SPACE COMMUNICATIONS AND NAVIGATION

SCaN Integrated Network
Monitor & Control Software Architecture
SysML Model of Trade Space Options

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Overview

- The Problem – Model NASA's Space Communication and Navigation (SCaN) Integrated Network Architecture (INA) to perform System of Systems & Trade Space architecture evaluation

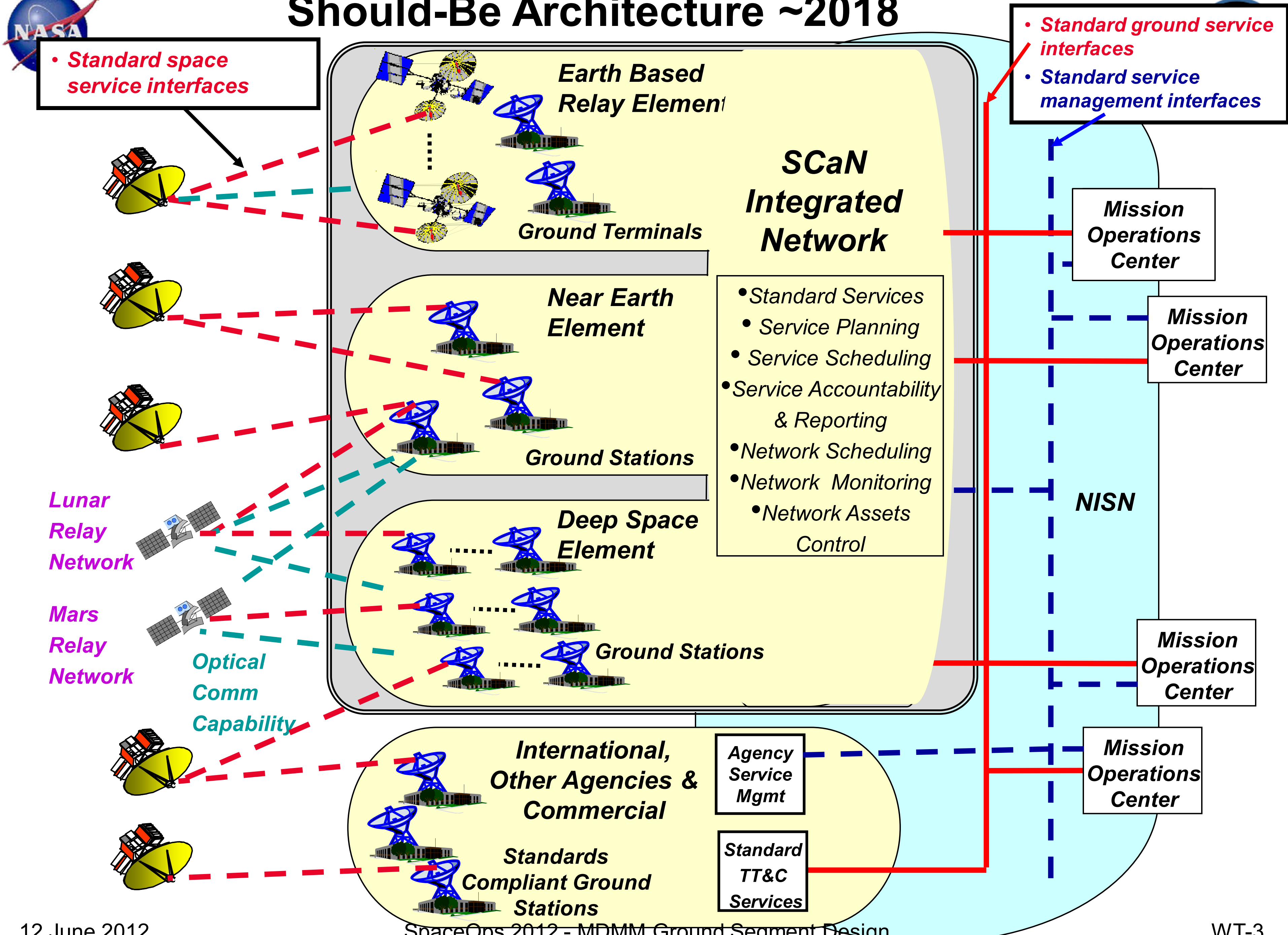
- Brief introduction to the SCaN Integrated Network Architecture
  - Described elsewhere at SpaceOps 2012, Tai, Wright & Bhasin

- Overview of the Network Control Trade Study
  - Brief introduction to the trade study and modeling methods
  - Review SysML model of the NCS-1 option

- Results & conclusions

See SO12 full paper for discussion of MBSE trade space modeling methods

Should-Be Architecture ~2018



Overview of the Trade Space Studies

- The SCaN Program System Engineering team has conducted a series of trade space studies to prune what started as a very large trade space
- Trade Space Study Cycles:
  - Cycle 1: Evaluate vastly different physical deployments of service execution and integrated network management system elements, highly centralized vs highly distributed; evaluate Continuity of Operation (COOP) impacts
  - Cycles 2-3: Evaluate different network control software / system architectures, evaluate COOP and security impacts; evaluate different network control team organizations
  - Cycles 4-5: Evaluate different planning and scheduling system approaches; evaluate different planning and scheduling team processes and organizations

Trade Study Process

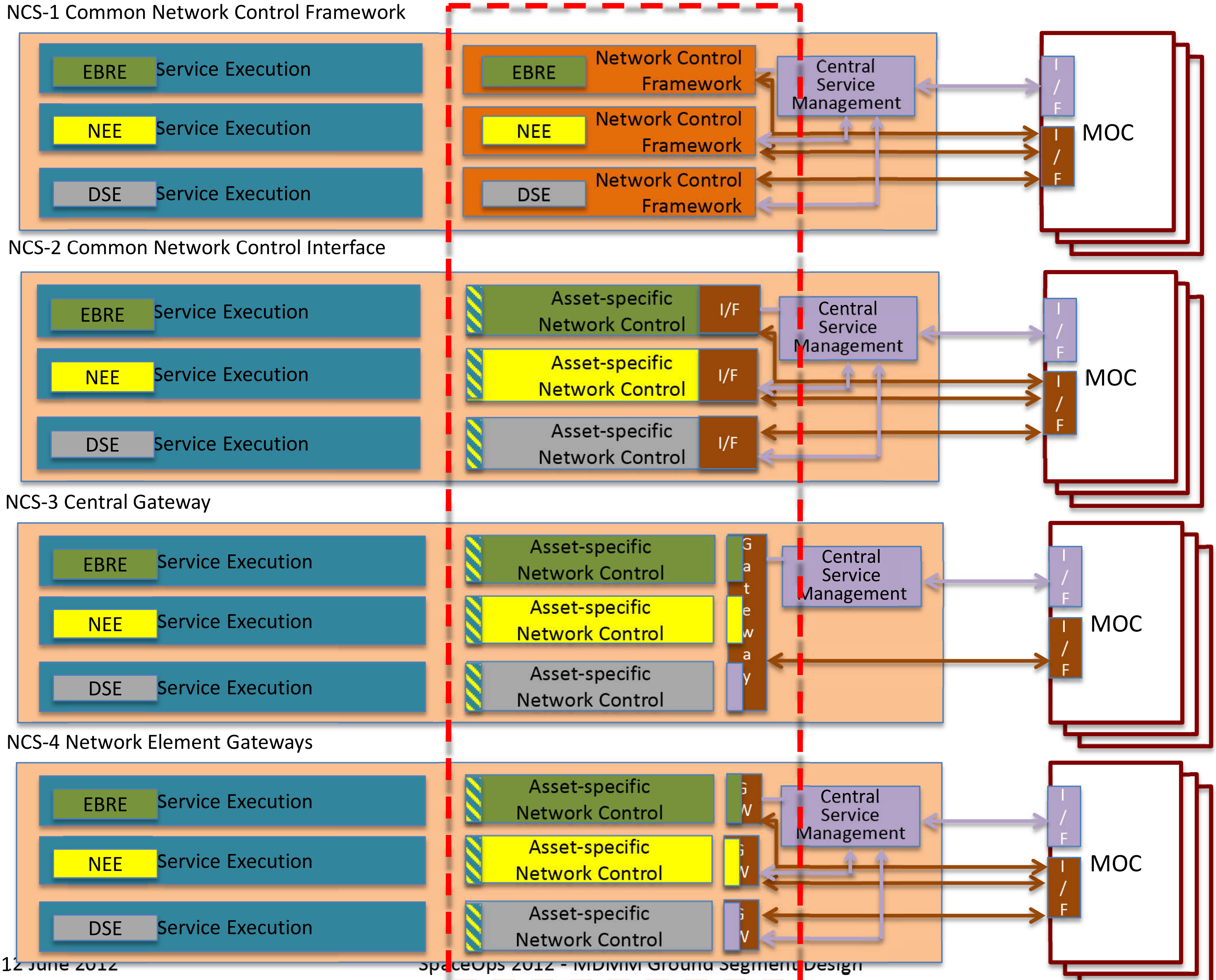
Each of the trade study cycles was initiated by producing a guiding document that typically covered the following topics in a compact form:

- An overall process flow for the trade study
- A description of each of the separate parts of the study e.g., software, hardware, operations
- Statement of the purpose and objectives of each part of the trade study
- Any assumptions and constraints
- The scope of the study, typically related to the baseline functional overview
- Description of how the network and system elements mapped into the trade study
- Definition of the trade space options to be considered
- Description of the approach to be used for the trade study
- Team composition, duration, and planned schedule for the effort

Integrated Network Architecture Trade Study Cycles 2-3

Based on conclusions of the Cycle 1 Study - Drill down into detailed analysis to refine the cost estimates for architecture selection during Cycles 2-3:

- Integrated Network Control Study
  - Covers Network Control functions (minus Network Scheduling)
    - Network Asset Configuration & Control
    - Network Asset Monitoring
    - Space Internetworking Management
- COOP Study
  - Address Network Control aspect of the COOP
  - Service Execution is no longer an issue for COOP after Cycle-1 decision
- Space Internetworking Study
  - Any changes required to Service Execution and Network Control functions.


NCS-1 Common Network Control Framework
EBRE
Service Execution
NEE
Service Execution
DSE
Service Execution
EBRE
Network Control Framework
NEE
Network Control Framework
DSE
Network Control Framework
Central Service Management
I/F
I/F
MOC
NCS-2 Common Network Control Interface
EBRE
Service Execution
NEE
Service Execution
DSE
Service Execution
Asset-specific Network Control
I/F
Asset-specific Network Control
I/F
Asset-specific Network Control
I/F
Central Service Management
I/F
I/F
MOC
NCS-3 Central Gateway
EBRE
Service Execution
NEE
Service Execution
DSE
Service Execution
Asset-specific Network Control
Asset-specific Network Control
Asset-specific Network Control
Gateway
Central Service Management
I/F
I/F
MOC
NCS-4 Network Element Gateways
EBRE
Service Execution
NEE
Service Execution
DSE
Service Execution
Asset-specific Network Control
GW
Asset-specific Network Control
GW
Asset-specific Network Control
GW
Central Service Management
I/F
I/F
MOC

Modeling Approach

- Initial Cycle 1 "modeling" was done using a combination of PowerPoint, Excel spreadsheets, and some analytical simulations of mission set loading and required network throughput
- As we moved into software and system Trade Study cycles more accurate models were required
- The team adopted Magic Draw / SysML and a Teamwork repository to coordinate the distributed effort
- Two centers provided the modeling leads: JPL for system and software models, GRC for operational activity models
  - JPL Team: Shames, Sindiy, Donahue, Levesque
  - GRC team: Kunath, Reinert, Barnes
- SMEs from GSFC and JPL provided the domain knowledge and reviewed the models
  - GSFC SMEs: Wright, Anderson, Kowal
  - JPL SMEs: Tai, Levesque, Barkley, Johnston, Wolgast
- Experts from the network elements and HQ, and a Red Team with a mission focus, reviewed interim and final results of each cycle

System Modeling Methods

- UML and SysML provide a series of diagram types, but it is up to the modeling team to determine which viewpoints and views best represent the system
- For these models we used these viewpoints - derived from CCSDS Reference Architecture for Space Data Systems (RASDS):
  - System software structures and data / control flows (function BDD structure and IBD composition)
  - System and software product line / variation points (function BDD generalization and specialization)
  - System deployment across multiple sites (site and function BDD showing allocation)
  - Software functional abstractions (abstract function activity and BDD generalization and specialization)
  - Information models (information object BDD)
- Use stereotypes and colors to make models readable and (more readily) interpretable, types, variations, specializations
- Develop a “Guide for the Perplexed” to hand-hold novices in reviewing HTML browse models

EBRE PoD Architecture Model

- The SN is doing a major upgrade called the Space Network Ground System Sustainment (SGSS) project
  - This is assumed to provide the primary viable approach for implementing the whole of the next generation SCaN architecture
  - Other options are also being studied
- The SGSS design (pre-PDR) has the following characteristics:
  - SGSS has the following elements: Space ground Link (SGL), User Services gateway (USG), Digital Signal Processor (DSP), Service Management (SM), Fleet Ground Management (FGM), Enterprise Infrastructure (EI)
  - The SGSS architecture is a quite modern concept, using a pool of shared, programmable servers 9including blades and FPGAs), a high speed set of networks, and an message bus based enterprise infrastructure
  - Service Management (SM) orchestrates the delivery of SGSS TT&C and User services. It provides the remote SN user service management interfaces and local SN operator interfaces for managing SN services.
  - The Fleet Ground Management (FGM) element manages and controls the TDRS Fleet, and manages the Ground Segment. Management and Control is isolated from user or TTC bearer data wherever possible. The element provides distinct capabilities in an integrated element – Fleet Management, Fleet Control, Ground Management, and Ground Control.
  - SGL, DSP & USG all have Control Test & Monitor functions. "Control, Test, & Monitor (CTM) functions manage, control and test each element. CTM functions accept service requests and provide service status on the control plane. CTM functions load software, load configurations, report detected faults, and provide performance information on the management plane."
- A primary purpose of the Cycle 2 studies is to assess whether the SGSS architecture is suitable for use in the other two network elements (DSE & NEE) or if some other alternatives are more functional, lower risk, or more cost effective

EBRE Level 2 Architecture

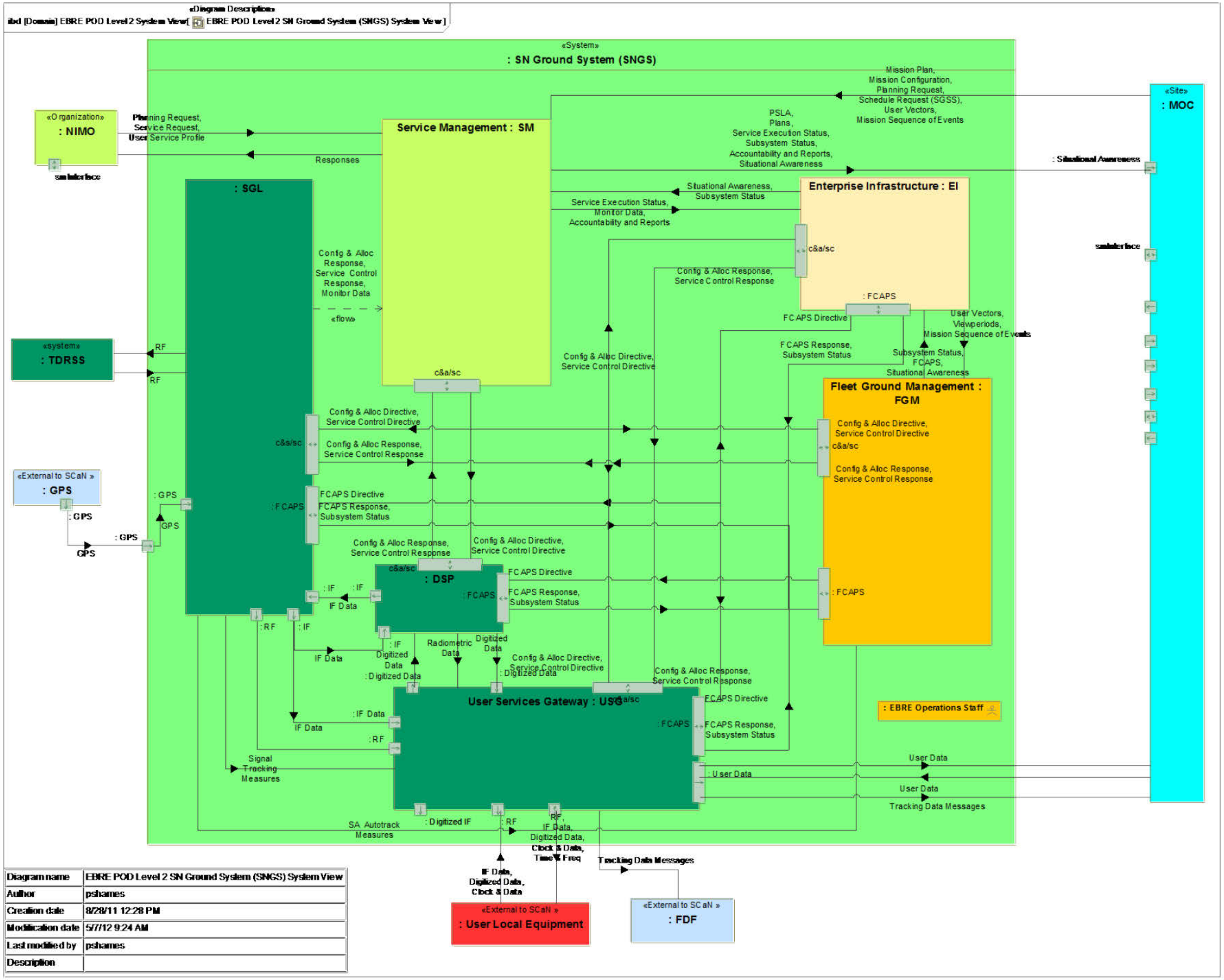
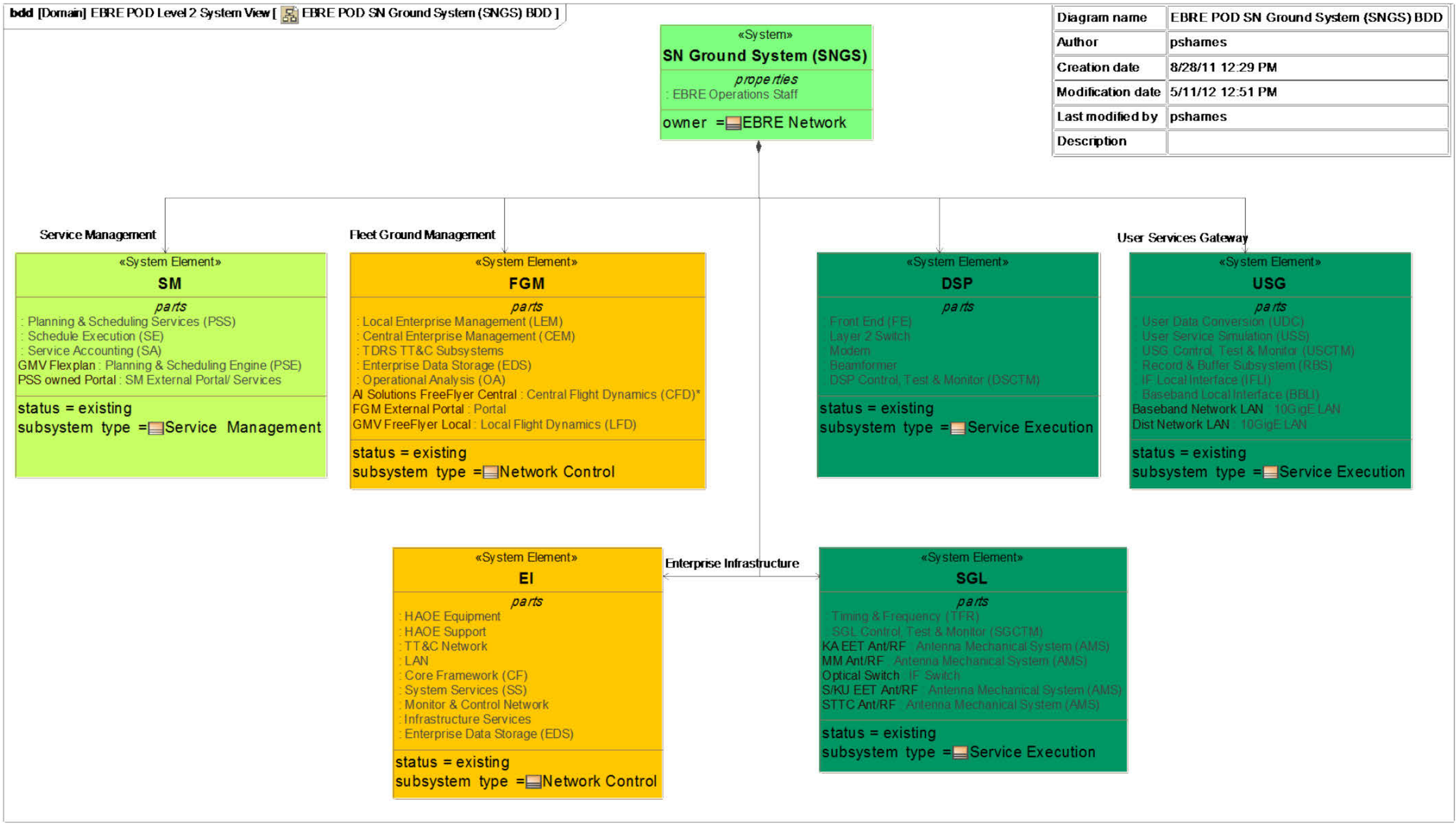


Diagram name	EBRE POD Level 2 SN Ground System (SNGS) System View
Author	pshames
Creation date	8/28/11 12:28 PM
Modification date	5/7/12 9:24 AM
Last modified by	pshames
Description	

NCS-1 EBRE Level 2 System Composition Model



EBRE Level 3 Service Management (SM) Software Architecture

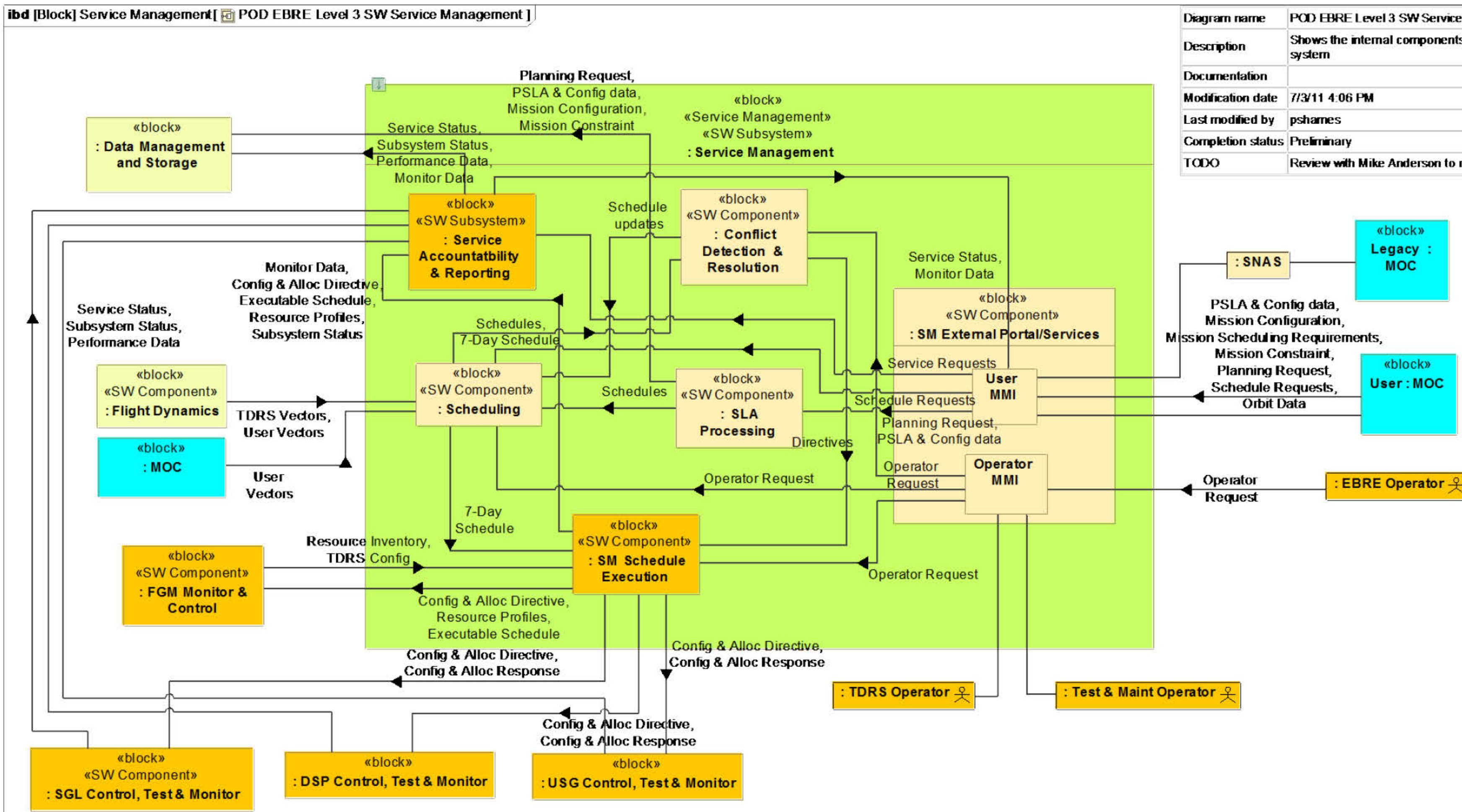


Diagram name	POD EBRE Level 3 SW Service Managemen
Description	Shows the internal components of the EBRE system
Documentation	
Modification date	7/3/11 4:06 PM
Last modified by	pshames
Completion status	Preliminary
TODO	Review with Mike Anderson to resolve questi

NCS-1 Integrated Overview

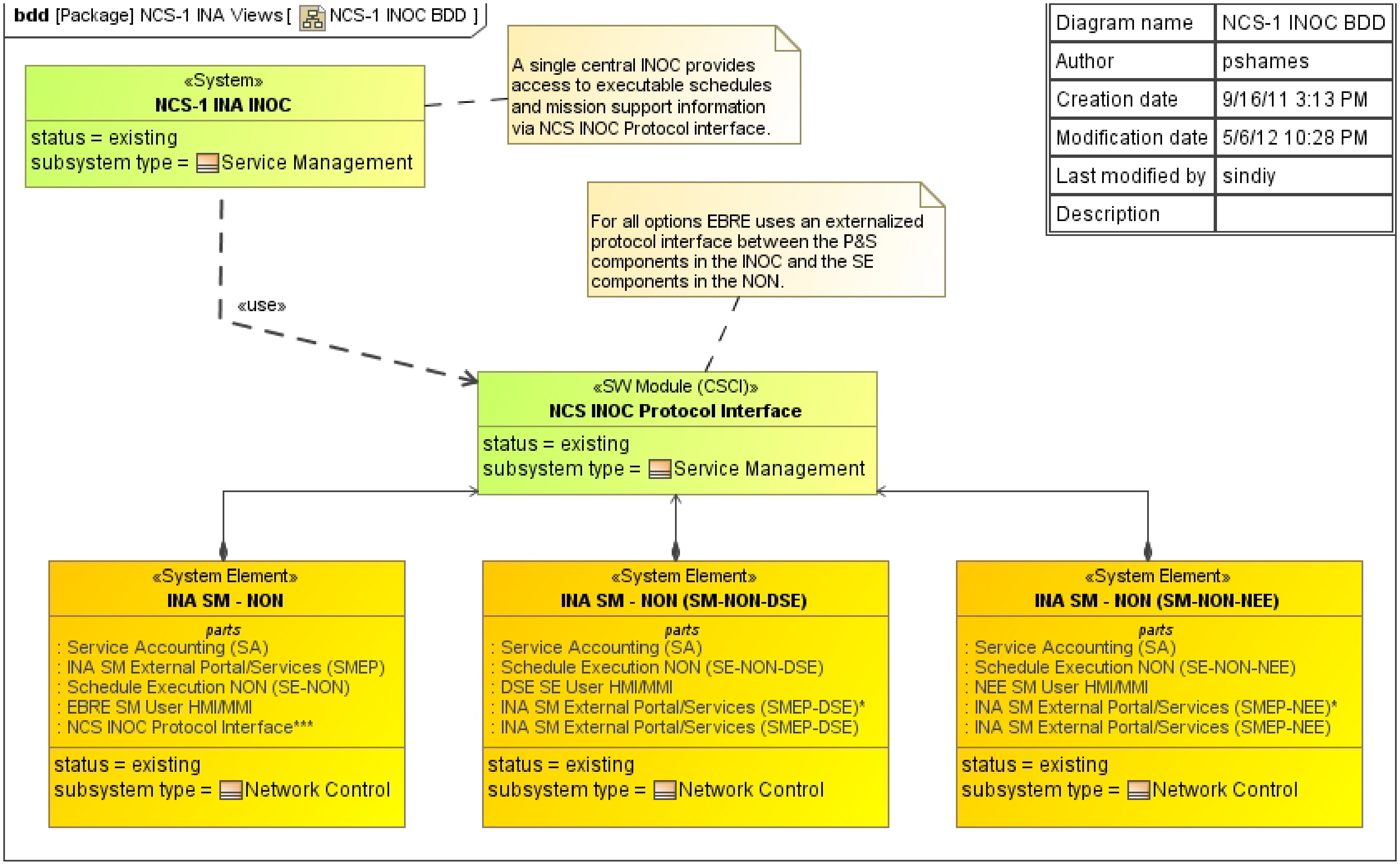
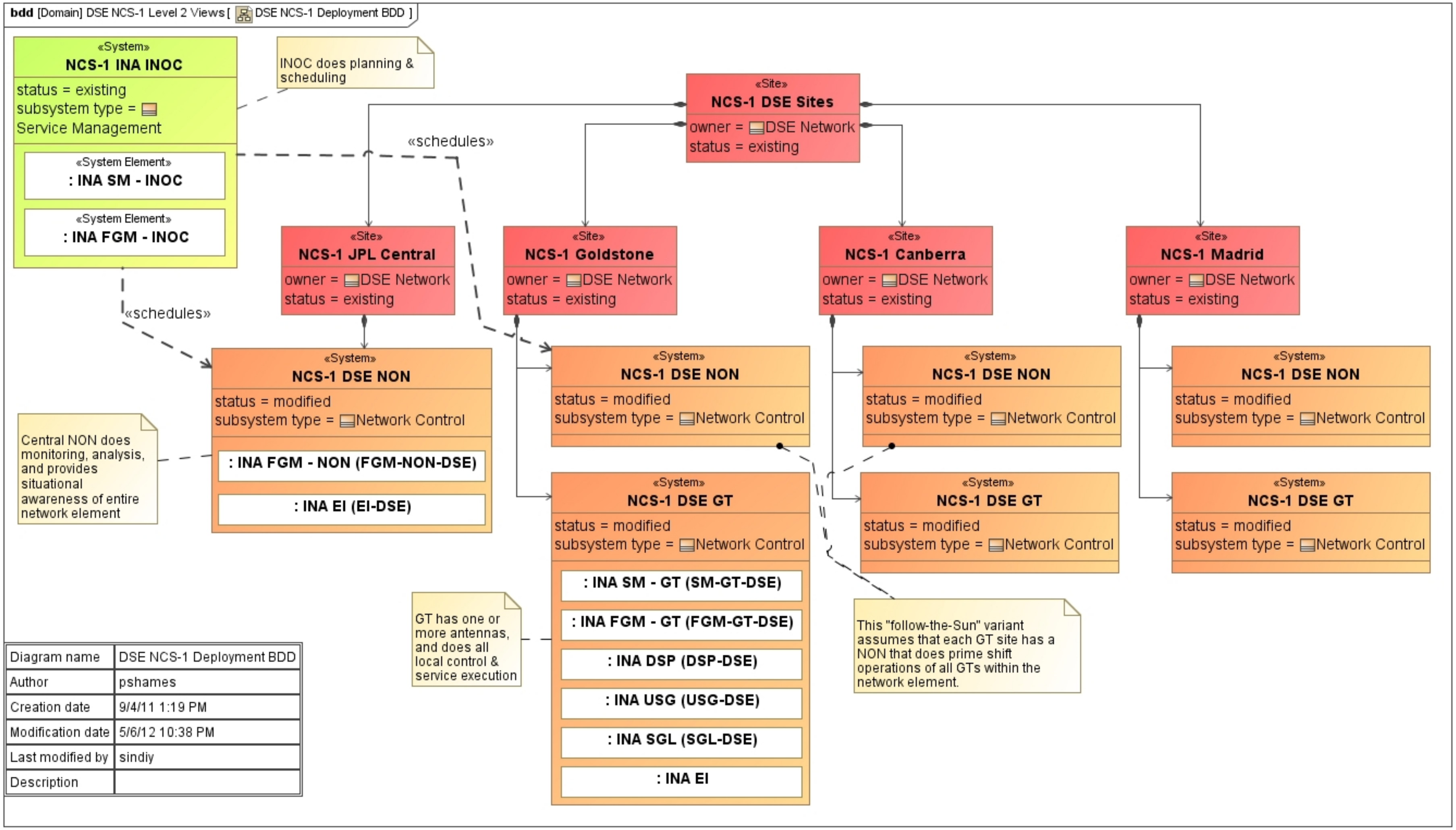
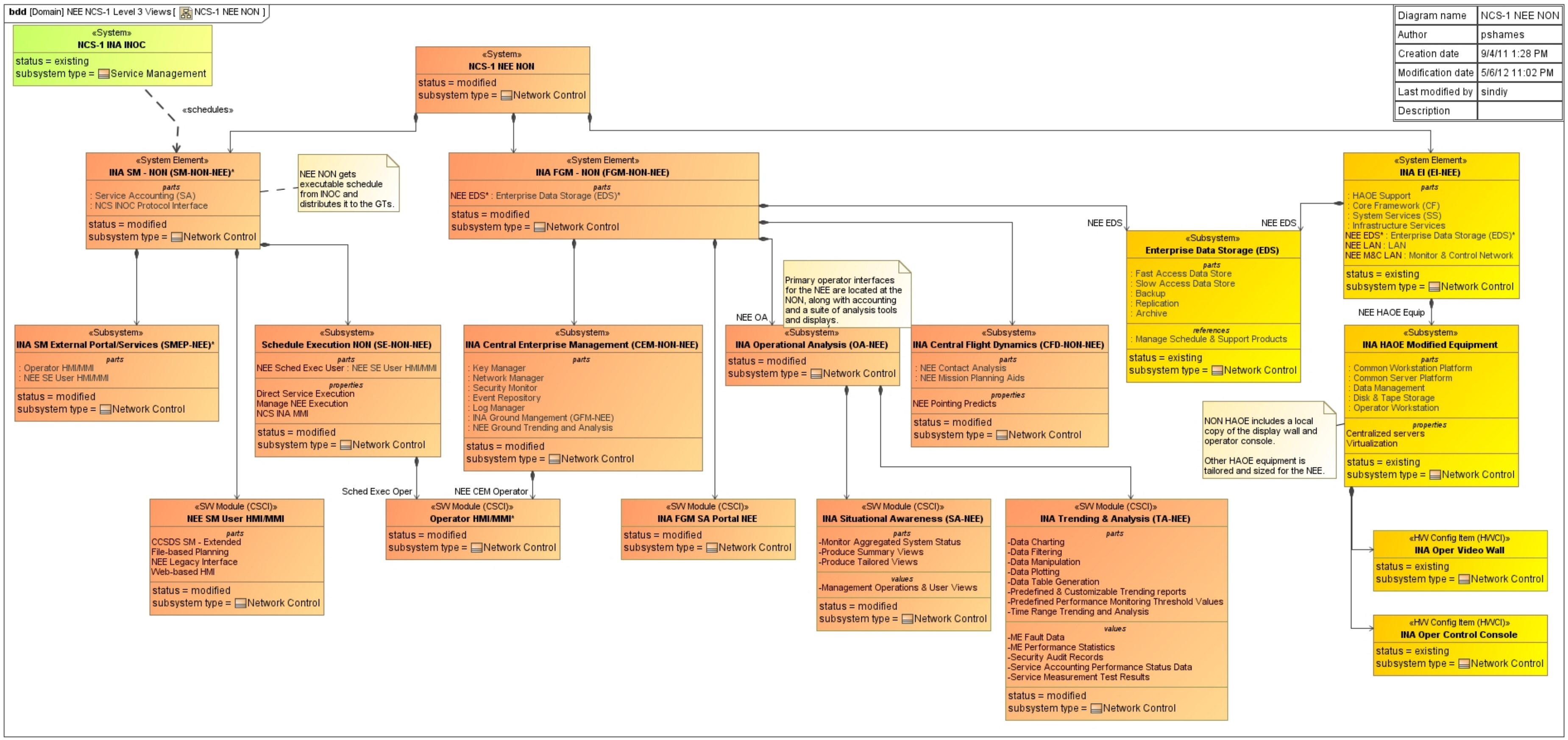


Diagram name	NCS-1 INOC BDD
Author	pshames
Creation date	9/16/11 3:13 PM
Modification date	5/6/12 10:28 PM
Last modified by	sindiy
Description	

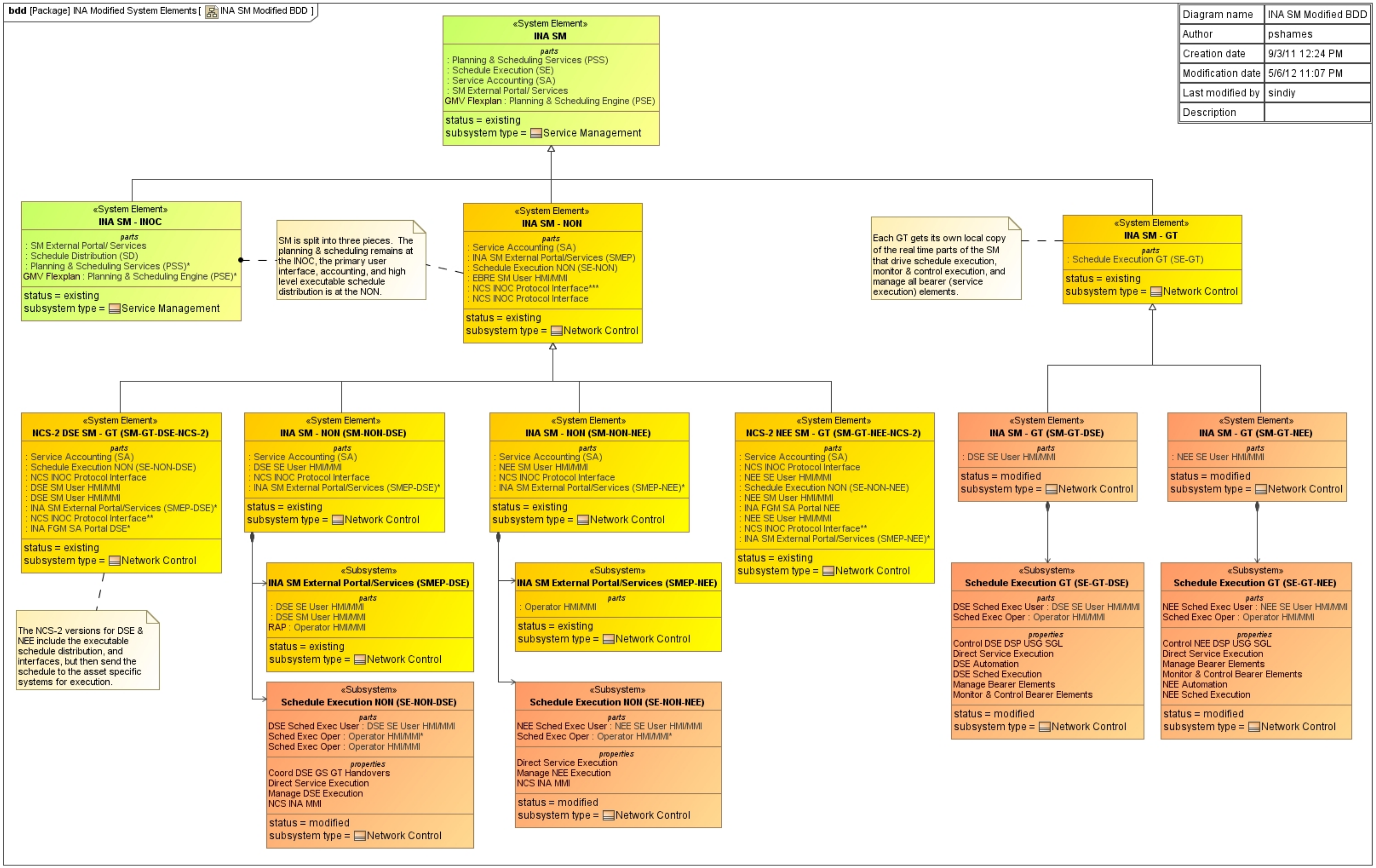
NCS-1 DSE Level 2 Deployment Model



NCS-1 NEE Level 3 NON Network Control Composition Model



Service Management (SM) Specialization

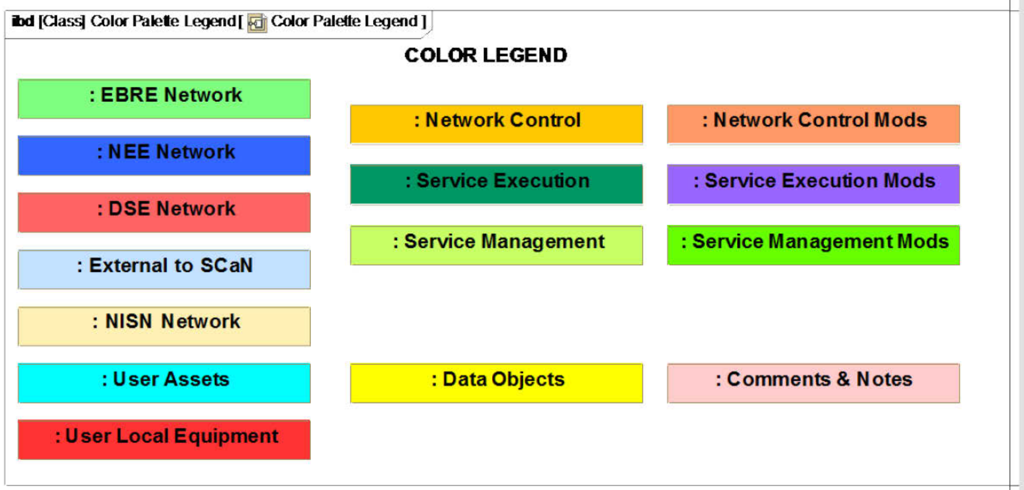


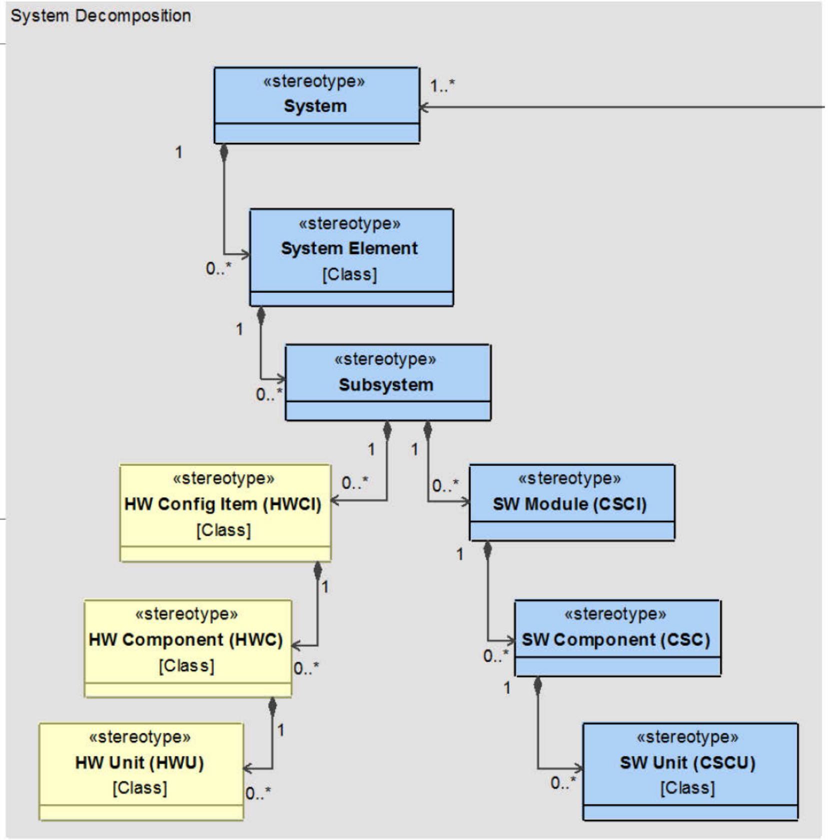
Conclusions

- SCaN has a very challenging problem in trying to integrate three quite diverse networks that have operated as independent entities for decades.
- Technical, operational, functional, cultural and political issues must be resolved.
- Doing several cycles of trade studies, and pruning the trade space, has allowed the technical problems to be worked.
- The Cycle 2 NCS analysis, costing, and scoring exercise have demonstrated that the NCS-1 approach, leveraging the new EBRE software, appears to be viable for the other two network elements
  - Prototyping of this approach must be done to validate this conclusion
- Having clearly articulated models of these systems and the possible options has aided the team's understanding of the problem
- These models have become an important part of analyzing the technical options and supporting the analysis of alternatives and the costing of the resulting designs.
- Using a model-based approach, with all the possibility of consistency checking, successive refinement, composability, and re-use, continues to bring significant advantages to future trade study cycles.

BACKUP

Model Color Palette & System Stereotpyes

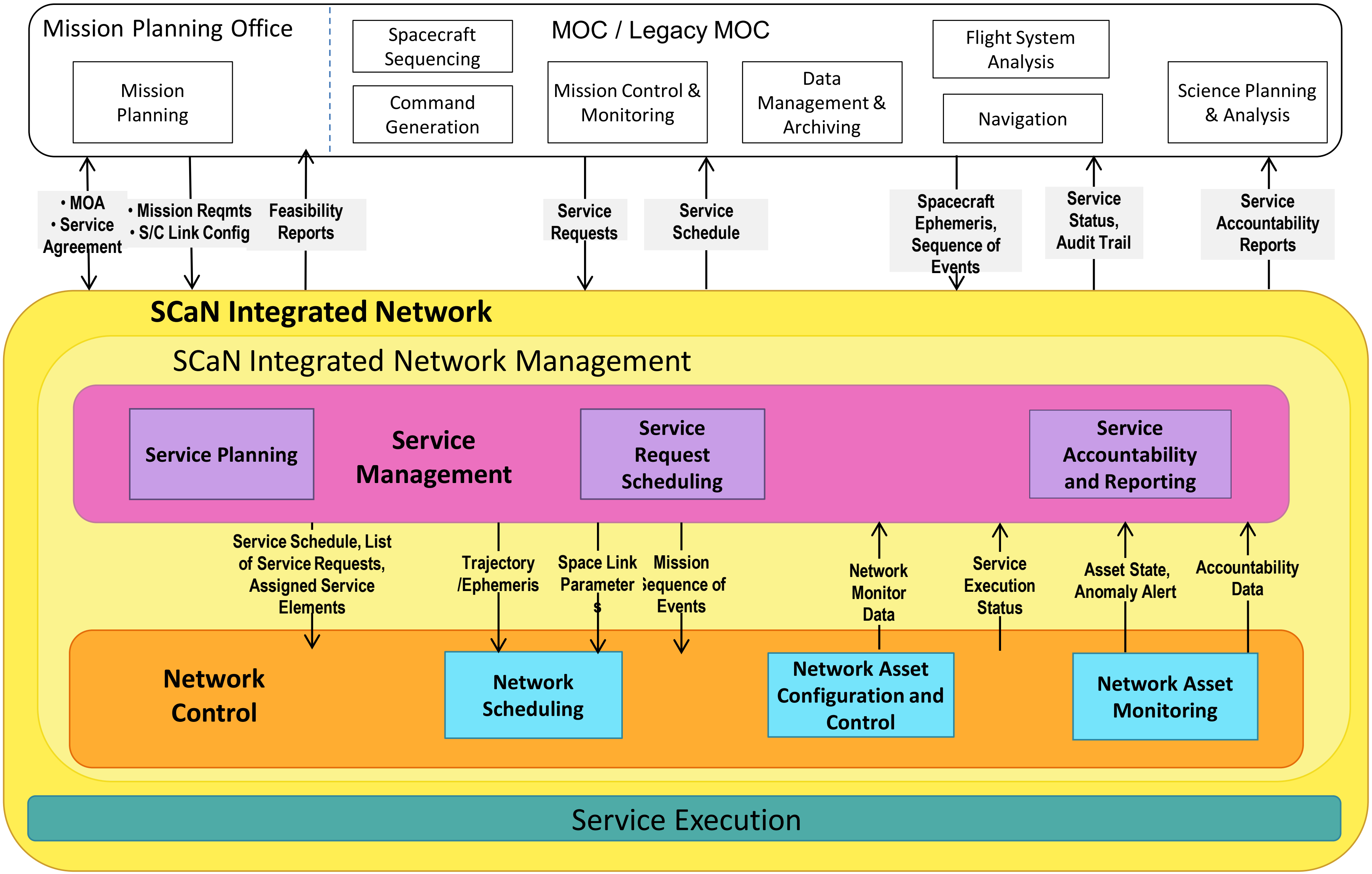




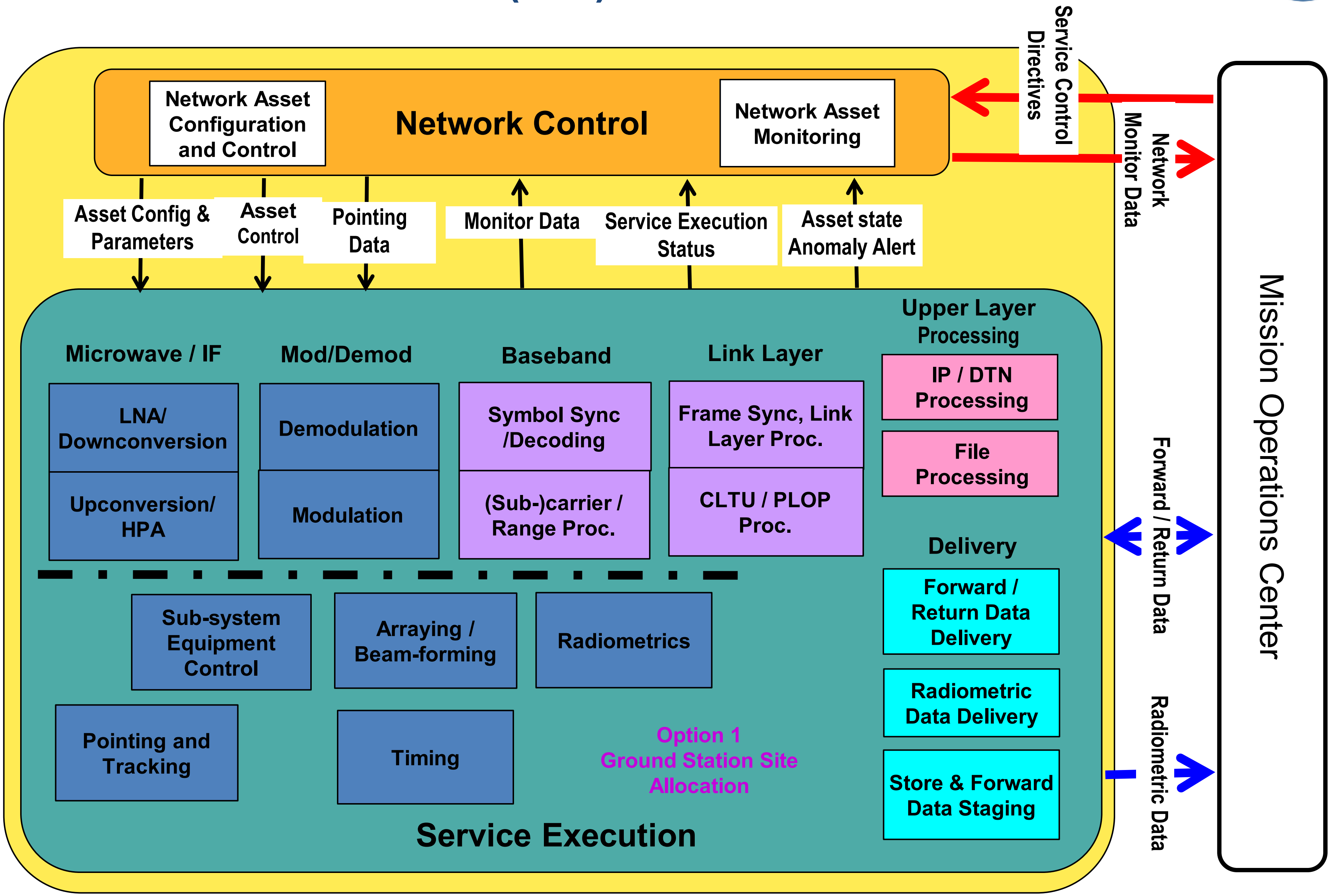
Problem Space
SCaN System of Systems Architecture Model

- NASA's Space Communications and Navigation (SCaN) office has responsibility for the DSN, SN and NEN communications networks
- These three networks are each 35-50 years old and have been evolving on their own for much of that time
- SCaN has been directed, by NASA HQ, to:
  1. develop a unified space communications and navigation network infrastructure capable of meeting both robotic and human exploration mission needs
  2. implement a networked communication and navigation infrastructure across space
  3. assure data communication protocols for Space Exploration missions are internationally interoperable
- A multi-center team (JPL, GSFC, GRC, HQ) has been studying how to accomplish this using an AoA / tradespace method since March 2008
- Formal modeling of the architecture options has been in work since March 2011

SCaN Integrated Network Management (INM) Overview



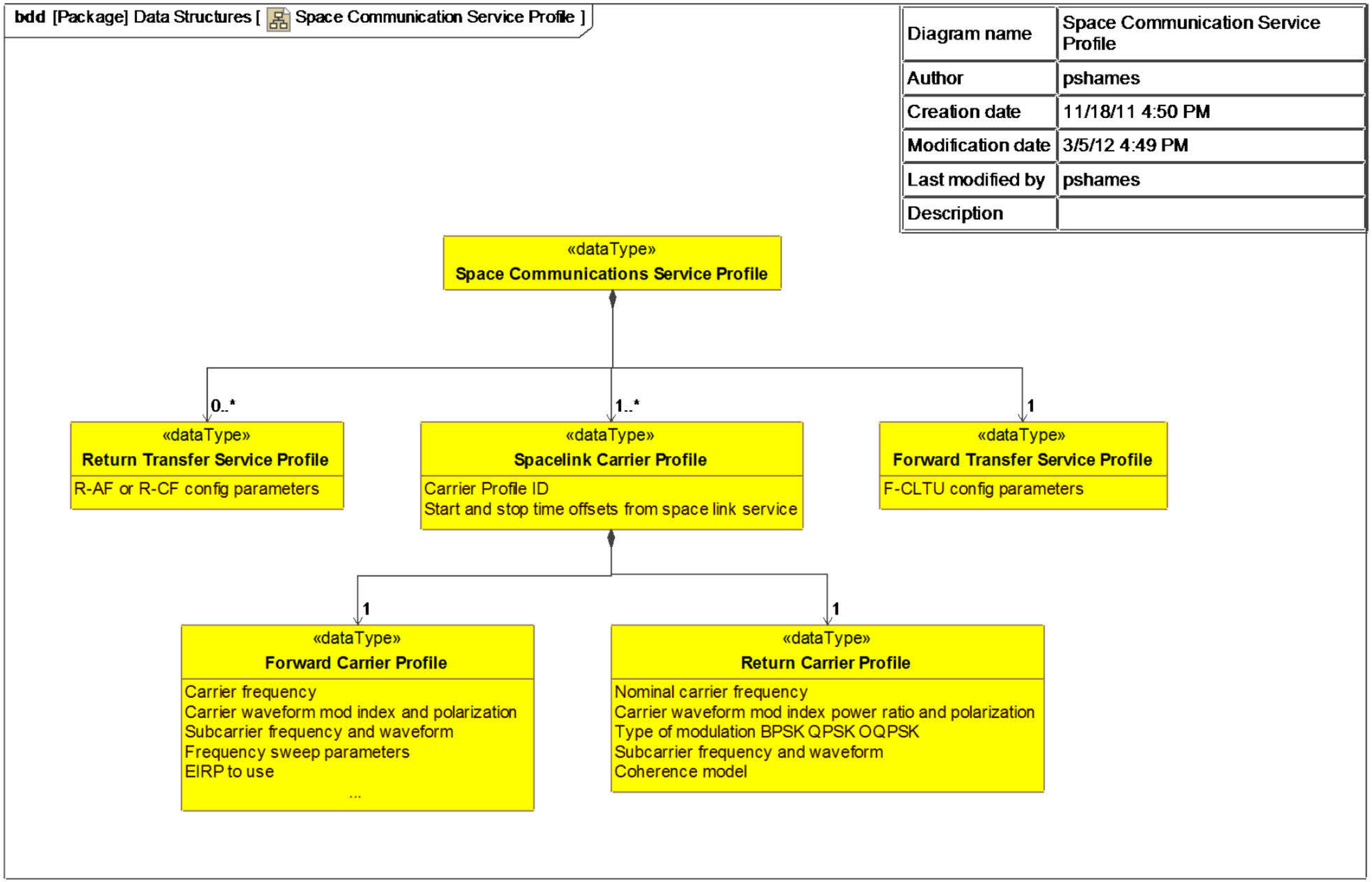
SCaN Integrated Service Execution (ISE) Overview



SCaN Standard Services

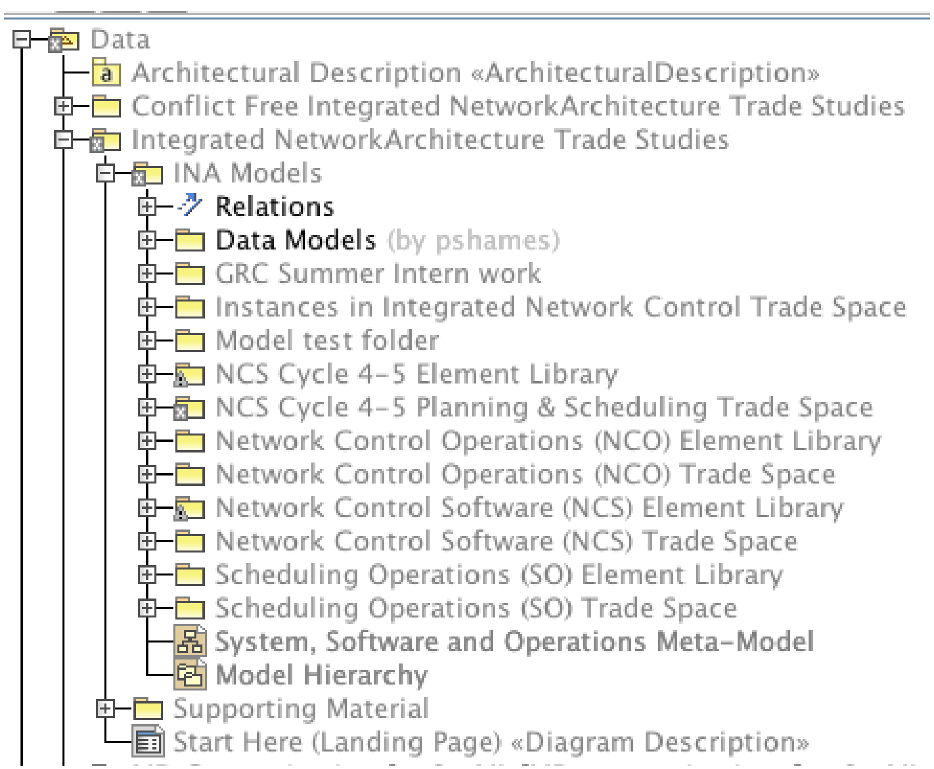
- **SCaN standard services are "off-the-shelf" capabilities readily available to space flight missions**
  - "Standard services" will be offered by all NASA Space Communications Networks
  - Legacy and other non-standard services will continue to be provided, but possibly at increased cost to the missions
- **Unless otherwise noted, SCaN standard service interfaces between mission ground elements and NASA Communication Service Infrastructure elements are based on CCSDS Space Link Extension (SLE) and Cross Support Transfer Service (CSTS)**
- **Space links conform to:**
  - CCSDS standards for space link protocols, synchronization and channel coding
  - CCSDS standards for RF and Modulation
  - SN RF and modulation (for SN)
  - Upper layer protocols like CFDP, DTN and IP (where applicable)
- **For all SCaN standard services, NISN provides the underlying wide-area networking services used to connect mission ground elements with NASA Communication Service Infrastructure elements**
  - For these services, NISN services are part of the "package"
  - NISN communication services that connect mission ground elements to each other for purposes other than space communications are not covered by this service architecture

Cycle 2-3 Space Comm Service Profile Info Model



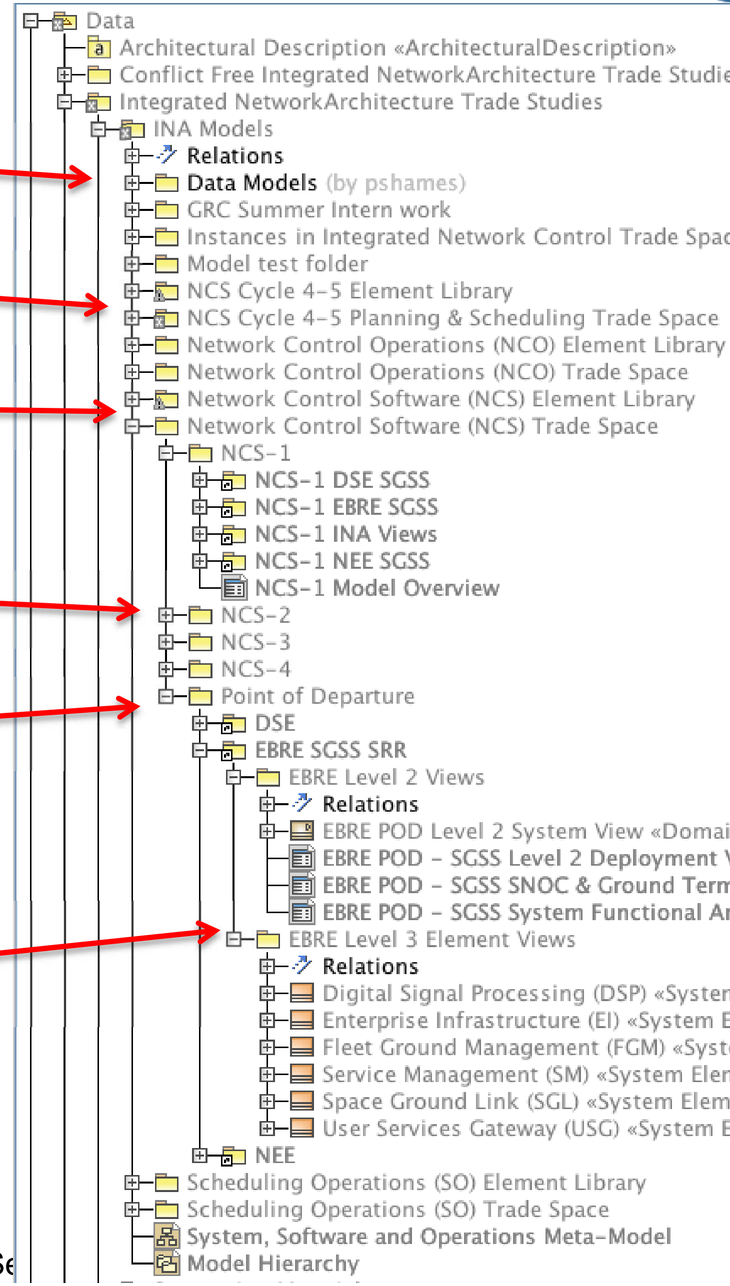
Modeling Methods for SoS & Trade Studies

- Develop containment hierarchy with slots for:
  - Global terminology, stereotypes, and overview
  - Data model
  - Libraries of components (software, hardware, facilities, staff)
  - Point of Departure (PoD) and trade space elements
  - Common views and specialized views as needed



Sub-set of Trade Study Model Hierarchy

- Data Models
- Separate sections for each trade study cycle
- Separate sections for re-use libraries and model options
- Separate sections for each trade study option
- PoD models for reference and re-use
- Views of different types at multiple levels of detail for each element



Summary of Modeling Process

The fundamental steps are:

- Define the problem space and scope, per stakeholder concerns
- Clarify the set of designs and artifacts to be produced at a high level
- Define the overall modeling framework approach to be used
- Identify the kinds of design artifacts needed to answer the questions being posed by the key stakeholders
- Select the set of viewpoints to be used – e.g. functional, physical, logical, information, organizational, deployment, etc, and the set of views to be produced
- Define the trade space and element library model hierarchy and at least the top two levels of decomposition of the hierarchy
- Develop any necessary stereotypes, element types, color codes to mark model elements and for visual indication of element properties
- Define the major types of elements to be used in the views and create the necessary libraries of composable objects
- Define and refine the major elements that will be used to produce the trade space models
- Compose the trade space models
- Analyze the trade space models
- Do not be afraid to go back to earlier steps, even step 2 or 3, and refine the framework and the models until they are adequate to the task

Considerations for Trade Space Modeling

- Using SysML & UML to model single systems is becoming better understood
  - It has a significant learning curve for the tools and the methods
  - Attention to viewpoints and views is important to produce readable models
- Trade space and System of Systems modeling appears to be less well understood
  - There is little support for it or literature on how to do it
  - The level of detail and completeness must be balanced with how models are to be expanded in future cycle
  - It appears to have a real value in helping teams document and understand complex system interactions and to explore a multi-dimensional trade space
  - It requires a different approach to modeling than single system models, and we are still learning how to do it
- It would probably be of use to document the method and some guidelines for doing SoS and trade space modeling
- Libraries of viewpoint specifications and “model parts” for re-use would also be a huge benefit where that is possible

Observations on Model Based System Engineering

- UML & SysML permit a lot of flexibility, both a blessing and a curse
  - Casual uses of modeling methods are quicker, but do not necessarily lend themselves to easy re-use
  - Drawings (PPT or other) do not equal models
  - Rigor takes more time (define views & viewpoints, libraries, stereotypes, modeling approach, terminology), but better supports re-use and refinement of model elements
  - Training in the methods & the tools is almost indispensable
- Adopting common approaches (SysML vs DoDAF vs ad hoc) and agreeing on common terminology is essential (and hard)
- Formal models take some getting used to: guides, tutorials, “Start here” and overview pages help a lot
- Distributed teams are tough to organize, partitioning the problem and allocating responsibility along obvious lines helps a lot
- Use of QVTO can assist in model analysis and metrics, even if model is not fully formed, i.e. size & complexity measures, completeness and connectivity measures
- Institutional security policies may make shared modeling complicated (firewalls, RSA token, full tunnel, user credentials)