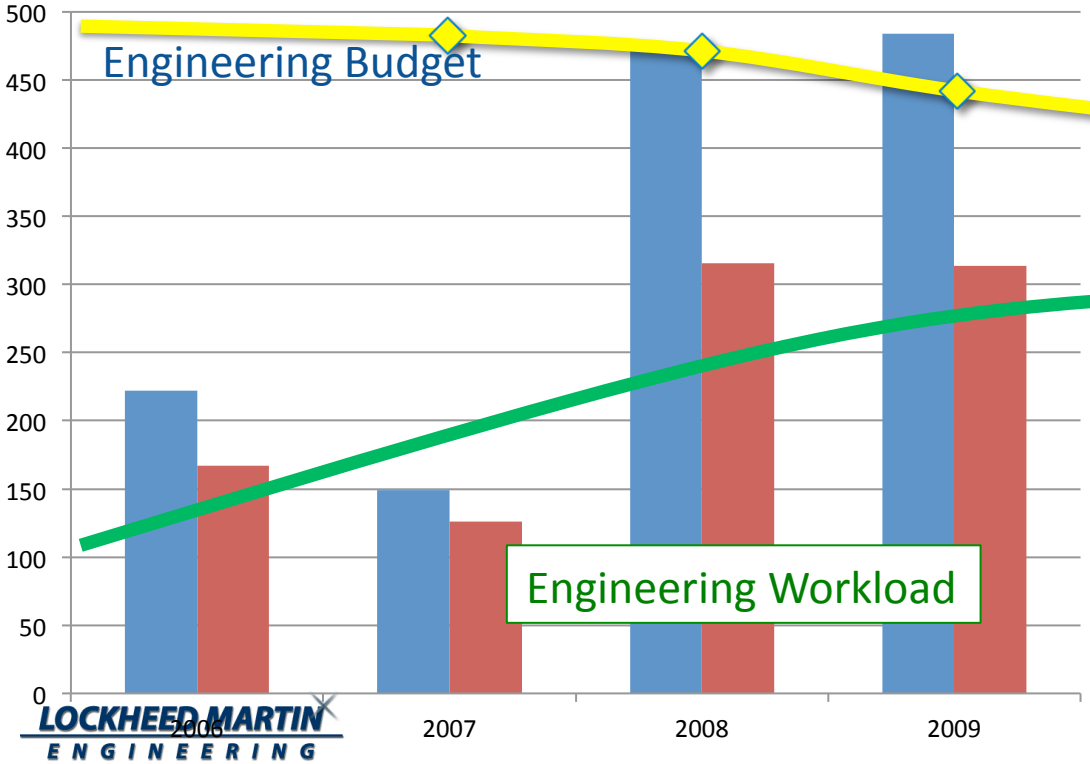
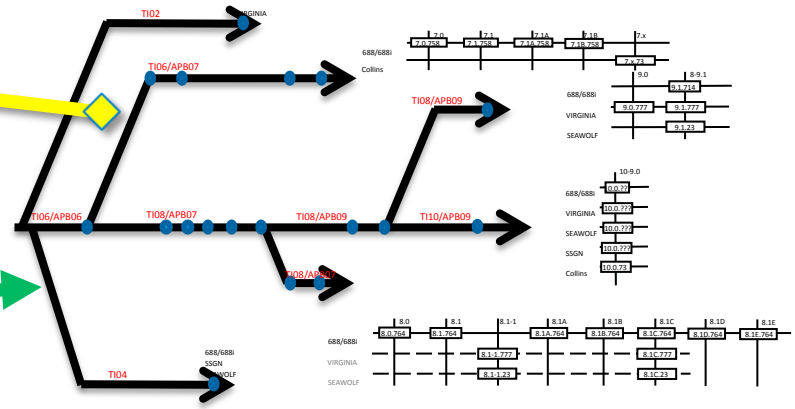
Anticipated Benefits of MBSE for SWFTS

Need for Change

- SWFTS Systems Engineering efforts have increased steadily in the past 3 years and Systems Engineering resources are stretched
  - Increasing number of Baseline Change Requests (BCR) processed per year
  - More concurrent baselines (baselines not retired) and more subsystems being added
  - Expanding System of Systems role, and Principal Systems Engineer IPT and Architecture Working Group support





Total BCRs

eBCRs

eBCR = Equivalent BCR
(deprecates replications)

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Systems Engineering Core Trend

- The efficiency to perform the SWFTS System Engineering has been improved through continuous process improvements, but we're reaching the limits.
  - DOORS automated Requirements Baseline Management, but Interfaces (IP addressing, IDL, etc.) are still managed manually
- The future growth in SE will drive the need for more SWFTS SE funding
  - In order to meet the continually increasing needs of the fleet without increased funding, the SWFTS SE process must become more efficient
- MBSE affects larger scope
    - SWFTS (Capabilities Definition & Baseline Management), JCIDS/ISP, and Subsystems
    - implies larger potential savings

MBSE Will Enable a More Efficient System Engineering Process

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ROI for SE&I

- Expect 13% additional savings to SE from MBSE
  - 25% in Capability Definition
  - Another 10% over DOORS in Baseline Management
- Savings won't be seen until 4th year
  - 2 years to implement model
  - 1 year transition overlap with current process

Future Research

MBSE of SWFTS Product Family

- Extend Current SWFTS MBSE Prototype to Full Information Model
  - May Discover Additional Limitations in UML, SysML, SoaML, and UPDM Standards. If so, Work With Standards Bodies as Needed to Update
- Develop Tool Ecology Around SWFTS Model to Support Process Re-Engineering
  - Validate in Parallel with Current Process Using TI12/APB11
- Extend SWFTS MBSE Towards TEAM SUBMARINE Enterprise Architecture
  - Assess Interactions of Proposed Baseline Change Requests
  - Directly Support Selected Subsystem Providers
  - Interface with Shipyard Models to Enable Integrated Ship Performance Impact Assessments
  - Support Full Life Cycle

References and Acknowledgement

- **References**
  - ***Model-Based System Development for Managing the Evolution of a Common Submarine Combat System,* Steven W. Mitchell, Lockheed Martin,** AFCEA-GMU C4I Center 2010 Symposium on Critical Issues in C4I, 18-19 May 2010
    - Paper and Briefing Available Here

- **Acknowledgement**
  - This research was supported by NAVSEA contract N00024-06-C-6272