POWER ELECTRONIC POWER DISTRIBUTION SYSTEM ARCHITECTURES VERSION 2.0

Technical Report

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Submitted by:
Carmen E. Araujo, David C. Gross, Karl Schoder,
Matthew Bosworth, Naqash Ali, Joshua Bush

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ELECTRIC SHIP RESEARCH AND DEVELOPMENT CONSORTIUM

MISSION STATEMENT

The Electric Ship Research and Development Consortium brings together in a single entity the combined programs and resources of leading electric power research institutions to advance near- to mid-term electric ship concepts. The consortium is supported through a grant from the United States Office of Naval Research.

2000 Levy Avenue, Suite 140 | Tallahassee, FL 32310 | www.esrdc.com

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1 EXECUTIVE SUMMARY

This report discusses the process, product, and purpose of the PEPDS System Model Version 2.0 which captures diverse stakeholder needs, analyzes black box and white box functions, defines black box and white box context and interfaces, and identifies measures of effectiveness and performance. The foregoing elements distill into a set of system requirements that result in the PEPDS functional architecture. These system requirements are being analyzed by the Mini-PEPDS Design Exercise whose objective is to validate the system requirements by creating a design and verifying that design against those requirements. Version 2.0 contains the Mini-PEPDS Design Exercise Iteration 1 Phase 1. This report is intended to accompany the PEPDS System Model Version 2.0 with the purpose of assisting the reader in navigating and understanding the model.

2 NOMENCLATURE

Nomenclature is defined in the PEPDS System Model Glossary provided in section 11.3, the MagicGrid® Book of Knowledge glossary from reference [1], and the No Magic Inc. Glossary of SysML Concepts from reference [2].

3 INTRODUCTION

The Power Electronic Power Distribution System (PEPDS) is a new power, energy, and control distribution concept enabled by technology development funded by the Office of Naval Research (ONR). "The goal of the PEPDS program is to achieve revolutionary changes to system design and operation by leveraging recent technological advances and developing both the applications to use them and the control and modeling capabilities needed to employ them" [3]. The PEPDS development program has five (5) main areas of science and technology development:

1. Navy Integrated Power Electronics Building Block (NiPEBB),
2. Navy Integrated Power and Energy Corridor (NiPEC),
3. Model is the Specification,
4. Control, and
5. System Simulation.

The technical approach for integrating this work is digital engineering grounded in Model-Based System Engineering (MBSE). The product of this MBSE effort is the PEPDS System Model which is a living document that will change and grow throughout the lifetime of the system.

This report discusses the process, product, and purpose of the PEPDS System Model Version 2.0 which captures diverse stakeholder needs, analyzes black box and white box functions, defines black box and white box context and interfaces, and identifies measures of effectiveness and performance. The foregoing elements distill into a set of system requirements that result in the PEPDS functional architecture. These system requirements are used for the initial solution space exploration through the Mini-PEPDS Design Exercise Iteration 1 Phase 1. This report is intended to accompany the PEPDS System Model Version 2.0 with the purpose of assisting the reader with navigating and understanding the model.

4 PROCESS

This section discusses the process used for developing the PEPDS System Model Version 2.0.

4.1 Contributors

The authors are chartered to lead the PEPDS functional architecture development. In that role, we established the PEPDS Architecture Team, see Table I, to provide a framework for PEPDS architecture studies and to enable collaborative research. The PEPDS Architecture Team uses the

Systems Modeling Language (SysML) to develop the PEPDS System Model with the Cameo Enterprise Architecture Version 2022 software, explained in detail in section 4.2. Consistent with similar projects at the Naval Sea Systems Command (NAVSEA), the PEPDS System Model follows the MagicGrid® Framework, explained in section 4.3.

Table I: PEPDS Architecture Team Members

Member Group	Research	Name	Role
FSU CAPS PS Team	Architectures Research Abilities Research System Integration Research	Karl Schoder	PEPDS Lead Architect, Principal Investigator
		Carmen E. Araujo	PEPDS Architecture Team Point of Contact, Lead Systems Engineer, Researcher
		David C. Gross	Systems Engineer, Researcher
		Matthew Bosworth	Researcher
		Naqash Ali	Systems Engineer, Researcher
		Joshua Bush	Systems Engineer, Researcher
		Sihun Song	Researcher
FSU CAPS TMM Team	Thermal Management Research	Juan Ordonez	Principal Investigator
		Christofer Marques	Researcher
		Chaianan Sailabada	Researcher
MIT Sea Grant Team	NiPEC Research Naval Architecture Research	Julie Chalfant	Principal Investigator
		Avi Chatterjee	Researcher
		Drake Platenberg	Researcher
		Emily Curran	Researcher
		Wade Meyers	Researcher
USC ERL Team	Controls Research	Herbert L. Ginn	Principal Investigator
UTA PPEL Team	Energy Storage Research	David A. Wetz	Principal Investigator
		Alex Johnston	Researcher
		Hayden Atchison	Researcher
		Shawn 'Tyler' Scoggin	Researcher
UWM SEES Team	Virtual Prototyping Research	Robert M. Cuzner	Principal Investigator
		Hamed Shabani	Researcher
		Jacob David Gudex	Researcher
		Sonia Bendre	Researcher
VT CPES Team	NiPEBB Research	Dong Dong	Principal Investigator
		Daniel Sathri	Researcher
		Marie Lawson	Researcher
ONR Team Members		Nathan Spivey	SME
NSWCPD Team Members		Christian Schegan	Chief Engineer, SME
		Aaron Scherr	SME
	Stability Design & Assessment Research	Robert 'Bob' Irwin	Principal Investigator, SME
		Shawn Plesnick	Co-Principal Investigator, SME
PEPDS Architecture Team Past Team Members	Michael 'Mischa' Steurer (FSU), Ceca Mijatovic (FSU), Salman Hussain (FSU), Jodie Bell (FSU), Matt Kruse (MIT), Aaron De La O Perez (USC), James Narey (UTA), William Joseph Koebel (UWM), Joey Authement (UWM), Jose Antonio Trujillo Parra (UWM), Rounak Siddaiah (UWM), Igor Cvetkovic (VT), Christina DiMarino (VT), Rolando Burgos (VT), Dushan Boroyevich (VT), Richard Zhang (VT)		

4.2 Model-Based Systems Engineering

MBSE is "the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases" [4]. The benefits of using an MBSE approach over a traditional document-based approach are enhanced communications, reduced developmental risk, improved quality, increased productivity, and enhanced knowledge transfer [5].

For the PEPDS System Model, the MBSE tool being used is the Cameo Enterprise Architecture Version 2022 software. The Cameo Enterprise Architecture, herein referred to as Cameo, is a product of CATIA No Magic owned by Dassault Systems. The Cameo supported modeling language selected for the PEPDS System Model is SysML. "Modeling languages are specifications which provide standardized guidelines and structures for expressing system information" [6]. SysML is one of the more frequently used modeling languages for MBSE and is a "graphical language that utilizes diagrams and tables in order to express system information and provides a standard set of nine diagram types which can be used to organize and express system information" [6]. The information expressed via a modeling language is often organized via an architecture framework [6]. The PEPDS System Model follows the MagicGrid® Framework which is discussed in section 4.3.

4.3 MagicGrid® Framework

The PEPDS System Model follows the MagicGrid® Framework defined by the first edition of the MagicGrid® Book of Knowledge by NoMagic, Inc. The MagicGrid® Framework is shown in Fig. 1. The MagicGrid® approach "includes the definition of the problem, solution, and implementation domains in the system model. They align with the processes defined by ISO/IEC/IEEE 15288 as follows: problem domain with the Stakeholder Needs Development process, solution domain with the Architecture Definition process, and implementation domain with the Design Definition process" [1]. "Each domain definition includes four different aspects of the system to be considered and captured in the model. These aspects match the four pillars of the SysML, that is, requirements, behavior, structure, and parameters" [1].

The PEPDS System Model Version 2.0 contains content for the entire Problem Domain, S1 System Requirements, and initial exploration into the S3 System Structure. One modification to the MagicGrid® Framework occurs in the PEPDS System Model Version 2.0 in the W4 MoEs for Subsystems section. Here, the PEPDS System Model Version 2.0 provides the Measures of Performance (MoPs) that make up each of the Measures of Effectiveness (MoEs), defined in B4, for PEPDS at a system level. The MoEs and MoPs for each subsystem are not yet defined but will pull from the MoEs and MoPs defined in the B4 and W4 sections.

The PEPDS System Model contains a MagicGrid® Index, shown in Fig. 2, that provides easy access to each section's content. Each section has a package diagram that will contain links to all the diagrams and tables created for that section. A copy of each section's package diagram is provided in section 11.4.

				PILLAR			
DOMAIN			Requirements	Behavior	Structure	Parameters	
	Problem	Black Box	B1-W1 Stakeholder Needs	B2 Use Cases	B3 System Context	B4 Measurements of Effectiveness	Specialty Engineering
		White Box		W2 Functional Analysis	W3 Logical Subsystems Communication	W4 MoEs for Subsystems	
	Solution		S1 System Requirements	S2 System Behavior	S3 System Structure	S4 System Parameters	Integrated Testing
			SS1 Subsystem Requirements	SS2 Subsystem Behavior	SS3 Subsystem Structure	SS4 Subsystem Parameters	
			...	...	...	...	Analysis
			C1 Component Requirements	C2 Component Behavior	C3 Component Structure	C4 Component Parameters	
	Implementation		I1 Physical Requirements	Software, Electrical, Mechanical			

Fig. 1: MagicGrid® Framework [1]

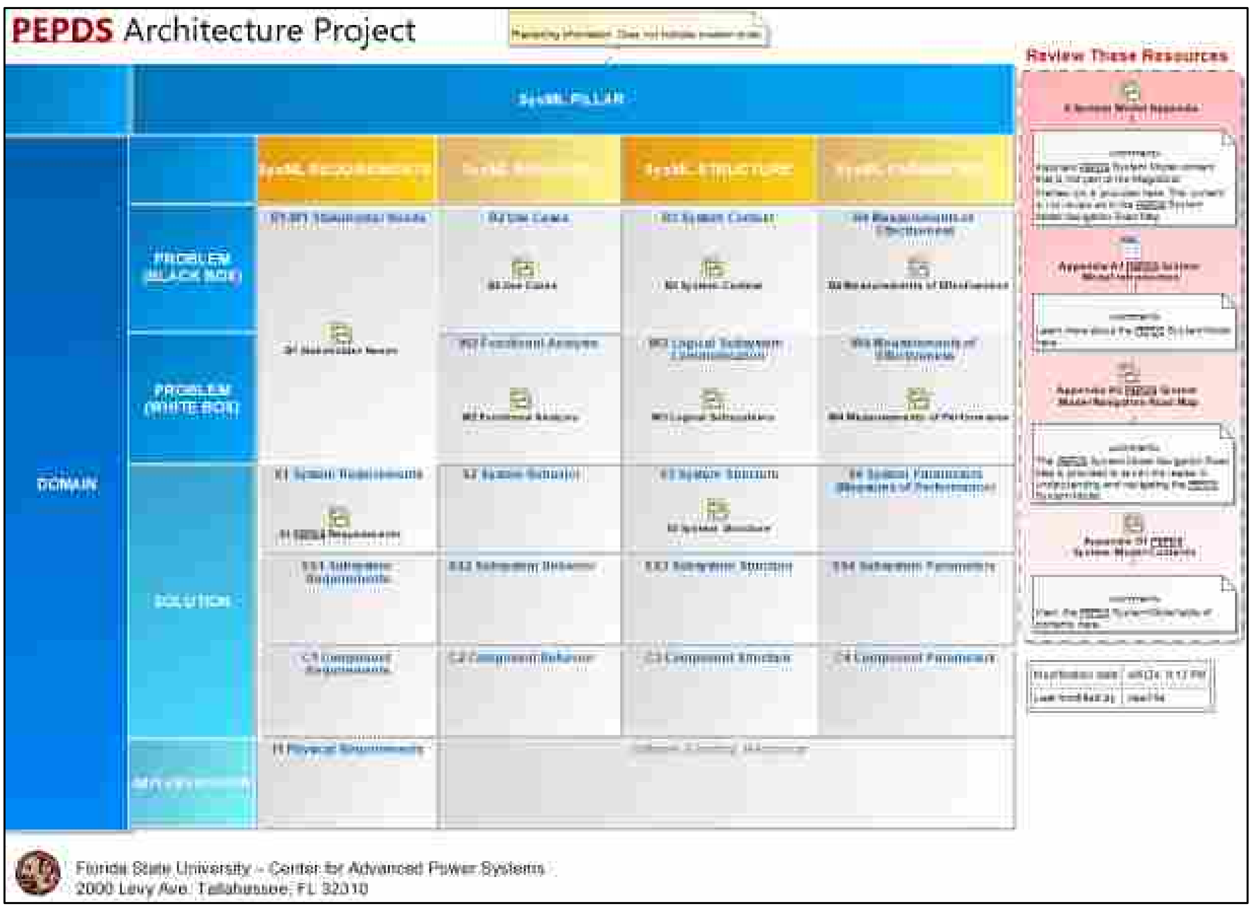

Fig. 2: PEPDS System Model MagicGrid® Index

4.4 PEPDS System Model Navigation Roadmap

To assist the reader in navigating and understanding the PEPDS System Model, a road map for navigating the model was created. Fig. 3 shows a high-level summarized version of the road map. A copy of the road map is provided in section 11.1. The PEPDS System Model can be explored using the MagicGrid® Index or the road map. This report will discuss each diagram in the model in the order suggested by the road map.

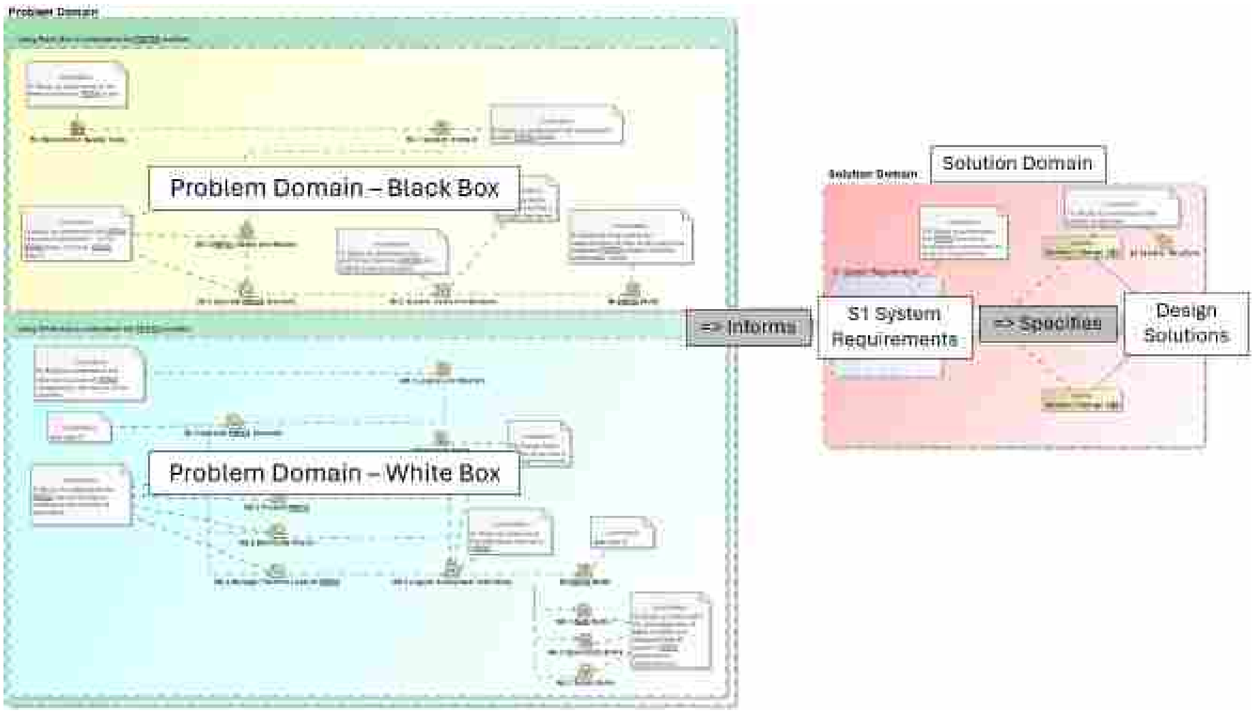

Fig. 3: Explanation of PEPDS System Model Road Map

5 PRODUCT

This section will walk the reader through the PEPDS System Model Version 2.0. The PEPDS System Model Version 2.0 captures diverse stakeholder needs, defines black box and white box context and interfaces, analyzes black box and white box functions, and identifies measures of effectiveness and performance. The foregoing elements are distilled into a set of system requirements that result in the PEPDS functional architecture. The PEPDS functional architecture is used for the initial exploration of the solution space through the PEPDS Architecture Team's Mini-PEPDS Design Exercise.

To view the model in Cameo, follow the instructions in section 10 to download, install, and use the Cameo Enterprise Architecture Reader, herein referred to as Cameo Reader. After opening the PEPDS System Model in the Cameo Reader, there will be a road map illustrating how the model developers suggest the reader should review the model. Sections 5.1, 5.2, and 5.3 of the report explain the PEPDS System Model contents in the order of the road map to enhance reader comprehension. A copy of the road map and each of the diagrams and tables reviewed with the road map are provided in Appendix B: PEPDS System Model Contents.

5.1 Black Box Problem Domain

A copy of each of the diagrams and tables reviewed in this section is provided in section 11.2.

5.1.1 B1 Stakeholder Needs Table

The B1 Stakeholder Needs Diagram defines what those involved in PEPDS require and desire. Within the model, they are represented as business requirements. Throughout the model, these business requirements are referenced to provide rationale for certain design choices. The PEPDS System Model Version 2.0 implements a tracing methodology, shown in Fig. 4, that allows tracing from all elements throughout the model to the stakeholder needs.

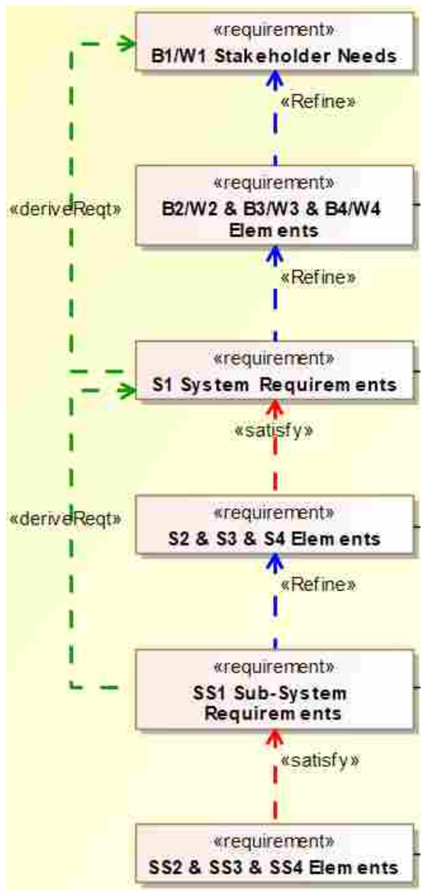

Fig. 4: Tracing Methodology [1]

The MagicGrid™ problem domain behavior (B2/W2), structure (B3/W3), and parameter (B4/W4) pillar elements refine the stakeholder needs (B1/W1). The refine relationship shows what elements are adding more information or expanding on the refined element. The B2/W2, B3/W3, B4/W4 elements are then refined by the S1 System Requirements. Since the S1 System Requirements are refining the problem domain elements that refine the stakeholder needs, they become derived requirements of the stakeholder needs, expressed as a deriveReq relationship. After the S1 System Requirements, a satisfy-refine pattern emerges. The MagicGrid™ solution domain behavior (S2), structure (S3), and parameter (S4) pillar elements need to satisfy the S1

System Requirements. The SS1 Subsystem Requirements then refine the S2, S3, S4 elements thus becoming derived requirements of the S1 System Requirements. This pattern continues for each level of abstraction of the solution domain. Implied relations are automatically identified through the MBSE software. Through the assignment of relationships and implied relationships, all system model elements are traced back to the stakeholder needs. This tracing methodology allows for verification and validation of the design solution.

5.1.2 B3.1 System Context

The B3.1 System Context diagram shows how PEPDS exists in its environment. PEPDS is an electric system existing on the electric ship. It interacts with other systems on the electric ship as well as external systems. These interfaces are defined in the B3.2 System Context Interfaces diagram discussed in section 5.1.6.

5.1.3 B2.1 Use Cases of PEPDS

After gaining an understanding of the system context, proceed to review the PEPDS concept of operations. The PEPDS System Model Version 2.0 defines the concept of operations in three diagrams that express what PEPDS does, but not how PEPDS does it.

The first step is to understand its use cases shown in the B2.1 PEPDS Use Cases diagram. An important requirement of PEPDS is to simplify its operation and maintenance to the point that minimal training on PEPDS is required for the crew. In addition to this, Maintain PEPDS is an included use case within the Operate PEPDS use case. This is because it is required that PEPDS can remain operational while maintenance is performed. The goal is that PEPDS always remains operational while away from the shipyard. This means that PEPDS' ability to operate in nominal and off-nominal conditions is required in addition to its ability to operate during times of maintenance. This concept is further elaborated on in the B2.2 PEPDS States and Modes diagram in section 5.1.4.

PEPDS is also required to have advanced functional control and simple least replaceable unit (LRU) replacement. This is part of the maintenance that must be executable by the crew. The crew is expected to be able to control the component and network functions through programming and reconfiguration as well as replace LRUs that are carriable by a single sailor and require minimal training for installation and removal.

5.1.4 B2.2 PEPDS States and Modes

The B2.2 PEPDS States and Modes diagram shows the states, modes, and transitions that exist for PEPDS. PEPDS states are Off, Operating, and Performing SHIPALT.

The Performing SHIPALT state is needed for the stakeholder need of having PEPDS installable as a unit at the shipyard. This expected PEPDS innovation consists of construction and testing being executable off the ship and avoiding intensive cabling after ship construction.

The operating state reflects the use cases defined in section 5.1.3. The Operating state has the modes of Operating in Nominal Condition, Operating in Off-Nominal Condition, and

Maintaining. The transitions between these modes defined in the diagram reflect multiple stakeholder needs. To minimize the possibilities of failures, condition-based maintenance plus (CBM+) is expected to be fully integrated into the PEPDS design. If a failure does occur, PEPDS is expected to be able to diagnose and prognose failures to autonomously recover when possible. If autonomous recovery is not possible, the crew must perform corrective maintenance. After repairs are completed, PEPDS is expected to be able to self-adapt to the repairs and upgrades as well as perform a self-check to ensure the system has fully recovered.

5.1.5 B2.3 Scenario: Operate PEPDS

The B2.3 Operate PEPDS Scenario diagram elaborates on select activities that occur while PEPDS is in the operating state defined in section 5.1.4. This diagram shows the exchange items that enter and leave PEPDS, where they come from or go to, and what activities they are used for during the Operate PEPDS scenario. The main functions of PEPDS, shown in gold, are Control PEPDS, Protect PEPDS, Distribute Power, and Manage Thermal Load of PEPDS. These functions occur simultaneously in a loop from when PEPDS is turned on to when it is turned off. The functions (depicted as behaviors in the model) define how the system achieves its capabilities (depicted as structures in the model). These behaviors and structures are further defined in the White Box Problem Domain review in section 5.2.

5.1.6 B3.2 System Context Interfaces

The B3.2 System Context Interfaces diagram displays the exchange items traveling across the PEPDS external interfaces. It shows all possible exchange items, not just the exchange items for one specific scenario like in the B2.3 Scenario: Operate PEPDS diagram discussed in section 5.1.5 .

5.1.7 B3.3/W3.3 Exchange Items

The B3.3/W3.3 Exchange Items diagram elaborates on the exchange items that travel in, out, and within PEPDS. The exchange items are color coded into what networks they belong to. In the problem domain, PEPDS contains four networks, a communication network, an electrical power network, an environmental load management network, and a hardware network.

5.1.8 B4 Measurements of Effectiveness

Based on the stakeholder needs defined in the B1 Stakeholder Needs Table discussed in section 5.1.1, three measurements of effectiveness (MoEs) were defined for PEPDS. These are RAM (reliability, availability, maintainability), operability, and safety. The B4 PEPDS MoEs diagram shows these MoEs as well as the measures of performance (MoPs) that are within them. The MoPs are defined further in the White Box Problem Domain review in section 5.2. These MoEs and MoPs measure how well a particular proposed PEPDS solution satisfies stakeholder needs. Review the B4 PEPDS MoEs traced to B1 Stakeholder Needs matrix to see how each MoE and MoP traces back to the stakeholder needs.

5.2 White Box Problem Domain

A copy of each of the diagrams and tables reviewed in this section is provided in section 11.2.2.

5.2.1 W3.1 Logical Architecture

The W3.1 Logical Architecture diagram defines the subsystems of PEPDS which are defined in the model as capabilities. These capabilities (depicted as structures in the model) represent what the system of interest can do, as contrasted with the functions (depicted as behaviors in the model) introduced in the B2.3 Scenario: Operate PEPDS diagram discussed in section 5.1.5. The PEPDS capabilities are the Control Capability, Protection Capability, Electrical Distribution Capability, and Thermal Management Capability. The Electrical Distribution Capability is split into three sub-capabilities which are the Energy Storage Capability, Power Transportation Capability, and Power Conversion Capability. The goal of making converters part of distribution is “to reduce cost, achieve control, improve performance, enable cyber security, and further reduce size and weight” [3]. The operational paradigms of future warships depend on energy storage creating a need for “integration of both point and distributed energy storage directly into the power distribution system” [3]. This is why the Energy Storage Capability, Power Transportation Capability, and Power Conversion Capability are defined as parts of the Electrical Distribution Capability.

Each PEPDS Capability is made up of components that are defined as either a Least Replaceable Unit (LRU) or Non-LRU. This approach to defining the components has the purpose of limiting unnecessary restrictions on the Solution Space while also encouraging PEPDS innovations defined in the B1 Stakeholder Needs Table discussed in section 5.1.1. LRUs are defined in the PEPDS Model as components that are easily installed, removed, and transported by a single sailor, have spares onboard, and that some are reprogrammable. Non-LRUs are defined in the PEPDS Model as components that are not easily installed, removed, and transported by a single sailor.

5.2.2 B2.3 Scenario: Operate PEPDS Part 2

Returning to the B2.3 Operate PEPDS Scenario diagram, discussed in section 5.1.5, each of the main functions of PEPDS, shown in gold, are executed by the PEPDS Capabilities defined in the B3.1/W3.1 System Context Interfaces and Logical Architecture diagram, discussed in section 5.2.1. Review the W2.1 Control PEPDS diagram discussed in section 5.2.3, the W2.2 Protect PEPDS diagram discussed in section 5.2.4, the W2.3 Distribute Power diagram discussed in section 5.2.5, and the W2.4 Manage Thermal Load of PEPDS diagram discussed in section 5.2.6 to see the behaviors carried out by each of the PEPDS Capabilities to fulfill these PEPDS functions.

5.2.3 W2.1 Control PEPDS

The W2.1 Control PEPDS diagram shows the behaviors of the control capability and the exchange items that are shared with other PEPDS Capabilities and external systems. The Control Capability has two functions. It controls the information within, entering, and exiting PEPDS and controls all PEPDS capabilities. The activities that occur in W2.1.1 Control Information are discussed in section 5.2.3.1 and the activities that occur in W2.1.2 Control PEPDS capabilities are discussed in section 5.2.3.2.

By controlling and processing information, the Control Capability updates the Control Strategy. The Control Strategy controls electrical power by commanding PEPDS Capabilities. Returning to the B3.3/W3.3 Exchange Items diagram discussed in section 5.1.7, the interface block named Control Strategy defines what is included in the Control Strategy which currently consists of the Operation Strategy, Protection Strategy, Maintenance Strategy, Forecasting Consequences, and Cybersecurity Operations. These individual strategies and activities were combined under the overarching term “Control Strategy” because when one changes, the others must change as well.

5.2.3.1 W2.1.1 Control Information

The W2.1.1 Control Information diagram shows the behaviors of the Control Capability and the exchange items that enter and exit the Control Information activity. The commands and feedback entering the Control Information activity are used to consistently monitor PEPDS needs and user needs. If feedback from the Protection Capability requires an immediate response, the Control Capability will override other planned activities as needed and proceed to the action “determine a course of action” within the W2.1.1.1 Control Capabilities activity. The Control Capability will determine a course of action based on the Protection Capability feedback. If the Protection Capability feedback does not show a need for an immediate response, one of three activities will occur based on the Control Strategy. As shown in the B2.3 Scenario: Operate PEPDS diagram discussed in 5.1.5, the PEPDS functions occur in a loop. So, if one Control Information activity is dependent on a different one, they will occur in the order needed. Just because one activity is chosen does not mean a different one will never occur. They will just proceed in the order necessary for the task at hand. These activities are W2.1.1.1 Control Capabilities, discussed in section 5.2.3.1.1, W2.1.1.2 Control Functions, discussed in section 5.2.3.1.2, and W2.1.1.3 Execute CBM+, discussed in section 5.2.3.1.3. All activities are followed by the track and improve activity which represents PEPDS’ ability to self-learn by tracking performance and CBM+ data and analyzing control and protection activities. At the end of the Control Information Activity, feedback is provided to the Crew and Ship Control.

5.2.3.1.1 W2.1.1.1 Control Capabilities

The Capability Control Path determines a course of action based on the analysis of power load demands, power source supply, and capability needs. If feedback from the Protection Capability requires an immediate response, the Control Capability will override other planned activities as needed and proceed to determine a course of action based on the Protection Capability feedback. After determining a course of action, the Control Strategy is updated.

5.2.3.1.2 W2.1.1.2 Control Functions

The Functional Control Path programs communication networks, power networks, and PEPDS components. Once the programming is completed, it performs an automated self-check to assess the effects of the changes.

5.2.3.1.3 W2.1.1.3 Execute CBM+

The CBM+ Path initiates the CBM+ process. Data is captured and stored locally for internal CBM+ analysis. Select captured data is transmitted to Ship Control which relays it to an external database to support external CBM+ processes. Raw data and externally analyzed data are used to perform an internal CBM+ analysis. If this analysis produces evidence of need for maintenance, the Control Capability will determine a course of action to address this in a future iteration of the looped process. This evidence of need for maintenance can be a system health change or a PEPDS failure.

5.2.3.2 W2.1.2 Control PEPDS Capabilities

The W2.1.2 Control PEPDS Capabilities diagram shows how the Control Capability executes the Control Strategy. As shown in the diagram, the Control Capability controls interfaces between PEPDS and external power systems, configures PEPDS networks and components, commands how power should be tailored, and addresses all other possible PEPDS Capability needs. It issues prioritized commands to PEPDS Capabilities as directed by the Control Strategy.

5.2.4 W2.2 Protect PEPDS

The W2.2 Protect PEPDS diagram shows the activities that occur for executing continuous protection and handling failures. The Protection Capability determines needs for safety, performance, and resilience based on the analysis of power source and load interfaces, analysis of PEPDS performance, commands by the Control Capability, and protection strategy in the Control Strategy. Based on the former, the Protection Capability will select a protection response. If a failure occurs, diagnosis and prognosis are performed before selecting a protection response to address the failure. Selected protection responses are sent to the Control Capability for execution. The protection feedback may recommend immediate response of the system because of imminent danger to personnel, PEPDS, or an external system, may require an eventual response, or may require no response.

5.2.5 W2.3 Distribute Power

The W2.3 Distribute Power diagram shows how the Electrical Distribution Capability transports, converts, and stores power. The Electrical Distribution Capability consists of the Power Transportation Capability, Power Conversion Capability, and Energy Storage all of which are commanded by the control capability. Electrical power is transported from the source to the load and undergoes conversion when needed. After going through all necessary power conversions, the electrical power can either be stored or transported. The diagram shows that electrical power must go through the Power Conversion Capability before entering the Energy Storage Capability. This does not mean electrical power will always undergo conversion. If it is in the correct form, then it will be transported directly to the Energy Storage Capability.

5.2.6 W2.4 Manage Thermal Load of PEPDS

PEPDS Capabilities will create environmental loads as an unintended side effect of their functions. The Thermal Management Capability manages these loads and since they are unintended side effects, they are only modeled in the W2.4 Manage Thermal Load of PEPDS diagram. This diagram shows that the Thermal Management Capability regulates PEPDS internal thermal load to facilitate PEPDS continuing operations. One of the stakeholder needs requires that a universal thermal interface is proposed. System designers will create a PEPDS solution that regulates its internal thermal load using the resources available on the ship. A solution should be able to access and use the already existing environmental management services on the ship. The possible environmental management services are defined in the B3.3/W3.3 Exchange Items diagram discussed in section 5.1.7. The currently defined environmental management services are chilled water and forced air.

5.2.7 W3.2 PEPDS Interface Diagram

The W3.2 PEPDS Interface Diagram shows the interfaces and exchange items between PEPDS Capabilities as well as between PEPDS Capabilities and external systems. These are the same exchange items and interfaces defined in the white box behavior diagrams shown in a different view. This view shows the networks needed for PEPDS to execute its functions. These networks are a communication network, electrical power network, and environmental load management network.

5.2.8 B4 Measurements of Effectiveness Part 2

Returning to the B4 Measurements of Effectiveness diagram, discussed in section 5.1.8, each MoE is broken down into its MoPs that are defined in the W4.1 RAM MoEs diagram discussed in section 5.2.9, the W4.2 Operability MoEs diagram discussed in section 5.2.10, and the W4.3 Safety MoEs diagram discussed in section 5.2.11. The MoEs and MoPs for each PEPDS Capability are not yet defined but will pull from the MoEs and MoPs in the W4 diagrams.

5.2.9 W4.1 RAM MoEs

The W4.1 RAM MoEs diagram identifies constraint calculations, thresholds, and goals for each MoP for the RAM MoE.

5.2.10 W4.2 Operability MoEs

The W4.2 Operability MoEs diagram identifies constraint calculations, thresholds, and goals for each MoP for the Operability MoE.

5.2.11 W4.3 Safety MoEs

The W4.3 Safety MoEs diagram identifies constraint calculations, thresholds, and goals for each MoP for the Safety MoE.

5.3 System Level Solution Domain

A copy of each of the diagrams and tables reviewed in this section is provided in section 11.2.3.

5.3.1 S1 PEPDS Requirements

The problem domain elements are distilled into a set of system requirements that result in the PEPDS functional architecture. These system requirements are available in the tables and diagrams contained in the S1 System Requirements package diagram, provided in section 11.2.3.1. The S1 System Requirements diagrams, provided in section 11.2.3.2, show the S1 PEPDS Requirements organized in their respective packages and are traced to stakeholder needs. The tracing between S1 and the Problem Domain is shown in the S1 System Requirements Traceability Matrices, provided in section 11.2.3.3. The S1 System Requirements Table, provided in section 11.2.3.5, shows all of the S1 system requirements along with their tracing, source, verification method, risk level, and revision date.

The PEPDS System Model Version 2.0 requirements are the same as in the PEPDS System Model Version 1.0. Revisions to these S1 System Requirements are scheduled for the PEPDS System Model Version 3.0.

5.3.2 S3 System Structure

The S1 System Requirements are used for the initial exploration of the solution space through the PEPDS Architecture Team's Mini-PEPDS Design Exercise. The objective of this exercise is to validate the system requirements by creating a design and verifying that design against those requirements. This exercise includes multiple phases and iterations to achieve its goal of improving the system requirements and problem domain by identifying gaps between the subject matter expert's research and the System Model. Fig. 5 shows the iterative process of the Mini-PEPDS Design Exercise. The subject matter experts provide information on ONR science and technology (S&T) that they are researching. This information is used in the Virtual Prototyping Process (VPP) analysis, the PEPDS System Model development, and the ship-wide modeling in the Rapid Ship Design Environment (RSDE). For the Mini-PEPDS Design Exercise, the VPP is used to provide inputs to RSDE in order to explore shipboard sizing and arrangement of PEPDS components [7] [8] [9] and determine their parameter objectives [10].

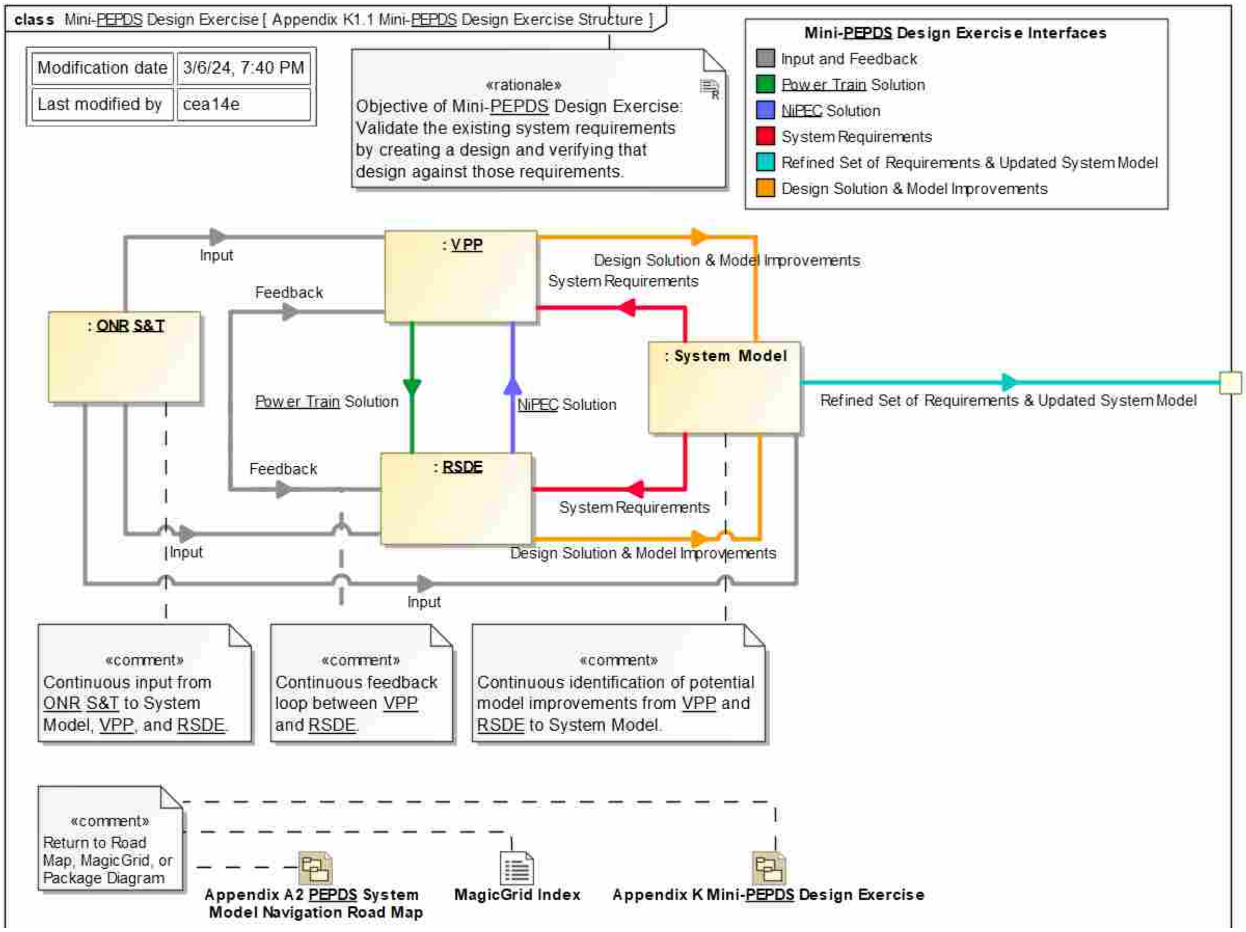

Fig. 5: Mini-PEPDS Design Exercise

The PEPDS System Model Version 2.0 contains Iteration 1 of the Mini-PEPDS Design Exercise where a single MVAC to MVAC power train was assessed in the VPP producing a point solution of the power train's component arrangements, sizes, and resulting technical performance measures. For this exercise, a PEPDS power train is "a cascaded connection of power stages between points of source and points of load (or feed)" [9]. Since "any physical section of NiPEC in the ship will consist of multiple power trains" [7], this power train point solution was used to develop the concept of a NiPEC segment. The PEPDS power train and NiPEC concept point solutions are shown in section 11.2.3.6.

5.3.3 Data Exchange

In tandem to the Mini-PEPDS Design Exercise, the authors are working to enhance the PEPDS System Model solution-space exploration capabilities by investigating techniques to enable integration with focus area models and analysis tools. One goal of the System Model is to grant access to all data generated and utilized by both system and developer teams. This principle holds particular significance in concurrent engineering, where seamless data exchange across diverse teams is vital for exploring design possibilities. Within the PEPDS framework, this exchange occurs on two fronts. Firstly, there is a document exchange among teams operating in distinct research domains, offering crucial insights for each team's research and analysis endeavors. Secondly, data flows between the various tools utilized by these teams. This involves sharing system parameters and variables among tools, ultimately defining the design space variables and parameters. To formalize a structured data exchange process among teams and establish the model as the definitive reference point, the authors have outlined specific use cases for data interchange. Initial modeling work was undertaken to visualize how a data exchange mechanism would fit within the unique context of PEPDS. The strategy aims to streamline processes and foster collaborative efforts among multidisciplinary teams. The Data Exchange diagrams are provided in section 11.3.

5.4 PEPDS System Model Future Improvements

The PEPDS System Model Version 2.0 ends at the S3 Solution Space System Structure. The PEPDS System Model is a living document that will change and grow throughout the lifetime of the system. It will continue to support system requirements, design, analysis, verification, and validation activities throughout development and later lifecycle phases [4].

Work continuing from Version 2.0 into Version 3.0 includes acquiring tools, enabling integration of the system model with focus area models, and exploring the PEPDS design trade space. Forthcoming work includes adding dynamic behavior to the system model.

6 PURPOSE

Using an MBSE approach for the PEPDS development process will enhance communication, reduce developmental risk, improve quality, increase productivity, and enhance knowledge transfer [5]. System designers will use the PEPDS System Model to understand the PEPDS functional architecture, propose alternative designs, select a preferred design, and build and qualify implementations. The PEPDS System Model will provide a framework for PEPDS architecture studies and enable collaborative research.

7 CONCLUSION AND RECOMMENDATIONS

The PEPDS Architecture Team has successfully baselined a functional architecture described in terms of needs, functions, structures, and measures transformed into a baselined set of functional requirements. The functional architecture baseline enabled initial exploration of the solution space. The PEPDS System Model has transitioned from its role in framing the problem to enabling exchange of technology research, data, and information and exploration of the PEPDS design trade space.

Forthcoming work includes adding dynamic behavior to the system model, acquiring tools, enabling integration of the system model with focus area models, and exploring the PEPDS design trade space.

8 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of the Architecture Team shown in Table I.

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10 Appendix A: How to Install and Use Cameo Enterprise Architecture Reader

Cameo Enterprise Architecture Reader is made for reading and previewing models created with Cameo Enterprise Architecture and is free of charge.

10.1 Instructions on Installing Cameo Enterprise Architecture Reader

Follow the instructions to install the Cameo Enterprise Architecture Reader:

1. Go to: https://www.magicdraw.com/main.php
2. Register as a User and Login.
3. Select **Download Reader** from the column on the left near the end.
4. Select **Cameo Enterprise Architecture** product and **19.0 SP1 LTR** version.
5. Select the download file link based on your operating system.
6. Download the file from the mirror site nearest you.
7. Open the file and follow the installation prompts.
   a. If you selected no_install.zip, extract the .zip file and follow the instructions in the **readme** HTML document under section "**Using no-install package**."

The Cameo Enterprise Architecture Reader is now ready for use. Proceed to section 10.2.

10.2 How to use Cameo Enterprise Architecture Reader

Open Cameo Enterprise Architecture Reader then, under file, select "open project" and open the ".mdzip" file of the model you would like to view.

Navigate the model in a fashion similar to a webpage. You can open diagrams/tables by double clicking the diagram/table or by right clicking the diagram/table and selecting "Open in New Tab". The diagrams/tables can be opened from a linked icon/element on a diagram or from the containment tree. To see two diagrams/tables side by side, right click the tab and select "new horizontal/vertical group." You can close diagrams/tables by clicking the back arrow (when applicable) or by clicking the X on the tab.

Utilize the zooming and the vertical and horizontal scrolling in order to increase readability.

You can print diagrams/tables by selecting file → print.

User manuals are available under "help." Resources to help you understand the SysML diagrams are the MagicGrid® Book of Knowledge from reference [1] and the No Magic Inc. Glossary of SysML Concepts from reference [2].

11 Appendix B: PEPDS System Model Contents

The following list provides the sections of Appendix B and defines their content's purpose:

- Section 11.1 Navigation Road Map begins on page 24. The road map, discussed in section 4.4, is used for the product review in section 5 of the technical report.

- Section 11.2 PEPDS System Model Review Contents begins on page 25. The diagrams in this section accompany the product review in section 5 of the technical report.

    - Section 11.2.1 Problem Domain Black Box Review begins on page 25. The diagrams in this section accompany the Black Box Problem Domain review in section 5.1 of the technical report.

    - Section 11.2.2 Problem Domain White Box Review begins on page 52. The diagrams in this section accompany the White Box Problem Domain review in section 5.2 of the technical report.

    - Section 11.2.3 Solution Domain Review begins on page 103. The diagrams in this section accompany the System Level Solution Domain review in section 5.3 of the technical report.

        - Section 11.2.3.1 S1 System Requirements on page 103 shows all of the tables, diagrams, and matrices used to define the S1 system requirements.

        - Section 11.2.3.2 S1 System Requirements Diagrams begins on page 104. These diagrams show the S1 system requirements organized in their respective packages and are traced to stakeholder needs.

        - Section 11.2.3.3 S1 System Requirements DeriveReq Matrices begins on page 119 and section 11.2.3.4 S1 System Requirements Refine Matrices begins on page 124. These matrices show the tracing between S1 and the Problem Domain.

        - Section 11.2.3.5 S1 System Requirements Table begins on page 131. This table provides all of the S1 system requirements along with their tracing, source, verification method, risk level, and revision date.

        - Section 11.2.3.6 S3 System Structure Solution Exploration begins on page 176. These diagrams show the results of the Mini-PEPDS Design Exercise Iteration 1.

- Section 11.3 System Model Appendix begins on page 189. The diagrams in this section are not reviewed in the product review in section 5 of the technical report. They are supplementary material that provide information that will enhance the understanding of the PEPDS System Model product, discussed in section 5, and the PEPDS Functional Architecture development process, discussed in section 4.

- Section 11.4 MagicGrid® Index Package Diagrams begins on page 256. The diagrams in this section are the package diagrams from the MagicGrid® Index discussed in section 4.3.

The following is the list of figures for Appendix B: PEPDS System Model Contents:

The following is the list of tables for Appendix B: PEPDS System Model Contents:

11.1 Navigation Road Map

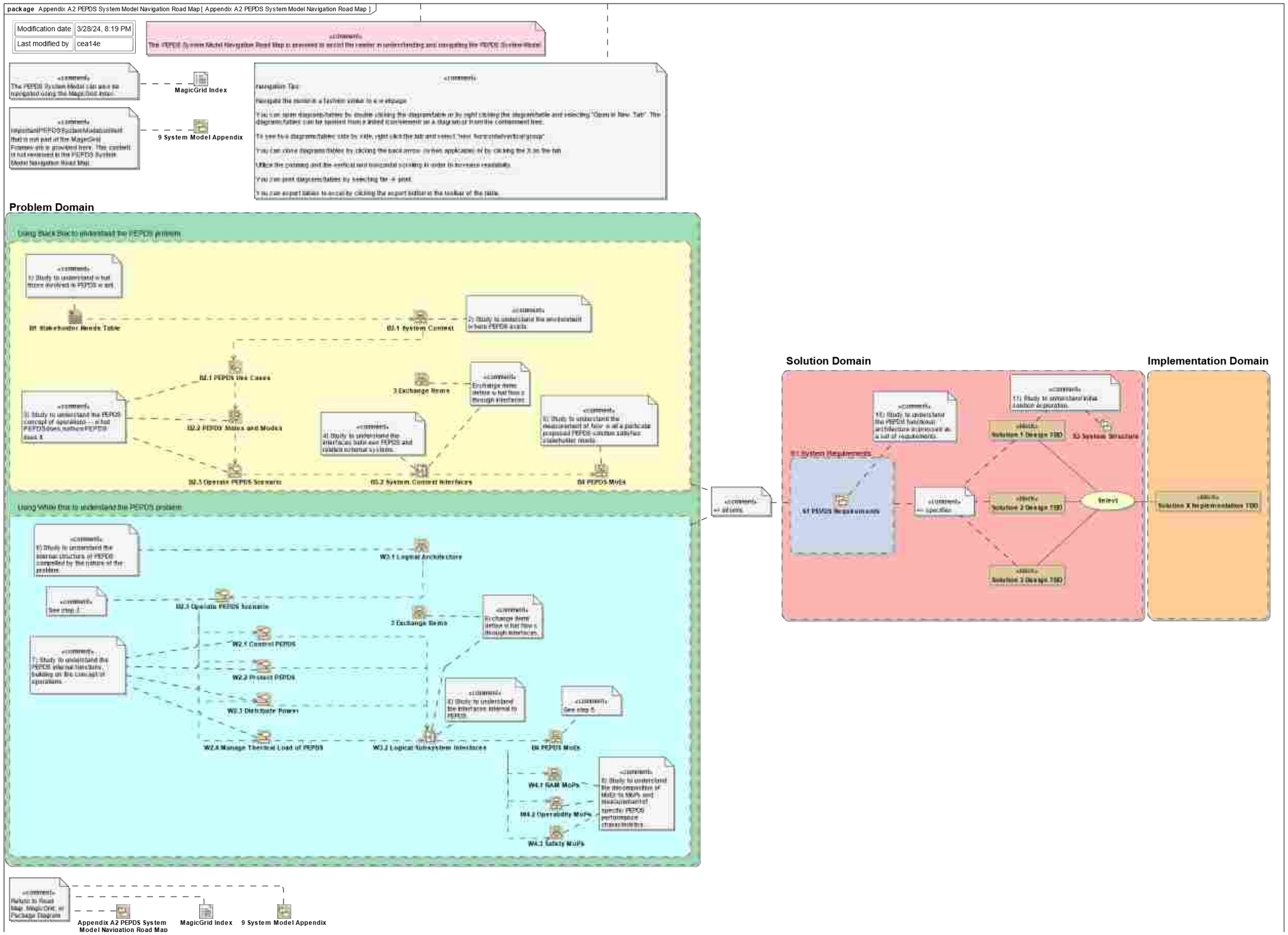


Fig. 6: Navigation Road Map

11.2 PEPDS System Model Review Contents

11.2.1 Problem Domain Black Box Review

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

Table II: B1 Stakeholder Needs Table

Id	Source	Name	Text
1	Navy	1 Power Delivery	Transfers power from power source to power load
1.1	Navy	1.1 Power Efficiency	Limit power loss during transmission and conversion
1.1.1	Navy	1.1.1 Fuel Efficiency	Reduce amount of fuel consumption
1.2	Navy	1.2 Power Density	High power rating relative to volume
1.3	Navy	1.3 Reliability	Long online time when measured by MTBF
1.4	Navy	1.4 Robustness	Compatible with various operating conditions and set points
1.5	Navy	1.5 Resiliency	Tolerant to critical scenarios such as faults and failure of device(s)
1.6	Navy	1.6 UPS	If demand is greater than supply (delta power), then provide provisional power for x time
2	Navy	2 Operability	System operation accomplished with reduced manning and logistics effort
2.1	Navy	2.1 Maintainability	Maintenance with reduced down time
2.2	Navy	2.2 Operator Trainability	Low training requirements in regard to time and technical skills
2.3	Operator	2.3 Safety	Safe handling conditions
2.3.1	Operator	2.3.1 Thermally Touchable	External environment at reasonable handling temperatures
2.3.2	Operator	2.3.2 Liftable	Weight and volume at a reasonable range for handling
2.3.3	Operator	2.3.3 Electrically Insulated	Insulation to limit current through operator
2.4	Navy	2.4 Long Life Expectancy	Long operable lifespan
3	Navy	3 Scalability	Greater power requirement met through serial and/or parallel connections
3.1	Navy	3.1 Serial Thermal Management	Universal thermal interface should be proposed
3.2	Navy	3.2 Parallel Redundancy	Parallel operation to provide continuous power to mission critical loads
3.3	Navy	3.3 Controllable	Coordination should allow for extension/addition of devices

Id	Source	Name	Text
3.3.1	Navy	3.3.1 Software Reliability	Continuous high-performance operation even in disruptive processes
3.3.2	Navy	3.3.2 Cyber Security	Resistant to malicious attacks against software and offers security observation
3.3.3	Navy	3.3.3 Dynamic Response	Can ramp up power in a short time; can provide x time over power in a short time slot
3.4	Navy	3.4 Standardizable	Fits in many classes of ship
3.5	Navy	3.5 Affordability	Reduce implementation and operation cost for life cycle
3.6	Navy	3.6 Hotswappable	Hotswappable "Plug-and-Play" applications
4	CAPS Power Systems	4 Model Objectives	PEPDS Model key objectives
4.1	CAPS Power Systems	4.1 Program Communication	To become a vehicle to communicate PEPDS work progress and accomplishments
4.2	CAPS Power System	4.2 Single Source of Truth	This model is formal representation of PEPDS system in order to make clear: (1) Its structure, interfaces, and internal and external relationships (2) The behaviors exhibited by the entity and its elements, both internally and externally (3) The global rules to which the entity and its elements must conform in order to meet the requirements allocated to them, initially and over the entity's operational lifetime
4.3	CAPS Power System	4.3 Program Guideline	To guide and support solutioning of PEPDS modular architecture
5	Navy	5 PEPDS Innovations	PEPDS innovations are dependent on using power electronics in an innovative way and utilizing advancements in technology and control capabilities
5.1	Navy	5.1 Ease of Installation as a Unit	Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction

Id	Source	Name	Text
5.2	Navy	5.2 Load Interface Design	Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the ship
5.3	Navy	5.3 Power Electronic Interfaces	All source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation
5.4	Navy	5.4 Self Learning	Ability to self-learn by tracking performance and CBM+ data and analyzing control and protection activities
5.5	Navy	5.5 Integrated Control	Integrated electrical, thermal, and mechanical control
5.6	Navy	5.6 Functional Control	Control component and network functions through programming and reconfiguration
5.7	Navy	5.7 Adaptive Controls	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades
5.8	Navy	5.8 Automated Self-check	Have self-diagnosis or automated self-check after controls upgrades which would be an advanced concept of CHIL with regression tests embedded in PEPDS (integrated “digital twin”) – including cybersecurity aspects
5.9	Navy	5.9 Integrated CBM+	Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.
5.1	Navy	5.10 Comprehensive Application of the LRU Approach to the Entire System Design	Maximize the dependence on LRUs while minimizing the different types of LRUs
5.11	Navy	5.11 Simplified LRU Replacement	Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities

Id	Source	Name	Text
5.12	Navy	5.12 Minimal Redundant Elements	Provide power quality to loads using fewer components by using distributed resources and integrated functionality such as advanced power electronic control across many converters, active filtering across many converters, and distributed storage
5.13	Navy	5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control
5.14	Navy	5.14 Distributed Power Conversion	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements
5.15	Navy	5.15 Reduce Conventional Switchgear	Integrate functionality of switchgear within the power electronics framework in order to reduce or eliminate use of conventional external switchgear and provide current limiting function - thereby reducing risk from high fault currents and hence improving reliability

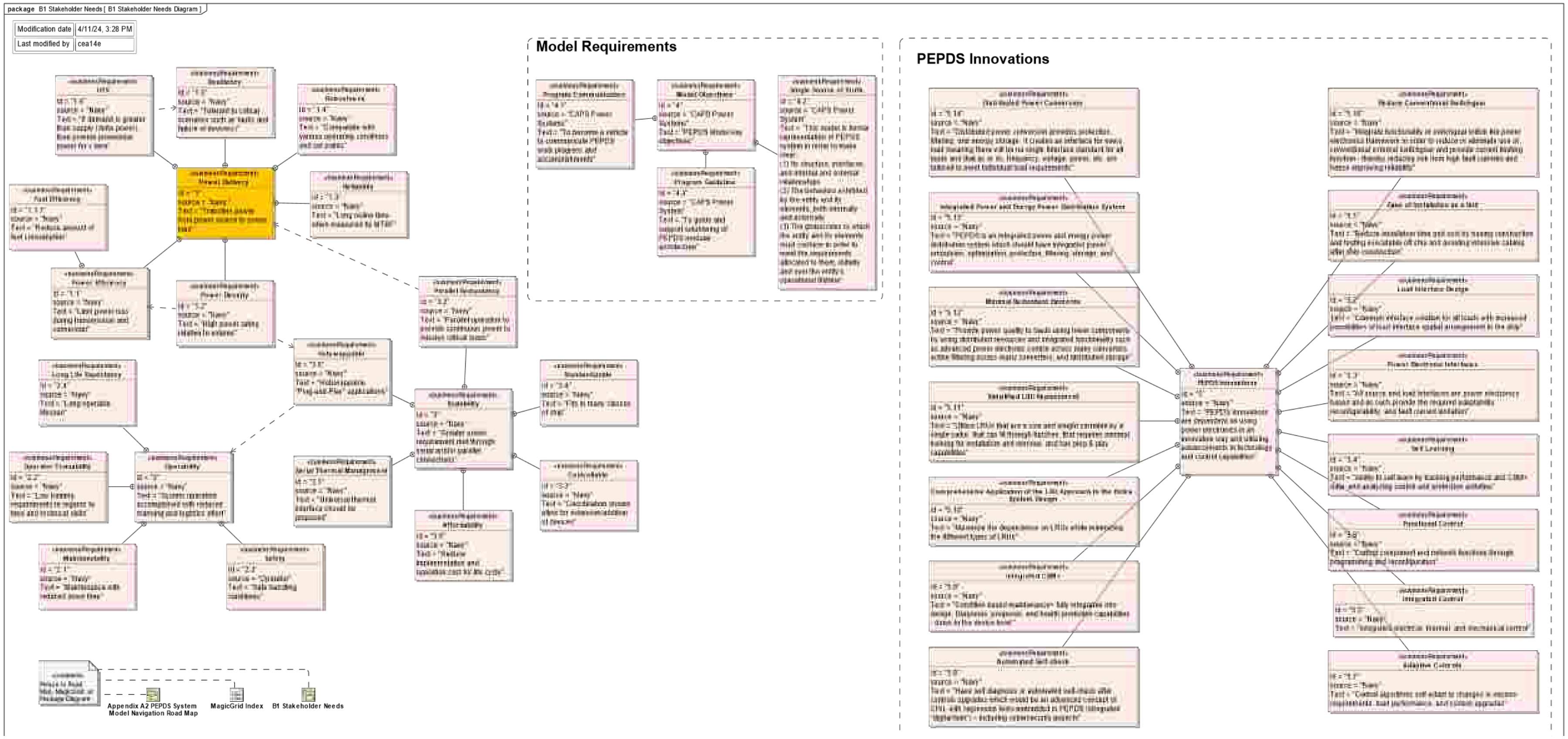


Fig. 7: B1 Stakeholder Needs Diagram

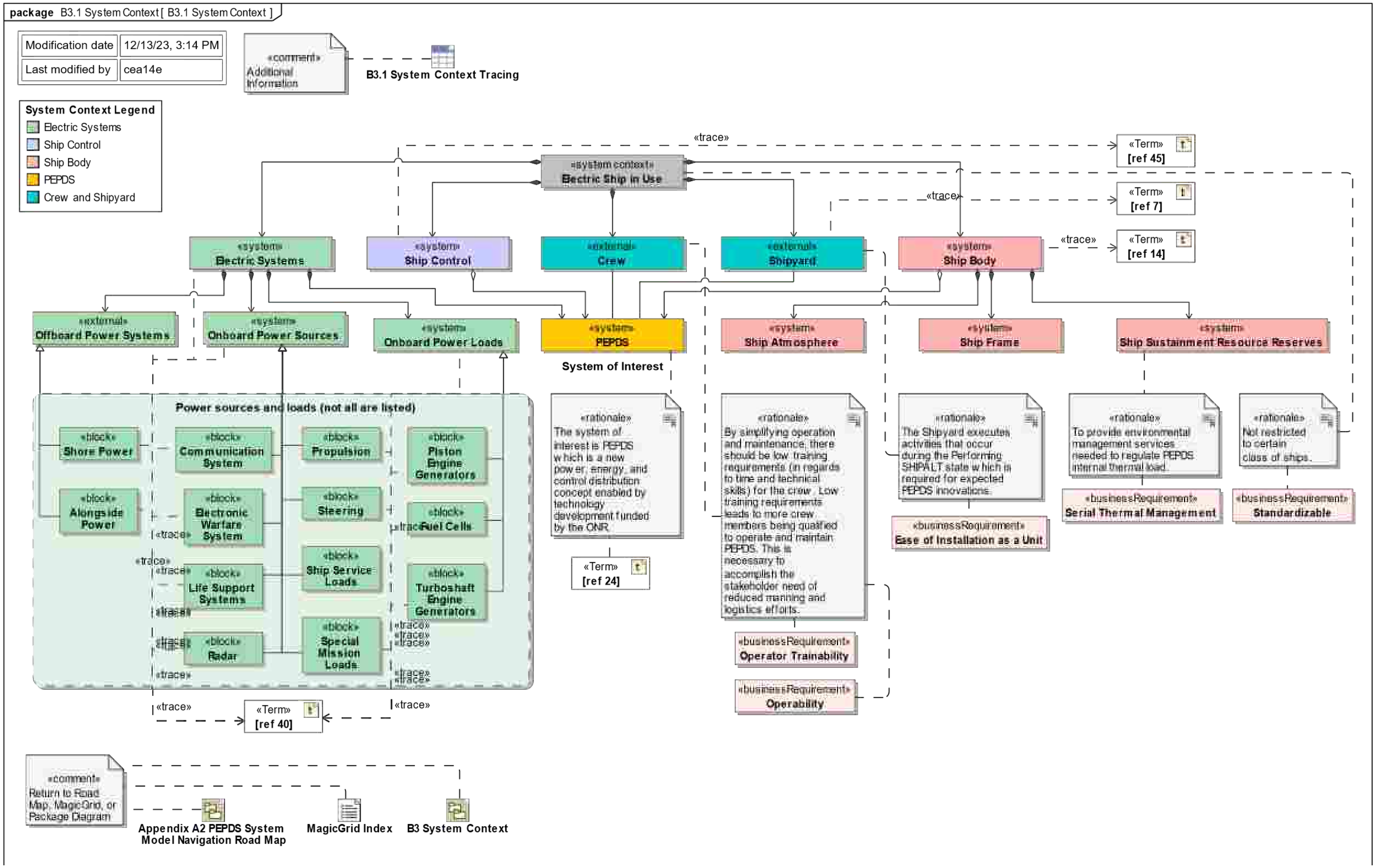


Fig. 8: B3.1 System Context

Table III: B3.1 System Context Tracing

Name	Rationale	Refines	Refined Stakeholder Needs Text	Traced To
Crew	By simplifying operation and maintenance, there should be low training requirements (in regard to time and technical skills) for the crew. Low training requirements lead to more crew members being qualified to operate and maintain PEPDS. This is necessary to accomplish the stakeholder need of reduced manning and logistics efforts.	2.2 Operator Trainability 2 Operability	Low training requirements in regard to time and technical skills System operation accomplished with reduced manning and logistics effort	
Electric Ship in Use	Not restricted to certain class of ships.	3.4 Standardizable	Fits in many classes of ship	
Electric Systems				[ref 40]
Offboard Power Systems				[ref 40]
Onboard Power Loads				[ref 40]
Onboard Power Sources				[ref 40]
PEPDS	The system of interest is PEPDS which is a new power, energy, and control distribution concept enabled by technology development funded by the ONR.			[ref 24]
Ship Atmosphere				[ref 14]
Ship Body				[ref 14]
Ship Control				[ref 45]
Ship Frame				[ref 14]
Ship Sustainment Resource Reserves	To provide environmental management services needed to regulate PEPDS internal thermal load.	3.1 Serial Thermal Management	Universal thermal interface should be proposed	[ref 14]
Shipyard	The Shipyard executes activities that occur during the Performing SHIPALT state which is required for expected PEPDS innovations.	5.1 Ease of Installation as a Unit	Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction	[ref 7]

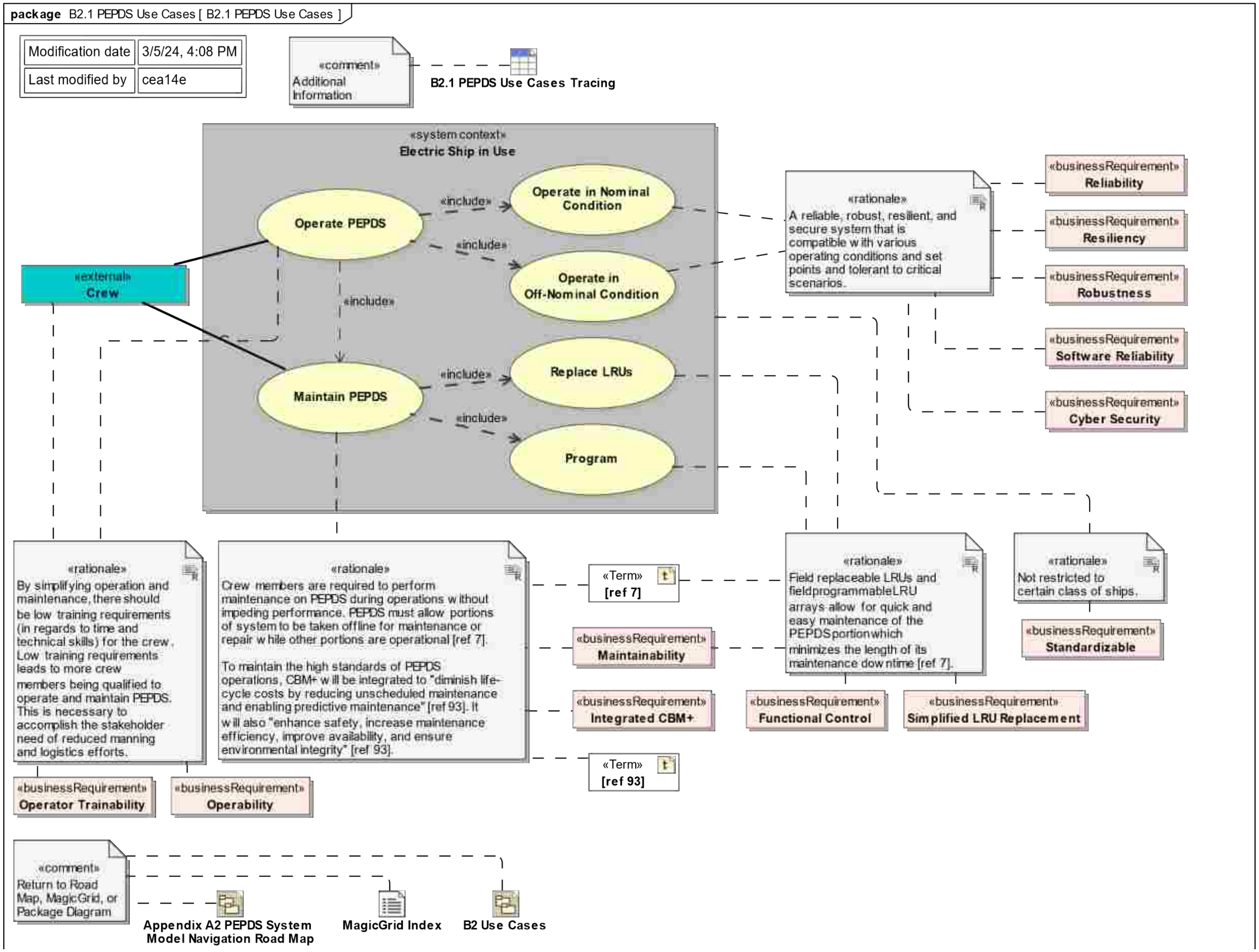


Fig. 9: B2.1 PEPDS Use Case

Table IV: B2.1 PEPDS Use Cases Tracing

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Crew	By simplifying operation and maintenance, there should be low training requirements (in regard to time and technical skills) for the crew. Low training requirements lead to more crew members being qualified to operate and maintain PEPDS. This is necessary to accomplish the stakeholder need of reduced manning and logistics efforts.	2.2 Operator Trainability 2 Operability	Low training requirements in regard to time and technical skills System operation accomplished with reduced manning and logistics effort	
Electric Ship in Use	Not restricted to certain class of ships.	3.4 Standardizable	Fits in many classes of ship	
Maintain PEPDS	Crew members are required to perform maintenance on PEPDS during operations without impeding performance. PEPDS must allow portions of system to be taken offline for maintenance or repair while other portions are operational [ref 7]. To maintain the high standards of PEPDS operations, CBM+ will be integrated to "diminish life-cycle costs by reducing unscheduled maintenance and enabling predictive maintenance" [ref 93]. It will also "enhance safety, increase maintenance efficiency, improve availability, and ensure environmental integrity" [ref 93].	5.9 Integrated CBM+ 2.1 Maintainability 2 Operability 2.2 Operator Trainability	Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level. Maintenance with reduced down time System operation accomplished with reduced manning and logistics effort Low training requirements in regard to time and technical skills	[ref 7] [ref 93]
Operate in Nominal Condition	A reliable, robust, resilient, and secure system that is compatible with various operating conditions and set points and tolerant to critical scenarios.	1.4 Robustness 1.3 Reliability 3.3.2 Cyber Security 3.3.1 Software Reliability	Compatible with various operating conditions and set pointsLong online time when measured by MTBFResistant to malicious attacks against software and offers security observationContinuous high-performance operation even in disruptive processes	
Operate in Off-Nominal Condition	A reliable, robust, resilient, and secure system that is compatible with various operating conditions and set points and tolerant to critical scenarios.	1.5 Resiliency 1.4 Robustness 3.3.1 Software	Tolerant to critical scenarios such as faults and failure of device(s) Compatible with various operating conditions and set points	

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
		Reliability 3.3.2 Cyber Security	Continuous high-performance operation even in disruptive processes Resistant to malicious attacks against software and offers security observation	
Operate PEPDS	By simplifying operation and maintenance, there should be low training requirements (in regard to time and technical skills) for the crew. Low training requirements lead to more crew members being qualified to operate and maintain PEPDS. This is necessary to accomplish the stakeholder need of reduced manning and logistics efforts.	1.3 Reliability 1.4 Robustness 1.5 Resiliency 2 Operability 2.2 Operator Trainability 3.3.1 Software Reliability 3.3.2 Cyber Security	Long online time when measured by MTBFCompatible with various operating conditions and set pointsTolerant to critical scenarios such as faults and failure of device(s)System operation accomplished with reduced manning and logistics effortLow training requirements in regard to time and technical skillsContinuous high performance operation even in disruptive processesResistant to malicious attacks against software and offers security observation	
Program	Field replaceable LRUs and field programmable LRU arrays allow for quick and easy maintenance of the PEPDS portion which minimizes the length of its maintenance downtime [ref 7].	5.6 Functional Control	Control component and network functions through programming and reconfiguration	[ref 7]
Replace LRUs	Field replaceable LRUs and field programmable LRU arrays allow for quick and easy maintenance of the PEPDS portion which minimizes the length of its maintenance downtime [ref 7].	5.11 Simplified LRU Replacement	Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	[ref 7]

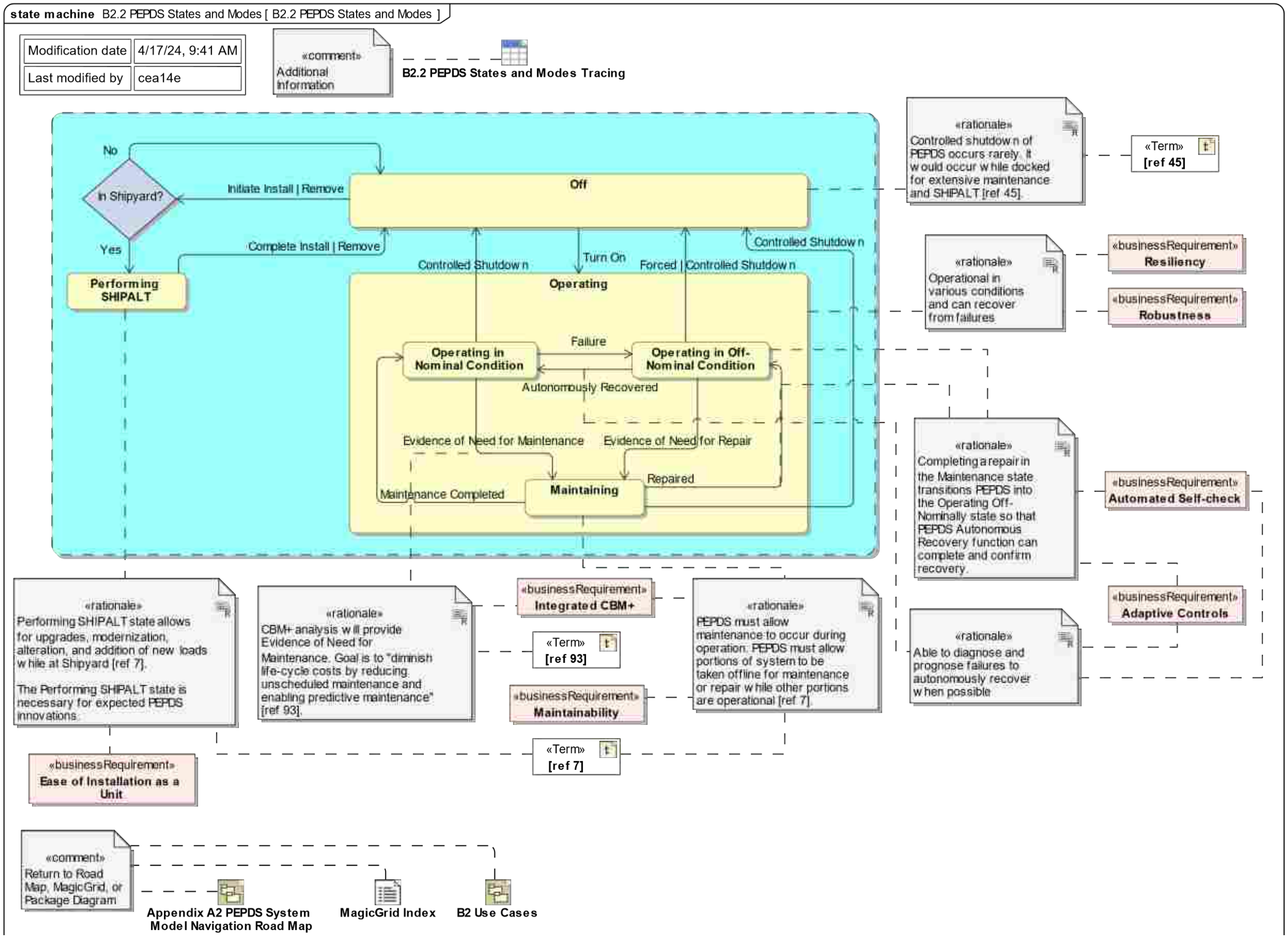


Fig. 10: B2.2 PEPDS States and Modes

Table V: B2.2 PEPDS States and Modes Tracing

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Operating	Operational in various conditions and can recover from failures	1.5 Resiliency 1.4 Robustness	Tolerant to critical scenarios such as faults and failure of device(s) Compatible with various operating conditions and set points	
Off	Controlled shutdown of PEPDS occurs rarely. It would occur while docked for extensive maintenance and SHIPALT [ref 45].			[ref 45]
Operating in Nominal Condition	Operational in various conditions and can recover from failures	1.4 Robustness 1.5 Resiliency	Compatible with various operating conditions and set points Tolerant to critical scenarios such as faults and failure of device(s)	
Operating in Off-Nominal Condition	Completing a repair in the Maintenance state transitions PEPDS into the Operating Off-Nominally state so that PEPDS Autonomous Recovery function can complete and confirm recovery.	1.5 Resiliency 1.4 Robustness 5.7 Adaptive Controls 5.8 Automated Self-check	Tolerant to critical scenarios such as faults and failure of device(s) Compatible with various operating conditions and set points Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades Have self-diagnosis or automated self-check after controls upgrades which would be an advanced concept of CHIL with regression tests embedded in PEPDS (integrated “digital twin”) – including cybersecurity aspects	
Maintaining	PEPDS must allow maintenance to occur during operation. PEPDS must allow portions of system to be taken offline for maintenance or repair while other portions are operational [ref 7].	2.1 Maintainability 5.9 Integrated CBM+	Maintenance with reduced down time Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	[ref 7]
Performing SHIPALT	Performing SHIPALT state allows for upgrades, modernization, alteration, and addition of new loads while at Shipyard [ref 7].The Performing	5.1 Ease of Installation as a Unit	Reduce installation time and cost by having construction and testing executable off ship and avoiding	[ref 45] [ref 7]

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
	SHIPALT state is necessary for expected PEPDS innovations.		intensive cabling after ship construction	
Autonomously Recovered	Able to diagnose and prognose failures to autonomously recover when possible	5.7 Adaptive Controls 5.8 Automated Self-check	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades Have self-diagnosis or automated self-check after controls upgrades which would be an advanced concept of CHIL with regression tests embedded in PEPDS (integrated "digital twin") – including cybersecurity aspects	
Evidence of Need for Maintenance	CBM+ analysis will provide Evidence of Need for Maintenance. Goal is to "diminish life-cycle costs by reducing unscheduled maintenance and enabling predictive maintenance" [ref 93].	5.9 Integrated CBM+	Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	[ref 93]
Maintenance Completed	CBM+ analysis will provide Evidence of Need for Maintenance. Goal is to "diminish life-cycle costs by reducing unscheduled maintenance and enabling predictive maintenance" [ref 93].			[ref 93]
Evidence of Need for Repair				
Repaired	Completing a repair in the Maintenance state transitions PEPDS into the Operating Off-Nominally state so that PEPDS Autonomous Recovery function can complete and confirm recovery.			
Failure	Operational in various conditions and can recover from failures			
Controlled Shutdown				[ref 45]
Controlled Shutdown				[ref 45]
Forced | Controlled Shutdown	Controlled shutdown of PEPDS occurs rarely. It would occur while docked for extensive maintenance and SHIPALT [ref 45].			[ref 45]
Turn On				
Initiate Install | Remove				

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Complete Install | Remove				
Do not begin SHIPALT outside shipyard				
Begin SHIPALT in shipyard				

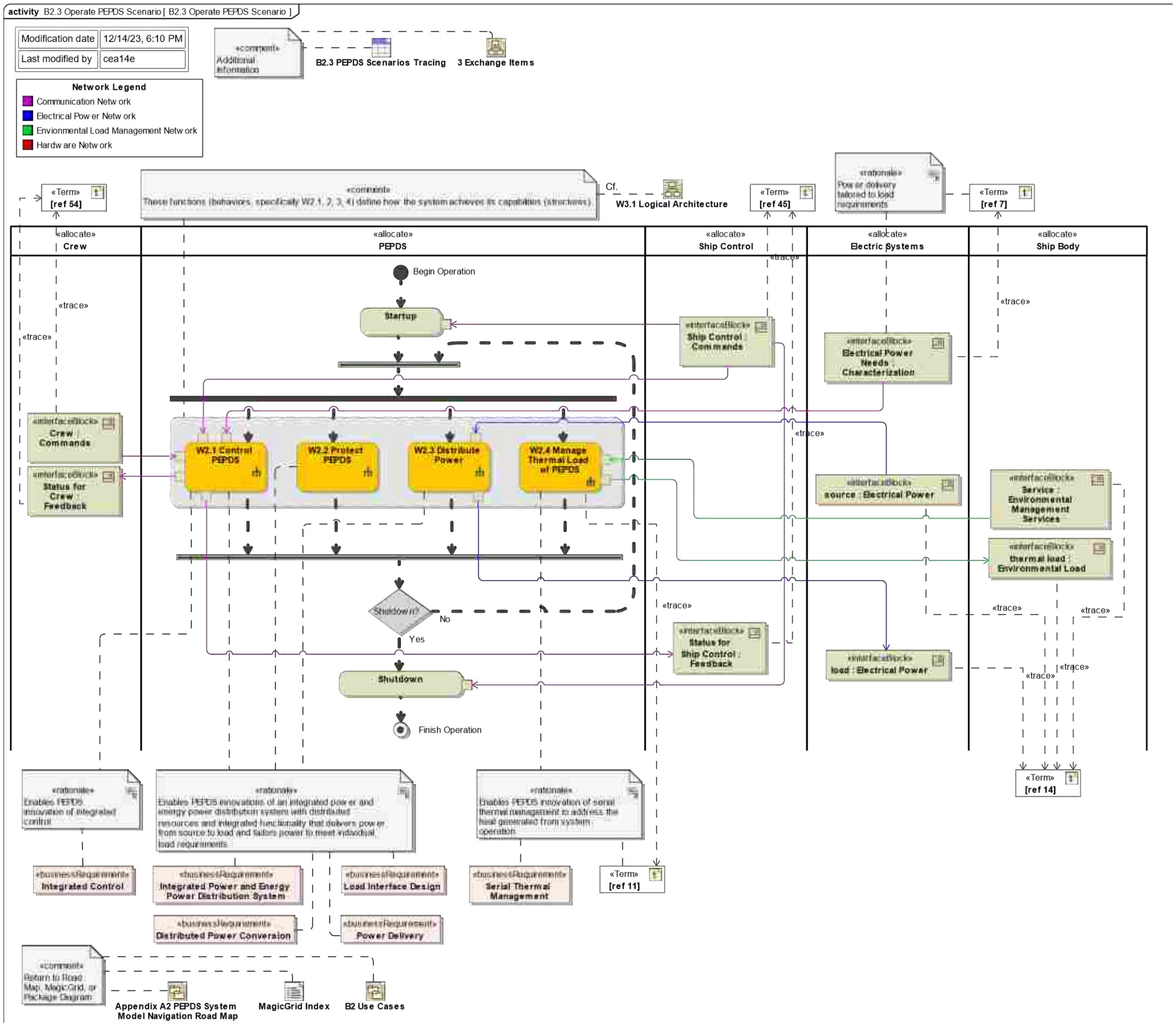


Fig. 11: B2.3 Operate PEPDS Scenario (Review Part 1)

Table VI: B2.3 PEPDS Scenarios Tracing

Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Crew	Commands				[ref 54]
Electrical Power Needs	Characterization	Power delivery tailored to load requirements			[ref 7]
load	Electrical Power				[ref 14]
Service	Environmental Management Services				[ref 14]
Ship Control	Commands				[ref 45]
source	Electrical Power				[ref 14]
Status for Crew	Feedback				[ref 54]
Status for Ship Control	Feedback				[ref 45]
thermal load	Environmental Load				[ref 14]
Shutdown					
Startup					
W2.1 Control PEPDS		Enables PEPDS innovations of an integrated power and energy power distribution system with distributed resources and integrated functionality that delivers power from source to load and tailors power to meet individual load requirements. Enables PEPDS innovation of integrated control	5.5 Integrated Control 5.13 Integrated Power and Energy Power Distribution System	Integrated electrical, thermal, and mechanical control PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
W2.2 Protect PEPDS		Enables PEPDS innovations of an integrated power and energy power distribution system with distributed resources and integrated functionality that delivers power from source to load and tailors power to meet individual load requirements.	5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	

Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
W2.3 Distribute Power		Enables PEPDS innovations of an integrated power and energy power distribution system with distributed resources and integrated functionality that delivers power from source to load and tailors power to meet individual load requirements.	5.13 Integrated Power and Energy Power Distribution System 5.14 Distributed Power Conversion 5.2 Load Interface Design 1 Power Delivery	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and controlDistributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirementsCommon interface solution for all loads with increased possibilities of load interface spatial arrangement in the shipTransfers power from power source to power load	
W2.4 Manage Thermal Load of PEPDS		Enables PEPDS innovation of serial thermal management to address the heat generated from system operation	3.1 Serial Thermal Management	Universal thermal interface should be proposed	[ref 11]

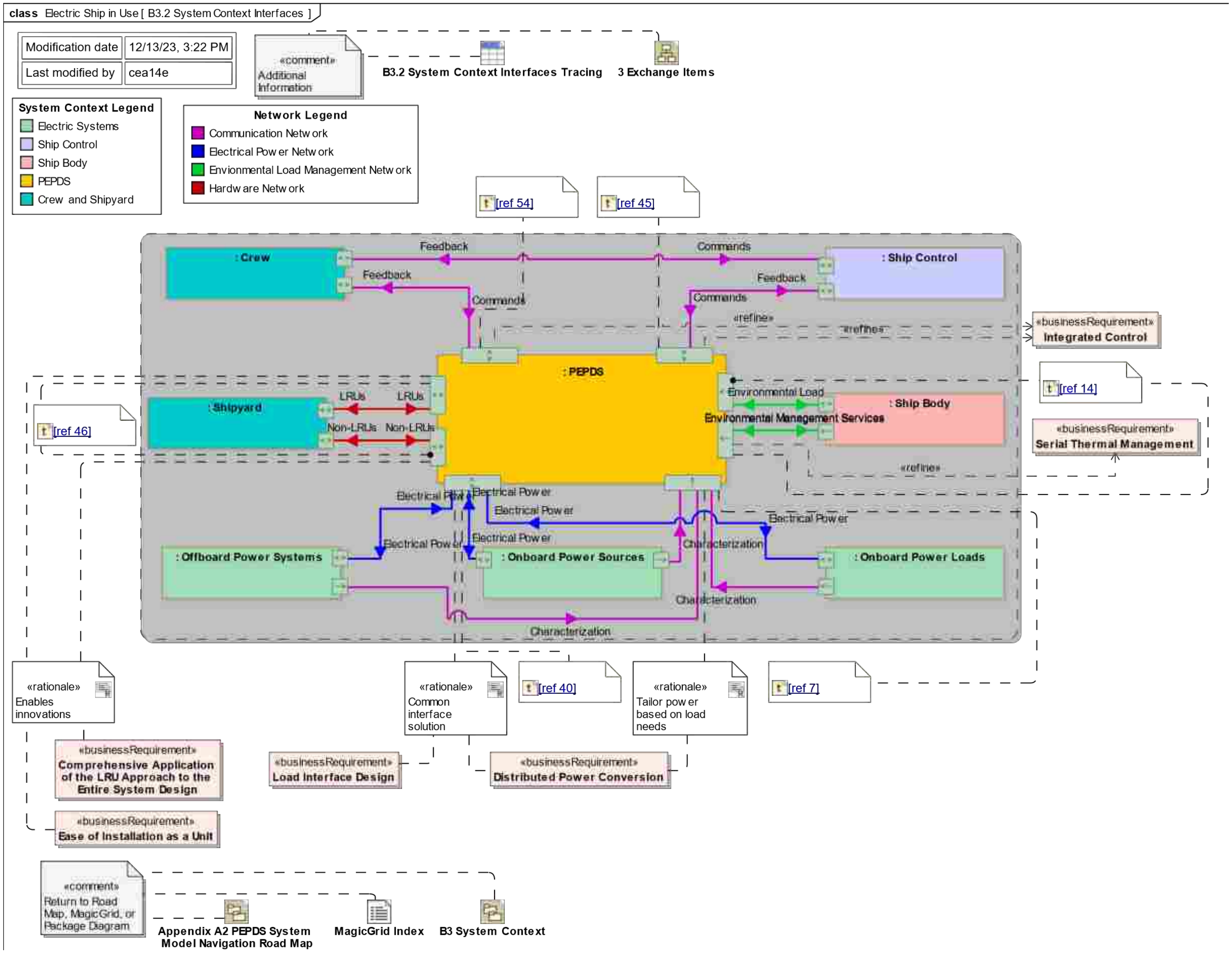


Fig. 12: B3.2 System Context Interfaces

Table VII: B3.2 System Context Interfaces Tracing

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Crew Interaction		5.5 Integrated Control	Integrated electrical, thermal, and mechanical control	[ref 54]
Environmental Load Exchange				[ref 14]
Environmental Management Services		3.1 Serial Thermal Management	Universal thermal interface should be proposed	[ref 14]
Electrical Power Exchange	Common interface solution	5.14 Distributed Power Conversion 5.2 Load Interface Design	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the ship	[ref 40]
Electrical Power Characterization	Tailor power based on load needs	5.14 Distributed Power Conversion	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements	[ref 7]
LRU Exchange	Enables innovations	5.10 Comprehensive Application of the LRU Approach to the Entire System Design	Maximize the dependence on LRUs while minimizing the different types of LRUs	[ref 46]
Non-LRU Exchange	Enables innovations	5.1 Ease of Installation as a Unit	Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction	[ref 46]
Ship Control Interaction		5.5 Integrated Control	Integrated electrical, thermal, and mechanical control	[ref 45]

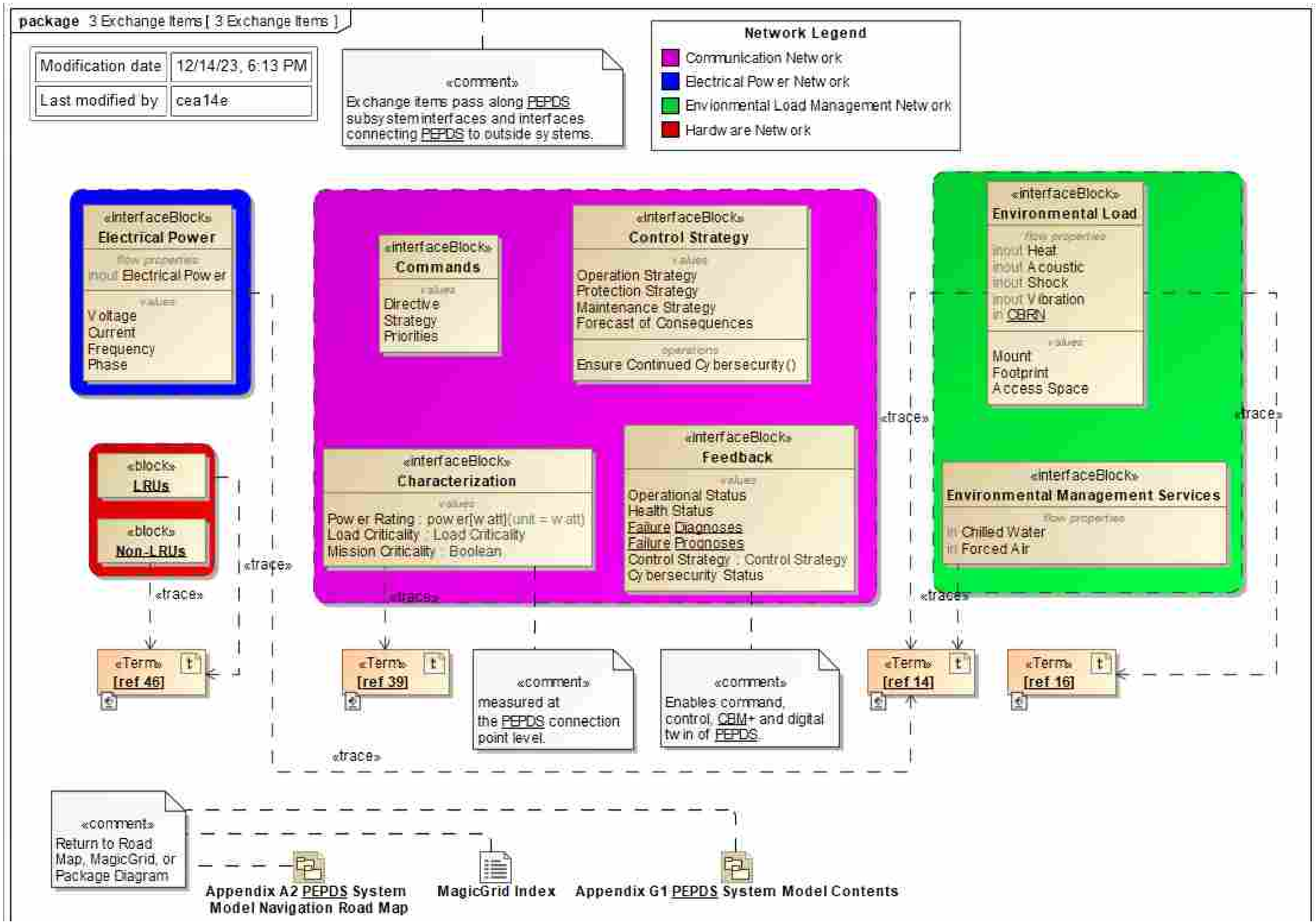


Fig. 13: B3.3/W3.3 Exchange Items

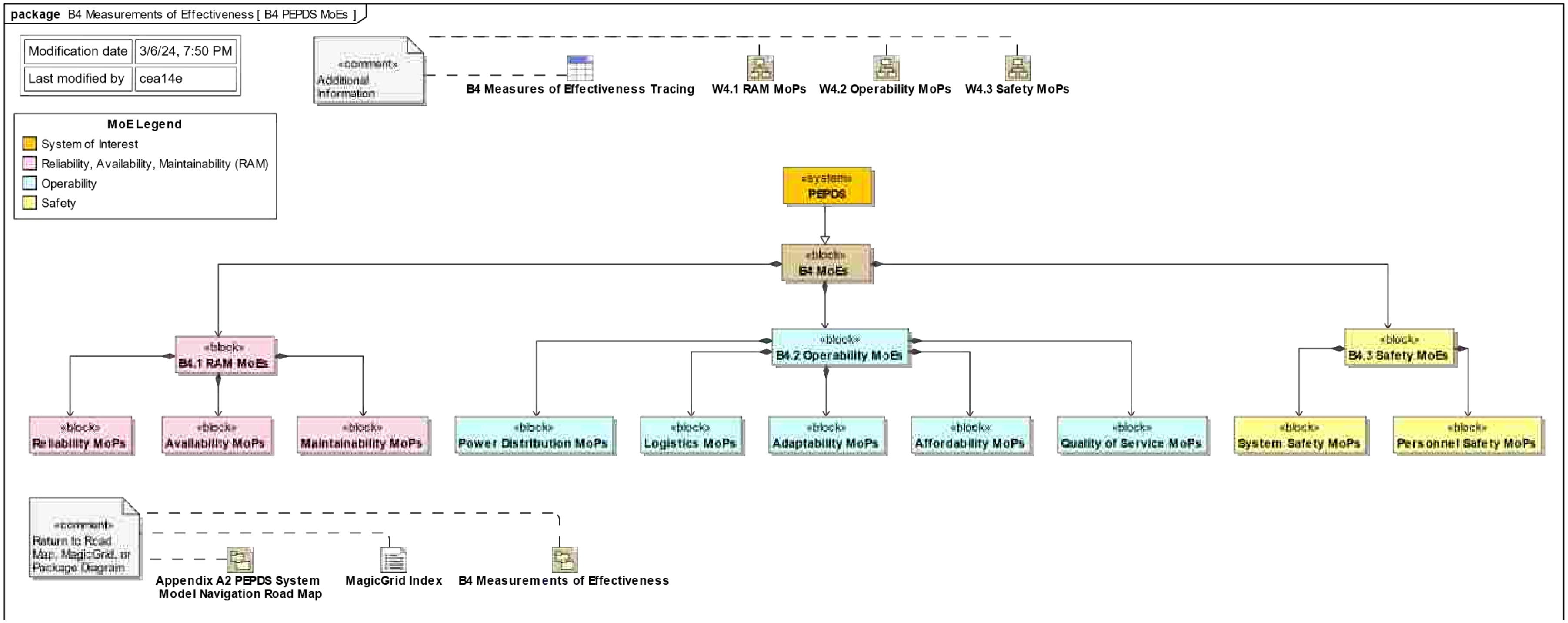


Fig. 14: B4 PEPDS MoEs (Review Part 1)

Table VIII: B4 Measures of Effectiveness Tracing

Owner	Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
B4.1 RAM MoEs	B4.1 RAM MoEs		1.3 Reliability 1.5 Resiliency 1.6 UPS 2.1 Maintainability 2.4 Long Life Expectancy 3.2 Parallel Redundancy 5.9 Integrated CBM+	Long online time when measured by MTBF Tolerant to critical scenarios such as faults and failure of device(s) If demand is greater than supply (delta power), then provide provisional power for x time Maintenance with reduced down time Long operable lifespan Parallel operation to provide continuous power to mission critical loads Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	[ref 33] [ref 35] [ref 23] [ref 37]

Owner	Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
B4.2 Operability MoEs	B4.2 Operability MoEs		1 Power Delivery 1.1 Power Efficiency 1.2 Power Density 1.4 Robustness 2 Operability 2.2 Operator Trainability 3 Scalability 3.3.3 Dynamic Response 3.4 Standardizable 3.5 Affordability 3.6 Hotswappable 5.1 Ease of Installation as a Unit 5.3 Power Electronic Interfaces 5.6 Functional Control 5.7 Adaptive Controls 5.11 Simplified LRU Replacement 5.12 Minimal Redundant Elements 5.15 Reduce Conventional Switchgear	Transfers power from power source to power load Limit power loss during transmission and conversion High power rating relative to volume Compatible with various operating conditions and set points System operation accomplished with reduced manning and logistics effort Low training requirements in regard to time and technical skills Greater power requirement met through serial and/or parallel connections Can ramp up power in a short time; can provide x time over power in a short time slot Fits in many classes of ship Reduce implementation and operation cost for life cycle Hotswappable "Plug-and-Play" applications Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction All source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation Control component and network functions through programming and reconfiguration Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities Provide power quality to loads using fewer components by using distributed resources and integrated functionality such as advanced power electronic control across many converters, active filtering across many converters, and distributed storage Integrate functionality of switchgear within the power electronics framework in order to reduce or eliminate use of conventional external switchgear and provide current limiting function - thereby reducing risk from high fault currents and hence improving reliability	[ref 38] [ref 36] [ref 53] [ref 39]

Owner	Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
B4.3 Safety MoEs	B4.3 Safety MoEs		2.3 Safety 2.3.1 Thermally Touchable 2.3.2 Liftable 2.3.3 Electrically Insulated 3.1 Serial Thermal Management 3.3.2 Cyber Security 5.8 Automated Self-check 5.11 Simplified LRU Replacement	Safe handling conditions External environment at reasonable handling temperatures Weight and volume at a reasonable range for handling Insulation to limit current through operator Universal thermal interface should be proposed Resistant to malicious attacks against software and offers security observation Have self-diagnosis or automated self-check after controls upgrades which would be an advanced concept of CHIL with regression tests embedded in PEPDS (integrated “digital twin”) – including cybersecurity aspects Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	
B4.1 RAM MoEs	Availability MoPs		2.1 Maintainability 1.3 Reliability	Maintenance with reduced down time Long online time when measured by MTBF	[ref 33]
B4.1 RAM MoEs	Maintainability MoPs		2.1 Maintainability 5.9 Integrated CBM+	Maintenance with reduced down time Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	
B4.1 RAM MoEs	Reliability MoPs		1.6 UPS 2.4 Long Life Expectancy 1.3 Reliability 3.2 Parallel Redundancy 1.5 Resiliency	If demand is greater than supply (delta power), then provide provisional power for x time Long operable lifespan Long online time when measured by MTBF Parallel operation to provide continuous power to mission critical loads Tolerant to critical scenarios such as faults and failure of device(s)	
B4.2 Operability MoEs	Adaptability MoPs		3.6 Hotswappable 3 Scalability 3.4 Standardizable 1.4 Robustness 5.7 Adaptive Controls 5.6 Functional Control	Hotswappable "Plug-and-Play" applications Greater power requirement met through serial and/or parallel connections Fits in many classes of ship Compatible with various operating conditions and set points Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades Control component and network functions through programming and reconfiguration	

Owner	Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
B4.2 Operability MoEs	Affordability MoPs		3.5 Affordability 5.1 Ease of Installation as a Unit	Reduce implementation and operation cost for life cycle Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction	
B4.2 Operability MoEs	Logistics MoPs		2.2 Operator Trainability 2 Operability 5.11 Simplified LRU Replacement 5.1 Ease of Installation as a Unit	Low training requirements in regard to time and technical skills System operation accomplished with reduced manning and logistics effort Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction	
B4.2 Operability MoEs	Power Distribution MoPs		1.1 Power Efficiency 3.3.3 Dynamic Response 1 Power Delivery 1.2 Power Density 5.12 Minimal Redundant Elements 5.3 Power Electronic Interfaces 5.15 Reduce Conventional Switchgear	Limit power loss during transmission and conversion Can ramp up power in a short time; can provide x time over power in a short time slot Transfers power from power source to power load High power rating relative to volume Provide power quality to loads using fewer components by using distributed resources and integrated functionality such as advanced power electronic control across many converters, active filtering across many converters, and distributed storage All source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation Integrate functionality of switchgear within the power electronics framework in order to reduce or eliminate use of conventional external switchgear and provide current limiting function - thereby reducing risk from high fault currents and hence improving reliability	
B4.2 Operability MoEs	Quality of Service MoPs				[ref 39]

Owner	Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
B4.3 Safety MoEs	Personnel Safety MoPs		2.3.1 Thermally Touchable 5.11 Simplified LRU Replacement 2.3.3 Electrically Insulated 2.3 Safety 3.1 Serial Thermal Management 2.3.2 Liftable	External environment at reasonable handling temperatures Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities Insulation to limit current through operator Safe handling conditions Universal thermal interface should be proposed Weight and volume at a reasonable range for handling	
B4.3 Safety MoEs	System Safety MoPs		3.1 Serial Thermal Management 3.3.2 Cyber Security 5.8 Automated Self-check 2.3 Safety	Universal thermal interface should be proposed Resistant to malicious attacks against software and offers security observation Have self-diagnosis or automated self-check after controls upgrades which would be an advanced concept of CHIL with regression tests embedded in PEPDS (integrated “digital twin”) – including cybersecurity aspects Safe handling conditions	

11.2.2 Problem Domain White Box Review

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

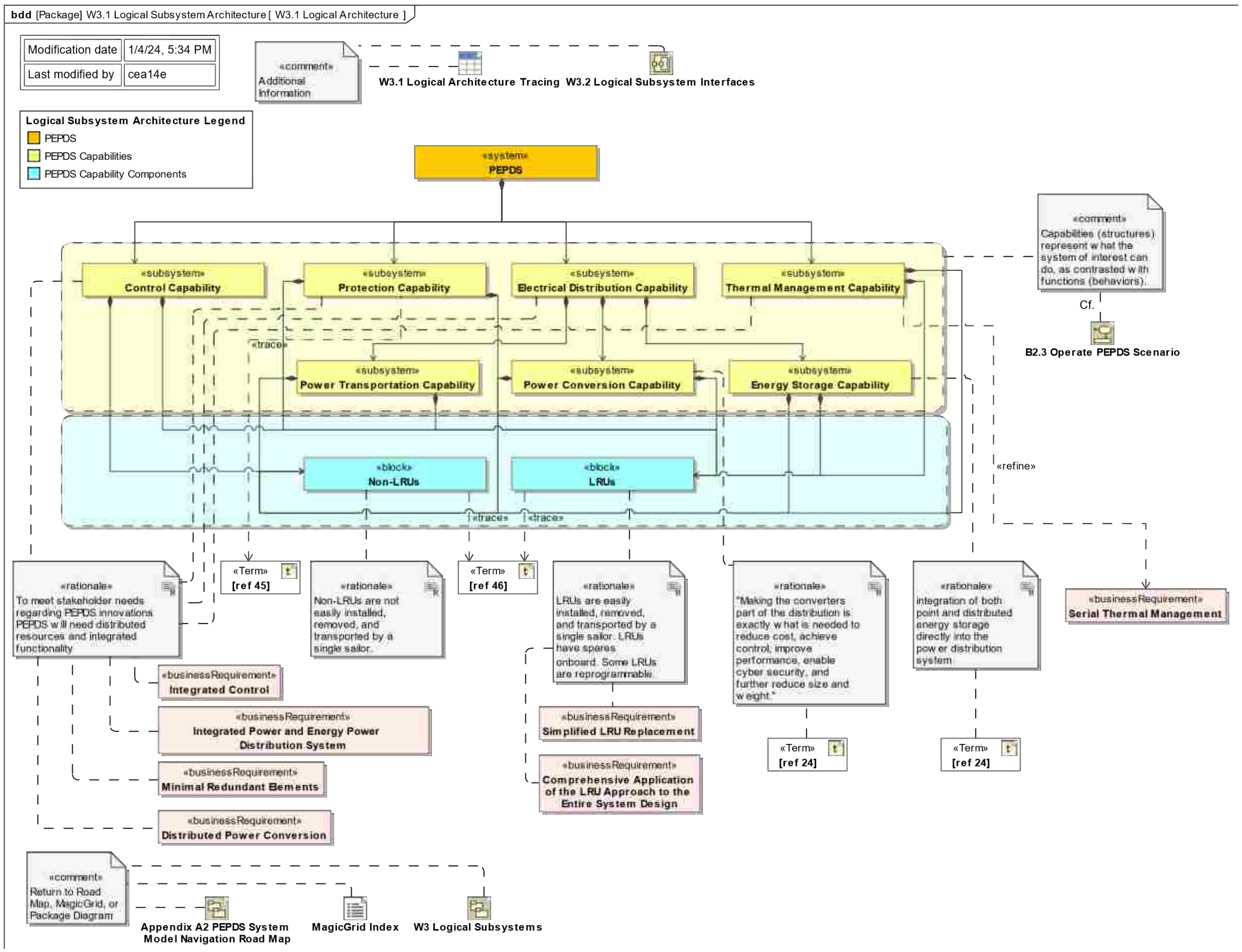


Fig. 15: W3.1 Logical Architecture

Table IX:W3.1 Logical Architecture Tracing

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Control Capability	To meet stakeholder needs regarding PEPDS innovations PEPDS will need distributed resources and integrated functionality	5.6 Functional Control 5.12 Minimal Redundant Elements 5.13 Integrated Power and Energy Power Distribution System 5.5 Integrated Control	Control component and network functions through programming and reconfiguration Provide power quality to loads using fewer components by using distributed resources and integrated functionality such as advanced power electronic control across many converters, active filtering across many converters, and distributed storage PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control Integrated electrical, thermal, and mechanical control	[ref 24]
Electrical Distribution Capability	To meet stakeholder needs regarding PEPDS innovations PEPDS will need distributed resources and integrated functionality	5.13 Integrated Power and Energy Power Distribution System 5.14 Distributed Power Conversion	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements	[ref 24]
Energy Storage Capability	integration of both point and distributed energy storage directly into the power distribution system	5.12 Minimal Redundant Elements	Provide power quality to loads using fewer components by using distributed resources and integrated functionality such as advanced power electronic control across many converters, active filtering across many converters, and distributed storage	[ref 24]

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
LRUs	LRUs are easily installed, removed, and transported by a single sailor. LRUs have spares onboard. Some LRUs are reprogrammable.	5.10 Comprehensive Application of the LRU Approach to the Entire System Design 5.11 Simplified LRU Replacement	Maximize the dependence on LRUs while minimizing the different types of LRUs Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	[ref 46]
Non-LRUs	Non-LRUs are not easily installed, removed, and transported by a single sailor.			[ref 46]
PEPDS	The system of interest is PEPDS which is a new power, energy, and control distribution concept enabled by technology development funded by the ONR.			[ref 24]
Power Conversion Capability	"Making the converters part of the distribution is exactly what is needed to reduce cost, achieve control, improve performance, enable cyber security, and further reduce size and weight."	5.12 Minimal Redundant Elements	Provide power quality to loads using fewer components by using distributed resources and integrated functionality such as advanced power electronic control across many converters, active filtering across many converters, and distributed storage	[ref 24]
Power Transportation Capability		1 Power Delivery	Transfers power from power source to power load	
Protection Capability	To meet stakeholder needs regarding PEPDS innovations PEPDS will need distributed resources and integrated functionality	5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	[ref 45]
Thermal Management Capability	To meet stakeholder needs regarding PEPDS innovations PEPDS will need distributed resources and integrated functionality	3.1 Serial Thermal Management	Universal thermal interface should be proposed	

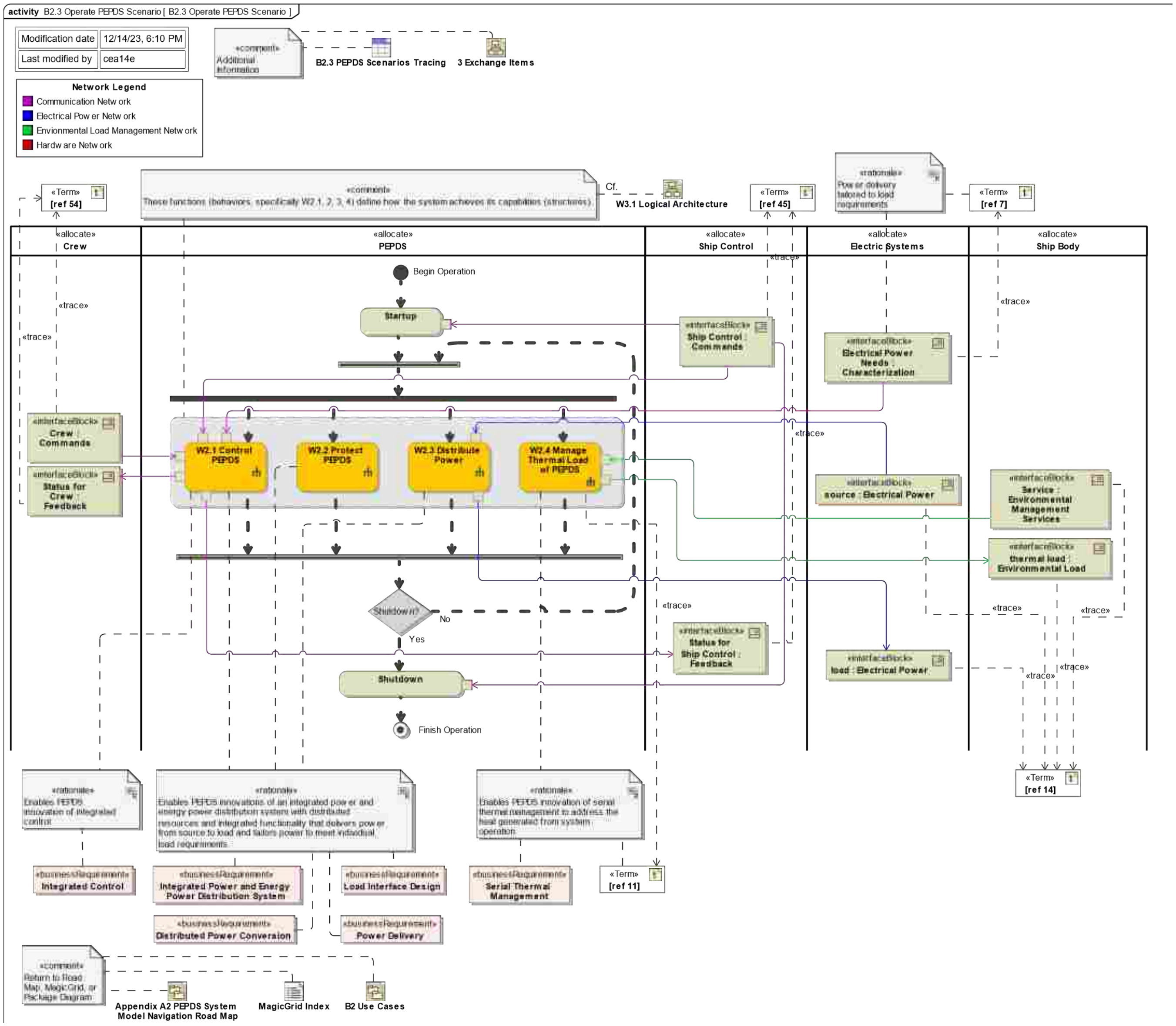


Fig. 16: B2.3 Operate PEPDS Scenario (Review Part 2)

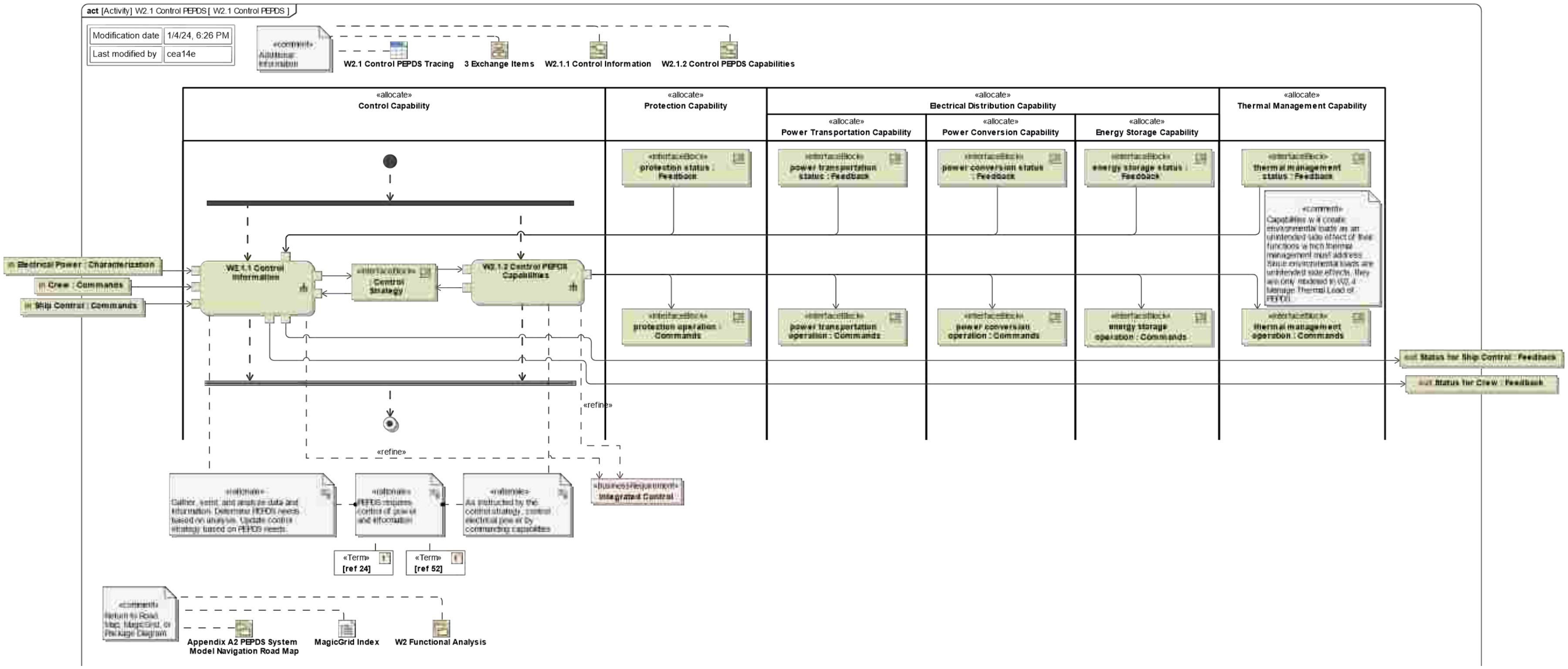


Fig. 17: W2.1 Control PEPDS

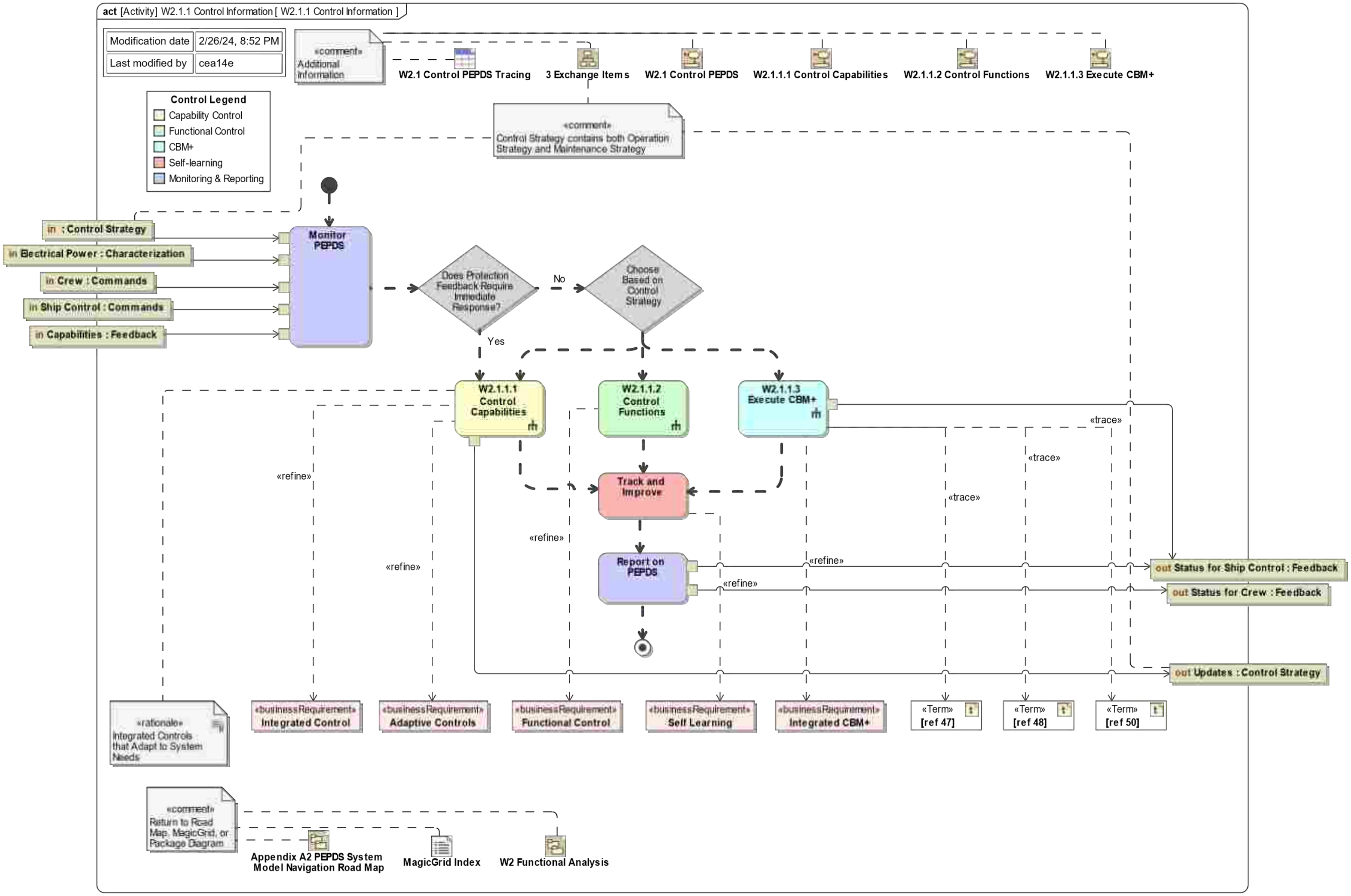


Fig. 18: W2.1.1 Control Information

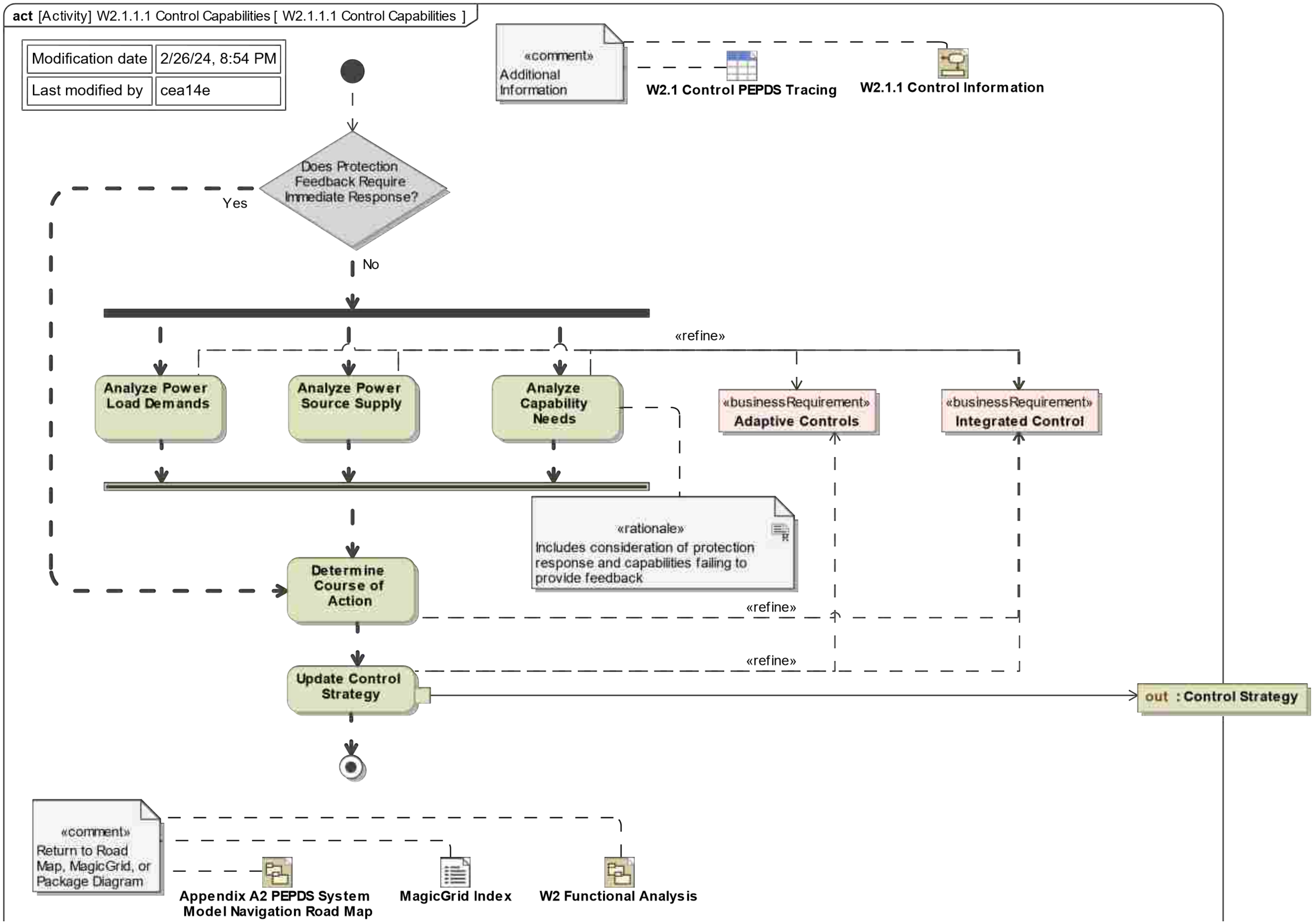


Fig. 19: W2.1.1.1 Control Capabilities

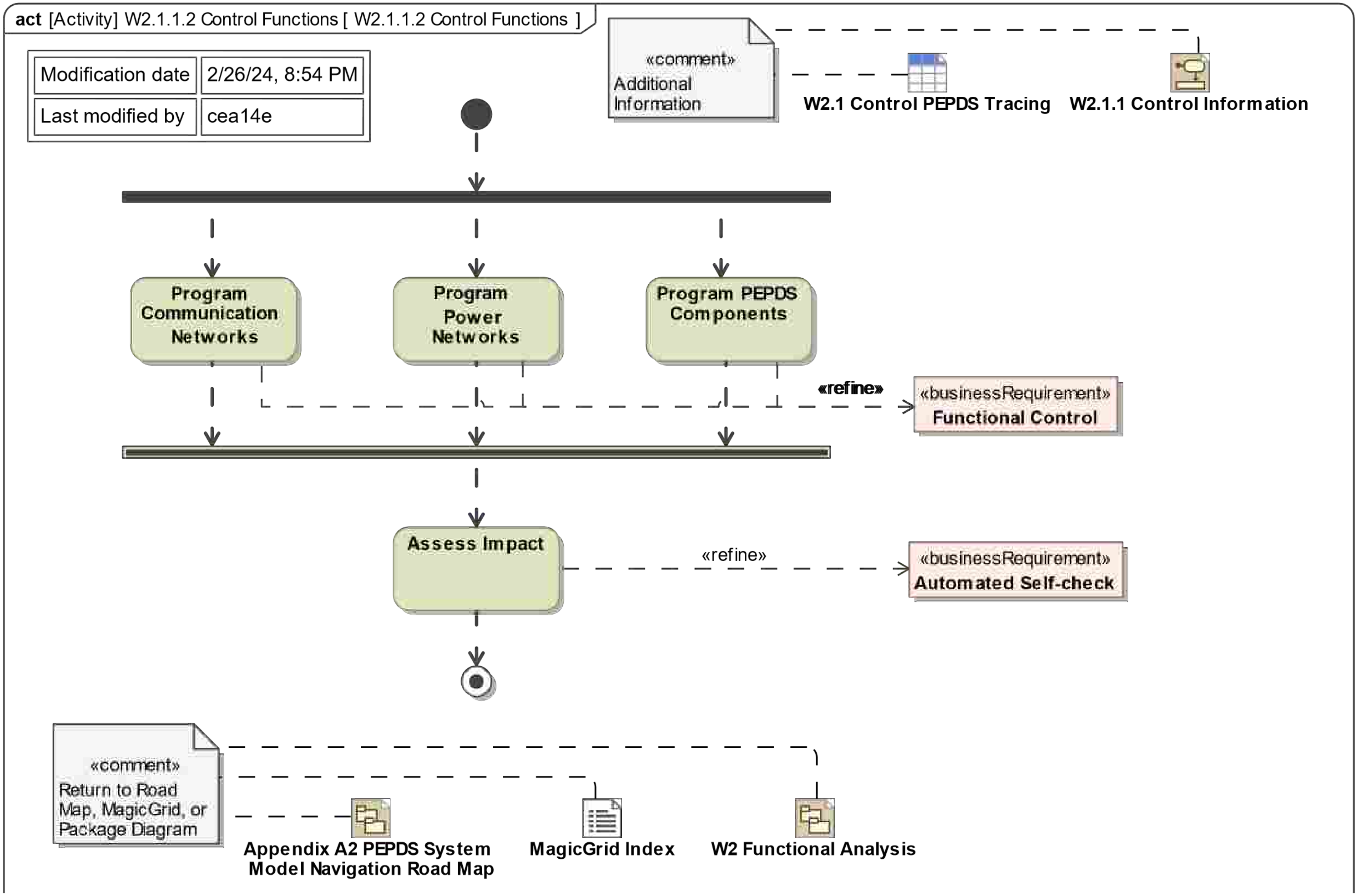


Fig. 20: W2.1.1.2 Control Functions

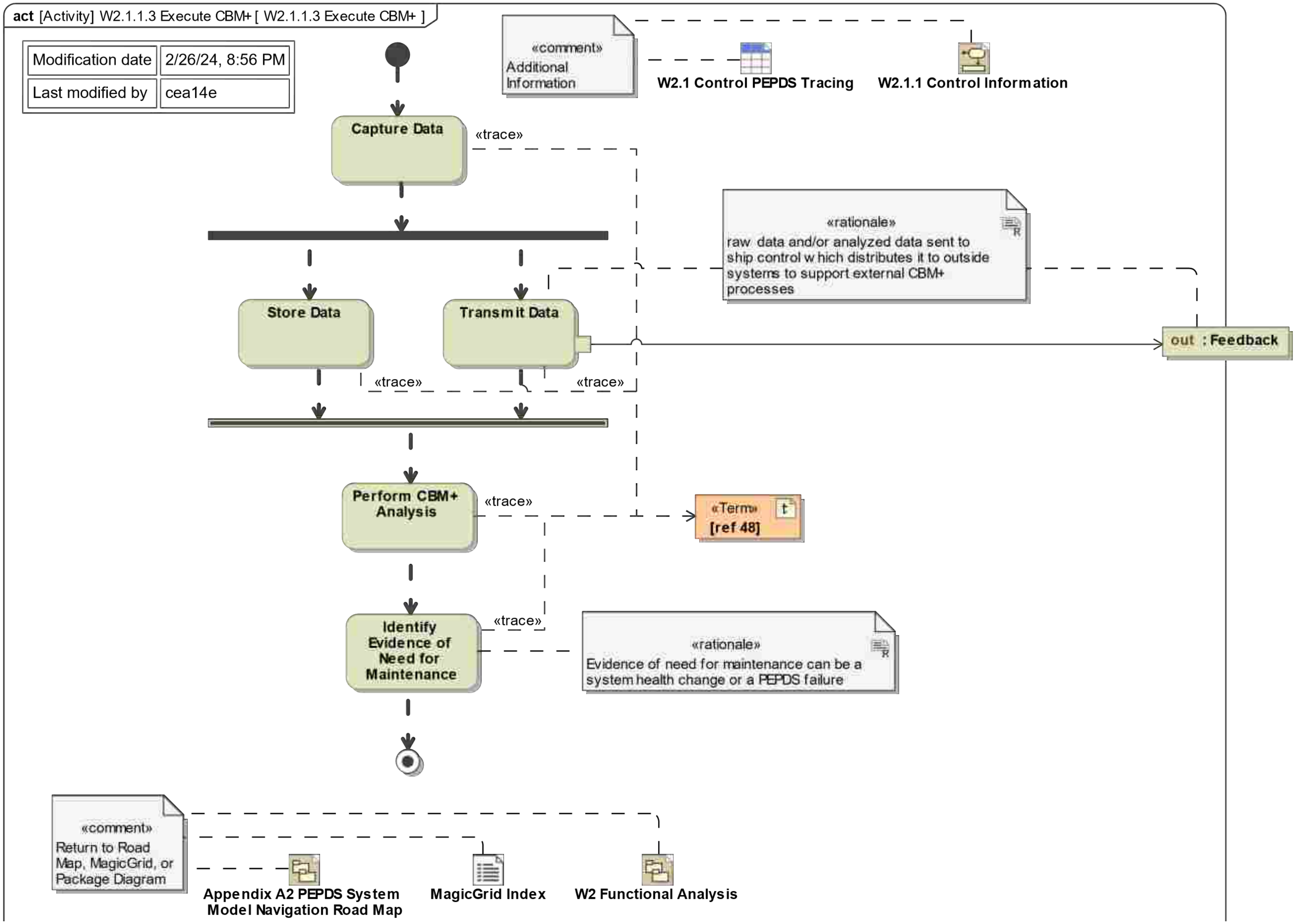


Fig. 21: W2.1.1.3 Execute CBM+

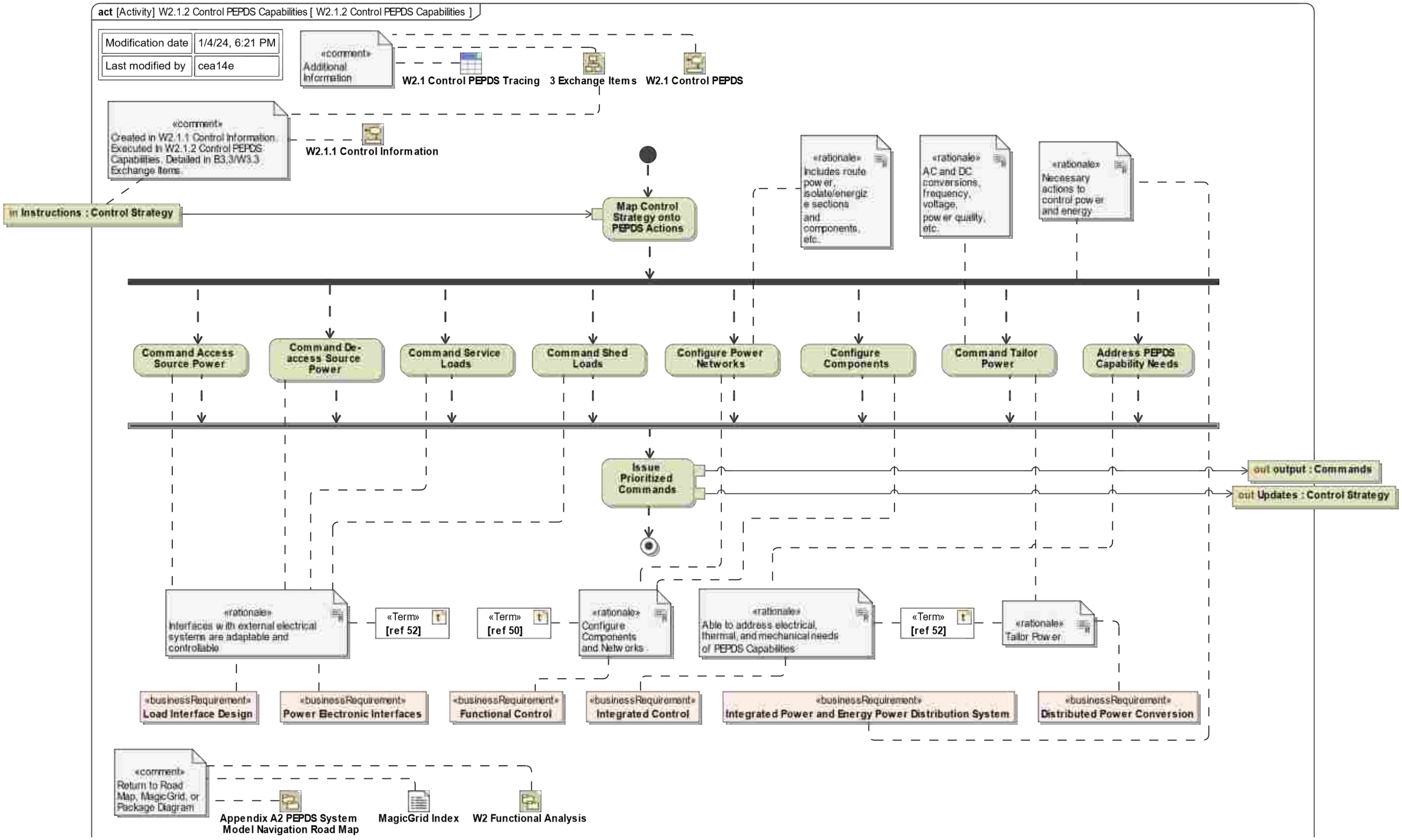


Fig. 22: W2.1.2 Control PEPDS Capabilities

Table X: W2.1 Control PEPDS Tracing

Owner	Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
W2.1 Control PEPDS		Control Strategy				
W2.1 Control PEPDS	energy storage operation	Commands				
W2.1 Control PEPDS	energy storage status	Feedback				
W2.1 Control PEPDS	power conversion operation	Commands				
W2.1 Control PEPDS	power conversion status	Feedback				
W2.1 Control PEPDS	power transportation operation	Commands				
W2.1 Control PEPDS	power transportation status	Feedback				
W2.1 Control PEPDS	protection operation	Commands				
W2.1 Control PEPDS	protection status	Feedback				
W2.1 Control PEPDS	thermal management operation	Commands				
W2.1 Control PEPDS	thermal management status	Feedback				
W2.1 Control PEPDS	W2.1.1 Control Information		PEPDS requires control of power and information Gather, send, and analyze data and information. Determine PEPDS needs based on analysis. Update control strategy based on PEPDS needs.	5.5 Integrated Control	Integrated electrical, thermal, and mechanical control	[ref 24] [ref 52]
W2.1 Control PEPDS	W2.1.2 Control PEPDS Capabilities		PEPDS requires control of power and information as instructed by the control strategy, control electrical power by commanding capabilities	5.5 Integrated Control	Integrated electrical, thermal, and mechanical control	[ref 24] [ref 52]

Owner	Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
W2.1.1 Control Information	Monitor PEPDS					
W2.1.1 Control Information	Report on PEPDS					
W2.1.1 Control Information	Track and Improve			5.4 Self Learning	Ability to self-learn by tracking performance and CBM+ data and analyzing control and protection activities	
W2.1.1 Control Information	W2.1.1.1 Control Capabilities		Integrated Controls that Adapt to System Needs	5.5 Integrated Control 5.7 Adaptive Controls	Integrated electrical, thermal, and mechanical control Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades	
W2.1.1 Control Information	W2.1.1.2 Control Functions			5.6 Functional Control	Control component and network functions through programming and reconfiguration	
W2.1.1 Control Information	W2.1.1.3 Execute CBM+			5.9 Integrated CBM+	Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	[ref 47] [ref 48] [ref 50]
W2.1.1.1 Control Capabilities	Analyze Capability Needs		Includes consideration of protection response and capabilities failing to provide feedback	5.5 Integrated Control 5.7 Adaptive Controls	Integrated electrical, thermal, and mechanical control Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades	
W2.1.1.1 Control Capabilities	Analyze Power Load Demands			5.7 Adaptive Controls	Control algorithms self-adapt to changes in mission	

Owner	Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
				5.5 Integrated Control	requirements, load performance, and system upgrades Integrated electrical, thermal, and mechanical control	
W2.1.1.1 Control Capabilities	Analyze Power Source Supply			5.7 Adaptive Controls 5.5 Integrated Control	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgradesIntegrated electrical, thermal, and mechanical control	
W2.1.1.1 Control Capabilities	Determine Course of Action			5.7 Adaptive Controls 5.5 Integrated Control	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades Integrated electrical, thermal, and mechanical control	
W2.1.1.1 Control Capabilities	Update Control Strategy			5.5 Integrated Control 5.7 Adaptive Controls	Integrated electrical, thermal, and mechanical control Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades	
W2.1.1.2 Control Functions	Assess Impact			5.8 Automated Self-check	Have self-diagnosis or automated self-check after controls upgrades which would be an advanced concept of CHIL with regression tests embedded in PEPDS (integrated "digital twin") – including cybersecurity aspects	

Owner	Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
W2.1.1.2 Control Functions	Program Communication Networks			5.6 Functional Control	Control component and network functions through programming and reconfiguration	
W2.1.1.2 Control Functions	Program PEPDS Components			5.6 Functional Control	Control component and network functions through programming and reconfiguration	
W2.1.1.2 Control Functions	Program Power Networks			5.6 Functional Control	Control component and network functions through programming and reconfiguration	
W2.1.1.3 Execute CBM+	Capture Data					[ref 48]
W2.1.1.3 Execute CBM+	Identify Evidence of Need for Maintenance		Evidence of need for maintenance can be a system health change or a PEPDS failure			[ref 48]
W2.1.1.3 Execute CBM+	Perform CBM+ Analysis					[ref 48]
W2.1.1.3 Execute CBM+	Store Data					[ref 48]
W2.1.1.3 Execute CBM+	Transmit Data		raw data and/or analyzed data sent to ship control which distributes it to outside systems to support external CBM+ processes			[ref 48]
W2.1.2 Control PEPDS Capabilities	Address PEPDS Capability Needs		Able to address electrical, thermal, and mechanical needs of PEPDS Capabilities	5.5 Integrated Control	Integrated electrical, thermal, and mechanical control	

Owner	Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
W2.1.2 Control PEPDS Capabilities	Command Access Source Power		Interfaces with external electrical systems are adaptable and controllable	5.2 Load Interface Design 5.3 Power Electronic Interfaces	Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the ship All source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation	[ref 52]
W2.1.2 Control PEPDS Capabilities	Command De-access Source Power		Interfaces with external electrical systems are adaptable and controllable	5.2 Load Interface Design 5.3 Power Electronic Interfaces	Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the shipAll source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation	[ref 52]
W2.1.2 Control PEPDS Capabilities	Command Service Loads		Interfaces with external electrical systems are adaptable and controllable	5.2 Load Interface Design 5.3 Power Electronic Interfaces	Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the ship All source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation	[ref 52]

Owner	Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
W2.1.2 Control PEPDS Capabilities	Command Shed Loads		Interfaces with external electrical systems are adaptable and controllable	5.2 Load Interface Design 5.3 Power Electronic Interfaces	Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the shipAll source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation	[ref 52]
W2.1.2 Control PEPDS Capabilities	Command Tailor Power		AC and DC conversions, frequency, voltage, power quality, etc. Tailor Power	5.14 Distributed Power Conversion	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements	[ref 52]
W2.1.2 Control PEPDS Capabilities	Configure Components		Configure Components and Networks	5.6 Functional Control	Control component and network functions through programming and reconfiguration	[ref 50]
W2.1.2 Control PEPDS Capabilities	Configure Power Networks		Includes route power, isolate/energize sections and components, etc. Configure Components and Networks	5.6 Functional Control	Control component and network functions through programming and reconfiguration	[ref 50]
W2.1.2 Control PEPDS Capabilities	Issue Prioritized Commands					
W2.1.2 Control PEPDS Capabilities	Map Control Strategy onto PEPDS Actions					

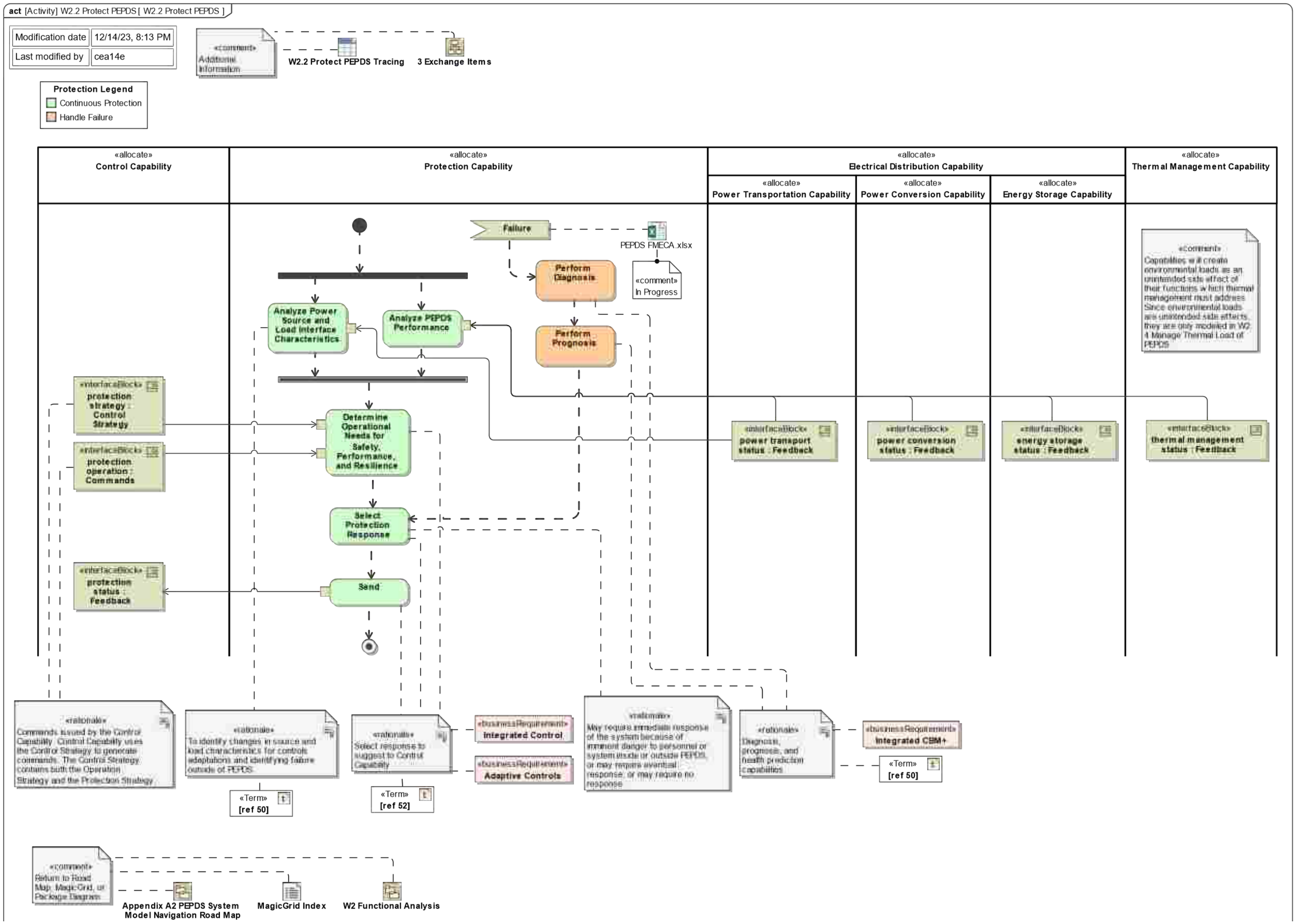


Fig. 23: W2.2 Protect PEPDS

Table XI: W2.2 Protect PEPDS Tracing

Name	Type	Rationale	Refines	Refined Stakeholder Needs Text	Traced To
Analyze PEPDS Performance			5.7 Adaptive Controls	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades	
Analyze Power Source and Load Interface Characteristics		To identify changes in source and load characteristics for controls adaptations and identifying failure outside of PEPDS.	5.7 Adaptive Controls	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades	[ref 50]
Determine Operational Needs for Safety, Performance, and Resilience		Select response to suggest to Control Capability	5.7 Adaptive Controls 5.5 Integrated Control	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades Integrated electrical, thermal, and mechanical control	[ref 52]
energy storage status	Feedback				
Perform Diagnosis		Diagnosis, prognosis, and health prediction capabilities	5.9 Integrated CBM+	Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	[ref 50]
Perform Prognosis		Diagnosis, prognosis, and health prediction capabilities	5.9 Integrated CBM+	Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	[ref 50]
power conversion status	Feedback				
power transport status	Feedback				
protection operation	Commands	Commands issued by the Control Capability. Control Capability uses the Control Strategy to generate commands. The Control Strategy contains both the Operation Strategy and the Protection Strategy.			

Name	Type	Rationale	Refines	Refined Stakeholder Needs Text	Traced To
protection status	Feedback				
protection strategy	Control Strategy	Commands issued by the Control Capability. Control Capability uses the Control Strategy to generate commands. The Control Strategy contains both the Operation Strategy and the Protection Strategy.			
Select Protection Response		May require immediate response of the system because of imminent danger to personnel or system inside or outside PEPDS; or may require eventual response; or may require no response. Select response to suggest to Control Capability	5.5 Integrated Control 5.7 Adaptive Controls	Integrated electrical, thermal, and mechanical control. Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades	[ref 52]
Send		Select response to suggest to Control Capability	5.7 Adaptive Controls 5.5 Integrated Control	Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades integrated electrical, thermal, and mechanical control	[ref 52]
thermal management status	Feedback				

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurance	Current Controls for Prevention/Detection	Detection	RPN
Control Capability	Control	PEPDS fail to de-energize specific section of system							
		PEPDS fails to analyze capability needs							
		PEPDS fails to analyze power load demands							
		PEPDS fails to analyze power source supply							
		PEPDS fails to assess impact of programming							
		PEPDS fails to command servicing and shedding of the loads							
		PEPDS fails to configure power networks and components							
		PEPDS fails to control source power							
		PEPDS fails to determine the correct course of action							
		PEPDS fails to issue prioritized commands							
		PEPDS fails to map control strategy onto PEPDS actions							
		PEPDS fails to perform CBM+							
		PEPDS fails to program communication networks							
		PEPDS fails to program components							
		PEPDS fails to program power networks							
		PEPDS fails to send feedback to crew and ship control							
		PEPDS fails to tailor power based on need							
		PEPDS fails to track and improve control strategy							
		PEPDS fails to track and improve need for maintenance							
		PEPDS fails to update control strategy							
		The control capability fails to control PEPDS capabilities							
		The control capability fails to establish an interface with the crew							
		The control capability fails to establish an interface with the energy storage capability							
		The control capability fails to establish an interface with the onboard and offboard power sources and loads							
		The control capability fails to establish an interface with the power conversion capability							
		The control capability fails to establish an interface with the power transportation capability							
		The control capability fails to establish an interface with the protection capability							
		The control capability fails to establish an interface with the ship control							
		The control capability fails to interface control strategy in the control activity							
		The control capability fails to monitor PEPDS							
		The control capability fails to receive feedback from all other capabilities							
		The control capability fails to send commands to all other capabilities							
		PEPDS fails to take counter measures to control abnormality in operations							
		PEPDS fails to address electrical power needs							
		PEPDS fails to address ship control commands							
		PEPDS fails to address crew commands							
Energy Storage Capability	Store Energy	Degradation of energy storage devices							
		Energy storage charge rate exceeds acceptable range							
		Energy storage discharge rate exceeds acceptable range							
		Energy Storage Overcharges							
		Energy Storage Overdischarges							
		PEPDS fail to receive power from energy storages							
		PEPDS fails to store energy							
		The energy storage capability fails to address commands from the control capability							
		The energy storage capability fails to address electrical power from the power conversion capability							
		The energy storage capability fails to deliver electrical power to power conversion capability							
		The energy storage capability fails to update energy storage status to the protection capability							
PEPDS	Allow Maintenance	Installation of LRU fails							
		Removal of LRU fails							
		PEPDS fails to perform device level maintenance							
	Establish Interface with External System	LRU fails to establish an interface with PEPDS							
		PEPDS fails to establish an interface with the shipyard							
		PEPDS fails to establish an interface with the onboard power systems							
		PEPDS fails to establish an interface with the crew							
		PEPDS fails to establish an interface with the electric ship							
		PEPDS fails to establish an interface with the offboard power systems							
	Transition States	PEPDS detects a failure but does not go to off-nominal state from nominal state							
		PEPDS fails to go to maintaining state from operating nominally state							
		PEPDS fails to go to maintaining state from operating off-nominally state							
		PEPDS fails to go to off state after maintenance							
		PEPDS fails to go to off state after performing SHIPALT							
		PEPDS fails to operate nominally after maintenance is completed							
		PEPDS fails to operate off-nominally after a repair is performed							
		PEPDS fails to recover autonomously from operating off-nominally							
		PEPDS fails to shutdown							
Power Conversion Capability	Convert Power	PEPDS fail to convert power for problems other than voltage, current, phase and frequency							
		Power conversion fails to meet current specification							
		Power conversion fails to meet frequency specification							
		Power conversion fails to meet phase specification							
		Power conversion fails to meet voltage specification							
		The power conversion capability fails to address commands from the control capability							
		The power conversion capability fails to address electrical power from the energy storage capability							
		The power conversion capability fails to address electrical power from the power transportation capability							
		The power conversion capability fails to establish an interface with the energy storage capability							
		The power conversion capability fails to update power conversion status to the protection capability							
Power Transportation Capability	Transport Power	Ark flashing							
		Conductor to ground short							
		External electrical short detected							
		Fault currents							
		Internal electrical short detected							
		Line to ground short							
		Line to line short							
		PEPDS fail to deliver power to loads							
		PEPDS fail to distribute power							
		PEPDS fail to receive power from off-board power sources							
		PEPDS fail to receive power from on-board power sources							
		The power transportation capability fails to accommodate electrical power from the power conversion capability							
		The power transportation capability fails to deliver electrical power to loads							
		The power transportation capability fails to establish an interface with the energy storage capability							
		The power transportation capability fails to establish an interface with the offboard power systems							
		The power transportation capability fails to establish an interface with the onboard power systems							
		The power transportation capability fails to establish an interface with the power conversion capability							
		The power transportation capability fails to process commands from the control capability							
		The power transportation capability fails to receive electrical power from sources							
		The power transportation capability fails to update power transportation status to the protection capability							
Protection Capability	Provide Protection	Change in System Functions							
		The protection capability fails to address commands from the control capability							
		The protection capability fails to analyze PEPDS performance based on feedback from other capabilities							
		The protection capability fails to analyze power and source interface characteristics							
		The protection capability fails to determine need for safety, performance and resilience based on protection strategy							
		The protection capability fails to diagnose or prognose the failure							
		The protection capability fails to establish an interface with the energy storage capability							
		The protection capability fails to establish an interface with the power conversion capability							
		The protection capability fails to establish an interface with the power transportation capability							
		The protection capability fails to select a protection response on detection of a fault							
		The protection capability fails to send the the protection status to the control capability							
		Uncontained cybersecurity intrusion							
		Undetected cybersecurity intrusion							
		Unresolved cybersecurity intrusion							
Thermal Management Capability	Manage Thermal Load	Inadequate capability to drain used coolant							
		Leakage in coolant system							
		PEPDS fails to maintain thermal situation during continuous operations							
		PEPDS fails to manage external environmental services							
		PEPDS fails to regulate environmental load from capabilities							
		The thermal management capability fails to address commands from the control capability							
		The thermal management capability fails to dissipate thermal load external to PEPDS							
		The thermal management capability fails to establish an interface with the control capability							
		The thermal management capability fails to establish an interface with the electric ship							
		The thermal management capability fails to establish an interface with the energy storage capability							
		The thermal management capability fails to establish an interface with the power conversion capability							
		The thermal management capability fails to establish an interface with the power transportation capability							
		The thermal management capability fails to establish an interface with the protection capability							
		The thermal management capability fails to regulate PEPDS internal thermla load							
		The thermal management capability fails to update thermal management status to the control capability							
		The thermal management capability fails to update thermal management to the protection strategy							
		Thermal degradation							
		Used coolant exposed to oxygen							
		PEPDS fails to address environmental management services							

Fig. 24: W2.2.1 PEPDS FMECA

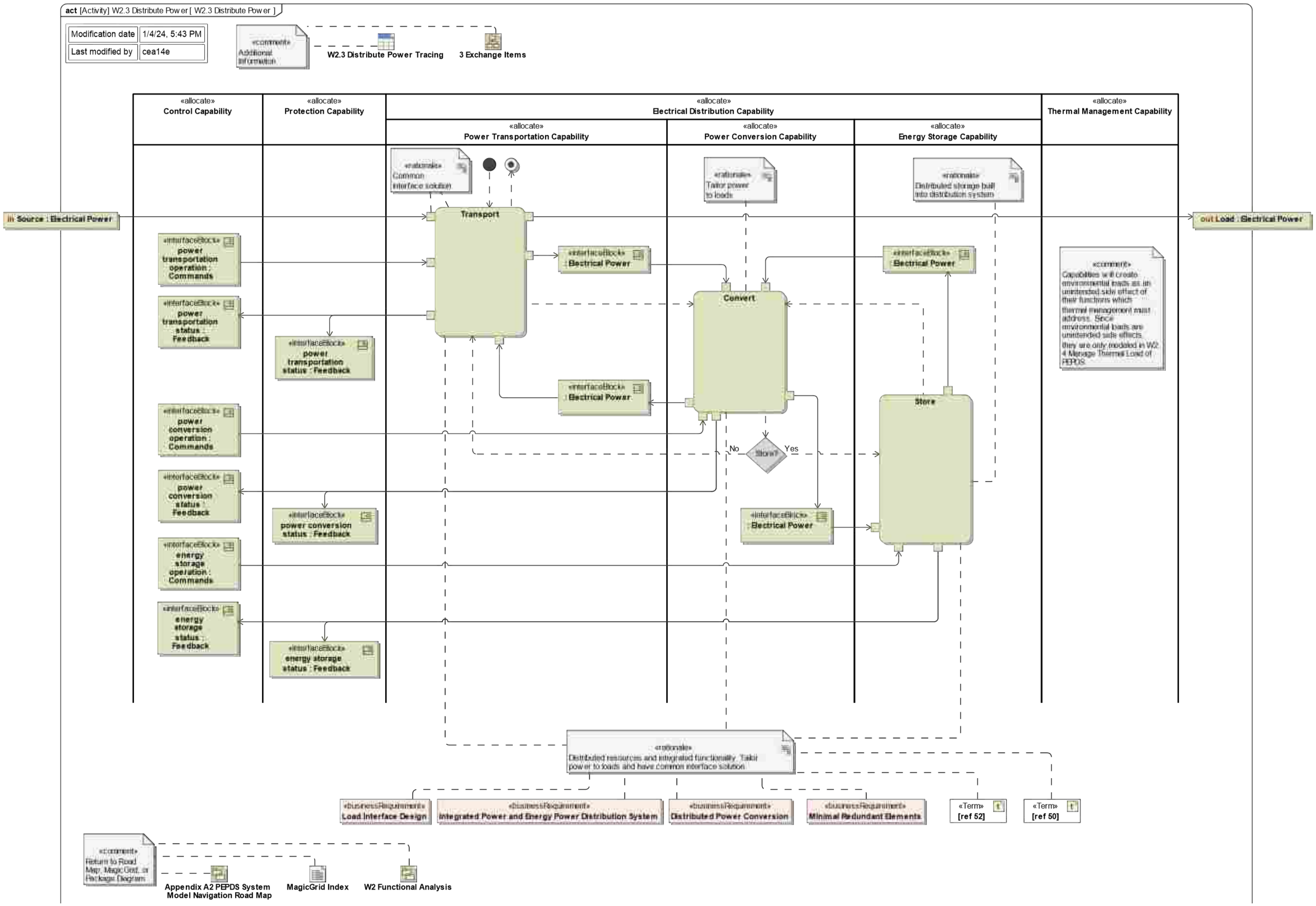


Fig. 25: W2.3 Distribute Power

Table XII: W2.3 Distribute Power Tracing

Name	Type	Rationale	Refine	Refined Stakeholder Need Text	Traced To
	Electrical Power		5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
	Electrical Power		5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
	Electrical Power		5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
	Electrical Power		5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
Convert		Distributed resources and integrated functionality. Tailor power to loads and have common interface solution.Tailor power to loads	5.14 Distributed Power Conversion	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements	[ref 52] [ref 50]
energy storage operation	Commands				
energy storage status	Feedback				
energy storage status	Feedback				
power conversion operation	Commands				
power conversion status	Feedback				
power conversion status	Feedback				

Name	Type	Rationale	Refine	Refined Stakeholder Need Text	Traced To
power transportation operation	Commands				
power transportation status	Feedback				
power transportation status	Feedback				
Store		Distributed resources and integrated functionality. Tailor power to loads and have common interface solution. Distributed storage built into distribution system	5.14 Distributed Power Conversion	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements	[ref 52] [ref 50]
Transport		Distributed resources and integrated functionality. Tailor power to loads and have common interface solution. Common interface solution	5.13 Integrated Power and Energy Power Distribution System 5.2 Load Interface Design	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the ship	[ref 52] [ref 50]

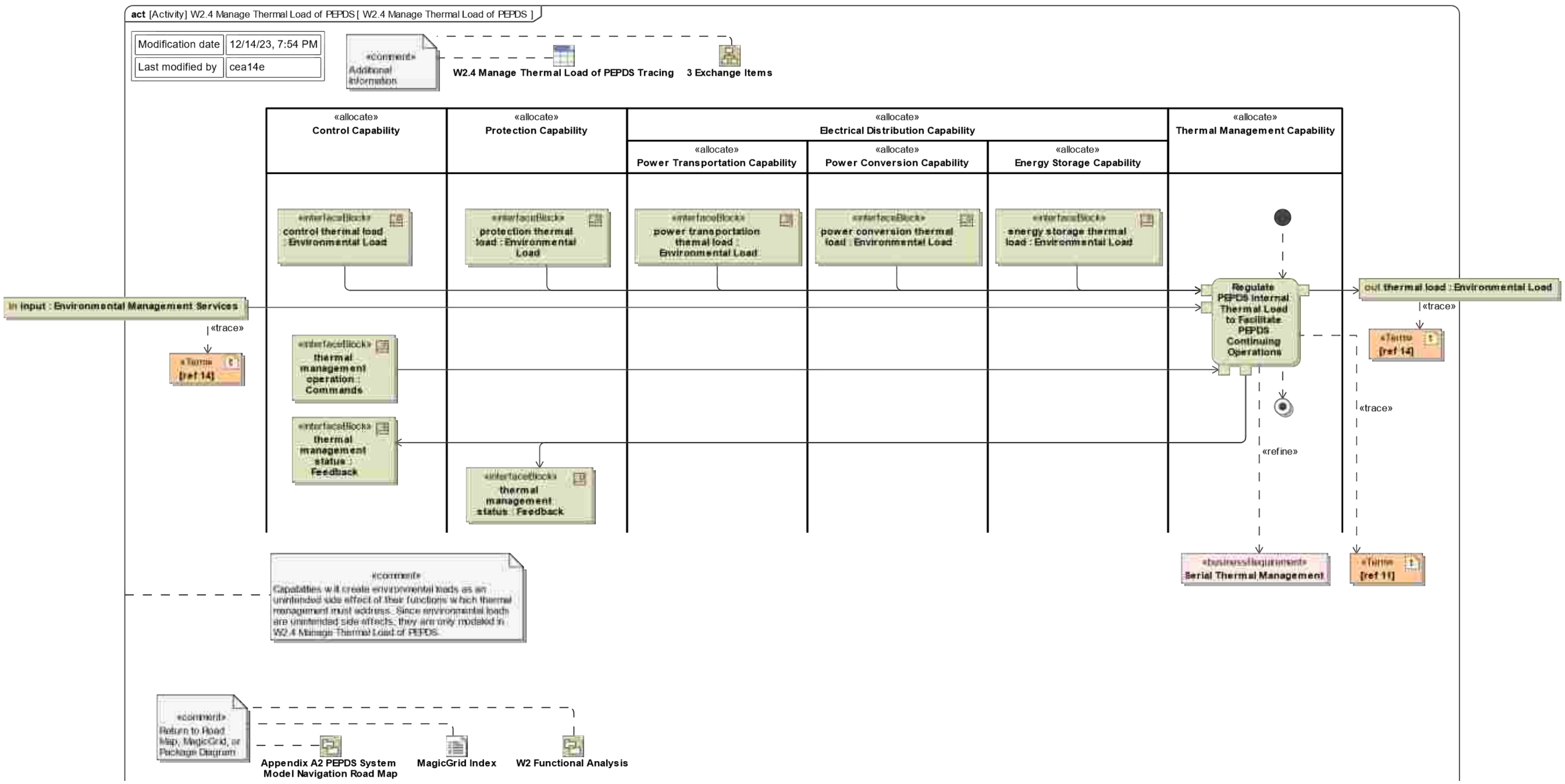


Fig. 26: W2.4 Manage Thermal Load of PEPDS

Table XIII: W2.4 Manage Thermal Load of PEPDS Tracing

Name	Type	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Regulate PEPDS Internal Thermal Load to Facilitate PEPDS Continuing Operations			3.1 Serial Thermal Management	Universal thermal interface should be proposed	[ref 11]
input1	Commands				
thermal management operation	Commands				
control thermal load	Environmental Load				
energy storage thermal load	Environmental Load				
input	Environmental Load				
output	Environmental Load				
power conversion thermal load	Environmental Load				
power transportation thermal load	Environmental Load				
protection thermal load	Environmental Load				
thermal load	Environmental Load				[ref 14]
input	Environmental Management Services				[ref 14]
input2	Environmental Management Services				
output1	Feedback				
thermal management status	Feedback				
thermal management status	Feedback				

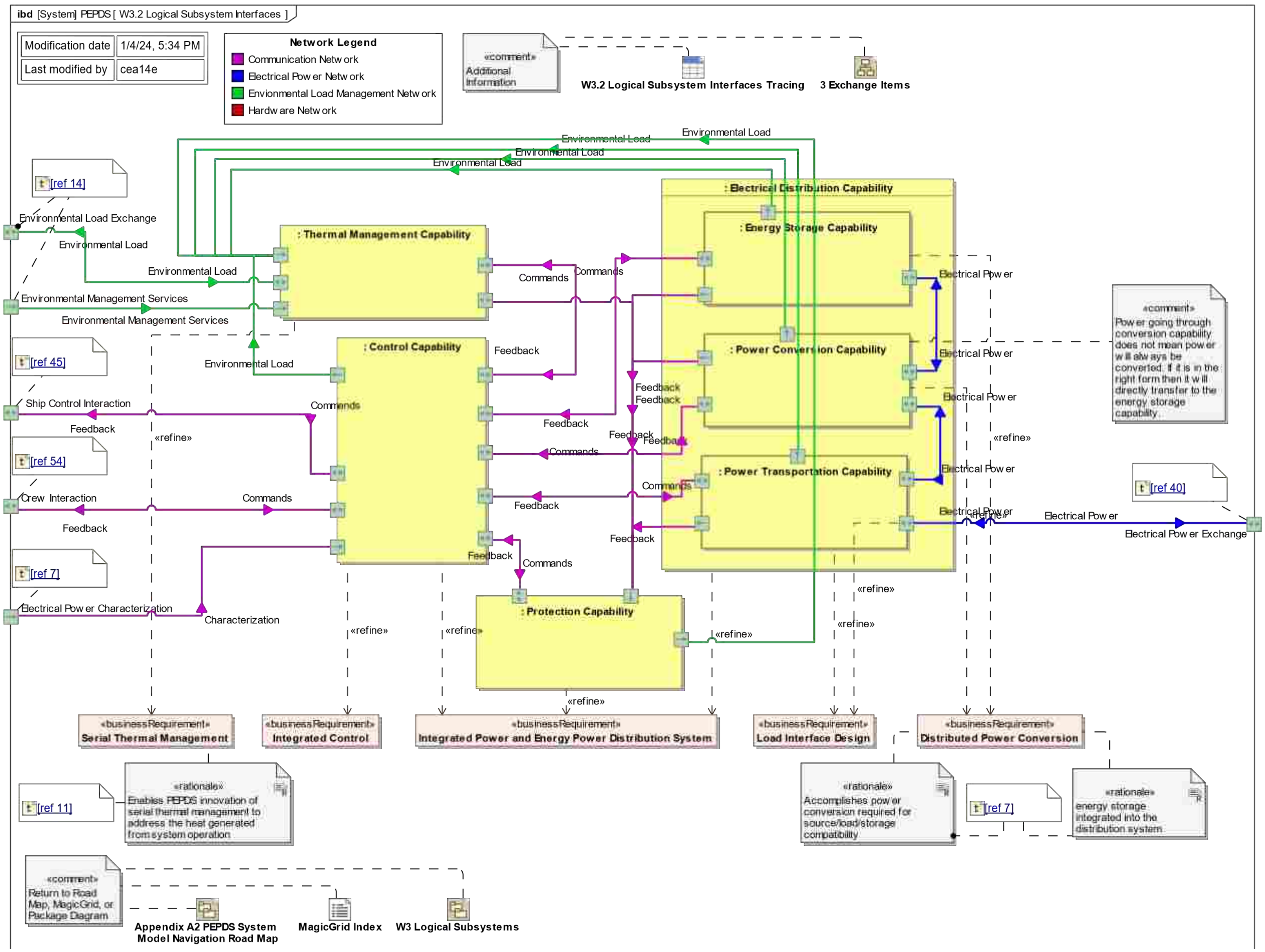


Fig. 27: W3.2 Logical Subsystem Interfaces

Table XIV: W3.2 Logical Subsystem Interfaces Tracing

Type	Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Control Capability			5.5 Integrated Control 5.13 Integrated Power and Energy Power Distribution System	Integrated electrical, thermal, and mechanical control PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
Electrical Distribution Capability			5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
Energy Storage Capability		energy storage integrated into the distribution system	5.14 Distributed Power Conversion	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements	[ref 7]
Power Conversion Capability		Accomplishes power conversion required for source/load/storage compatibility	5.14 Distributed Power Conversion	Distributed power conversion provides protection, filtering, and energy storage. It creates an interface for every load meaning there will be no single interface standard for all loads and that ac or dc, frequency, voltage, power, etc. are tailored to meet individual load requirements	[ref 7]
Power Transportation Capability			5.2 Load Interface Design	Common interface solution for all loads with increased possibilities of load interface spatial arrangement in the ship	
Protection Capability			5.13 Integrated Power and Energy Power Distribution System	PEPDS is an integrated power and energy power distribution system which should have integrated power, propulsion, optimization, protection, filtering, storage, and control	
Thermal Management Capability		Enables PEPDS innovation of serial thermal management to address the heat generated from system operation	3.1 Serial Thermal Management	Universal thermal interface should be proposed	[ref 11]

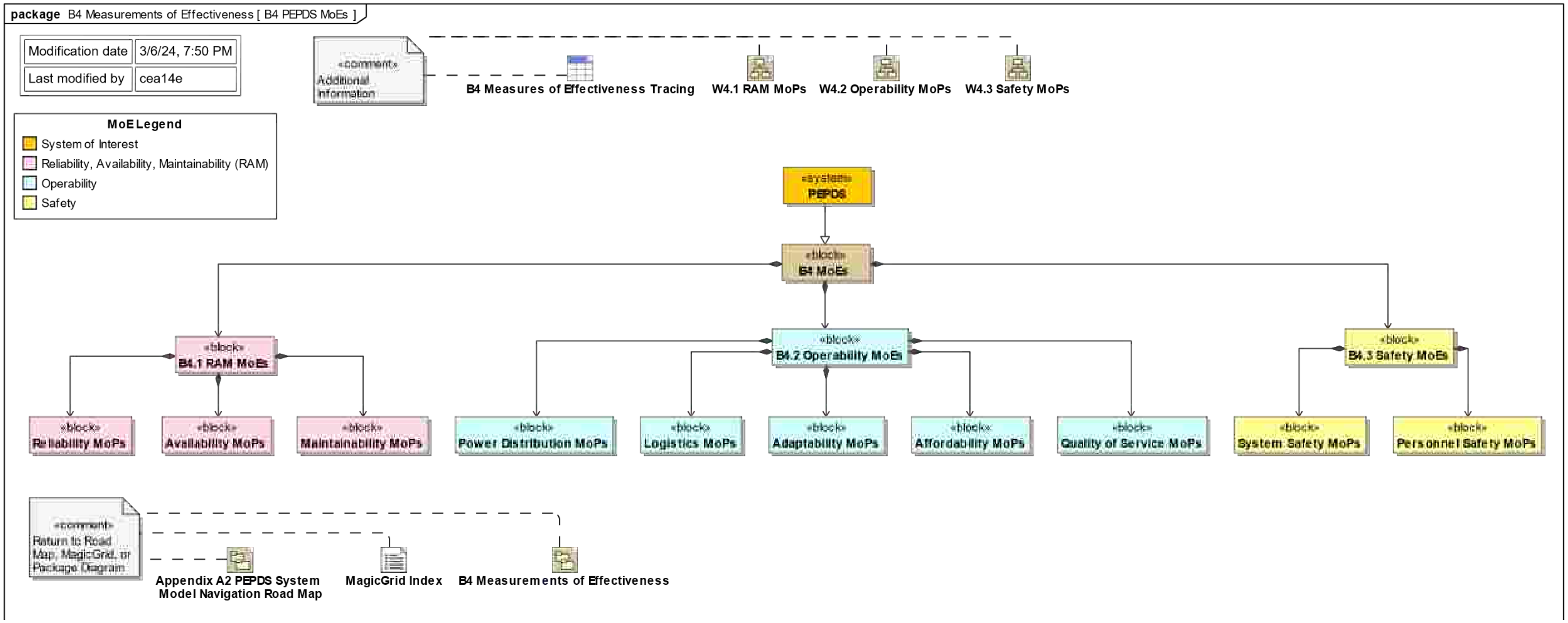


Fig. 28: B4 PEPDS MoEs (Review Part 2)

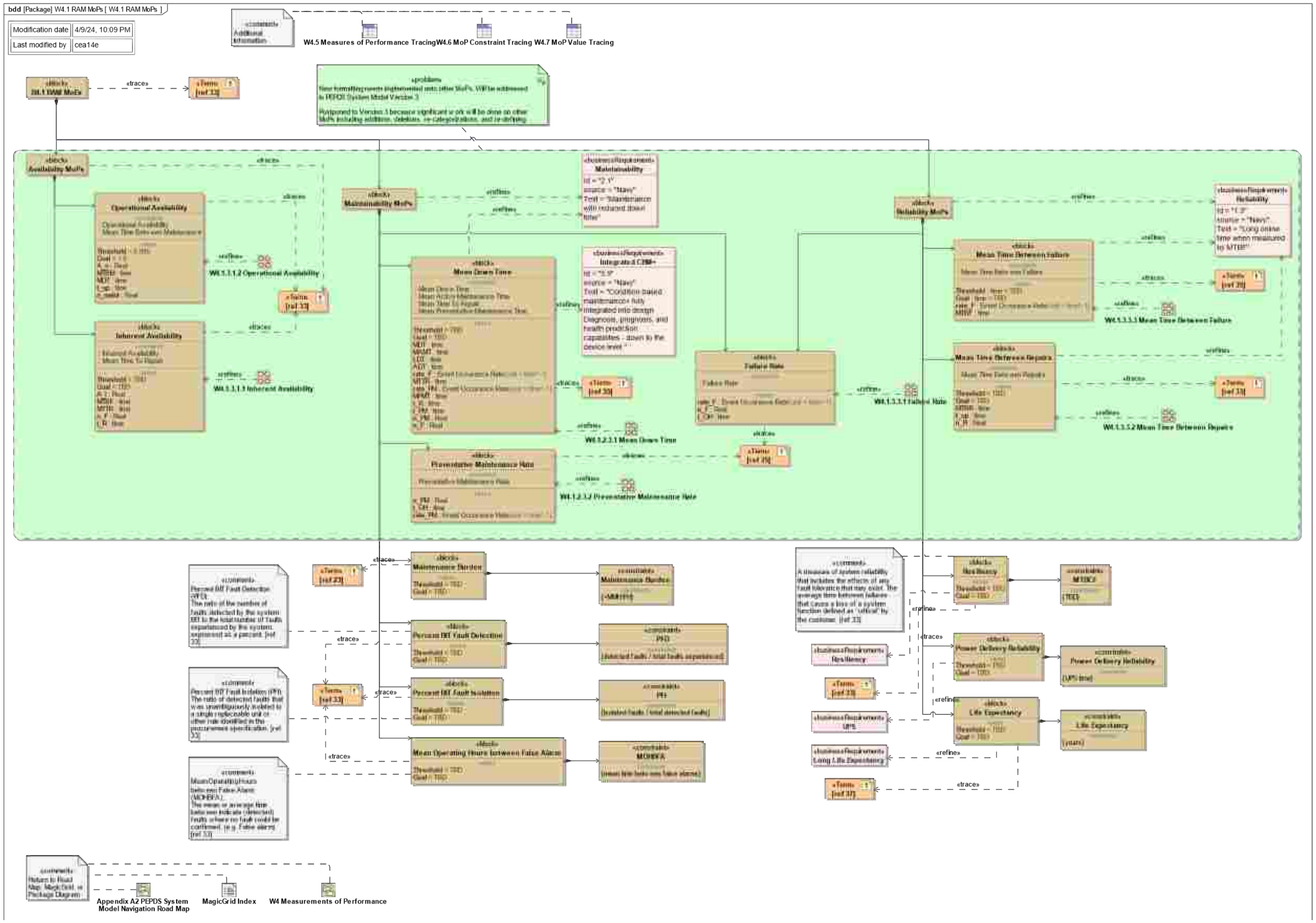


Fig. 29: W4.1 RAM MoPs

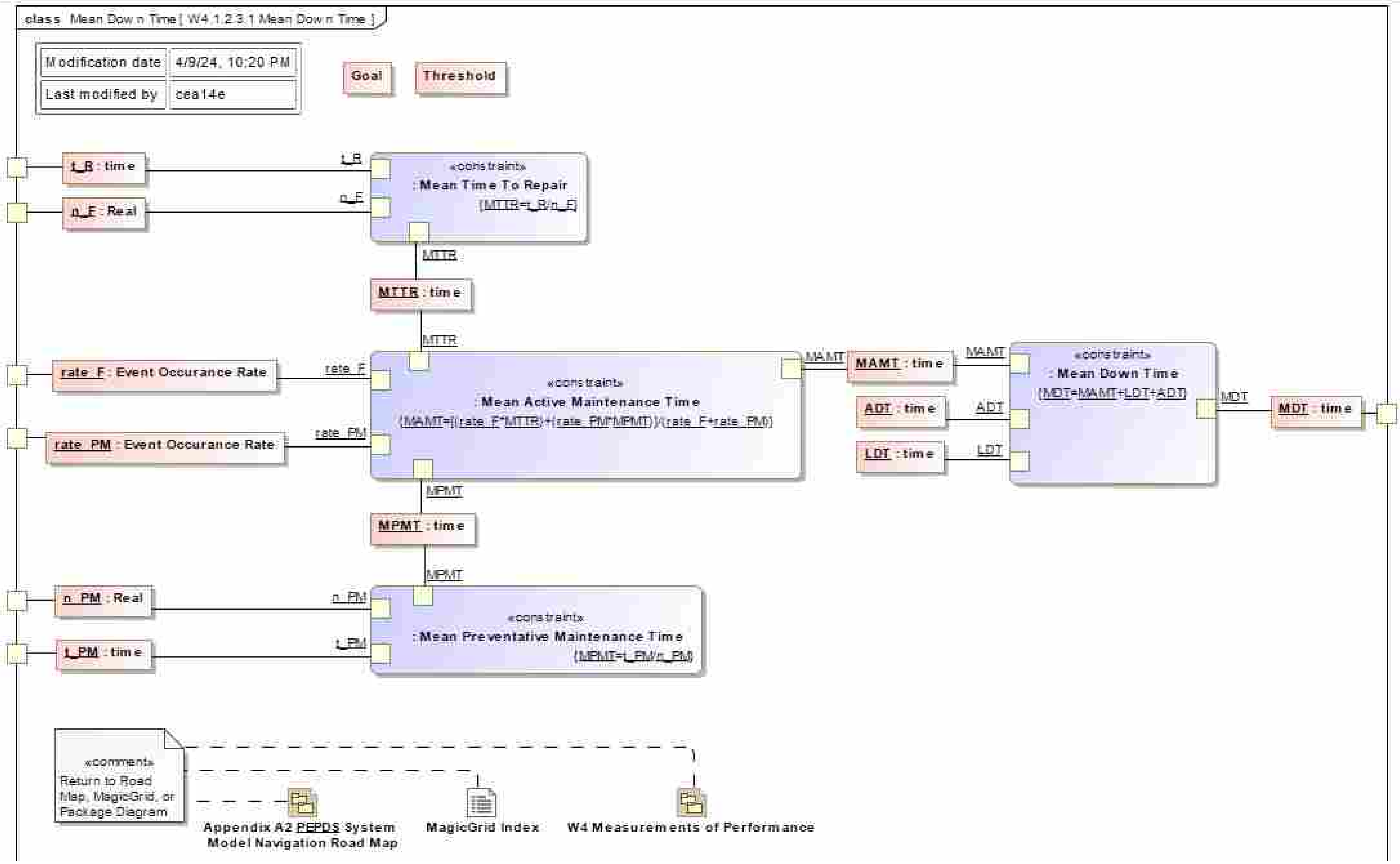


Fig. 30: W4.1.2.3.1 Mean Down Time

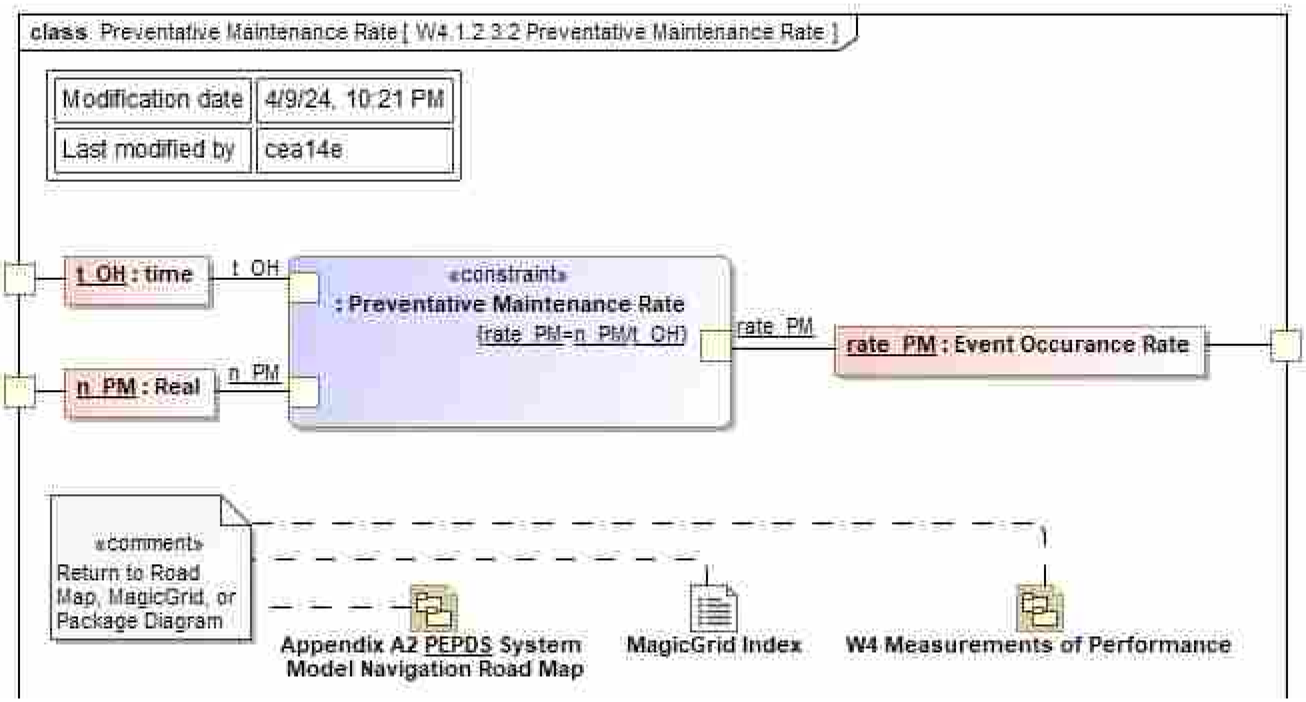


Fig. 31: W4.1.2.3.2 Preventative Maintenance Rate

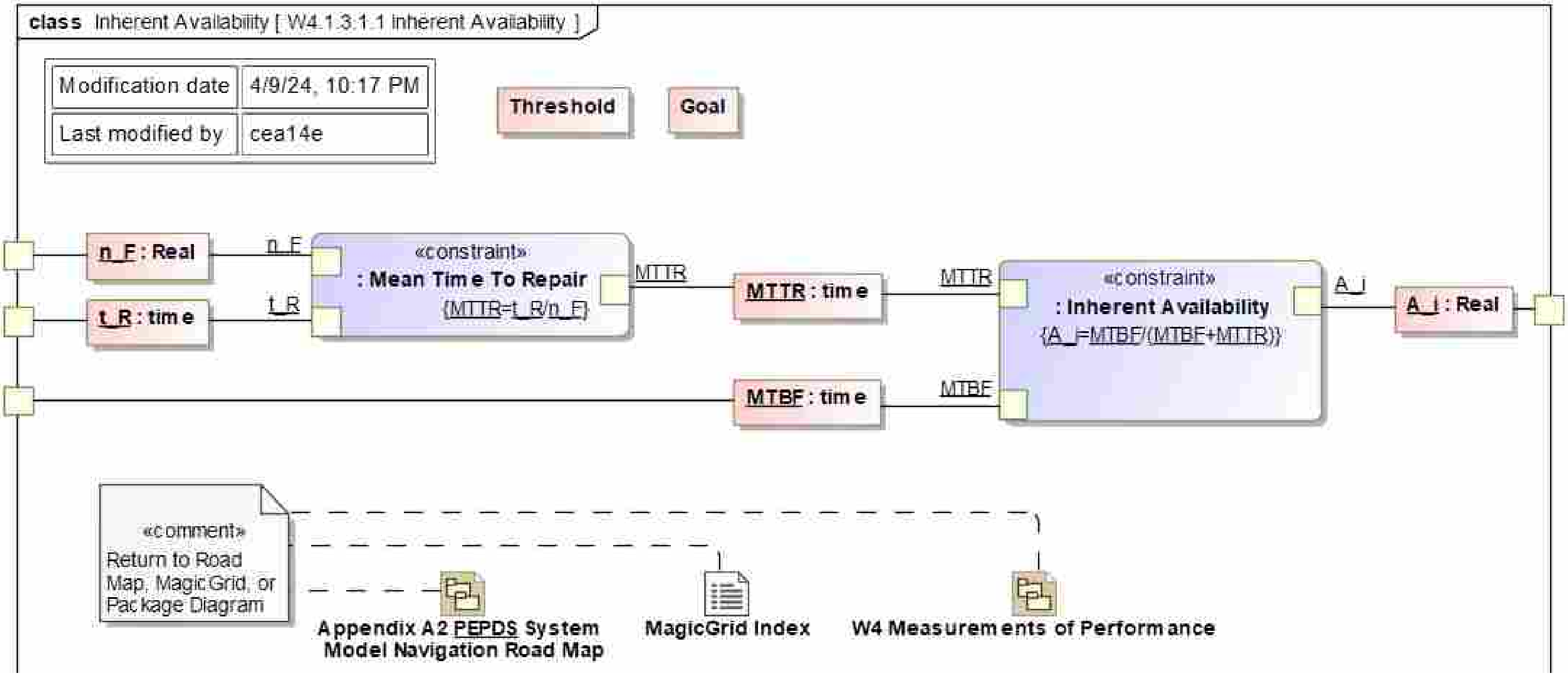


Fig. 32: W4.1.3.1.1 Inherent Availability

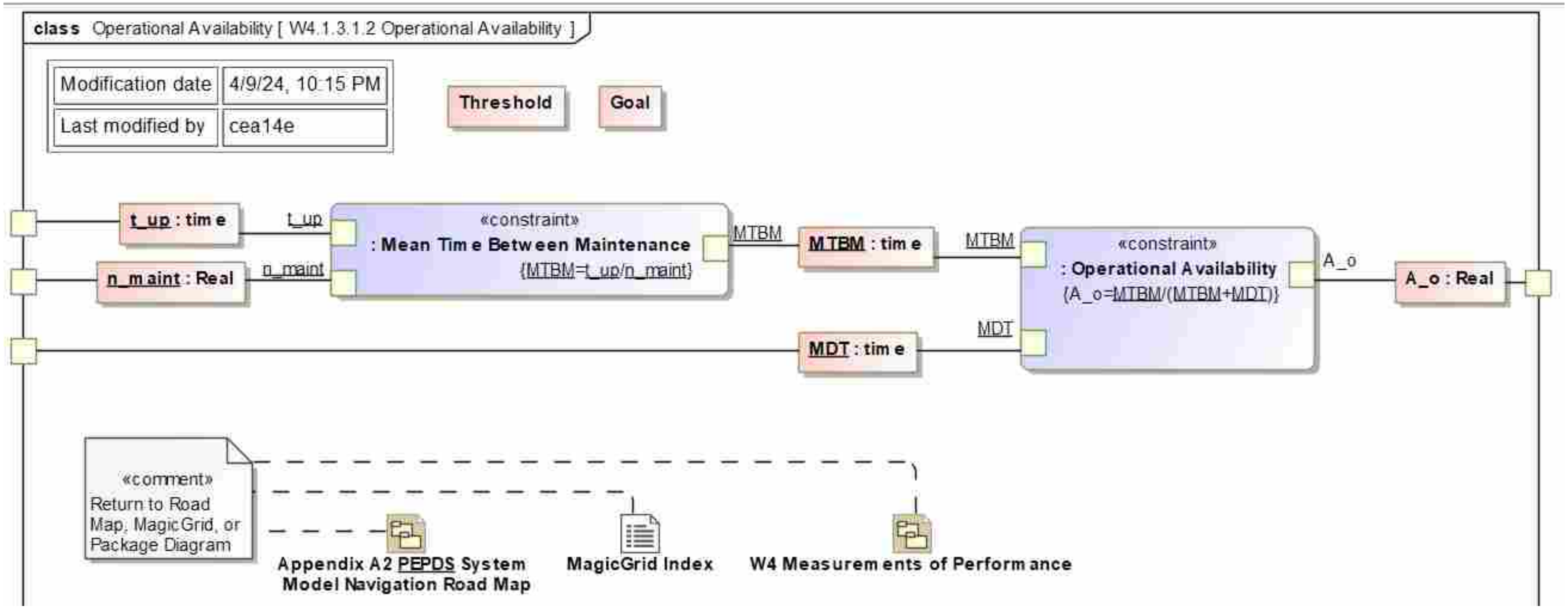


Fig. 33: W4.1.3.1.2 Operational Availability

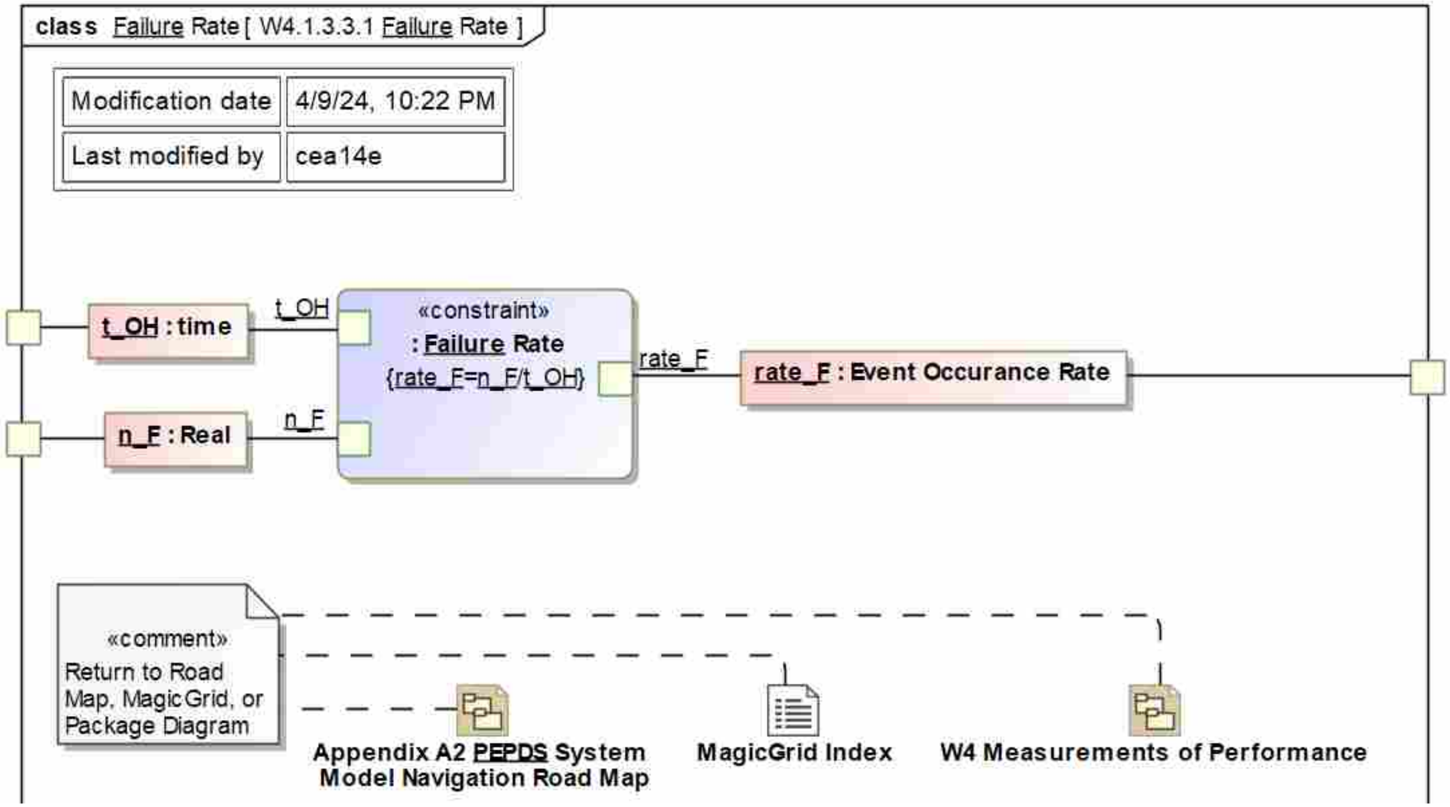


Fig. 34: W4.1.3.3.1 Failure Rate

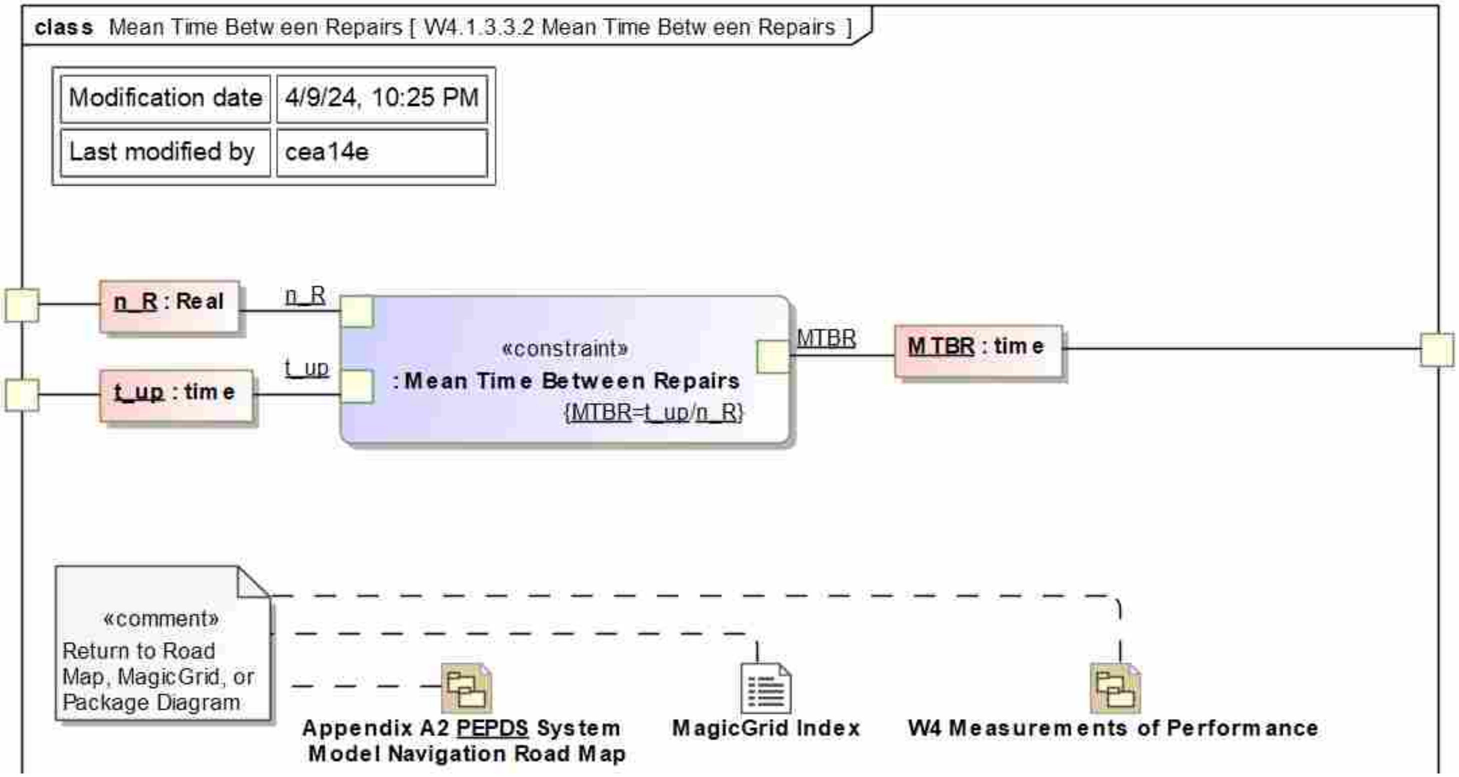


Fig. 35: W4.1.3.3.2 Mean Time Between Repairs

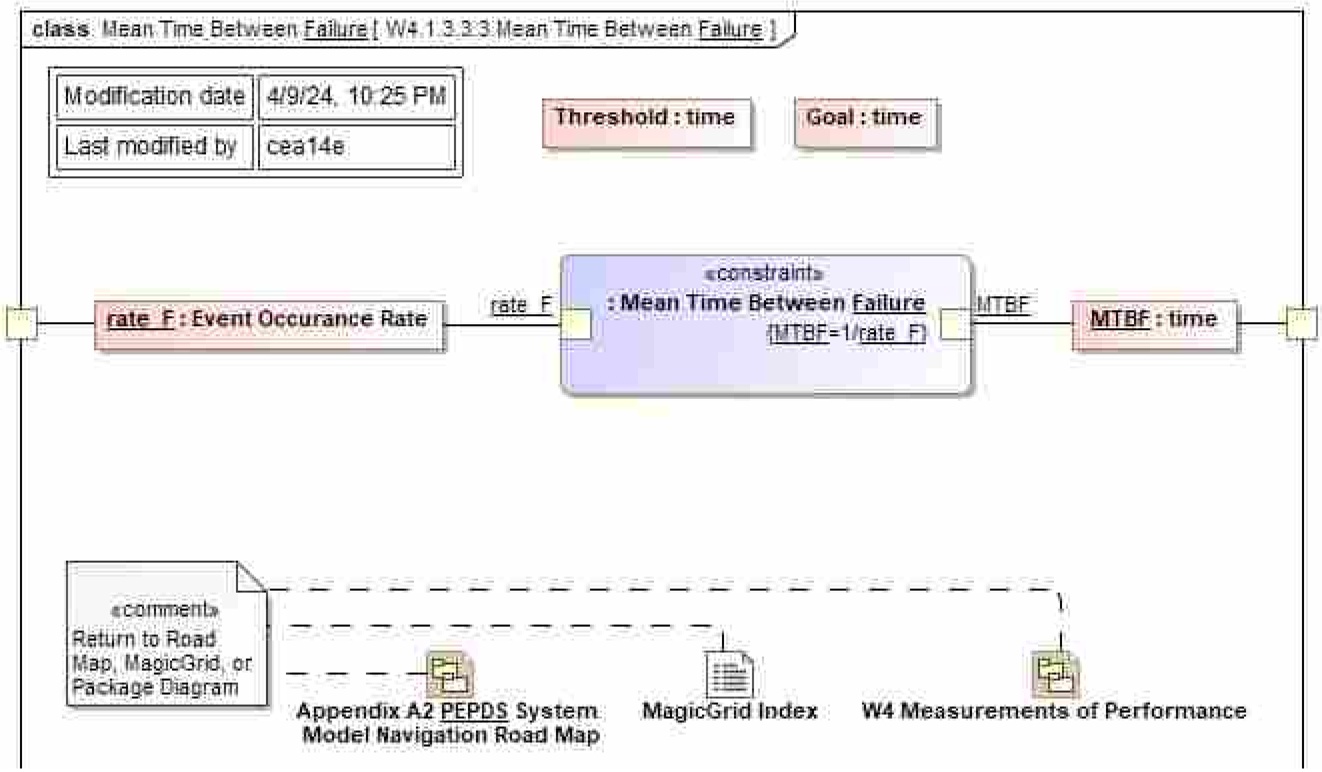


Fig. 36: W4.1.3.3.3 Mean Time Between Failure

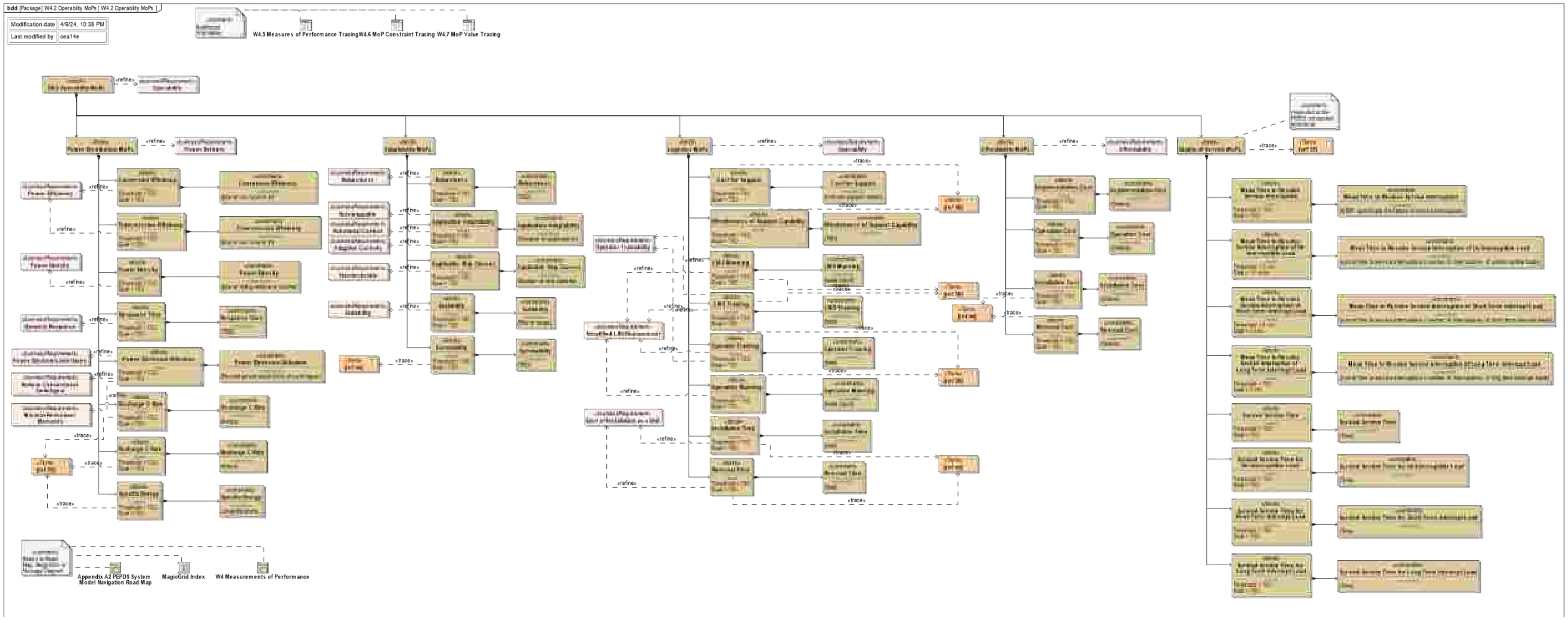


Fig. 37: W4.2 Operability MoPs

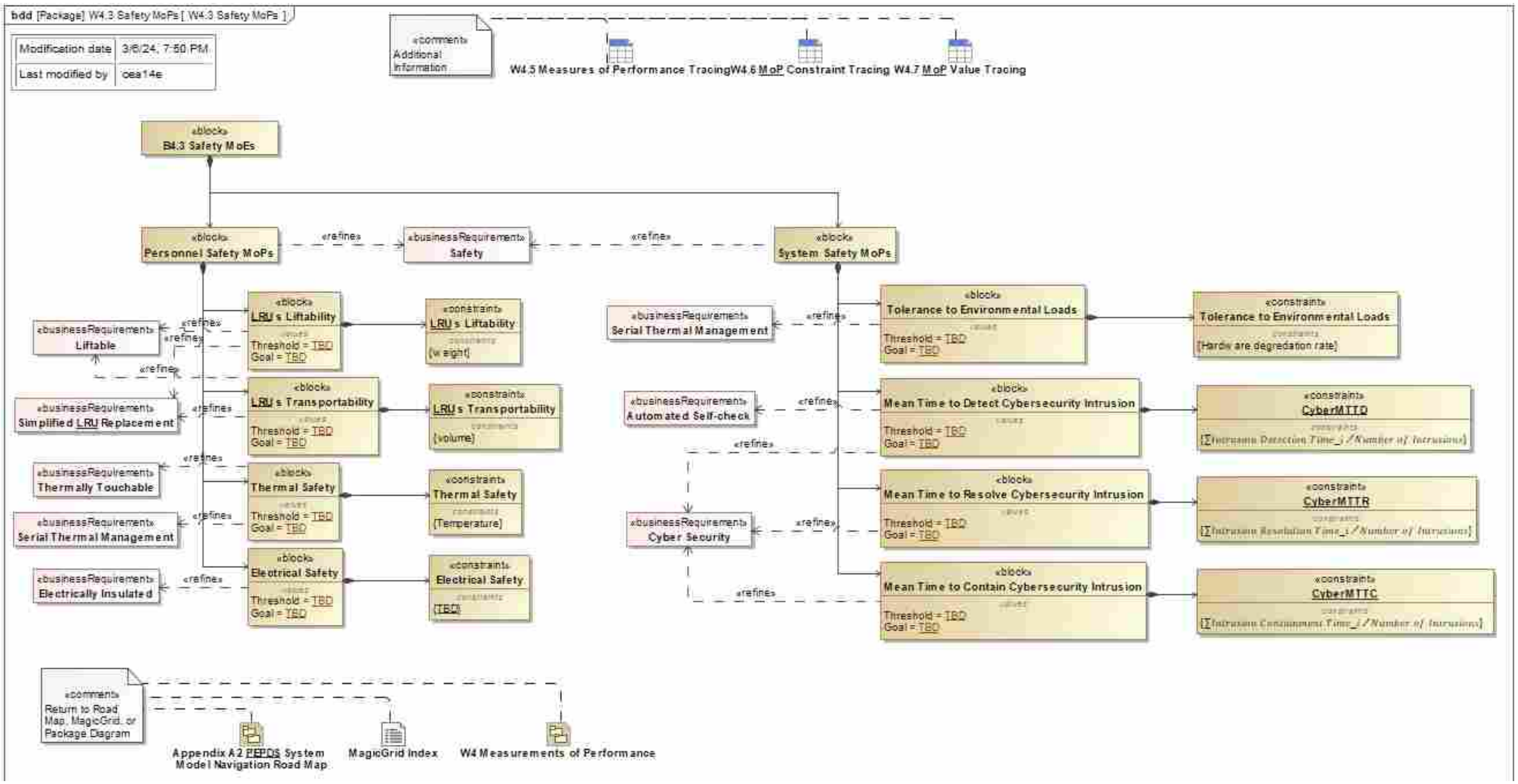


Fig. 38: W4.3 Safety MoPs

Table XV: W4.4 MoP List

Owner	Name	MoPs
B4.2 Operability MoEs	Adaptability MoPs	Application Adaptability Applicable Ship Classes Robustness Scalability Survivability
B4.2 Operability MoEs	Affordability MoPs	Removal Cost Operation Cost Implementation Cost Installation Cost
B4.2 Operability MoEs	Logistics MoPs	LMS Manning Installation Time Operator Training Effectiveness of Support Capability Operation Manning Cost for Support LMS Training Removal Time
B4.2 Operability MoEs	Power Distribution MoPs	Conversion Efficiency Recharge C Rate Specific Energy Response Time Power Electronic Utilization Discharge C Rate Power Density Transmission Efficiency
B4.2 Operability MoEs	Quality of Service MoPs	Survival Service Time for Un-Interruptible Load Survival Service Time for Short Term Interrupt Load Mean Time to Resolve Service Interruption Survival Service Time for Long Term Interrupt Load Mean Time to Resolve Service Interruption of Long Term Interrupt Load Mean Time to Resolve Service Interruption of Short Term Interrupt Load Survival Service Time Mean Time to Resolve Service Interruption of Un-Interruptible Load

Owner	Name	MoPs
B4.1 RAM MoEs	Availability MoPs	Inherent Availability Operational Availability
B4.1 RAM MoEs	Maintainability MoPs	Mean Operating Hours between False Alarm Percent BIT Fault Detection Preventative Maintenance Rate Mean Down Time Percent BIT Fault Isolation Failure Rate Maintenance Burden
B4.1 RAM MoEs	Reliability MoPs	Mean Time Between Failure Resiliency Power Delivery Reliability Quality of Service MoPs Mean Time Between Repairs Failure Rate Life Expectancy
B4.3 Safety MoEs	Personnel Safety MoPs	LRU s Liftability LRU s Transportability Thermal Safety Electrical Safety
B4.3 Safety MoEs	System Safety MoPs	Mean Time to Contain Cybersecurity Intrusion Mean Time to Resolve Cybersecurity Intrusion Tolerance to Environmental Loads Mean Time to Detect Cybersecurity Intrusion

Table XVI: W4.5 Measures of Performance Tracing

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Applicable Ship Classes		3.4 Standardizable	Fits in many classes of ship	
Application Adaptability		3.6 Hotswappable 5.6 Functional Control 5.7 Adaptive Controls	Hotswappable "Plug-and-Play" applications Control component and network functions through programming and reconfiguration Control algorithms self-adapt to changes in mission requirements, load performance, and system upgrades	
Conversion Efficiency		1.1 Power Efficiency	Limit power loss during transmission and conversion	
Cost for Support				[ref 38]
Discharge C Rate				[ref 53]
Effectiveness of Support Capability				[ref 38]
Electrical Safety		2.3.3 Electrically Insulated	Insulation to limit current through operator	
Failure Rate				[ref 35]
Implementation Cost				
Inherent Availability				[ref 33]
Installation Cost				[ref 44]
Installation Time		5.1 Ease of Installation as a Unit	Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction	[ref 44]
Life Expectancy		2.4 Long Life Expectancy	Long operable lifespan	[ref 37]
LMS Manning		5.11 Simplified LRU Replacement	Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	[ref 38]
LMS Training		2.2 Operator Trainability 5.11 Simplified LRU Replacement	Low training requirements in regard to time and technical skills Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	[ref 38]
LRU s Liftability		2.3.2 Liftable 5.11 Simplified LRU Replacement	Weight and volume at a reasonable range for handling Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that	

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
			requires minimal training for installation and removal, and has plug & play capabilities	
LRU s Transportability		2.3.2 Liftable 5.11 Simplified LRU Replacement	Weight and volume at a reasonable range for handling Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	
Maintenance Burden				[ref 23]
Mean Down Time		2.1 Maintainability 5.9 Integrated CBM+	Maintenance with reduced down time Condition based maintenance+ fully integrated into design. Diagnosis, prognosis, and health prediction capabilities - down to the device level.	[ref 35]
Mean Operating Hours between False Alarm				[ref 33]
Mean Time Between Failure		1.3 Reliability	Long online time when measured by MTBF	[ref 35]
Mean Time Between Repairs		1.3 Reliability	Long online time when measured by MTBF	[ref 33]
Mean Time to Contain Cybersecurity Intrusion		3.3.2 Cyber Security	Resistant to malicious attacks against software and offers security observation	
Mean Time to Detect Cybersecurity Intrusion		5.8 Automated Self-check 3.3.2 Cyber Security	Have self-diagnosis or automated self-check after controls upgrades which would be an advanced concept of CHIL with regression tests embedded in PEPDS (integrated “digital twin”) – including cybersecurity aspects Resistant to malicious attacks against software and offers security observation	
Mean Time to Resolve Cybersecurity Intrusion		3.3.2 Cyber Security	Resistant to malicious attacks against software and offers security observation	
Mean Time to Resolve Service Interruption				[ref 39]
Mean Time to Resolve Service Interruption of Long-Term Interrupt Load				[ref 39]
Mean Time to Resolve Service Interruption of Short-Term Interrupt Load				[ref 39]
Mean Time to Resolve Service Interruption of Un-Interruptible Load				[ref 39]
Operation Cost				

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Operation Manning		5.11 Simplified LRU Replacement	Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	[ref 36]
Operational Availability				[ref 33]
Operator Training		2.2 Operator Trainability 5.11 Simplified LRU Replacement	Low training requirements in regard to time and technical skills Utilize LRUs that are a size and weight carriable by a single sailor, that can fit through hatches, that requires minimal training for installation and removal, and has plug & play capabilities	[ref 36]
Percent BIT Fault Detection				[ref 33]
Percent BIT Fault Isolation				[ref 33]
Power Delivery Reliability		1.6 UPS	If demand is greater than supply (delta power), then provide provisional power for x time	
Power Density		1.2 Power Density	High power rating relative to volume	
Power Electronic Utilization		5.3 Power Electronic Interfaces 5.15 Reduce Conventional Switchgear 5.12 Minimal Redundant Elements	All source and load interfaces are power electronics based and as such provide the required adaptability, reconfigurability, and fault current limitation Integrate functionality of switchgear within the power electronics framework in order to reduce or eliminate use of conventional external switchgear and provide current limiting function - thereby reducing risk from high fault currents and hence improving reliability Provide power quality to loads using fewer components by using distributed resources and integrated functionality such as advanced power electronic control across many converters, active filtering across many converters, and distributed storage	
Preventative Maintenance Rate				[ref 35]
Recharge C Rate				[ref 53]
Removal Cost				[ref 44]
Removal Time		5.1 Ease of Installation as a Unit	Reduce installation time and cost by having construction and testing executable off ship and avoiding intensive cabling after ship construction	[ref 44]
Resiliency		1.5 Resiliency	Tolerant to critical scenarios such as faults and failure of device(s)	[ref 33]

Name	Rationale	Refines	Refined Stakeholder Need Text	Traced To
Response Time		3.3.3 Dynamic Response	Can ramp up power in a short time; can provide x time over power in a short time slot	
Robustness		1.4 Robustness	Compatible with various operating conditions and set points	
Scalability		3 Scalability	Greater power requirement met through serial and/or parallel connections	
Specific Energy				[ref 53]
Survivability				[ref 44]
Survival Service Time				[ref 39]
Survival Service Time for Long Term Interrupt Load				[ref 39]
Survival Service Time for Short Term Interrupt Load				[ref 39]
Survival Service Time for Un-Interruptible Load				[ref 39]
Thermal Safety		2.3.1 Thermally Touchable 3.1 Serial Thermal Management	External environment at reasonable handling temperatures Universal thermal interface should be proposed	
Tolerance to Environmental Loads		3.1 Serial Thermal Management	Universal thermal interface should be proposed	
Transmission Efficiency		1.1 Power Efficiency	Limit power loss during transmission and conversion	

Table XVII: W4.6 MoP Constraint Tracing

Name	Constraint Equations	Traced To
Applicable Ship Classes	Number of ship classes	
Application Adaptability	Number of applications	
Conversion Efficiency	power out / power in	
Cost for Support	cost per support action	[ref 38]
CyberMTTC	$\sum Intrusion\ Containment\ Time\_i\ /\ Number\ of\ Intrusions$	
CyberMTTD	$\sum Intrusion\ Detection\ Time\_i\ /\ Number\ of\ Intrusions$	
CyberMTTR	$\sum Intrusion\ Resolution\ Time\_i\ /\ Number\ of\ Intrusions$	
Discharge C Rate	Amps	[ref 53]
Effectiveness of Support Capability	TBD	[ref 38]
Electrical Safety	TBD	
Failure Rate	rate_F=n_F/t_OH	[ref 35]
Implementation Cost	Dollars	
Inherent Availability	A_i=MTBF/(MTBF+MTTR)	[ref 33]
Installation Cost	Dollars	[ref 44]
Installation Time	time	[ref 44]
Life Expectancy	years	[ref 37]
LMS Manning	head count	[ref 38]
LMS Training	time	[ref 38]
LRUs Liftability	weight	
LRUs Transportability	volume	
Maintenance Burden	=MMH/FH	[ref 23]
Mean Active Maintenance Time	MAMT=[(rate_F*MTTR)+(rate_PM*MPMT)]/(rate_F+rate_PM)	[ref 35]
Mean Down Time	MDT=MAMT+LDT+ADT	[ref 35]
Mean Preventative Maintenance Time	MPMT=t_PM/n_PM	[ref 35]
Mean Time Between Failure	MTBF=1/rate_F	[ref 35]
Mean Time Between Maintenance	MTBM=t_up/n_maint	[ref 33]
Mean Time Between Repairs	MTBR=t_up/n_R	[ref 33]
Mean Time to Repair	MTTR=t_R/n_F	[ref 35]
Mean Time to Resolve Service Interruption	MTBF; specifically the failure of service interruption	[ref 39]
Mean Time to Resolve Service Interruption of Long-Term Interrupt Load	sum of time to service interruptions / number of interruptions; of long-term interrupt loads	[ref 39]
Mean Time to Resolve Service Interruption of Short-Term Interrupt Load	sum of time to service interruptions / number of interruptions; of short-term interrupt loads	[ref 39]
Mean Time to Resolve Service Interruption of Un-Interruptible Load	sum of time to service interruptions / number of interruptions; of uninterruptible loads	[ref 39]
MOHBFA	mean time between false alarms	[ref 33]

Name	Constraint Equations	Traced To
MTBCF	TBD	[ref 33]
Operation Cost	Dollars	
Operation Manning	head count	[ref 36]
Operational Availability	A_o=MTBM/(MTBM+MDT)	[ref 33]
Operator Training	time	[ref 36]
PFD	detected faults / total faults experienced	[ref 33]
PFI	isolated faults / total detected faults	[ref 33]
Power Delivery Reliability	UPS time	
Power Density	power rating relative to volume	
Power Electronic Utilization	Percent power electronics of switchgear	
Preventative Maintenance Rate	rate_PM=n_PM/t_OH	[ref 35]
Quality of Service	MTBF	[ref 39]
Recharge C Rate	Amps	[ref 53]
Removal Cost	Dollars	[ref 44]
Removal Time	time	[ref 44]
Response Time	TBD	
Robustness	TBD	
Scalability	Power range	
Specific Energy	Joule/Kilogram	[ref 53]
Survivability	TBD	[ref 44]
Survival Service Time	Time	[ref 39]
Survival Service Time for Long Term Interrupt Load	Time	[ref 39]
Survival Service Time for Short Term Interrupt Load	Time	[ref 39]
Survival Service Time for Un-Interruptible Load	Time	[ref 39]
Thermal Safety	Temperature	
Tolerance to Environmental Loads	Hardware degradation rate	
Transmission Efficiency	power out / power in	

Table XVIII: W4.7 MoP Value Tracing

MoE	MoP Type	Name	Constraints	Values	Value Traced To
B4.2 Operability MoEs	Power Distribution MoPs	Transmission Efficiency	Transmission Efficiency	Threshold = TBD Goal = TBD	
B4.3 Safety MoEs	System Safety MoPs	Tolerance to Environmental Loads	Tolerance to Environmental Loads	Threshold = TBD Goal = TBD	
B4.3 Safety MoEs	Personnel Safety MoPs	Thermal Safety	Thermal Safety	Threshold = TBD Goal = TBD	

MoE	MoP Type	Name	Constraints	Values	Value Traced To
B4.2 Operability MoEs	Quality of Service MoPs	Survival Service Time for Un-Interruptible Load	Survival Service Time for Un-Interruptible Load	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Quality of Service MoPs	Survival Service Time for Short Term Interrupt Load	Survival Service Time for Short Term Interrupt Load	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Quality of Service MoPs	Survival Service Time for Long Term Interrupt Load	Survival Service Time for Long Term Interrupt Load	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Quality of Service MoPs	Survival Service Time	Survival Service Time	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Adaptability MoPs	Survivability	Survivability	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Power Distribution MoPs	Specific Energy	Specific Energy	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Adaptability MoPs	Scalability	Scalability	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Adaptability MoPs	Robustness	Robustness	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Power Distribution MoPs	Response Time	Response Time	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Reliability MoPs	Resiliency	MTBCF	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Logistics MoPs	Removal Time	Removal Time	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Affordability MoPs	Removal Cost	Removal Cost	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Power Distribution MoPs	Recharge C Rate	Recharge C Rate	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Maintainability MoPs	Preventative Maintenance Rate	Preventative Maintenance Rate	n_PM : Real t_OH : ISO80000-3 Space and Time::Quantities::time::time rate_PM : 1 Problem Domain::2 White Box::W4 Measurements of Performance::Value Types::Event Occurrence Rate	
B4.2 Operability MoEs	Power Distribution MoPs	Power Electronic Utilization	Power Electronic Utilization	Threshold = TBD Goal = TBD	

MoE	MoP Type	Name	Constraints	Values	Value Traced To
B4.2 Operability MoEs	Power Distribution MoPs	Power Density	Power Density	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Reliability MoPs	Power Delivery Reliability	Power Delivery Reliability	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Maintainability MoPs	Percent BIT Fault Isolation	PFI	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Maintainability MoPs	Percent BIT Fault Detection	PFD	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Logistics MoPs	Operator Training	Operator Training	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Availability MoPs	Operational Availability	Operational Availability Mean Time Between Maintenance	Threshold = 0.995 Goal = 1.0 A_o : Real MTBM : ISO80000-3 Space and Time::Quantities::time::time MDT : ISO80000-3 Space and Time::Quantities::time::time t_up : ISO80000-3 Space and Time::Quantities::time::time n_maint : Real	
B4.2 Operability MoEs	Logistics MoPs	Operation Manning	Operation Manning	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Affordability MoPs	Operation Cost	Operation Cost	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Quality of Service MoPs	Mean Time to Resolve Service Interruption of Un-Interruptible Load	Mean Time to Resolve Service Interruption of Un-Interruptible Load	Threshold = 2 sec Goal = 10 msec	[ref 39]
B4.2 Operability MoEs	Quality of Service MoPs	Mean Time to Resolve Service Interruption of Short-Term Interrupt Load	Mean Time to Resolve Service Interruption of Short-Term Interrupt Load	Threshold = 5 min Goal = 2 sec	[ref 39]
B4.2 Operability MoEs	Quality of Service MoPs	Mean Time to Resolve Service Interruption of Long-Term Interrupt Load	Mean Time to Resolve Service Interruption of Long-Term Interrupt Load	Threshold = TBD Goal = 5 min	[ref 39]
B4.2 Operability MoEs	Quality of Service MoPs	Mean Time to Resolve Service Interruption	Mean Time to Resolve Service Interruption	Threshold = TBD Goal = TBD	

MoE	MoP Type	Name	Constraints	Values	Value Traced To
B4.3 Safety MoEs	System Safety MoPs	Mean Time to Resolve Cybersecurity Intrusion	CyberMTTR	Threshold = TBD Goal = TBD	
B4.3 Safety MoEs	System Safety MoPs	Mean Time to Detect Cybersecurity Intrusion	CyberMTTD	Threshold = TBD Goal = TBD	
B4.3 Safety MoEs	System Safety MoPs	Mean Time to Contain Cybersecurity Intrusion	CyberMTTC	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Reliability MoPs	Mean Time Between Repairs	Mean Time Between Repairs	Threshold = TBD Goal = TBD MTBR : ISO80000-3 Space and Time::Quantities::time::time t_up : ISO80000-3 Space and Time::Quantities::time::time n_R : Real	
B4.1 RAM MoEs	Reliability MoPs	Mean Time Between Failure	Mean Time Between Failure	Threshold : ISO80000-3 Space and Time::Quantities::time::time = TBD Goal : ISO80000-3 Space and Time::Quantities::time::time = TBD rate_F : 1 Problem Domain::2 White Box::W4 Measurements of Performance::Value Types::Event Occurrence Rate MTBF : ISO80000-3 Space and Time::Quantities::time::time	
B4.1 RAM MoEs	Maintainability MoPs	Mean Operating Hours between False Alarm	MOHBFA	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Maintainability MoPs	Mean Down Time	Mean Down Time Mean Active Maintenance Time Mean Time to Repair Mean Preventative Maintenance Time	Threshold = TBD Goal = TBD MDT : ISO80000-3 Space and Time::Quantities::time::time MAMT : ISO80000-3 Space and Time::Quantities::time::time LDT : ISO80000-3 Space and Time::Quantities::time::time ADT : ISO80000-3 Space and Time::Quantities::time::time rate_F : 1 Problem Domain::2 White	

MoE	MoP Type	Name	Constraints	Values	Value Traced To
				Box::W4 Measurements of Performance::Value Types::Event Occurrence Rate MTTR : ISO80000-3 Space and Time::Quantities::time::time rate_PM : 1 Problem Domain::2 White Box::W4 Measurements of Performance::Value Types::Event Occurrence Rate MPMT : ISO80000-3 Space and Time::Quantities::time::time t_R : ISO80000-3 Space and Time::Quantities::time::time t_PM : ISO80000-3 Space and Time::Quantities::time::time n_PM : Real n_F : Real	
B4.1 RAM MoEs	Maintainability MoPs	Maintenance Burden	Maintenance Burden	Threshold = TBD Goal = TBD	
B4.3 Safety MoEs	Personnel Safety MoPs	LRU s Transportability	LRU s Transportability	Threshold = TBD Goal = TBD	
B4.3 Safety MoEs	Personnel Safety MoPs	LRU s Liftability	LRU s Liftability	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Logistics MoPs	LMS Training	LMS Training	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Logistics MoPs	LMS Manning	LMS Manning	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Reliability MoPs	Life Expectancy	Life Expectancy	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Logistics MoPs	Installation Time	Installation Time	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Affordability MoPs	Installation Cost	Installation Cost	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Availability MoPs	Inherent Availability	Inherent Availability Mean Time to Repair	Threshold = TBD Goal = TBD A_i : Real MTBF : ISO80000-3 Space and Time::Quantities::time::time MTTR : ISO80000-3 Space and	

MoE	MoP Type	Name	Constraints	Values	Value Traced To
				Time::Quantities::time::time n_F : Real t_R : ISO80000-3 Space and Time::Quantities::time::time	
B4.2 Operability MoEs	Affordability MoPs	Implementation Cost	Implementation Cost	Threshold = TBD Goal = TBD	
B4.1 RAM MoEs	Reliability MoPs Maintainability MoPs	Failure Rate	Failure Rate	rate_F : 1 Problem Domain::2 White Box::W4 Measurements of Performance::Value Types::Event Occurrence Rate n_F : Real t_OH : ISO80000-3 Space and Time::Quantities::time::time	
B4.3 Safety MoEs	Personnel Safety MoPs	Electrical Safety	Electrical Safety	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Logistics MoPs	Effectiveness of Support Capability	Effectiveness of Support Capability	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Power Distribution MoPs	Discharge C Rate	Discharge C Rate	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Logistics MoPs	Cost for Support	Cost for Support	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Power Distribution MoPs	Conversion Efficiency	Conversion Efficiency	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Adaptability MoPs	Application Adaptability	Application Adaptability	Threshold = TBD Goal = TBD	
B4.2 Operability MoEs	Adaptability MoPs	Applicable Ship Classes	Applicable Ship Classes	Threshold = TBD Goal = TBD	

11.2.3 Solution Domain Review

11.2.3.1 S1 System Requirements

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

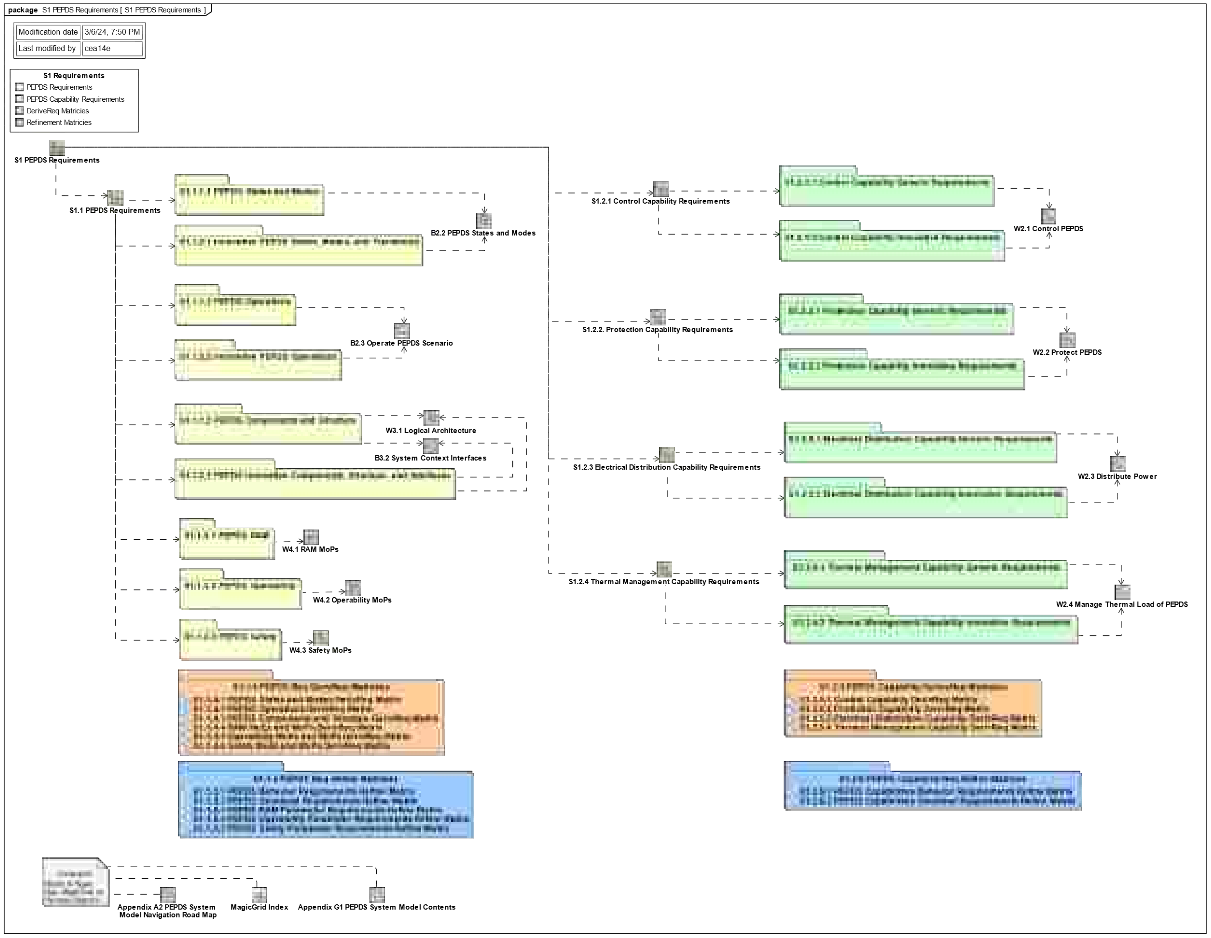


Fig. 39: S1 PEPDS Requirements

11.2.3.2 S1 System Requirements Diagrams

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

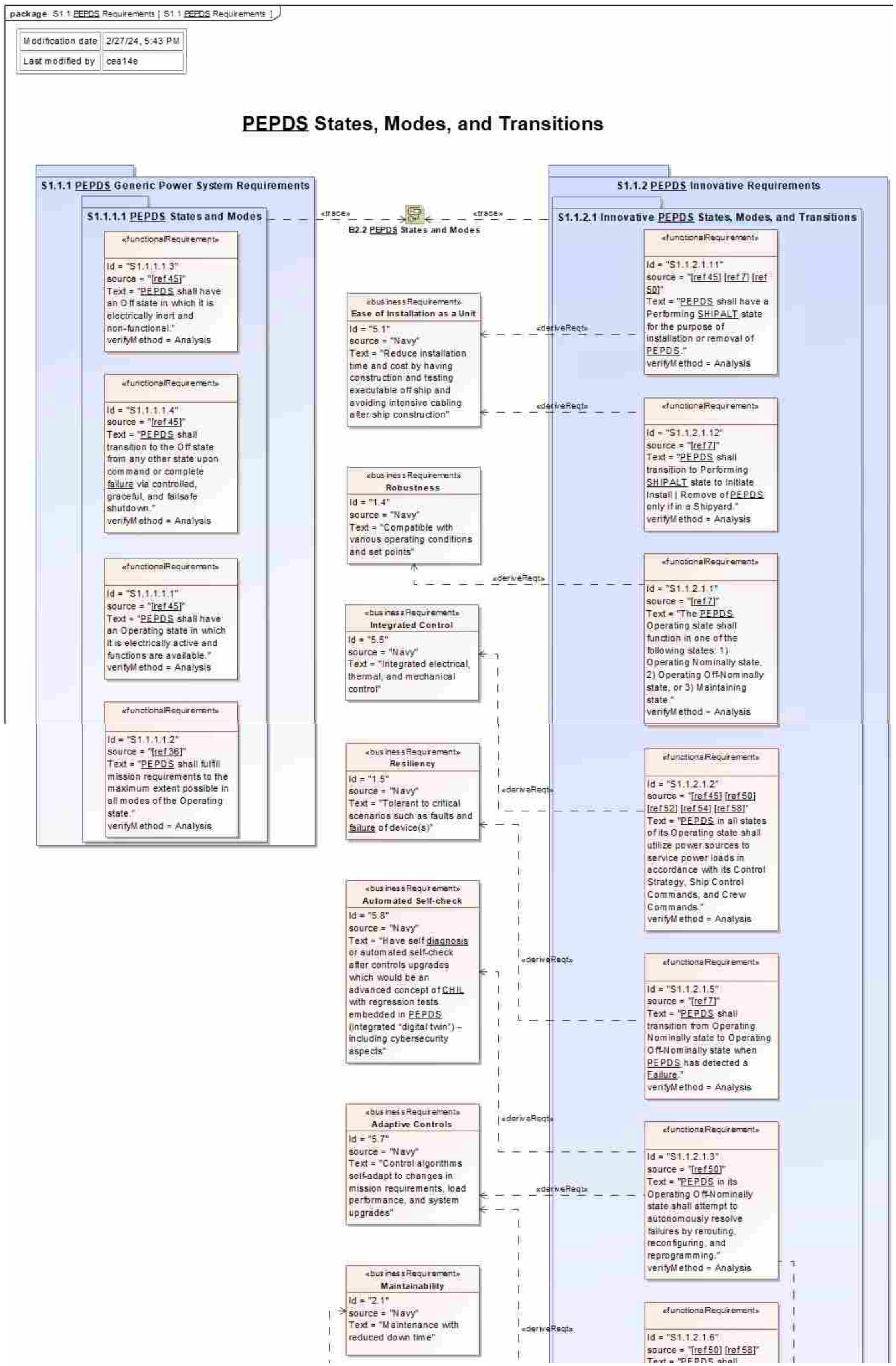


Fig. 40: S1.1 PEPDS Requirements Part 1.1

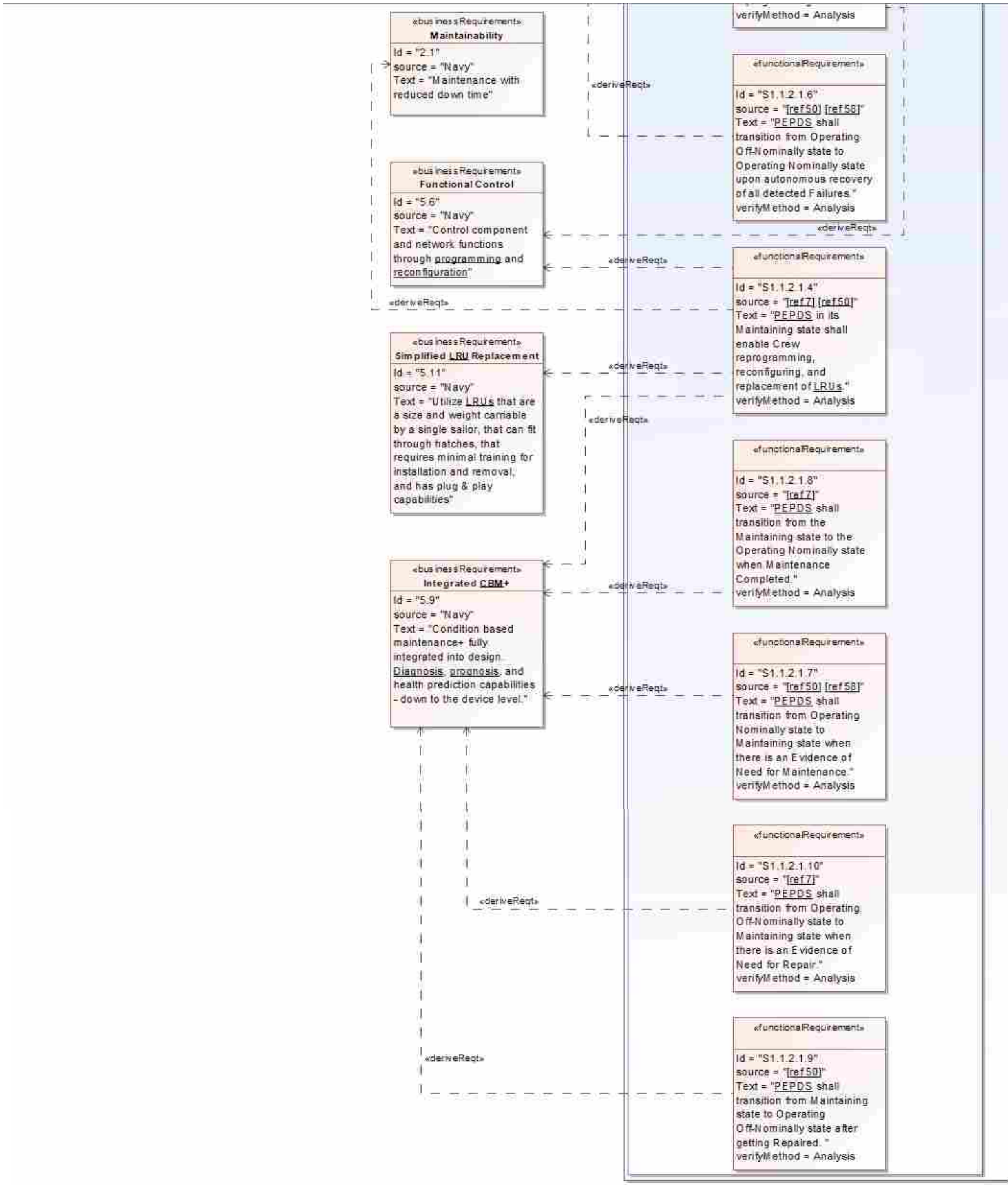


Fig. 41: S1.1 PEPDS Requirements Part 1.2

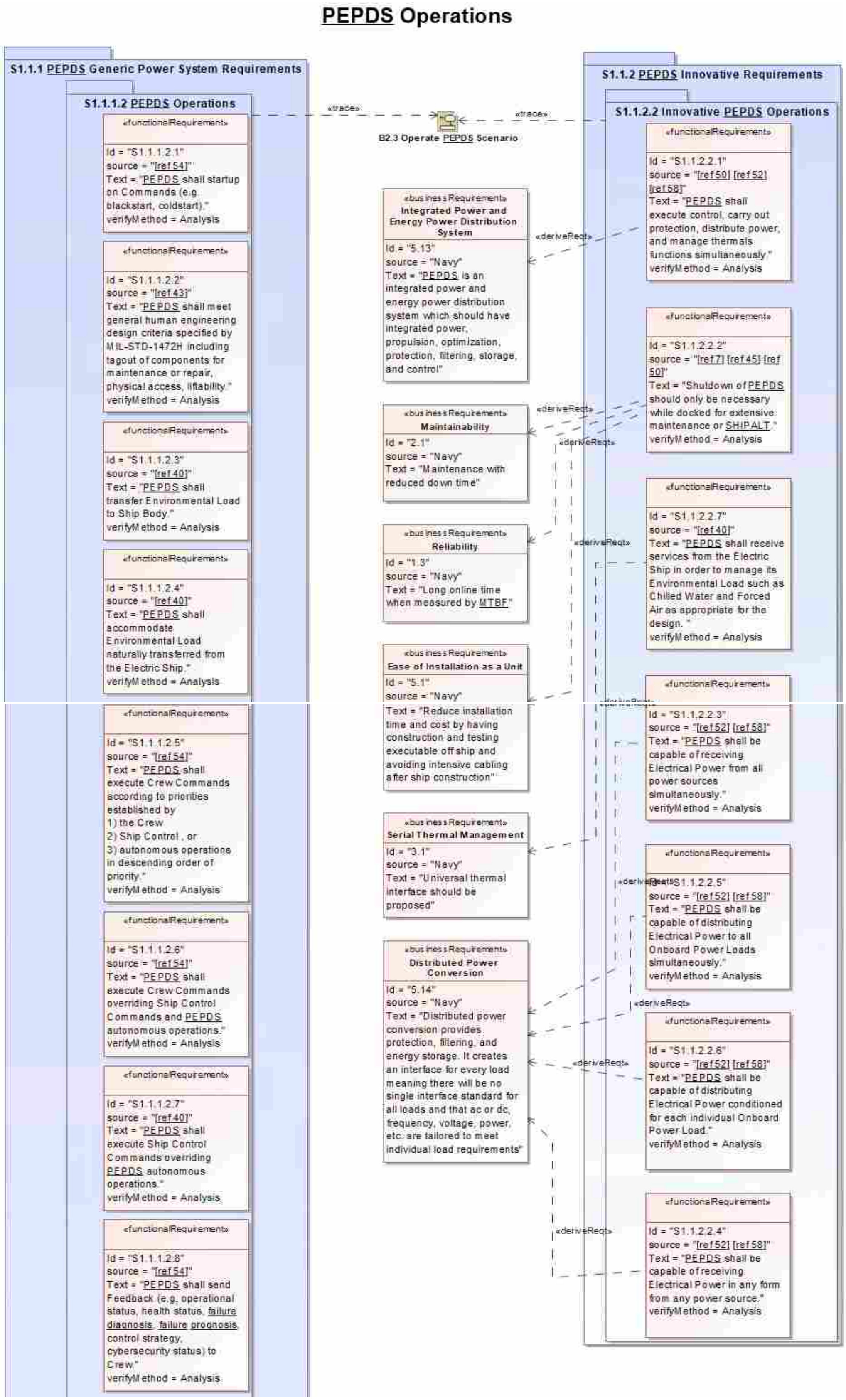


Fig. 42: S1.1 PEPDS Requirements Part 2.1

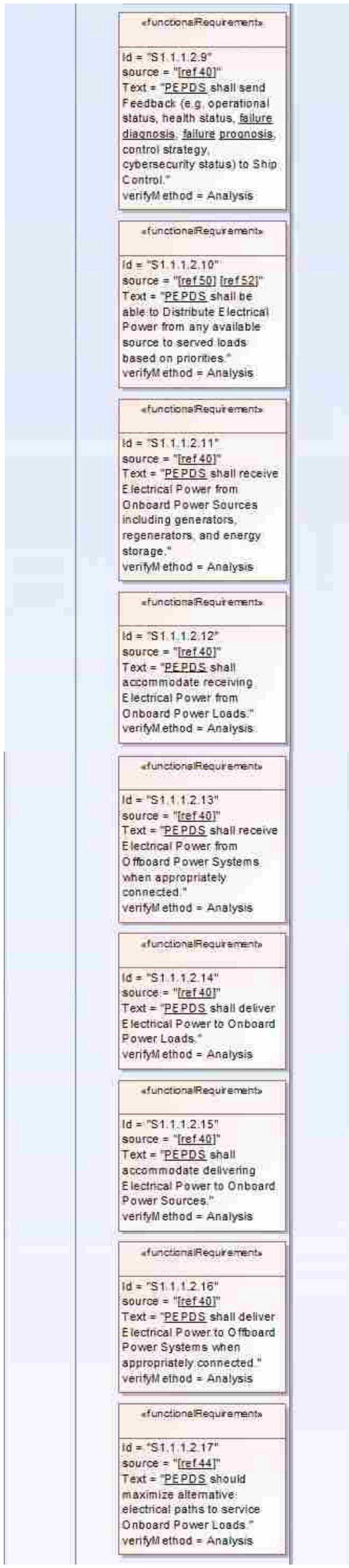


Fig. 43: S1.1 PEPDS Requirements Part 2.2

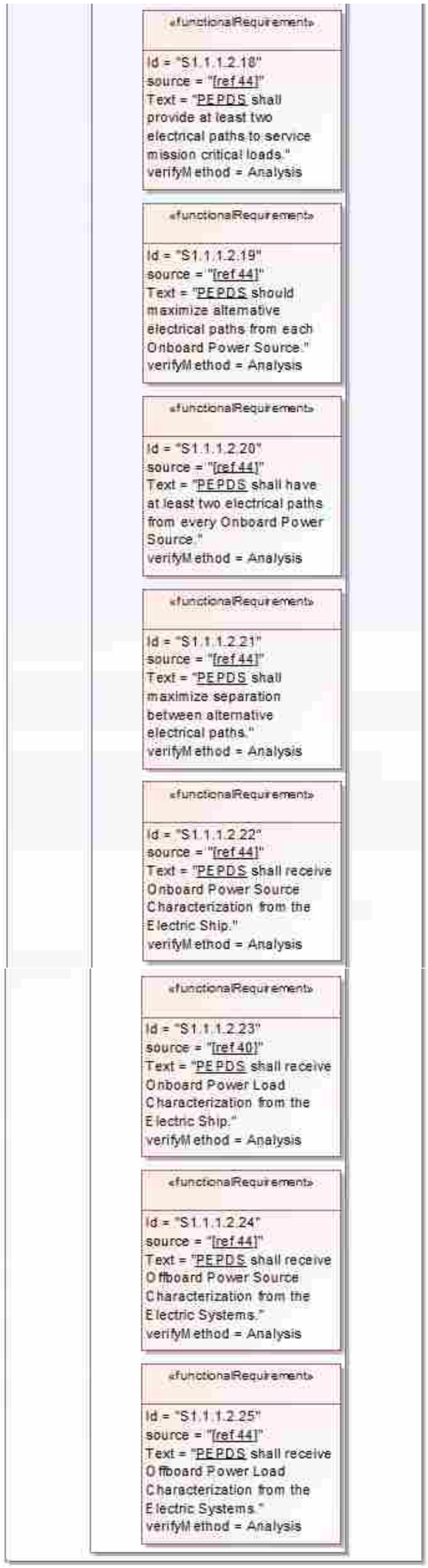


Fig. 44: S1.1 PEPDS Requirements Part 2.3

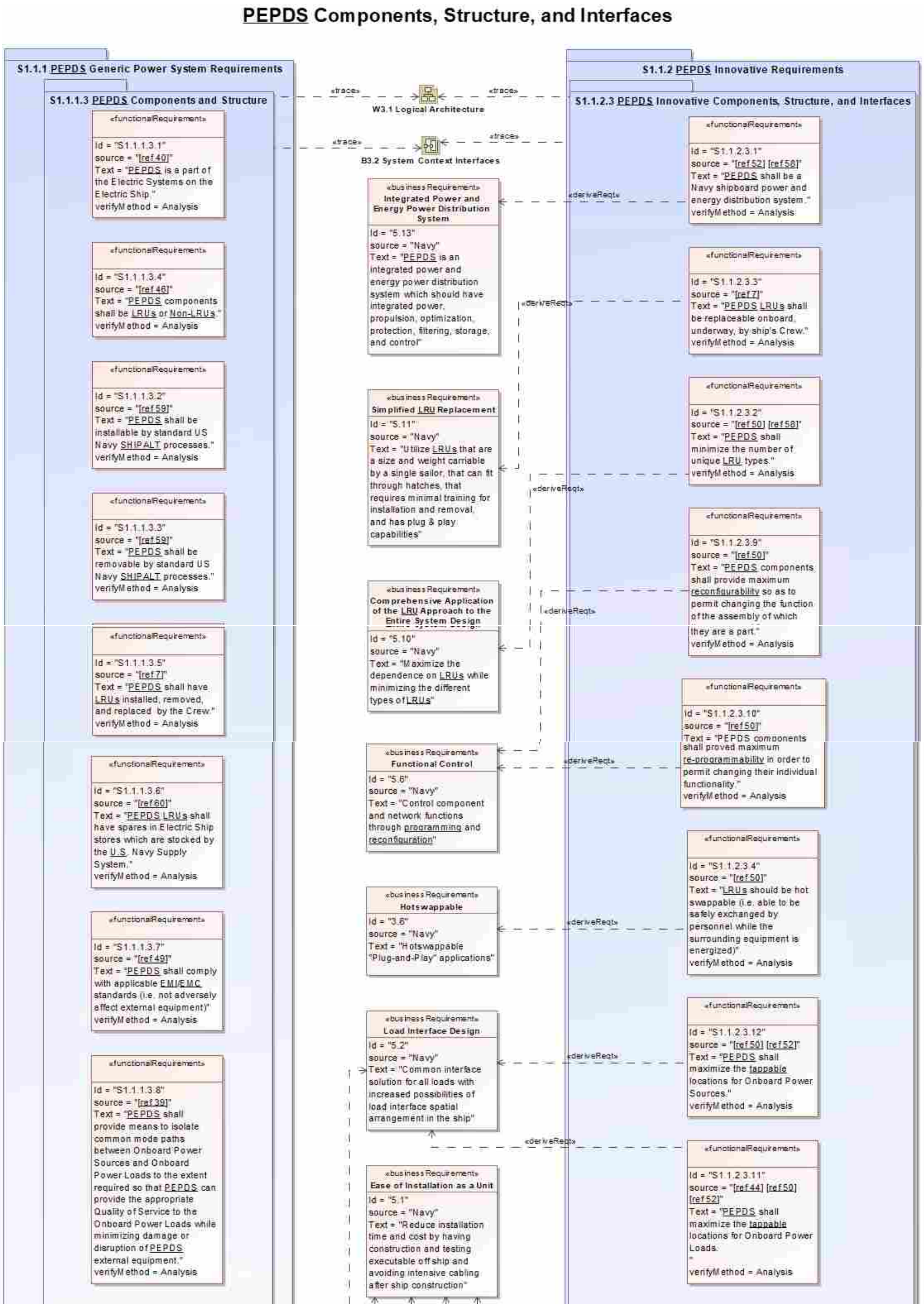


Fig. 45: S1.1 PEPDS Requirements Part 3.1

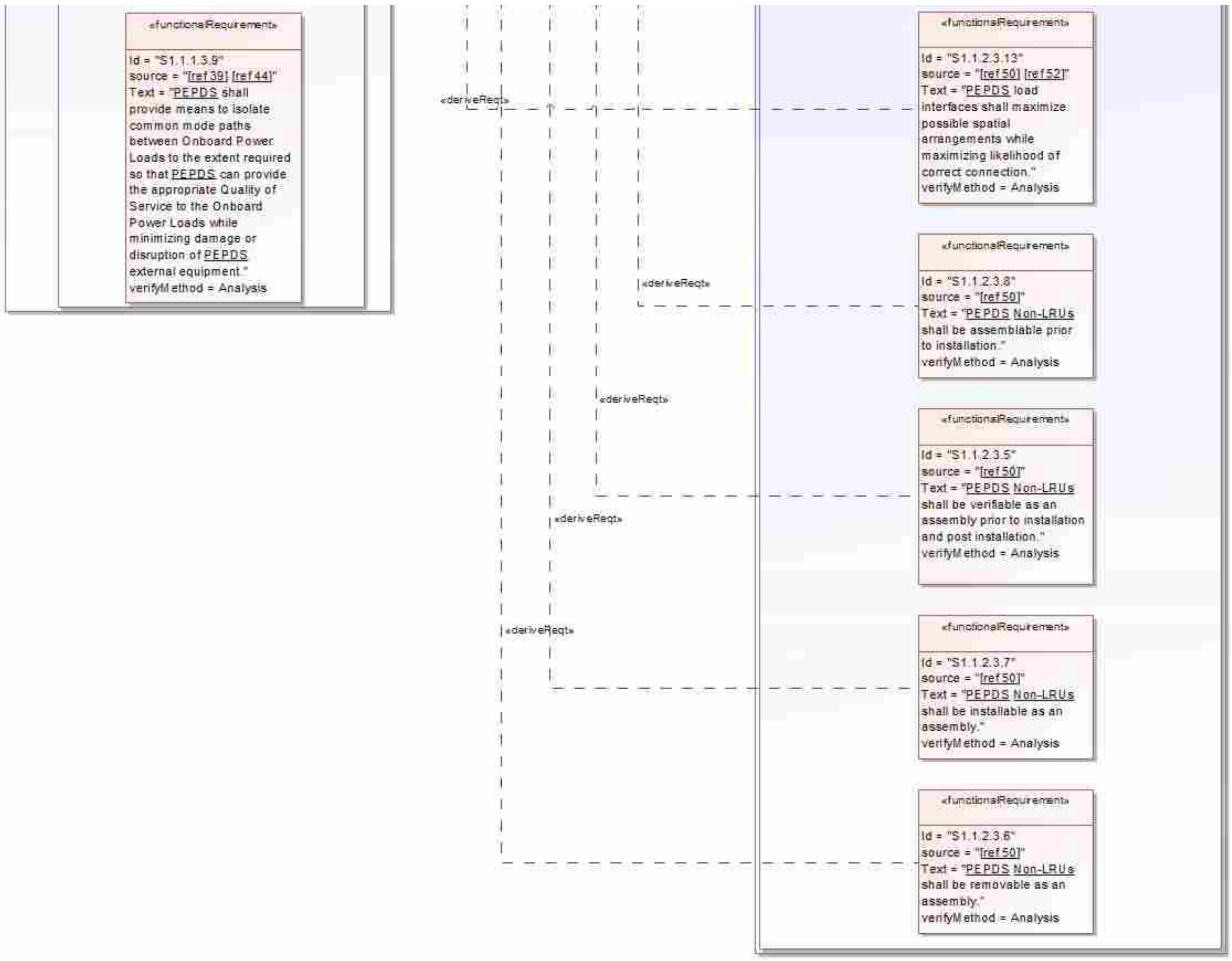


Fig. 46: S1.1 PEPDS Requirements Part 3.2

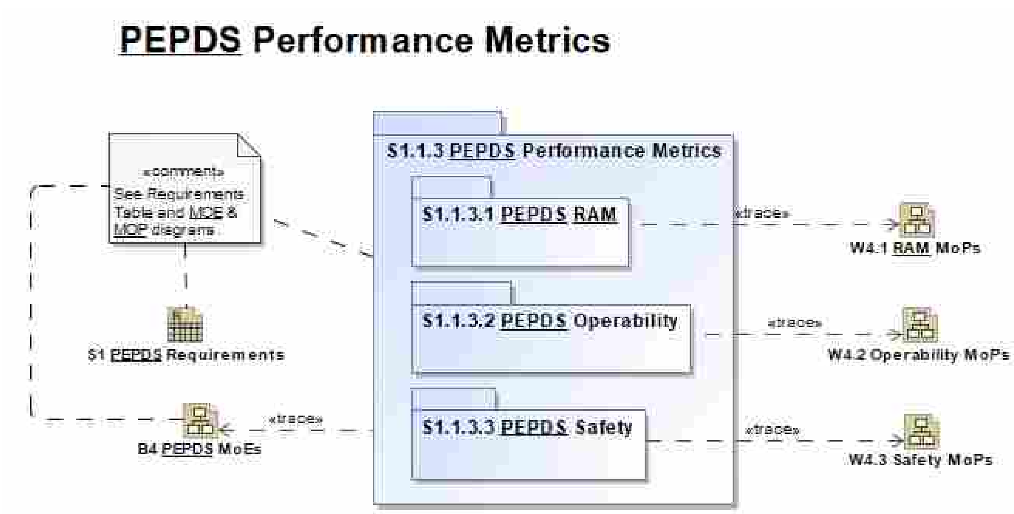


Fig. 47: S1.1 PEPDS Requirements Part 4

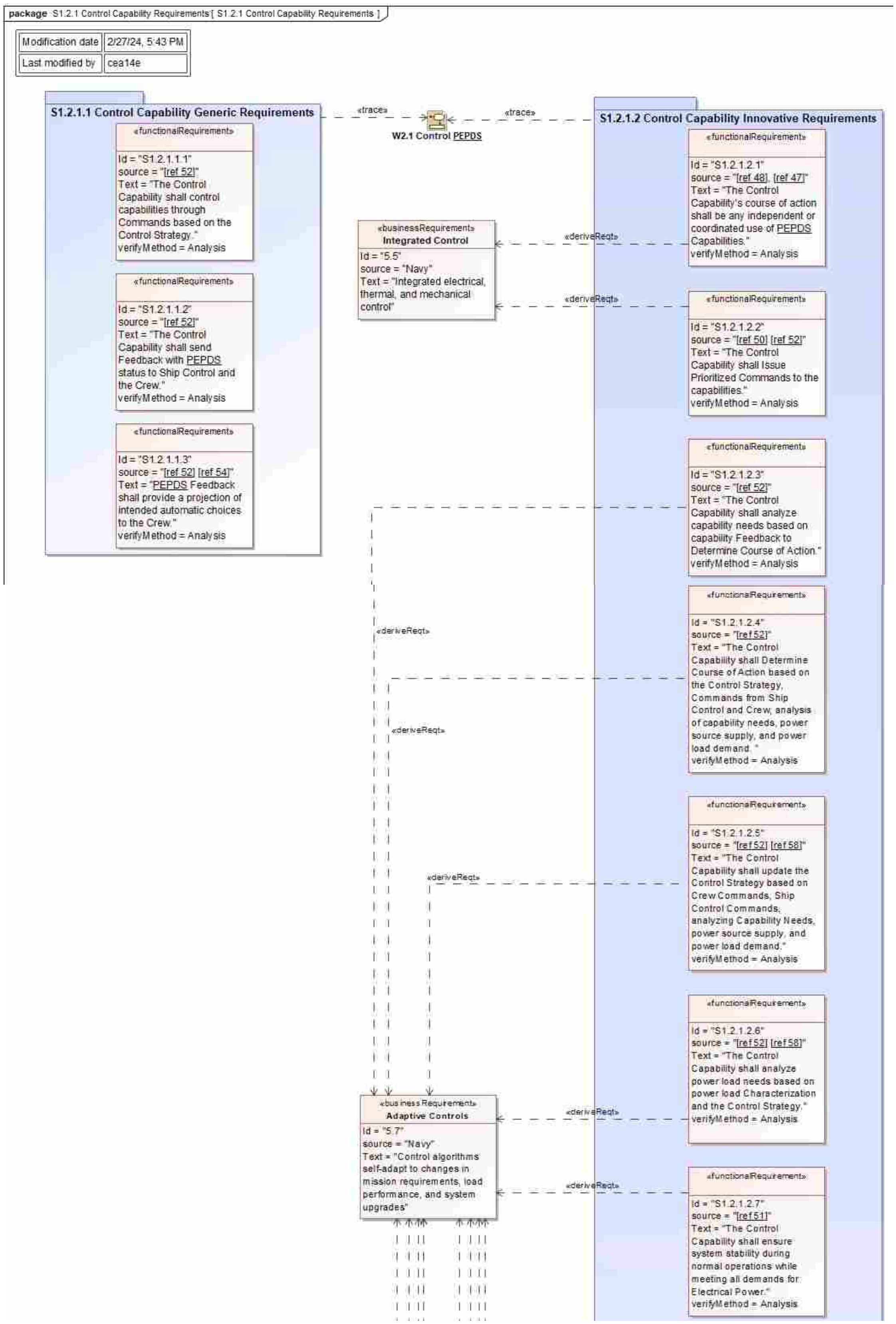


Fig. 48: S1.2.1 Control Capability Requirement Part 1

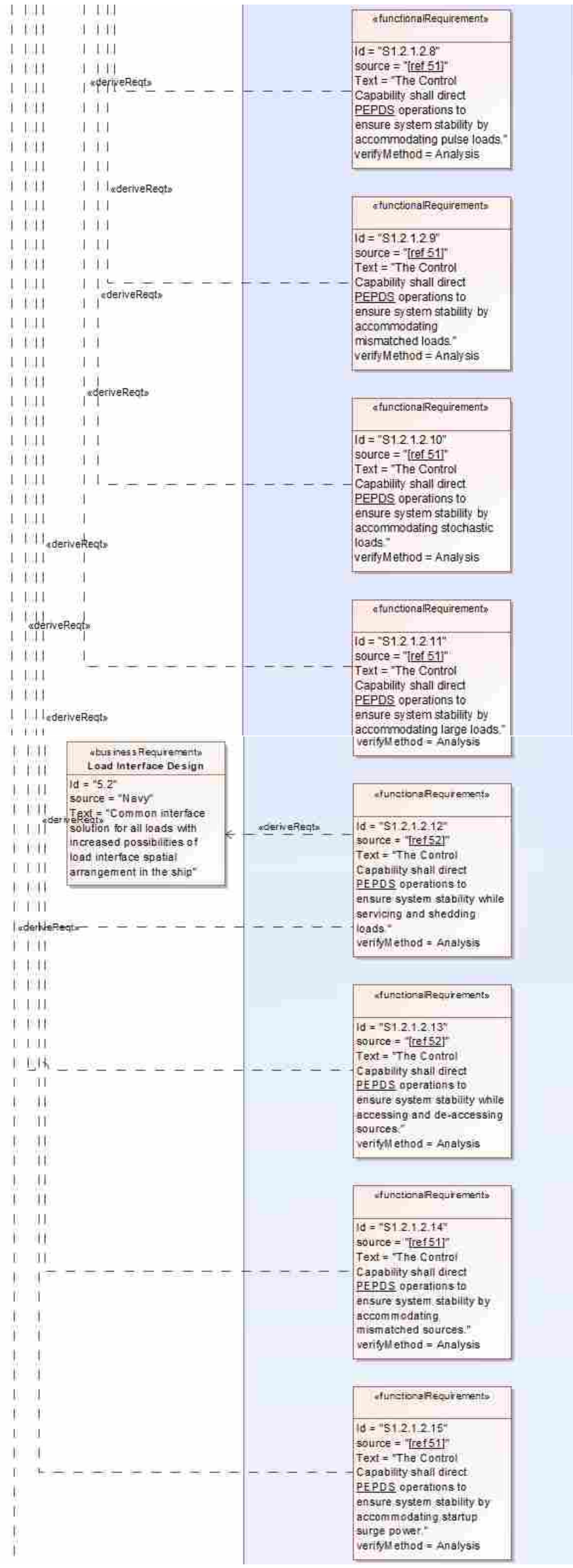


Fig. 49: S1.2.1 Control Capability Requirement Part 2

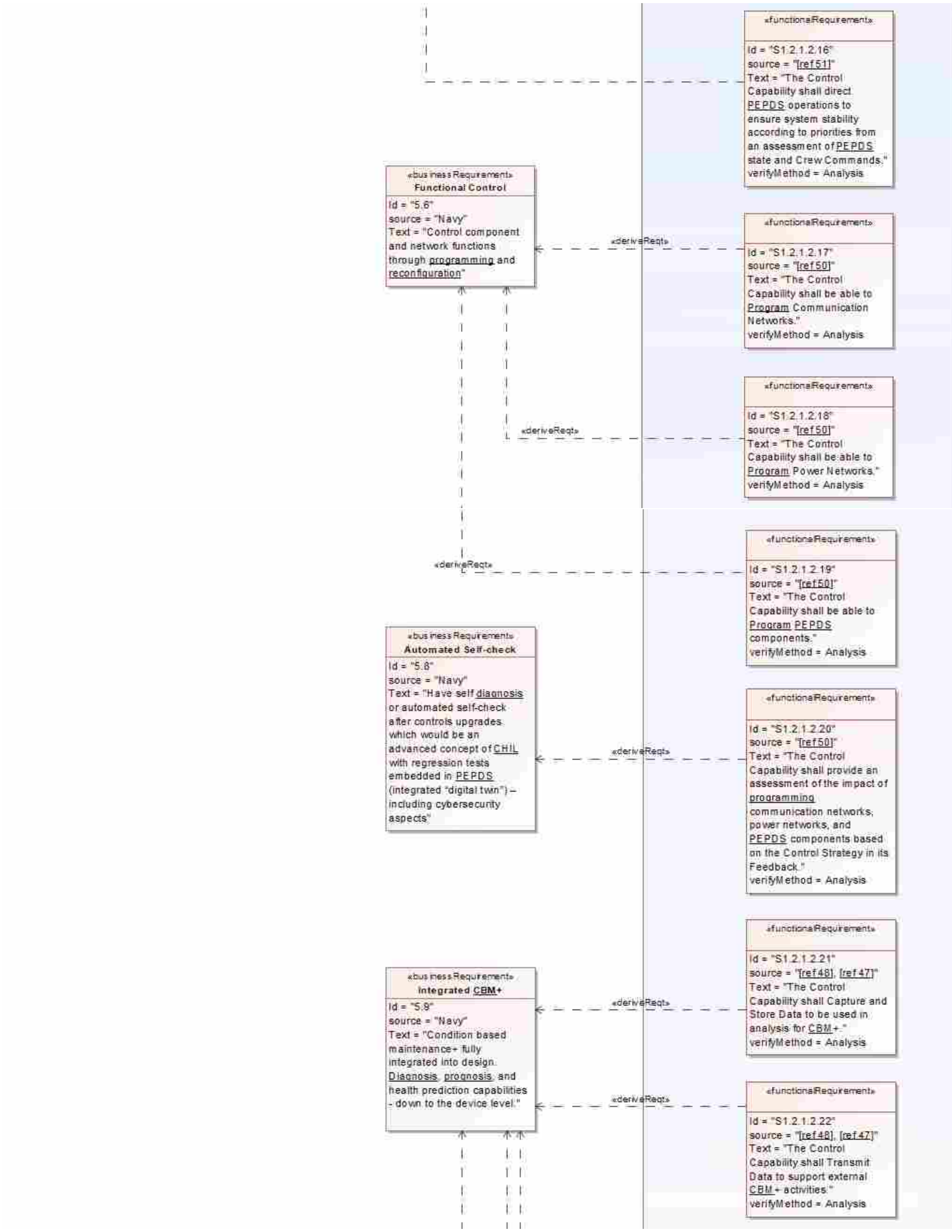


Fig. 50: S1.2.1 Control Capability Requirement Part 3

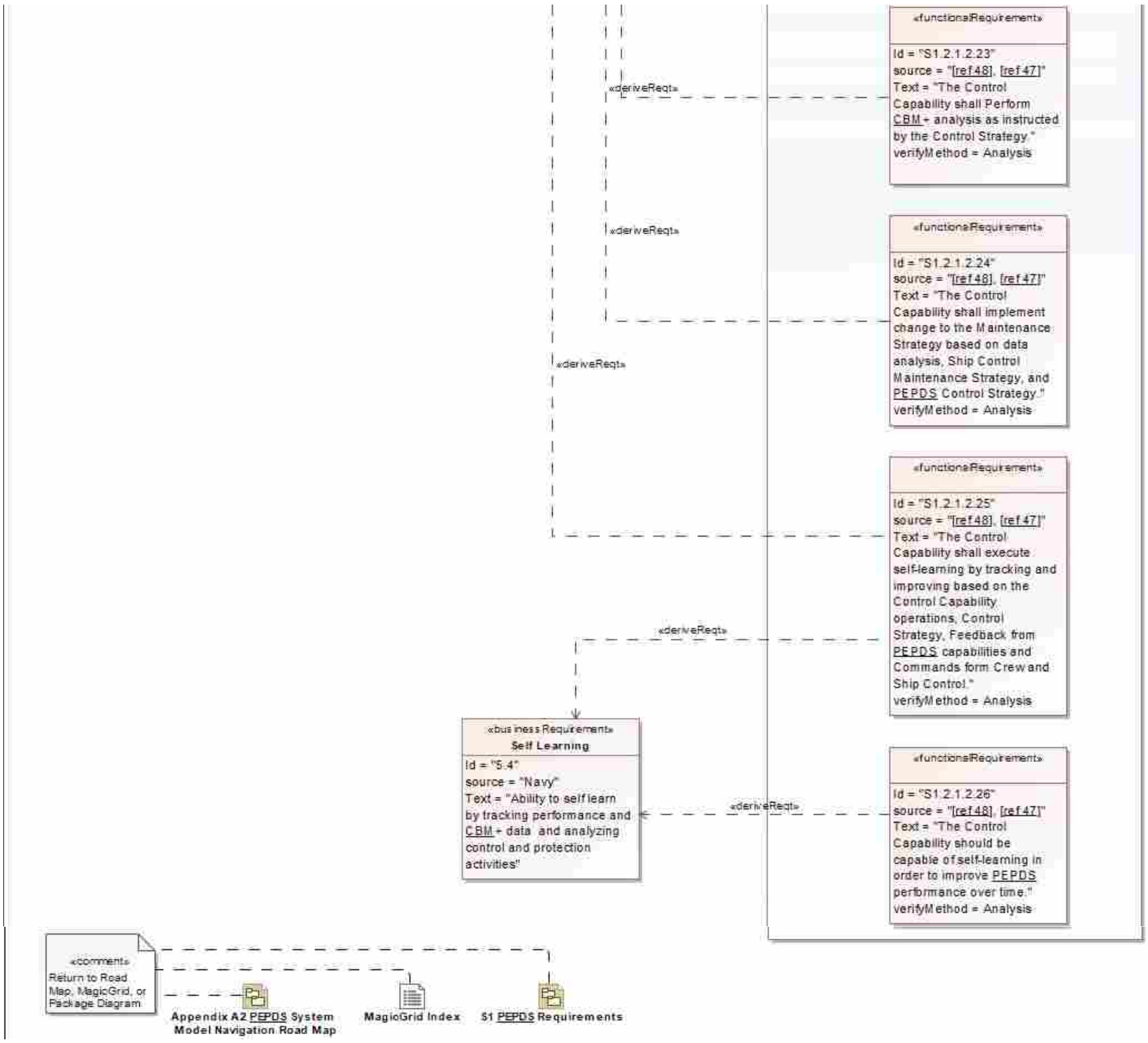


Fig. 51: S1.2.1 Control Capability Requirement Part 4

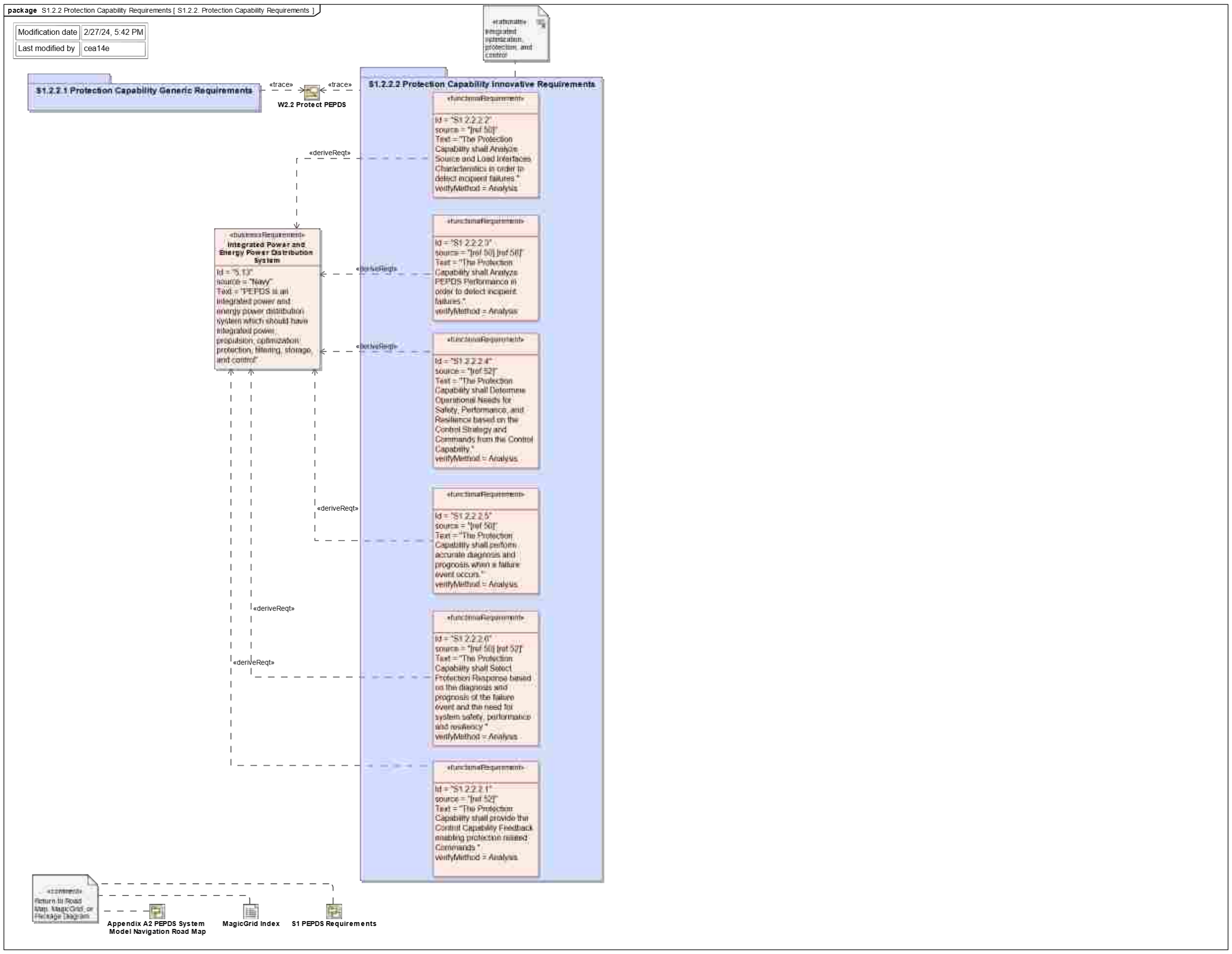


Fig. 52: S1.2.2. Protection Capability Requirements

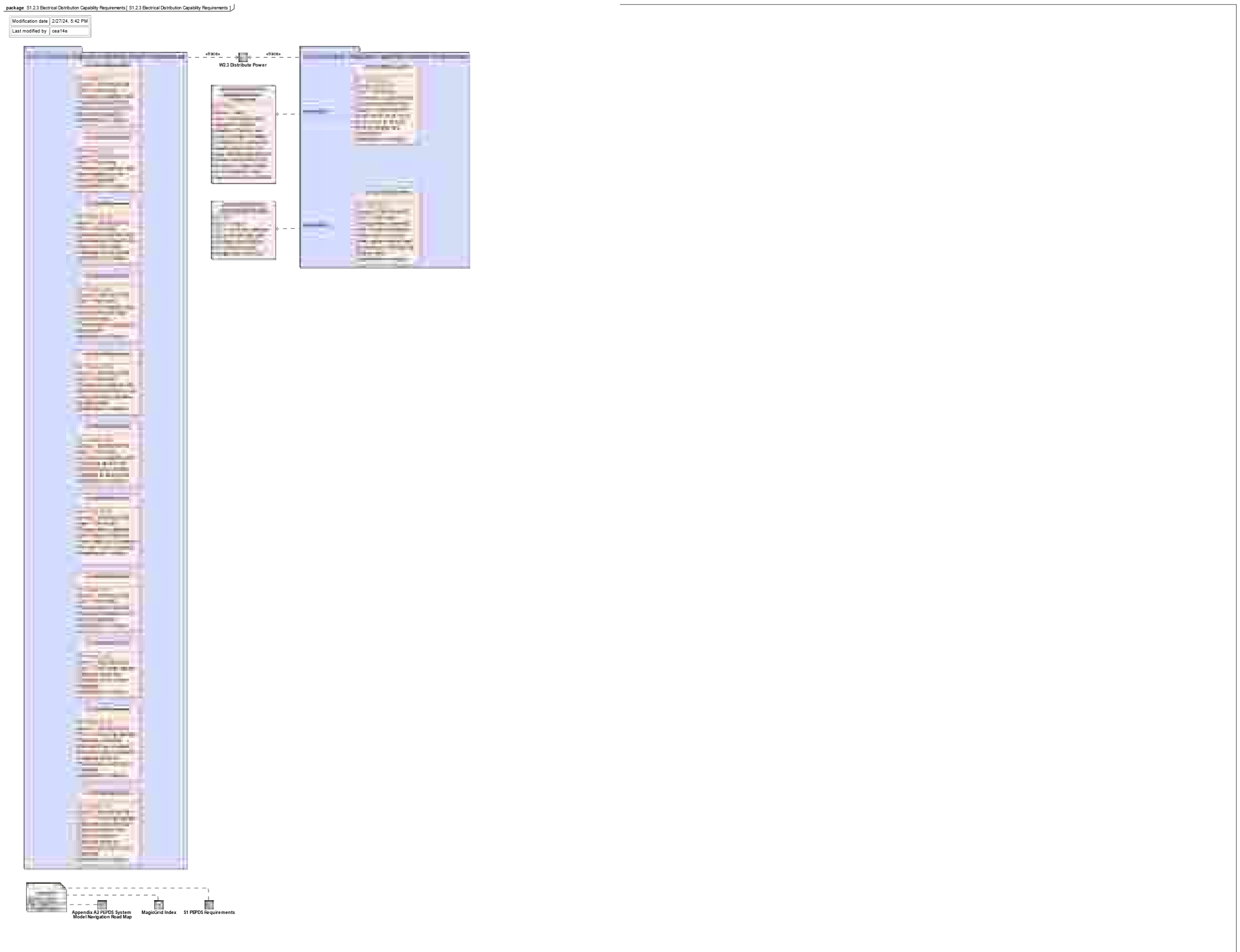


Fig. 53: S1.2.3 Electrical Distribution Capability Requirements

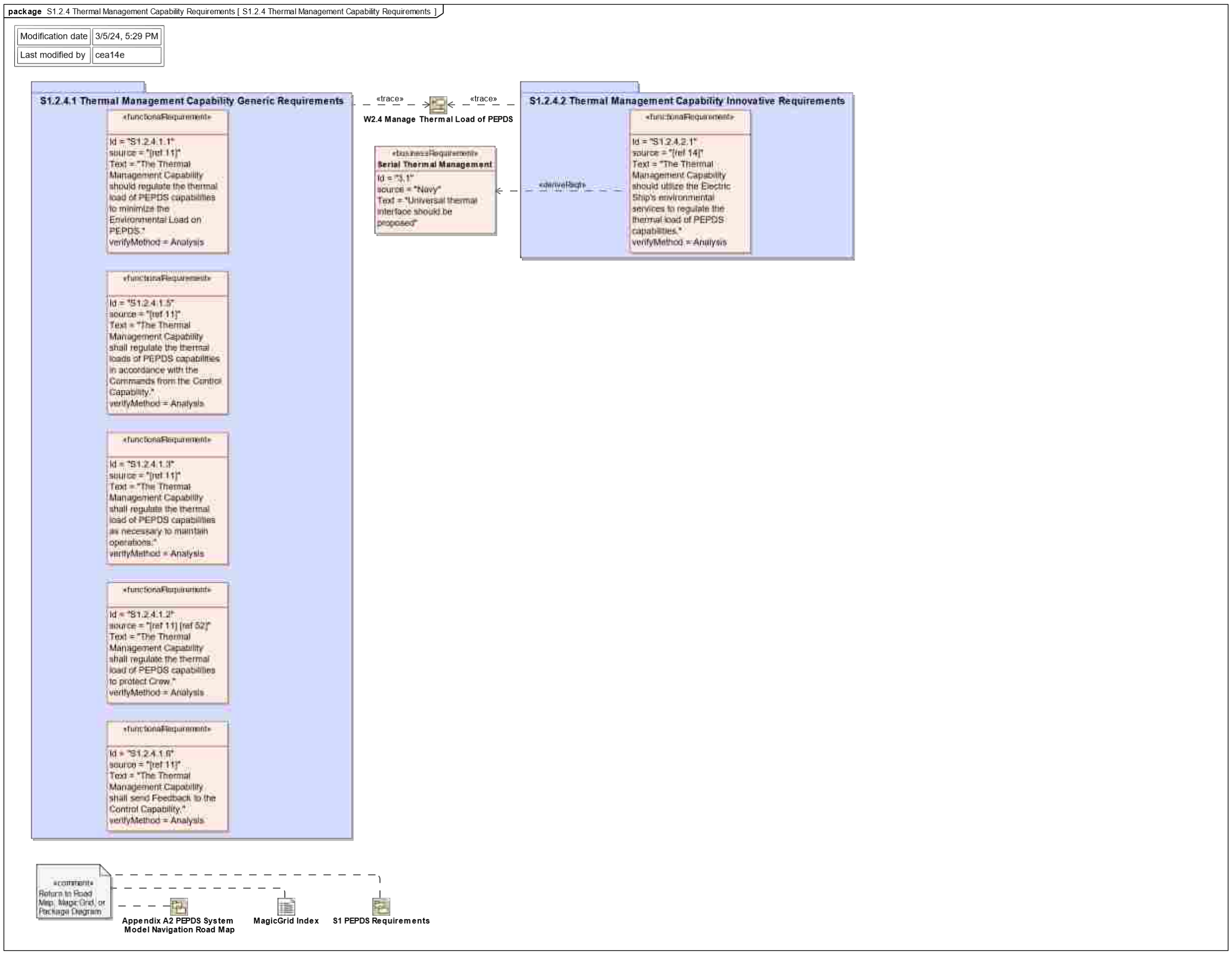


Fig. 54: S1.2.4 Thermal Management Capability Requirements

11.2.3.3 S1 System Requirements DeriveReq Matrices

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

Fig. 55: S1.1.4.1 PEPDS States and Modes DerivReq Matrix

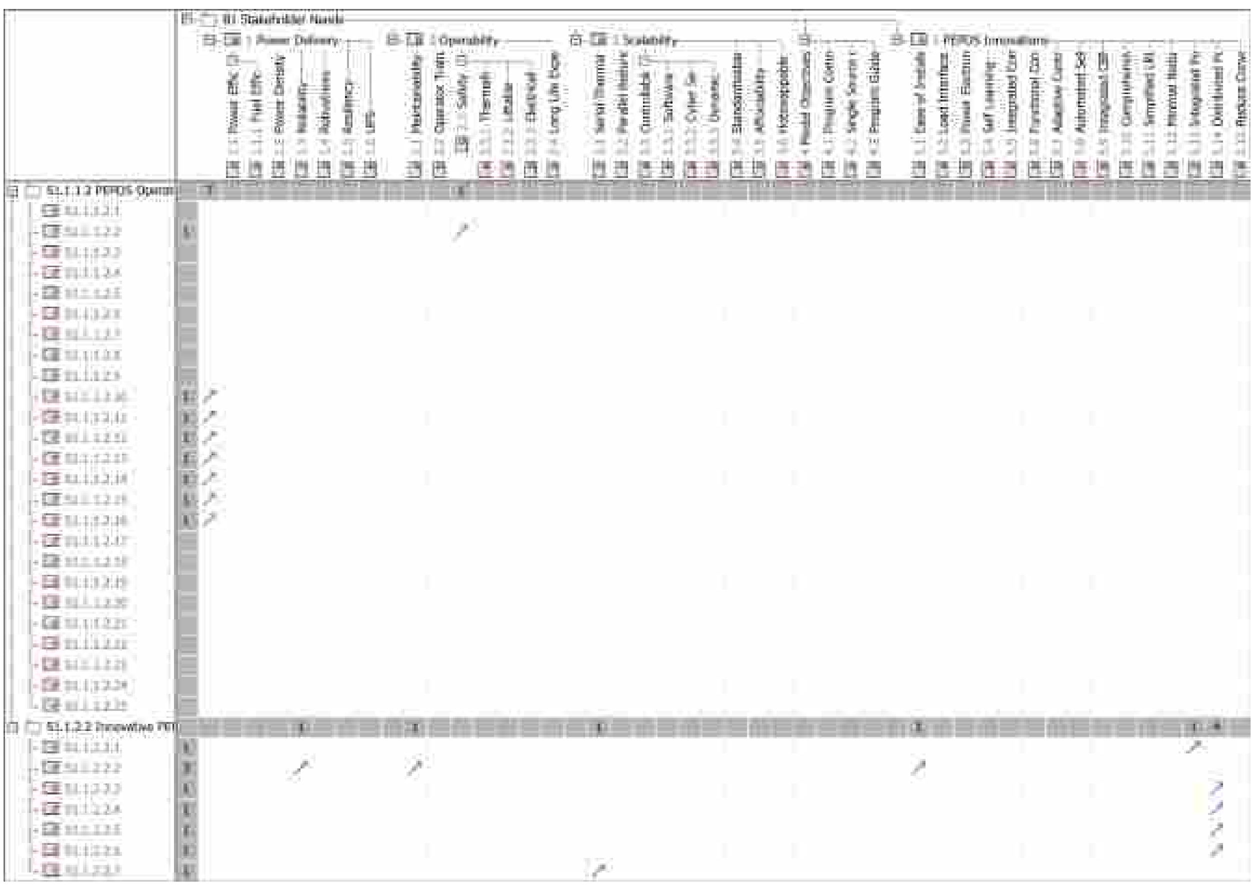


Fig. 56: S1.1.4.2 PEPDS Operations DerivReq Matrix

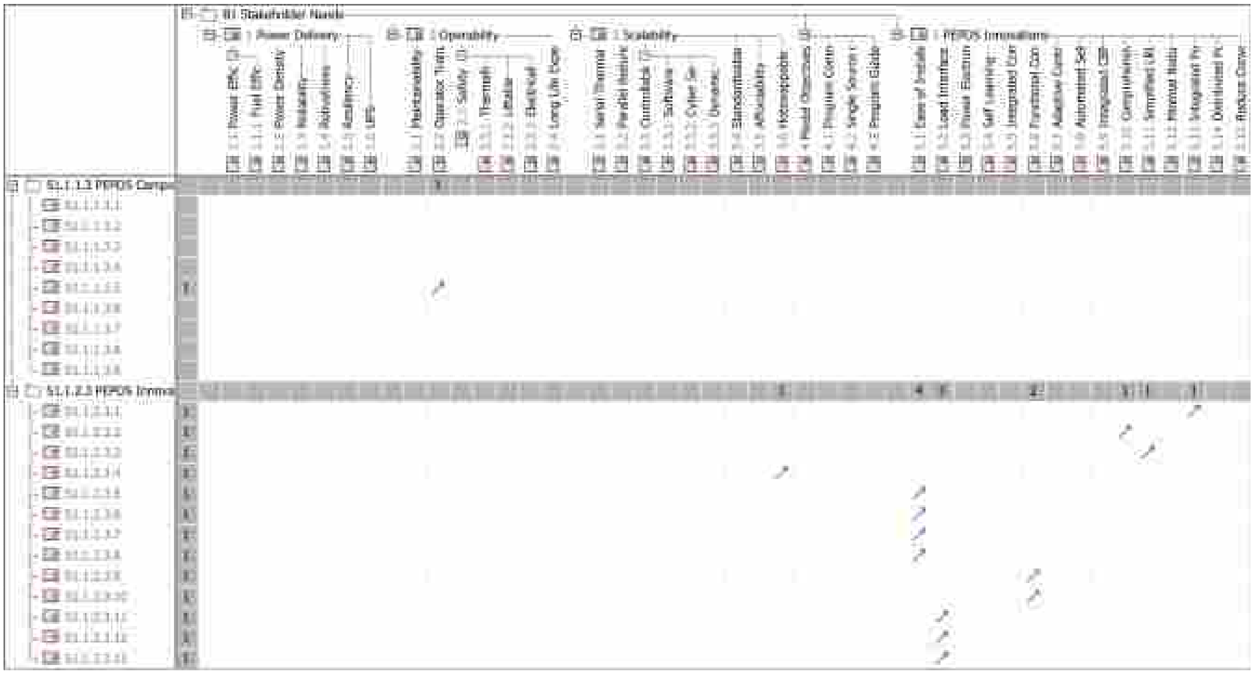


Fig. 57:S1.1.4.3 PEPDS Components and Structure DerivReq Matrix

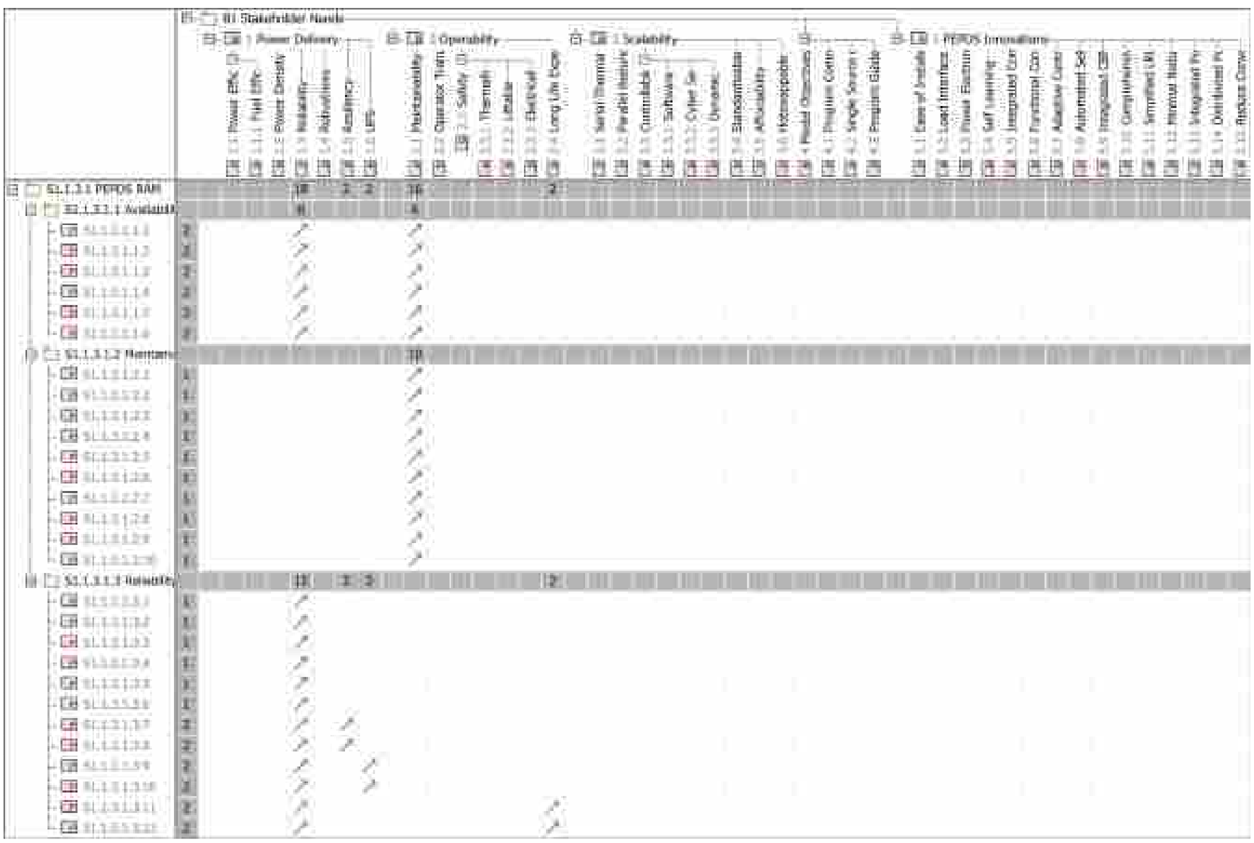


Fig. 58: S1.1.4.4 RAM MoEs and MoPs DerivReq Matrix

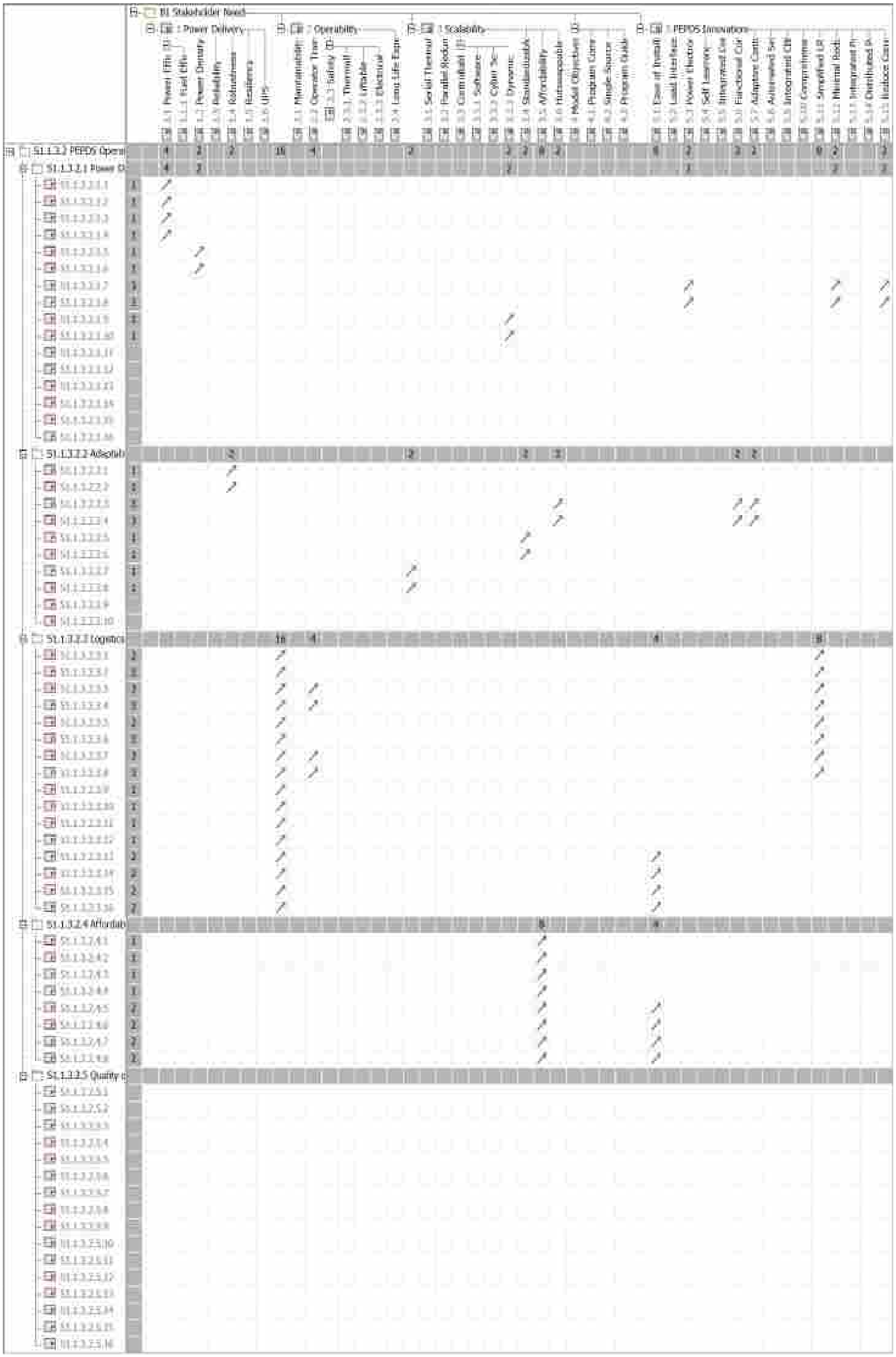


Fig. 59:S1.1.4.5 Operability MoEs and MoPs DerivReq Matrix

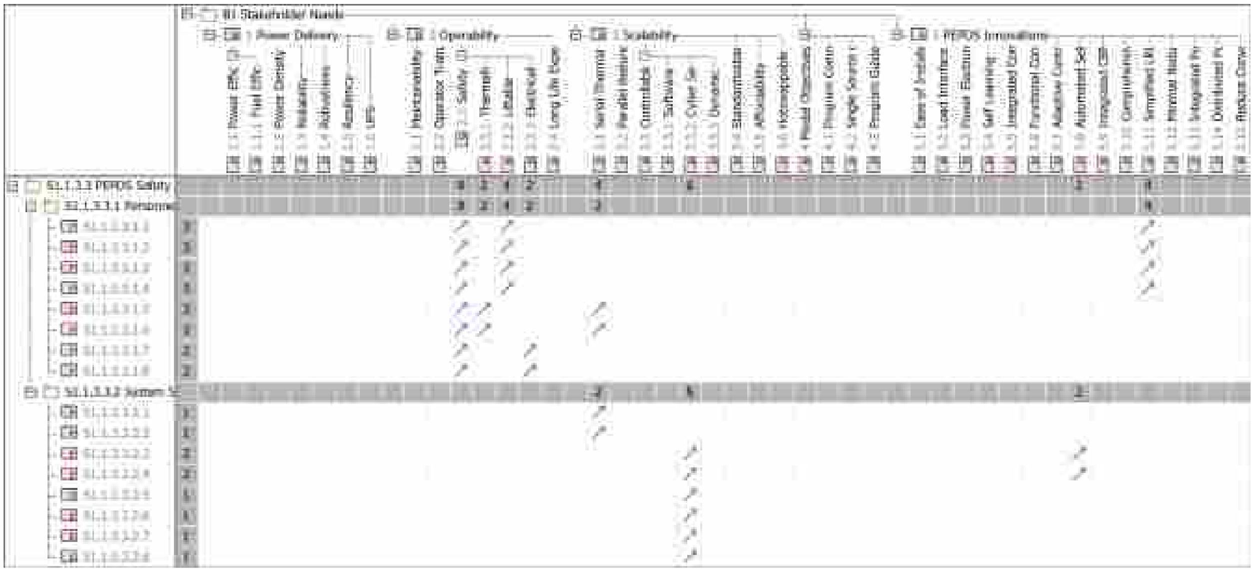


Fig. 60: S1.1.4.6 Safety MoEs and MoPs DerivReq Matrix

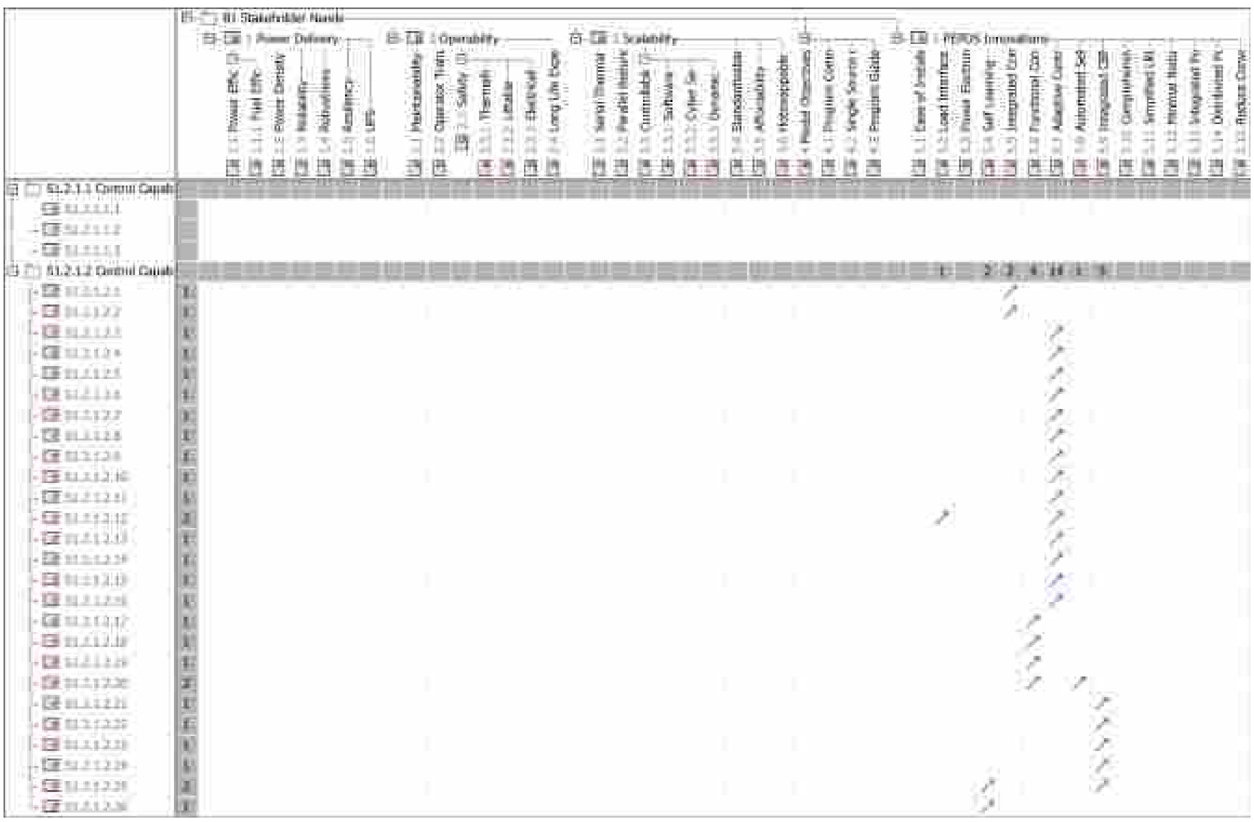


Fig. 61: S1.2.5.1 Control Capability DerivReq Matrix

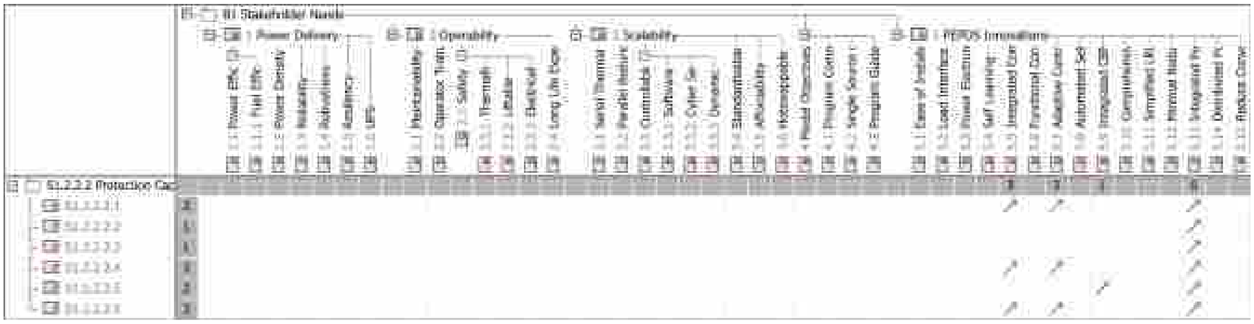


Fig. 62: S1.2.5.2 Protection Capability DerivReq Matrix

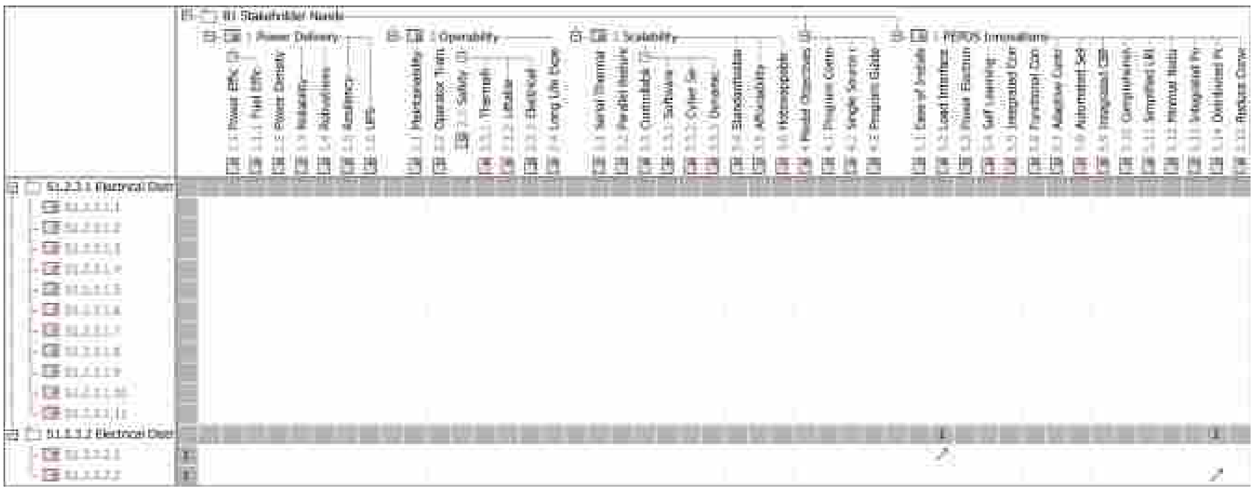


Fig. 63: S1.2.5.3 Electrical Distribution Capability DerivReq Matrix

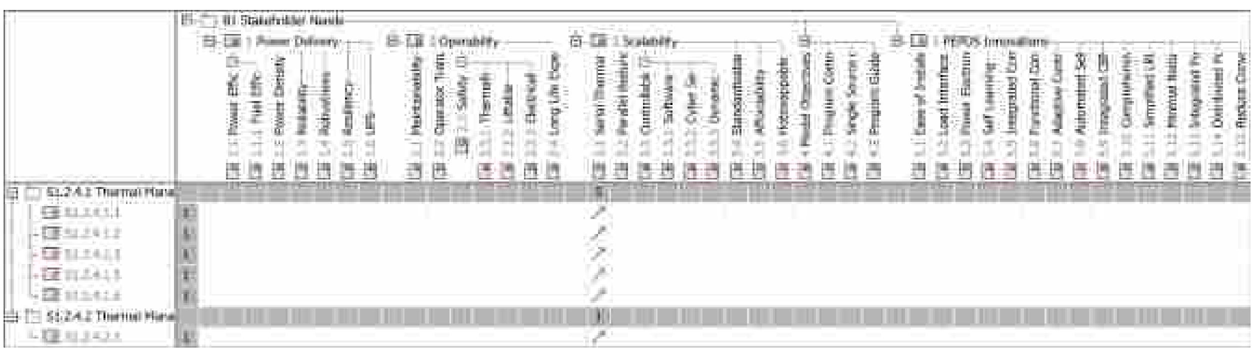


Fig. 64: S1.2.5.4 Thermal Management Capability DerivReq Matrix

11.2.3.4 S1 System Requirements Refine Matrices

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

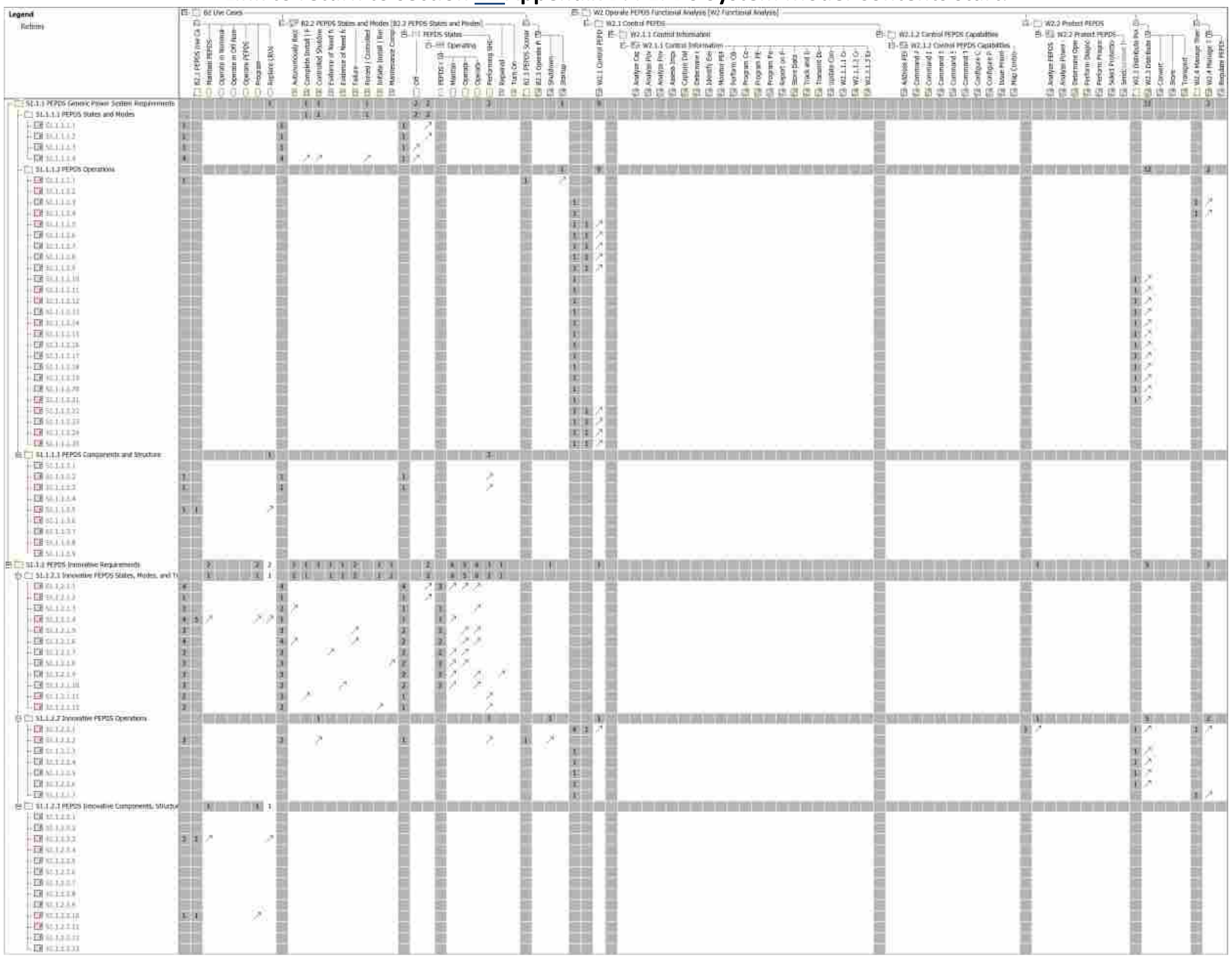


Fig. 65: S1.1.5.1 PEPDS Behavior Requirements Refine Matrix

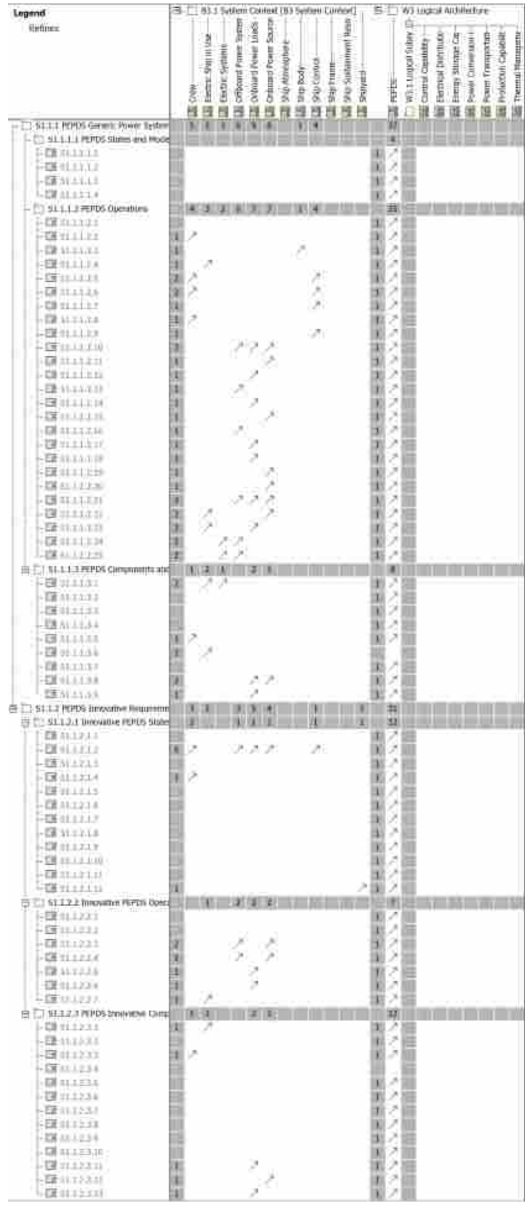


Fig. 66: S1.1.5.2 PEPDS Structural Requirements Refine Matrix

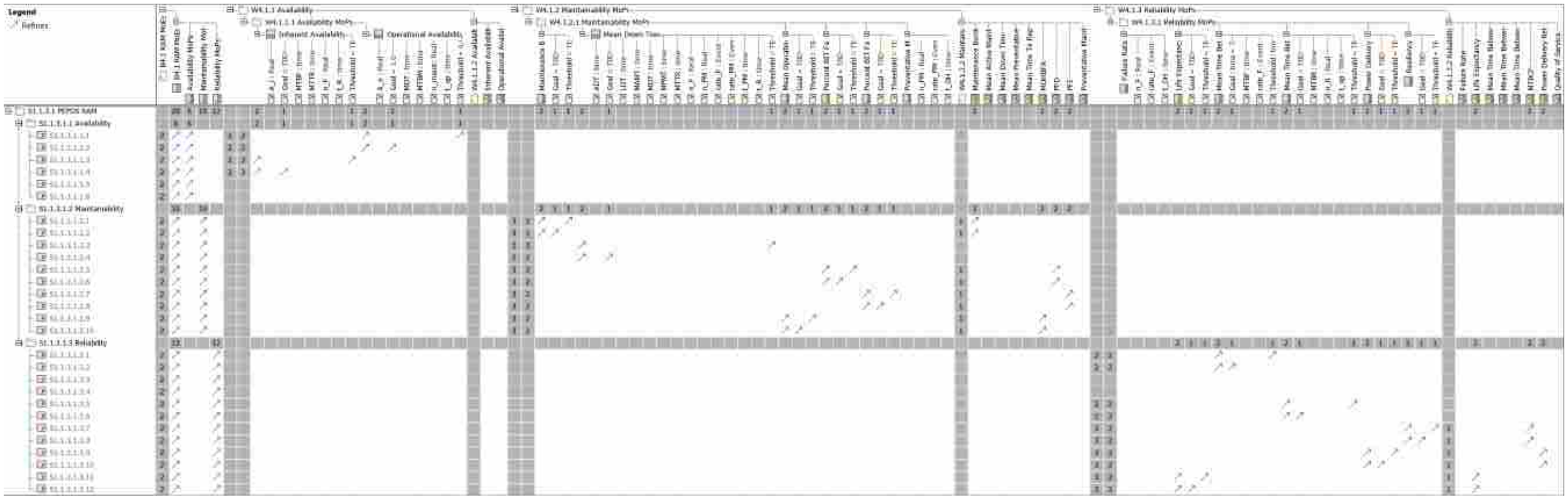


Fig. 67: S1.1.5.3 PEPDS RAM Parameter Requirements Refine Matrix

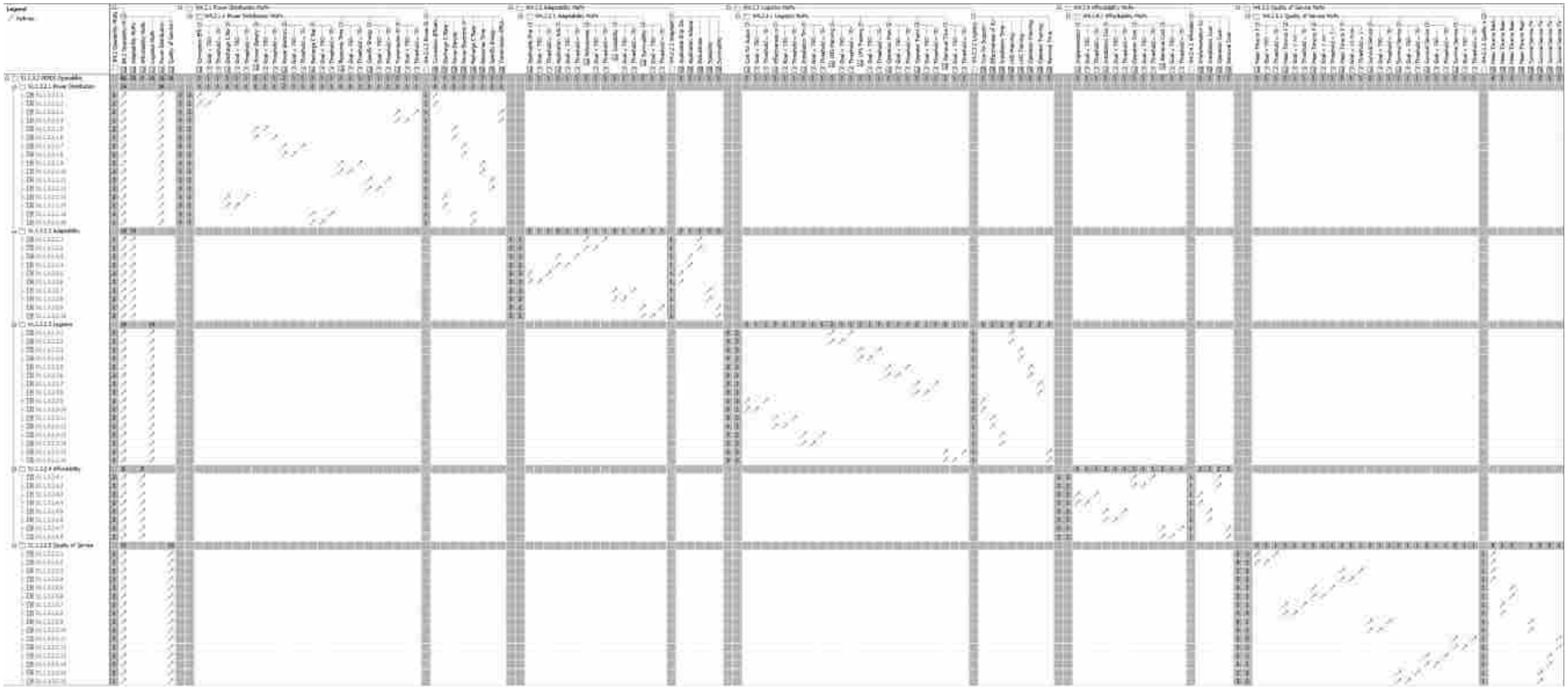


Fig. 68: S1.1.5.4 PEPDS Operability Parameter Requirements Refine Matrix

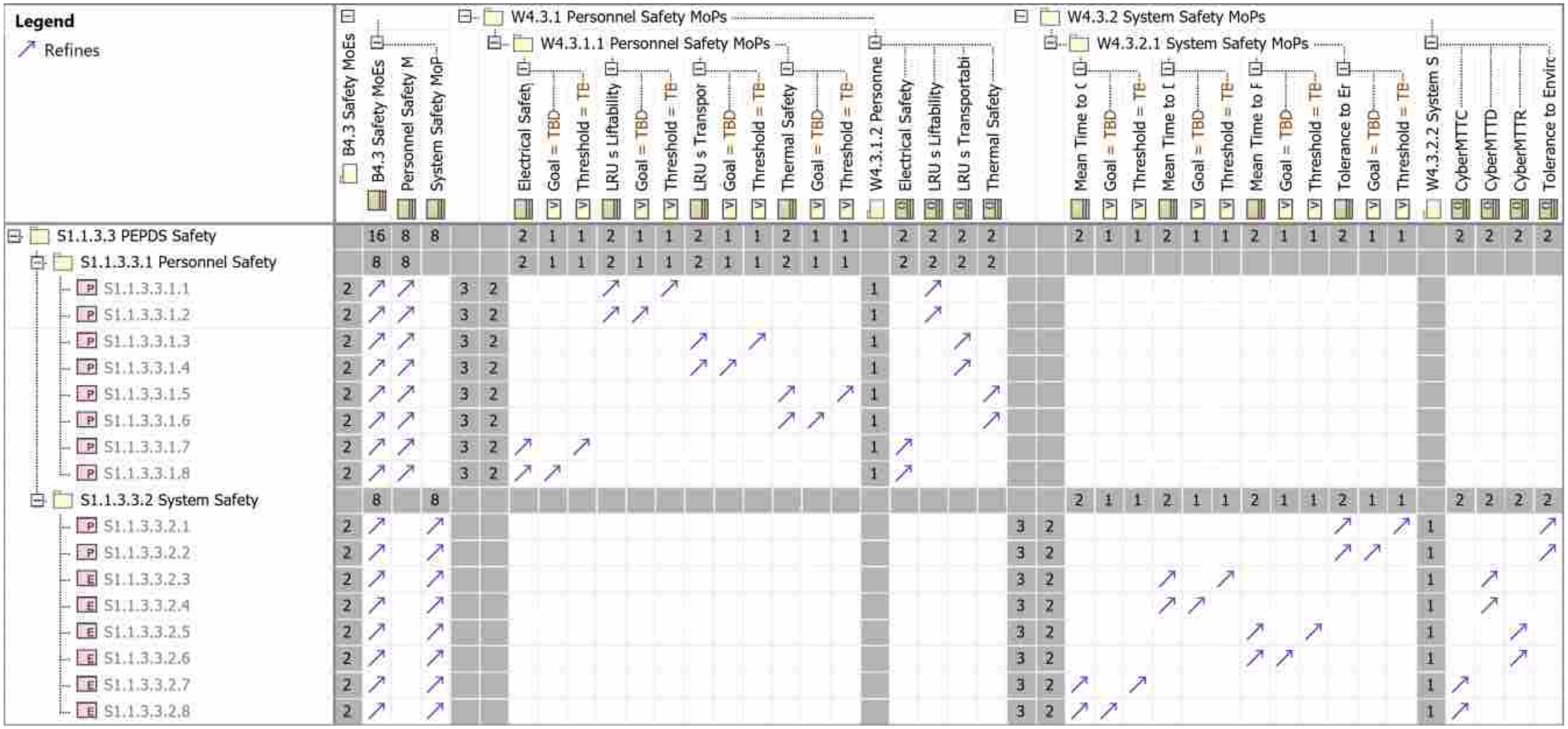


Fig. 69: S1.1.5.5 PEPDS Safety Parameter Requirements Refine Matrix

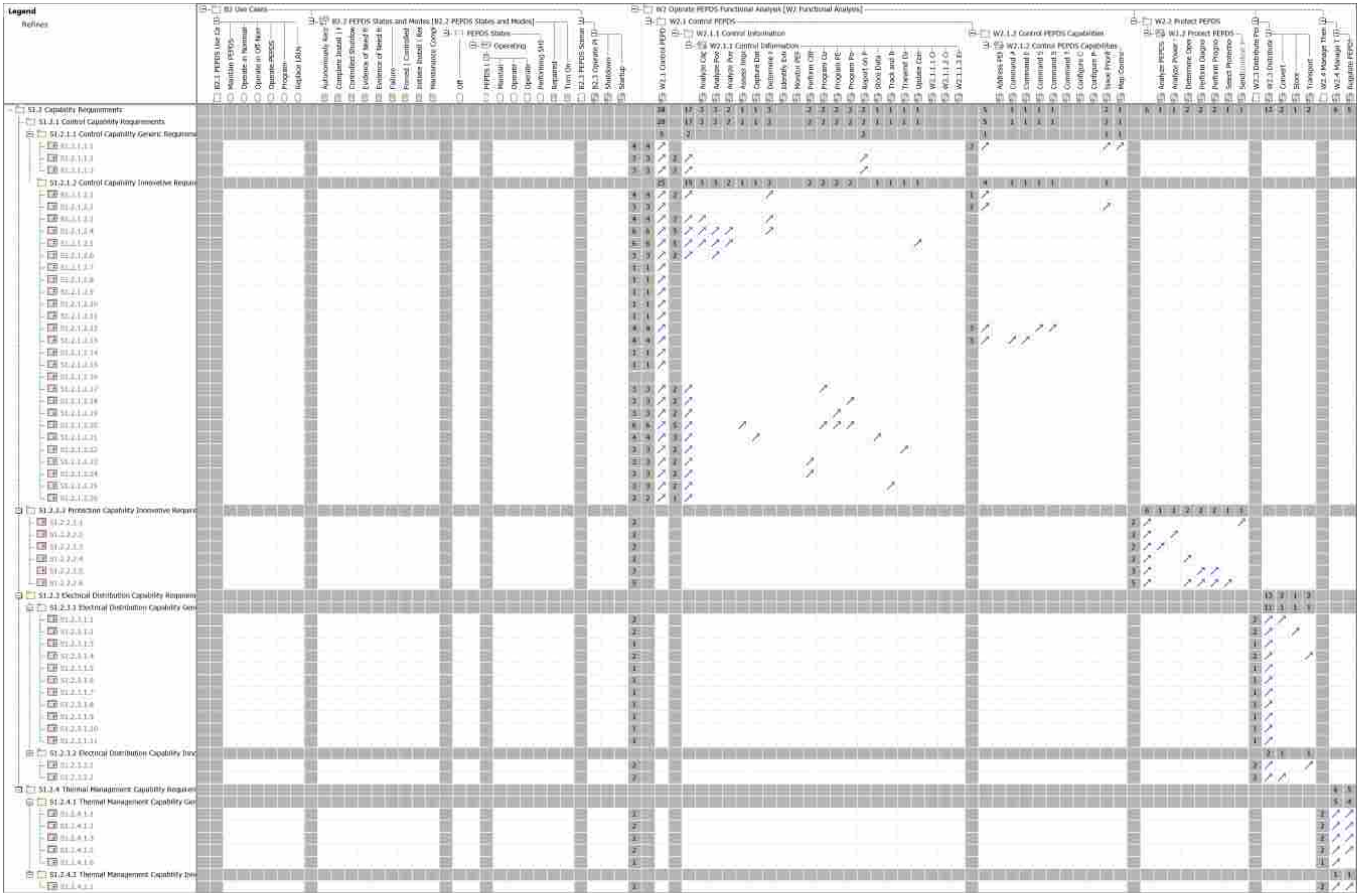


Fig. 70: S1.2.6.1 PEPDS Capabilities Behavior Requirements Refine Matrix

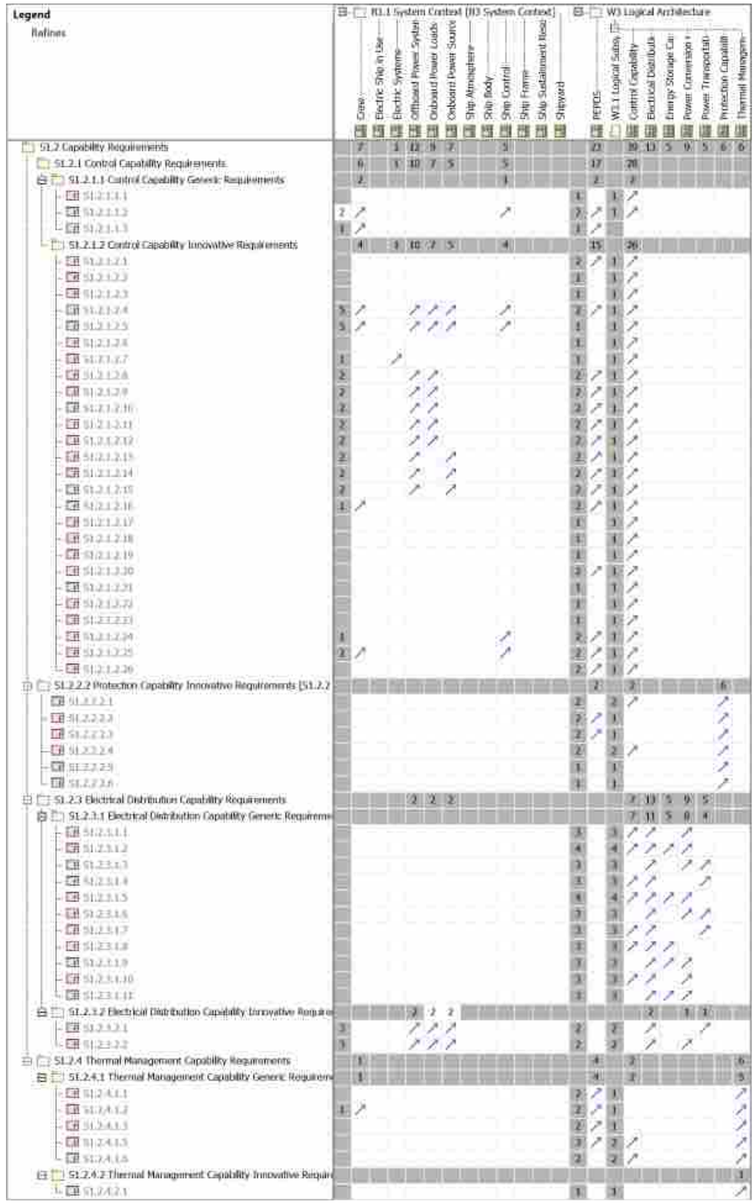


Fig. 71: S1.2.6.2 PEPDS Capabilities Structural Requirements Refine Matrix

11.2.3.5 S1 System Requirements Table

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

Table XIX: S1 PEPDS Requirements

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1 PEPDS Requirements							
S1.1.1 PEPDS Generic Power System Requirements							
S1.1.1.1 PEPDS States and Modes							
S1.1.1.1.1	PEPDS shall have an Operating state in which it is electrically active and functions are available.	Operating PEPDS		[ref 45]	Analysis		2022.11.15
S1.1.1.1.2	PEPDS shall fulfill mission requirements to the maximum extent possible in all modes of the Operating state.	Operating PEPDS	1.4 Robustness 1.5 Resiliency	[ref 36]	Analysis		2022.11.15
S1.1.1.1.3	PEPDS shall have an Off state in which it is electrically inert and non-functional.	Off PEPDS		[ref 45]	Analysis		2022.11.15
S1.1.1.1.4	PEPDS shall transition to the Off state from any other state upon command or complete failure via controlled, graceful, and failsafe shutdown.	Complete Install | Remove Controlled Shutdown Forced | Controlled Shutdown Off Failure Commands PEPDS		[ref 45]	Analysis		2022.11.15
S1.1.1.2 PEPDS Operations							

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.1.2.1	PEPDS shall startup on Commands (e.g. blackstart, coldstart).	Startup Commands PEPDS		[ref 54]	Analysis		2022.11.15
S1.1.1.2.2	PEPDS shall meet general human engineering design criteria specified by MIL-STD-1472H including tagout of components for maintenance or repair, physical access, liftability.	Crew PEPDS	2.3 Safety	[ref 43]	Analysis		2022.11.15
S1.1.1.2.3	PEPDS shall transfer Environmental Load to Ship Body.	W2.4 Manage Thermal Load of PEPDS Ship Body Environmental Load PEPDS		[ref 40]	Analysis		2022.11.15
S1.1.1.2.4	PEPDS shall accommodate Environmental Load naturally transferred from the Electric Ship.	W2.4 Manage Thermal Load of PEPDS Electric Ship in Use Environmental Load PEPDS		[ref 40]	Analysis		2022.11.15
S1.1.1.2.5	PEPDS shall execute Crew Commands according to priorities established by 1) the Crew 2) Ship Control , or 3) autonomous operations in descending order of priority.	W2.1 Control PEPDS Crew Ship Control Commands PEPDS		[ref 54]	Analysis		2022.11.15
S1.1.1.2.6	PEPDS shall execute Crew Commands overriding Ship Control Commands and PEPDS autonomous operations.	W2.1 Control PEPDS Crew Ship Control Commands PEPDS	S1.1.1.2.5	[ref 54]	Analysis		2022.11.15
S1.1.1.2.7	PEPDS shall execute Ship Control Commands overriding PEPDS autonomous operations.	W2.1 Control PEPDS Ship Control Commands PEPDS	S1.1.1.2.5	[ref 40]	Analysis		2022.11.15
S1.1.1.2.8	PEPDS shall send Feedback (e.g. operational status, health status, failure diagnosis, failure	W2.1 Control PEPDS Crew Feedback		[ref 54]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
	prognosis, control strategy, cybersecurity status) to Crew.	Control Strategy PEPDS					
S1.1.1.2.9	PEPDS shall send Feedback (e.g. operational status, health status, failure diagnosis, failure prognosis, control strategy, cybersecurity status) to Ship Control.	W2.1 Control PEPDS Ship Control Feedback Control Strategy PEPDS		[ref 40]	Analysis		2022.11.15
S1.1.1.2.10	PEPDS shall be able to Distribute Electrical Power from any available source to served loads based on priorities.	W2.3 Distribute Power Onboard Power Sources Offboard Power Systems Onboard Power Loads Electrical Power PEPDS	1 Power Delivery	[ref 50] [ref 52]	Analysis		2022.11.15
S1.1.1.2.11	PEPDS shall receive Electrical Power from Onboard Power Sources including generators, regenerators, and energy storage.	W2.3 Distribute Power Onboard Power Sources Electrical Power PEPDS	1 Power Delivery	[ref 40]	Analysis		2022.11.15
S1.1.1.2.12	PEPDS shall accommodate receiving Electrical Power from Onboard Power Loads.	W2.3 Distribute Power Onboard Power Loads Electrical Power PEPDS	1 Power Delivery	[ref 40]	Analysis		2022.11.15
S1.1.1.2.13	PEPDS shall receive Electrical Power from Offboard Power Systems when appropriately connected.	W2.3 Distribute Power Offboard Power Systems Electrical Power PEPDS	1 Power Delivery	[ref 40]	Analysis		2022.11.15
S1.1.1.2.14	PEPDS shall deliver Electrical Power to Onboard Power Loads.	W2.3 Distribute Power Onboard Power Loads Electrical Power PEPDS	1 Power Delivery	[ref 40]	Analysis		2022.11.15
S1.1.1.2.15	PEPDS shall accommodate delivering Electrical Power to Onboard Power Sources.	W2.3 Distribute Power Onboard Power Sources Electrical Power PEPDS	1 Power Delivery	[ref 40]	Analysis		2022.11.15
S1.1.1.2.16	PEPDS shall deliver Electrical Power to Offboard Power Systems when appropriately connected.	W2.3 Distribute Power Offboard Power Systems Electrical Power PEPDS	1 Power Delivery	[ref 40]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.1.2.17	PEPDS should maximize alternative electrical paths to service Onboard Power Loads.	W2.3 Distribute Power Onboard Power Loads PEPDS		[ref 44]	Analysis		2022.11.15
S1.1.1.2.18	PEPDS shall provide at least two electrical paths to service mission critical loads.	W2.3 Distribute Power Onboard Power Loads PEPDS		[ref 44]	Analysis		2022.11.15
S1.1.1.2.19	PEPDS should maximize alternative electrical paths from each Onboard Power Source.	W2.3 Distribute Power Onboard Power Sources PEPDS		[ref 44]	Analysis		2022.11.15
S1.1.1.2.20	PEPDS shall have at least two electrical paths from every Onboard Power Source.	W2.3 Distribute Power Onboard Power Sources PEPDS		[ref 44]	Analysis		2022.11.15
S1.1.1.2.21	PEPDS shall maximize separation between alternative electrical paths.	W2.3 Distribute Power Onboard Power Sources Offboard Power Systems Onboard Power Loads PEPDS		[ref 44]	Analysis		2022.11.15
S1.1.1.2.22	PEPDS shall receive Onboard Power Source Characterization from the Electric Ship.	W2.1 Control PEPDS Onboard Power Sources Electric Ship in Use Characterization PEPDS		[ref 44]	Analysis		2022.11.15
S1.1.1.2.23	PEPDS shall receive Onboard Power Load Characterization from the Electric Ship.	W2.1 Control PEPDS Onboard Power Loads Electric Ship in Use Characterization PEPDS		[ref 40]	Analysis		2022.11.15
S1.1.1.2.24	PEPDS shall receive Offboard Power Source Characterization from the Electric Systems.	W2.1 Control PEPDS Offboard Power Systems Electric Systems Characterization PEPDS		[ref 44]	Analysis		2022.11.15
S1.1.1.2.25	PEPDS shall receive Offboard Power Load Characterization from the Electric Systems.	W2.1 Control PEPDS Offboard Power Systems Electric Systems Characterization PEPDS		[ref 44]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.1.3 PEPDS Components and Structure							
S1.1.1.3.1	PEPDS is a part of the Electric Systems on the Electric Ship.	Electric Systems Electric Ship in Use PEPDS		[ref 40]	Analysis		2022.11.15
S1.1.1.3.2	PEPDS shall be installable by standard US Navy SHIPALT processes.	Performing SHIPALT PEPDS		[ref 59]	Analysis		2022.11.15
S1.1.1.3.3	PEPDS shall be removable by standard US Navy SHIPALT processes.	Performing SHIPALT PEPDS		[ref 59]	Analysis		2022.11.15
S1.1.1.3.4	PEPDS components shall be LRUs or Non-LRUs.	PEPDS LRUs Non-LRUs		[ref 46]	Analysis		2022.11.15
S1.1.1.3.5	PEPDS shall have LRUs installed, removed, and replaced by the Crew.	Replace LRUs PEPDS LRUs Crew	2.2 Operator Trainability	[ref 7]	Analysis		2022.11.15
S1.1.1.3.6	PEPDS LRUs shall have spares in Electric Ship stores which are stocked by the U.S. Navy Supply System.	LRUs Electric Ship in Use		[ref 60]	Analysis		2022.11.15
S1.1.1.3.7	PEPDS shall comply with applicable EMI/EMC standards (i.e. not adversely affect external equipment)	PEPDS		[ref 49]	Analysis		2022.11.15
S1.1.1.3.8	PEPDS shall provide means to isolate common mode paths between Onboard Power Sources and Onboard Power Loads to the extent required so that PEPDS can provide the appropriate Quality of Service to the Onboard Power Loads while minimizing damage or disruption of PEPDS external equipment.	PEPDS Onboard Power Sources Onboard Power Loads Quality of Service		[ref 39]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.1.3.9	PEPDS shall provide means to isolate common mode paths between Onboard Power Loads to the extent required so that PEPDS can provide the appropriate Quality of Service to the Onboard Power Loads while minimizing damage or disruption of PEPDS external equipment.	PEPDS Onboard Power Loads Quality of Service		[ref 39] [ref 44]	Analysis		2022.11.15
S1.1.2 PEPDS Innovative Requirements							
S1.1.2.1 Innovative PEPDS States, Modes, and Transitions							
S1.1.2.1.1	The PEPDS Operating state shall function in one of the following states: 1) Operating Nominally state, 2) Operating Off-Nominally state, or 3) Maintaining state.	Operating in Nominal Condition Maintaining Operating in Off-Nominal Condition Operating PEPDS	1.4 Robustness	[ref 7]	Analysis		2022.11.15
S1.1.2.1.2	PEPDS in all states of its Operating state shall utilize power sources to service power loads in accordance with its Control Strategy, Ship Control Commands, and Crew Commands.	Operating Onboard Power Sources Offboard Power Systems Onboard Power Loads Crew Ship Control Control Strategy Commands PEPDS	5.5 Integrated Control 1 Power Delivery	[ref 45] [ref 50] [ref 52] [ref 54] [ref 58]	Analysis		2022.11.15
S1.1.2.1.3	PEPDS in its Operating Off-Nominally state shall attempt to autonomously resolve failures by rerouting, reconfiguring, and reprogramming.	Autonomously Recovered Operating in Off-Nominal Condition Failure PEPDS	5.7 Adaptive Controls 5.6 Functional Control 5.8 Automated Self-check	[ref 50]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.2.1.4	PEPDS in its Maintaining state shall enable Crew reprogramming, reconfiguring, and replacement of LRUs.	Maintain PEPDS Program Replace LRUs Maintaining Crew LRUs PEPDS	5.9 Integrated CBM+ 5.11 Simplified LRU Replacement 5.6 Functional Control 2.1 Maintainability	[ref 7] [ref 50]	Analysis		2022.11.15
S1.1.2.1.5	PEPDS shall transition from Operating Nominally state to Operating Off-Nominally state when PEPDS has detected a Failure.	Failure Operating in Nominal Condition Operating in Off-Nominal Condition Failure PEPDS	1.5 Resiliency	[ref 7]	Analysis		2022.11.15
S1.1.2.1.6	PEPDS shall transition from Operating Off-Nominally state to Operating Nominally state upon autonomous recovery of all detected Failures.	Autonomously Recovered Failure Operating in Nominal Condition Operating in Off-Nominal Condition Failure PEPDS	5.7 Adaptive Controls	[ref 50] [ref 58]	Analysis		2022.11.15
S1.1.2.1.7	PEPDS shall transition from Operating Nominally state to Maintaining state when there is an Evidence of Need for Maintenance.	Evidence of Need for Maintenance Operating in Nominal Condition Maintaining PEPDS	5.9 Integrated CBM+	[ref 50] [ref 58]	Analysis		2022.11.15
S1.1.2.1.8	PEPDS shall transition from the Maintaining state to the Operating Nominally state when Maintenance Completed.	Operating in Nominal Condition Maintaining Maintenance Completed PEPDS	5.9 Integrated CBM+	[ref 7]	Analysis		2022.11.15
S1.1.2.1.9	PEPDS shall transition from Maintaining state to Operating Off-Nominally state after getting Repaired.	Maintaining Operating in Off-Nominal Condition Repaired PEPDS	5.9 Integrated CBM+	[ref 50]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.2.1.10	PEPDS shall transition from Operating Off-Nominally state to Maintaining state when there is an Evidence of Need for Repair.	Evidence of Need for Repair Maintaining Operating in Off-Nominal Condition PEPDS	5.9 Integrated CBM+	[ref 7]	Analysis		2022.11.15
S1.1.2.1.11	PEPDS shall have a Performing SHIPALT state for the purpose of installation or removal of PEPDS.	Complete Install | Remove Performing SHIPALT PEPDS	5.1 Ease of Installation as a Unit	[ref 45] [ref 7] [ref 50]	Analysis		2022.11.15
S1.1.2.1.12	PEPDS shall transition to Performing SHIPALT state to Initiate Install | Remove of PEPDS only if in a Shipyard.	Initiate Install | Remove Performing SHIPALT Shipyard PEPDS	5.1 Ease of Installation as a Unit	[ref 7]	Analysis		2022.11.15
S1.1.2.2 Innovative PEPDS Operations							
S1.1.2.2.1	PEPDS shall execute control, carry out protection, distribute power, and manage thermals functions simultaneously.	W2.1 Control PEPDS W2.2 Protect PEPDS W2.3 Distribute Power W2.4 Manage Thermal Load of PEPDS PEPDS	5.13 Integrated Power and Energy Power Distribution System	[ref 50] [ref 52] [ref 58]	Analysis		2022.11.15
S1.1.2.2.2	Shutdown of PEPDS should only be necessary while docked for extensive maintenance or SHIPALT.	Controlled Shutdown Performing SHIPALT Shutdown PEPDS	2.1 Maintainability 1.3 Reliability 5.1 Ease of Installation as a Unit	[ref 7] [ref 45] [ref 50]	Analysis		2022.11.15
S1.1.2.2.3	PEPDS shall be capable of receiving Electrical Power from all power sources simultaneously.	W2.3 Distribute Power Offboard Power Systems Onboard Power Sources Electrical Power PEPDS	5.14 Distributed Power Conversion	[ref 52] [ref 58]	Analysis		2022.11.15
S1.1.2.2.4	PEPDS shall be capable of receiving Electrical Power in any form from any power source.	W2.3 Distribute Power Offboard Power Systems Onboard Power Sources Electrical Power PEPDS	5.14 Distributed Power Conversion	[ref 52] [ref 58]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.2.2.5	PEPDS shall be capable of distributing Electrical Power to all Onboard Power Loads simultaneously.	W2.3 Distribute Power Onboard Power Loads Electrical Power PEPDS	5.14 Distributed Power Conversion	[ref 52] [ref 58]	Analysis		2022.11.16
S1.1.2.2.6	PEPDS shall be capable of distributing Electrical Power conditioned for each individual Onboard Power Load.	W2.3 Distribute Power Onboard Power Loads Electrical Power PEPDS	5.14 Distributed Power Conversion	[ref 52] [ref 58]	Analysis		2022.11.16
S1.1.2.2.7	PEPDS shall receive services from the Electric Ship in order to manage its Environmental Load such as Chilled Water and Forced Air as appropriate for the design.	W2.4 Manage Thermal Load of PEPDS Electric Ship in Use Environmental Management Services Environmental Load PEPDS	3.1 Serial Thermal Management	[ref 40]	Analysis		2022.11.15
S1.1.2.3 PEPDS Innovative Components, Structure, and Interfaces							
S1.1.2.3.1	PEPDS shall be a Navy shipboard power and energy distribution system.	Electric Ship in Use PEPDS	5.13 Integrated Power and Energy Power Distribution System	[ref 52] [ref 58]	Analysis		2022.11.15
S1.1.2.3.2	PEPDS shall minimize the number of unique LRU types.	LRUs PEPDS	5.10 Comprehensive Application of the LRU Approach to the Entire System Design	[ref 50] [ref 58]	Analysis		2022.11.15
S1.1.2.3.3	PEPDS LRUs shall be replaceable onboard, underway, by ship's Crew.	Maintain PEPDS Replace LRUs Crew LRUs PEPDS	5.11 Simplified LRU Replacement	[ref 7]	Analysis		2022.11.15
S1.1.2.3.4	LRUs should be hot swappable (i.e. able to be safely exchanged by personnel while the surrounding equipment is energized)	LRUs	3.6 Hotswappable	[ref 50]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.2.3.5	PEPDS Non-LRUs shall be verifiable as an assembly prior to installation and post installation.	Non-LRUs PEPDS	5.1 Ease of Installation as a Unit	[ref 50]	Analysis		2022.11.15
S1.1.2.3.6	PEPDS Non-LRUs shall be removable as an assembly.	Non-LRUs PEPDS	5.1 Ease of Installation as a Unit	[ref 50]	Analysis		2022.11.15
S1.1.2.3.7	PEPDS Non-LRUs shall be installable as an assembly.	Non-LRUs PEPDS	5.1 Ease of Installation as a Unit	[ref 50]	Analysis		2022.11.15
S1.1.2.3.8	PEPDS Non-LRUs shall be assemblable prior to installation.	Non-LRUs PEPDS	5.1 Ease of Installation as a Unit	[ref 50]	Analysis		2022.11.15
S1.1.2.3.9	PEPDS components shall provide maximum reconfigurability so as to permit changing the function of the assembly of which they are a part.	Non-LRUs LRUs PEPDS	5.6 Functional Control	[ref 50]	Analysis		2022.11.15
S1.1.2.3.10	PEPDS components shall provide maximum re-programmability in order to permit changing their individual functionality.	Program Non-LRUs LRUs PEPDS	5.6 Functional Control	[ref 50]	Analysis		2022.11.15
S1.1.2.3.11	PEPDS shall maximize the tappable locations for Onboard Power Loads.	Onboard Power Loads PEPDS	5.2 Load Interface Design	[ref 44] [ref 50] [ref 52]	Analysis		2022.11.15
S1.1.2.3.12	PEPDS shall maximize the tappable locations for Onboard Power Sources.	Onboard Power Sources PEPDS	5.2 Load Interface Design	[ref 50] [ref 52]	Analysis		2022.11.15
S1.1.2.3.13	PEPDS load interfaces shall maximize possible spatial arrangements while maximizing likelihood of correct connection.	Onboard Power Loads PEPDS	5.2 Load Interface Design	[ref 50] [ref 52]	Analysis		2022.11.15
S1.1.3 PEPDS Performance Metrics							
S1.1.3.1 PEPDS RAM							
S1.1.3.1.1 Availability							
S1.1.3.1.1.1	PEPDS shall maximize Operational Availability	B4.1 RAM MoEs Availability MoPs B4 MoEs	2.1 Maintainability 1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
	achieving a minimum threshold of 0.995.	PEPDS Operational Availability Threshold = 0.995					
S1.1.3.1.1.2	PEPDS should maximize Operational Availability achieving a minimum goal of 1.0.	B4.1 RAM MoEs Availability MoPs B4 MoEs PEPDS Operational Availability Goal = 1.0	2.1 Maintainability 1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.1.3	PEPDS shall maximize Inherent Availability achieving a minimum threshold of TBD.	B4.1 RAM MoEs Availability MoPs B4 MoEs PEPDS Inherent Availability Threshold = TBD	2.1 Maintainability 1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.1.4	PEPDS should maximize Inherent Availability achieving a minimum goal of TBD.	B4.1 RAM MoEs Availability MoPs B4 MoEs PEPDS Inherent Availability Goal = TBD	2.1 Maintainability 1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.1.5	PEPDS shall maximize Achieved Availability achieving a minimum threshold of TBD.	B4.1 RAM MoEs Availability MoPs B4 MoEs PEPDS	2.1 Maintainability 1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.1.6	PEPDS should maximize Achieved Availability achieving a minimum goal of TBD.	B4.1 RAM MoEs Availability MoPs B4 MoEs PEPDS	2.1 Maintainability 1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.2 Maintainability							
S1.1.3.1.2.1	PEPDS shall minimize Maintenance Burden achieving a maximum threshold of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Maintenance Burden Maintenance Burden Threshold = TBD	2.1 Maintainability	[ref 23] [ref 33]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.1.2.2	PEPDS should minimize Maintenance Burden achieving a maximum goal of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Maintenance Burden Maintenance Burden Goal = TBD	2.1 Maintainability	[ref 23] [ref 33]	Analysis		2022.11.15
S1.1.3.1.2.3	PEPDS shall minimize Mean Down Time achieving a maximum threshold of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Mean Down Time Threshold = TBD	2.1 Maintainability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.2.4	PEPDS should minimize Mean Down Time achieving a maximum goal of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Mean Down Time Goal = TBD	2.1 Maintainability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.2.5	PEPDS shall maximize Percent Fault Detection achieving a minimum threshold of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Percent BIT Fault Detection PFD Threshold = TBD	2.1 Maintainability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.2.6	PEPDS should maximize Percent Fault Detection achieving a minimum goal of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Percent BIT Fault Detection PFD Goal = TBD	2.1 Maintainability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.2.7	PEPDS shall maximize Percent Fault Isolation achieving a minimum threshold of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Percent BIT Fault Isolation	2.1 Maintainability	[ref 33]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		PFI Threshold = TBD					
S1.1.3.1.2.8	PEPDS should maximize Percent Fault Isolation achieving a minimum goal of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Percent BIT Fault Isolation PFI Goal = TBD	2.1 Maintainability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.2.9	PEPDS shall maximize Mean Operating Hours Between False Alarms achieving a minimum threshold of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Mean Operating Hours between False Alarm MOHBFA Threshold = TBD	2.1 Maintainability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.2.10	PEPDS should maximize Mean Operating Hours Between False Alarms achieving a minimum goal of TBD.	B4.1 RAM MoEs Maintainability MoPs B4 MoEs PEPDS Mean Operating Hours between False Alarm MOHBFA Goal = TBD	2.1 Maintainability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3 Reliability							
S1.1.3.1.3.1	PEPDS shall maximize MTBF achieving a minimum threshold of 30,000 hours.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Mean Time Between Failure Threshold : ISO80000-3 Space and Time::Quantities::time::time = TBD	1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.1.3.2	PEPDS should maximize MTBF achieving a minimum goal of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Mean Time Between Failure Goal : ISO80000-3 Space and Time::Quantities::time::time = TBD	1.3 Reliability	[ref 33] [ref 35]	Analysis		2022.11.15
S1.1.3.1.3.3	PEPDS shall maximize MTBM achieving a minimum threshold of 7,000 hours.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS	1.3 Reliability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3.4	PEPDS shall maximize MTBM achieving a minimum goal of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS	1.3 Reliability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3.5	PEPDS shall maximize MTBR achieving a minimum threshold of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Mean Time Between Repairs Threshold = TBD	1.3 Reliability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3.6	PEPDS should maximize MTBR achieving a minimum goal of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Mean Time Between Repairs Goal = TBD	1.3 Reliability	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3.7	PEPDS shall maximize Resiliency achieving a minimum threshold of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Resiliency MTBCF Threshold = TBD	1.3 Reliability 1.5 Resiliency	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3.8	PEPDS should maximize Resiliency achieving a minimum goal of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs	1.3 Reliability 1.5 Resiliency	[ref 33]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		PEPDS Resiliency MTBCF Goal = TBD					
S1.1.3.1.3.9	PEPDS shall maximize Power Delivery Reliability achieving a minimum threshold of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Power Delivery Reliability Power Delivery Reliability Threshold = TBD	1.3 Reliability 1.6 UPS	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3.10	PEPDS should maximize Power Delivery Reliability achieving a minimum goal of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Power Delivery Reliability Power Delivery Reliability Goal = TBD	1.3 Reliability 1.6 UPS	[ref 33]	Analysis		2022.11.15
S1.1.3.1.3.11	PEPDS shall maximize Life Expectancy achieving a minimum threshold of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Life Expectancy Life Expectancy Threshold = TBD	2.4 Long Life Expectancy 1.3 Reliability	[ref 33] [ref 37]	Analysis		2022.11.15
S1.1.3.1.3.12	PEPDS should maximize Life Expectancy achieving a minimum goal of TBD.	B4.1 RAM MoEs Reliability MoPs B4 MoEs PEPDS Life Expectancy Life Expectancy Goal = TBD	2.4 Long Life Expectancy 1.3 Reliability	[ref 33] [ref 37]	Analysis		2022.11.15
S1.1.3.2 PEPDS Operability							
S1.1.3.2.1 Power Distribution							

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.2.1.1	PEPDS shall maximize Conversion Efficiency achieving a minimum threshold of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Conversion Efficiency Conversion Efficiency Threshold = TBD	1.1 Power Efficiency	[ref 36]	Analysis		2022.11.15
S1.1.3.2.1.2	PEPDS should maximize Conversion Efficiency achieving a minimum goal of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Conversion Efficiency Conversion Efficiency Goal = TBD	1.1 Power Efficiency	[ref 36]	Analysis		2022.11.15
S1.1.3.2.1.3	PEPDS shall maximize Transmission Efficiency achieving a minimum threshold of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Transmission Efficiency Transmission Efficiency Threshold = TBD	1.1 Power Efficiency	[ref 36]	Analysis		2022.11.15
S1.1.3.2.1.4	PEPDS should maximize Transmission Efficiency achieving a minimum goal of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Transmission Efficiency Transmission Efficiency Goal = TBD	1.1 Power Efficiency	[ref 36]	Analysis		2022.11.15
S1.1.3.2.1.5	PEPDS should maximize Power Density achieving a minimum goal of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Power Density Power Density Goal = TBD	1.2 Power Density	[ref 36]	Analysis		2022.11.15
S1.1.3.2.1.6	PEPDS shall maximize Power Density achieving a minimum threshold of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs	1.2 Power Density	[ref 36]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		PEPDS Power Density Power Density Threshold = TBD					
S1.1.3.2.1.7	PEPDS shall maximize Power Electronic Utilization e.g. to characterize loads and sources, increase reliability, reduce response time (e.g. switching), increase reconfigurability, and enable programming achieving a minimum threshold of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Power Electronic Utilization Power Electronic Utilization Threshold = TBD	5.3 Power Electronic Interfaces 5.12 Minimal Redundant Elements 5.15 Reduce Conventional Switchgear	[ref 50] [ref 52] [ref 58]	Analysis		2022.11.15
S1.1.3.2.1.8	PEPDS should maximize Power Electronic Utilization, e.g. to characterize loads and sources, increase reliability, reduce response time (e.g. switching), increase reconfigurability, and enable programming achieving a minimum goal of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Power Electronic Utilization Power Electronic Utilization Goal = TBD	5.3 Power Electronic Interfaces 5.12 Minimal Redundant Elements 5.15 Reduce Conventional Switchgear	[ref 50] [ref 52] [ref 58]	Analysis		2022.11.15
S1.1.3.2.1.9	PEPDS shall minimize Response Time achieving a maximum threshold of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Response Time Response Time Threshold = TBD	3.3.3 Dynamic Response	[ref 24]	Analysis		2022.11.15
S1.1.3.2.1.10	PEPDS should minimize Response Time achieving a maximum goal of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Response Time Response Time Goal = TBD	3.3.3 Dynamic Response	[ref 24]	Analysis		2022.11.15
S1.1.3.2.1.11	PEPDS shall achieve [TBD] threshold for Specific Energy.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS		[ref 53]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Specific Energy Specific Energy Threshold = TBD					
S1.1.3.2.1.12	PEPDS should achieve [TBD] goal for Specific Energy.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Specific Energy Specific Energy Goal = TBD		[ref 53]	Analysis		2022.11.15
S1.1.3.2.1.13	PEPDS shall minimize Discharge C Rate achieving a maximum threshold of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Discharge C Rate Discharge C Rate Threshold = TBD		[ref 53]	Analysis		2022.11.15
S1.1.3.2.1.14	PEPDS should minimize Discharge C Rate achieving a maximum goal of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Discharge C Rate Discharge C Rate Goal = TBD		[ref 53]	Analysis		2022.11.15
S1.1.3.2.1.15	PEPDS shall minimize Recharge C Rate achieving a maximum threshold of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Recharge C Rate Recharge C Rate Threshold = TBD		[ref 53]	Analysis		2022.11.15
S1.1.3.2.1.16	PEPDS should minimize Recharge C Rate achieving a maximum goal of TBD.	B4.2 Operability MoEs Power Distribution MoPs B4 MoEs PEPDS Recharge C Rate Recharge C Rate Goal = TBD		[ref 53]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.2.2 Adaptability							
S1.1.3.2.2.1	PEPDS shall maximize Robustness achieving a minimum threshold of TBD.	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Robustness Robustness Threshold = TBD	1.4 Robustness	[ref 36]	Analysis		2022.11.15
S1.1.3.2.2.2	PEPDS should maximize Robustness achieving a minimum goal of TBD	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Robustness Robustness Goal = TBD	1.4 Robustness	[ref 36]	Analysis		2022.11.15
S1.1.3.2.2.3	PEPDS shall maximize Application Adaptability achieving a minimum threshold of TBD.	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Application Adaptability Application Adaptability Threshold = TBD	3.6 Hotswappable 5.6 Functional Control 5.7 Adaptive Controls	[ref 50] [ref 58]	Analysis		2022.11.15
S1.1.3.2.2.4	PEPDS should maximize Application Adaptability achieving a minimum goal of TBD.	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Application Adaptability Application Adaptability Goal = TBD	3.6 Hotswappable 5.6 Functional Control 5.7 Adaptive Controls	[ref 50] [ref 58]	Analysis		2022.11.15
S1.1.3.2.2.5	PEPDS shall maximize the number of Applicable Ship Classes for which it is suitable achieving a minimum threshold of TBD.	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Applicable Ship Classes Applicable Ship Classes Threshold = TBD	3.4 Standardizable	[ref 36]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.2.2.6	PEPDS should maximize the number of Applicable Ship Classes for which it is suitable achieving a minimum goal of TBD.	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Applicable Ship Classes Applicable Ship Classes Goal = TBD	3.4 Standardizable	[ref 36]	Analysis		2022.11.15
S1.1.3.2.2.7	PEPDS shall maximize Scalability achieving a minimum threshold of TBD.	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Scalability Scalability Threshold = TBD	3 Scalability	[ref 24]	Analysis		2022.11.15
S1.1.3.2.2.8	PEPDS should maximize Scalability achieving a minimum goal of TBD.	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Scalability Scalability Goal = TBD	3 Scalability	[ref 24]	Analysis		2022.11.15
S1.1.3.2.2.9	PEPDS shall maximize Survivability achieving a minimum threshold of TBD. (e.g., managing casualty power).	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Survivability Survivability Threshold = TBD		[ref 44]	Analysis		2022.11.15
S1.1.3.2.2.10	PEPDS should maximize Survivability achieving a minimum goal of TBD. (e.g., managing casualty power).	B4.2 Operability MoEs Adaptability MoPs B4 MoEs PEPDS Survivability Survivability Goal = TBD		[ref 44]	Analysis		2022.11.15
S1.1.3.2.3 Logistics							

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.2.3.1	PEPDS shall minimize LMS Manning achieving a maximum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS LMS Manning LMS Manning Threshold = TBD	2 Operability 5.11 Simplified LRU Replacement	[ref 38]	Analysis		2022.11.15
S1.1.3.2.3.2	PEPDS should minimize LMS Manning achieving a maximum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS LMS Manning LMS Manning Goal = TBD	2 Operability 5.11 Simplified LRU Replacement	[ref 38]	Analysis		2022.11.15
S1.1.3.2.3.3	PEPDS shall minimize LMS Training achieving a maximum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS LMS Training LMS Training Threshold = TBD	2 Operability 2.2 Operator Trainability 5.11 Simplified LRU Replacement	[ref 38]	Analysis		2022.11.15
S1.1.3.2.3.4	PEPDS should minimize LMS Training achieving a maximum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS LMS Training LMS Training Goal = TBD	2 Operability 2.2 Operator Trainability 5.11 Simplified LRU Replacement	[ref 38]	Analysis		2022.11.15
S1.1.3.2.3.5	PEPDS shall minimize Operator Manning achieving a maximum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Operation Manning Operation Manning Threshold = TBD	2 Operability 5.11 Simplified LRU Replacement	[ref 36]	Analysis		2022.11.15
S1.1.3.2.3.6	PEPDS should minimize Operator Manning achieving a maximum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs	2 Operability 5.11 Simplified LRU Replacement	[ref 36]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		PEPDS Operation Manning Operation Manning Goal = TBD					
S1.1.3.2.3.7	PEPDS shall minimize Operator Training achieving a maximum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Operator Training Operator Training Threshold = TBD	2 Operability 2.2 Operator Trainability 5.11 Simplified LRU Replacement	[ref 36]	Analysis		2022.11.15
S1.1.3.2.3.8	PEPDS should minimize Operator Training achieving a maximum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Operator Training Operator Training Goal = TBD	2 Operability 2.2 Operator Trainability 5.11 Simplified LRU Replacement	[ref 36]	Analysis		2022.11.15
S1.1.3.2.3.9	PEPDS shall minimize Cost for Support achieving a maximum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Cost for Support Cost for Support Threshold = TBD	2 Operability	[ref 38]	Analysis		2022.11.15
S1.1.3.2.3.10	PEPDS should minimize Cost for Support achieving a maximum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Cost for Support Cost for Support Goal = TBD	2 Operability	[ref 38]	Analysis		2022.11.15
S1.1.3.2.3.11	PEPDS shall maximize Effectiveness of Support Capability achieving a minimum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Effectiveness of Support Capability	2 Operability	[ref 38]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Effectiveness of Support Capability Threshold = TBD					
S1.1.3.2.3.12	PEPDS should maximize Effectiveness of Support Capability achieving a minimum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Effectiveness of Support Capability Effectiveness of Support Capability Goal = TBD	2 Operability	[ref 38]	Analysis		2022.11.15
S1.1.3.2.3.13	PEPDS shall minimize its Installation Time achieving a maximum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Installation Time Installation Time Threshold = TBD	2 Operability 5.1 Ease of Installation as a Unit	[ref 44]	Analysis		2022.11.15
S1.1.3.2.3.14	PEPDS should minimize its Installation Time achieving a maximum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Installation Time Installation Time Goal = TBD	2 Operability 5.1 Ease of Installation as a Unit	[ref 44]	Analysis		2022.11.15
S1.1.3.2.3.15	PEPDS shall minimize its Removal Time achieving a maximum threshold of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Removal Time Removal Time Threshold = TBD	2 Operability 5.1 Ease of Installation as a Unit	[ref 44]	Analysis		2022.11.15
S1.1.3.2.3.16	PEPDS should minimize its Removal Time achieving a maximum goal of TBD.	B4.2 Operability MoEs Logistics MoPs B4 MoEs PEPDS Removal Time	2 Operability 5.1 Ease of Installation as a Unit	[ref 44]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Removal Time Goal = TBD					
S1.1.3.2.4 Affordability							
S1.1.3.2.4.1	PEPDS shall minimize Operation Cost achieving a maximum threshold of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Operation Cost Operation Cost Threshold = TBD	3.5 Affordability	[ref 36]	Analysis		2022.11.15
S1.1.3.2.4.2	PEPDS should minimize Operation Cost achieving a maximum goal of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Operation Cost Operation Cost Goal = TBD	3.5 Affordability	[ref 36]	Analysis		2022.11.15
S1.1.3.2.4.3	PEPDS shall minimize Implementation Cost achieving a maximum threshold of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Implementation Cost Implementation Cost Threshold = TBD	3.5 Affordability	[ref 36]	Analysis		2022.11.15
S1.1.3.2.4.4	PEPDS should minimize Implementation Cost achieving a maximum goal of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Implementation Cost Implementation Cost Goal = TBD	3.5 Affordability	[ref 36]	Analysis		2022.11.15
S1.1.3.2.4.5	PEPDS shall minimize Installation Cost achieving a maximum threshold of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Installation Cost	3.5 Affordability 5.1 Ease of Installation as a Unit	[ref 44] [ref 50]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Installation Cost Threshold = TBD					
S1.1.3.2.4.6	PEPDS should minimize Installation Cost achieving a maximum goal of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Installation Cost Installation Cost Goal = TBD	3.5 Affordability 5.1 Ease of Installation as a Unit	[ref 44] [ref 50]	Analysis		2022.11.15
S1.1.3.2.4.7	PEPDS shall minimize Removal Cost achieving a maximum threshold of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Removal Cost Removal Cost Threshold = TBD	3.5 Affordability 5.1 Ease of Installation as a Unit	[ref 44] [ref 50]	Analysis		2022.11.15
S1.1.3.2.4.8	PEPDS should minimize Removal Cost achieving a maximum goal of TBD.	B4.2 Operability MoEs Affordability MoPs B4 MoEs PEPDS Removal Cost Removal Cost Goal = TBD	3.5 Affordability 5.1 Ease of Installation as a Unit	[ref 44] [ref 50]	Analysis		2022.11.15
S1.1.3.2.5 Quality of Service							
S1.1.3.2.5.1	PEPDS shall minimize Mean Time to Resolve Service Interruption achieving a maximum threshold of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Mean Time to Resolve Service Interruption Mean Time to Resolve Service Interruption Threshold = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.2	PEPDS should minimize Mean Time to Resolve Service	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs		[ref 39]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
	Interruption achieving a maximum goal of TBD.	PEPDS Mean Time to Resolve Service Interruption Mean Time to Resolve Service Interruption Goal = TBD					
S1.1.3.2.5.3	PEPDS shall minimize Mean Time to Resolve Service Interruption for Un-Interruptible Load achieving a maximum threshold of 2 sec.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Mean Time to Resolve Service Interruption of Un-Interruptible Load Mean Time to Resolve Service Interruption Threshold = 2 sec		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.4	PEPDS should minimize Mean Time to Resolve Service Interruption for Un-Interruptible Load achieving a maximum goal of 10msec.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Mean Time to Resolve Service Interruption of Un-Interruptible Load Mean Time to Resolve Service Interruption Goal = 10 msec		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.5	PEPDS shall minimize Mean Time to Resolve Service Interruption for Short Term Interrupt Load achieving a maximum threshold of 5 min.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Mean Time to Resolve Service Interruption of Short-Term Interrupt Load Mean Time to Resolve Service Interruption of Short-Term Interrupt Load Threshold = 5 min		[ref 39]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.2.5.6	PEPDS should minimize Mean Time to Resolve Service Interruption for Short Term Interrupt Load achieving a maximum goal of 2 sec.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Mean Time to Resolve Service Interruption of Short-Term Interrupt Load Mean Time to Resolve Service Interruption of Short-Term Interrupt Load Goal = 2 sec		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.7	PEPDS shall minimize Mean Time to Resolve Service Interruption for Long Term Interrupt Load achieving a maximum threshold of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Mean Time to Resolve Service Interruption of Long-Term Interrupt Load Mean Time to Resolve Service Interruption of Long-Term Interrupt Load Threshold = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.8	PEPDS should minimize Mean Time to Resolve Service Interruption for Long Term Interrupt Load achieving a maximum goal of 5 min.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Mean Time to Resolve Service Interruption of Long-Term Interrupt Load Mean Time to Resolve Service Interruption of Long-Term Interrupt Load Goal = 5 min		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.9	PEPDS shall maximize Survival Service Time achieving a minimum threshold of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Survival Service Time		[ref 39]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Survival Service Time Threshold = TBD					
S1.1.3.2.5.10	PEPDS should maximize Survival Service Time achieving a minimum goal of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Survival Service Time Survival Service Time Goal = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.11	PEPDS shall maximize Survival Service Time for Un-Interruptible Load achieving a minimum threshold of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Survival Service Time for Un-Interruptible Load Survival Service Time for Un-Interruptible Load Threshold = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.12	PEPDS should maximize Survival Service Time for Un-Interruptible Load achieving a minimum goal of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Survival Service Time for Un-Interruptible Load Survival Service Time for Un-Interruptible Load Goal = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.13	PEPDS shall maximize Survival Service Time for Short Term Load achieving a minimum threshold of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Survival Service Time for Short Term Interrupt Load Survival Service Time for Short Term Interrupt Load Threshold = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.14	PEPDS should maximize Survival Service Time for Short	B4.2 Operability MoEs Quality of Service MoPs		[ref 39]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
	Term Load achieving a minimum goal of TBD.	B4 MoEs PEPDS Survival Service Time for Short Term Interrupt Load Survival Service Time for Short Term Interrupt Load Goal = TBD					
S1.1.3.2.5.15	PEPDS shall maximize Survival Service Time for Long Term Load achieving a minimum threshold of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Survival Service Time for Long Term Interrupt Load Survival Service Time for Long Term Interrupt Load Threshold = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.2.5.16	PEPDS should maximize Survival Service Time for Long Term Load achieving a minimum goal of TBD.	B4.2 Operability MoEs Quality of Service MoPs B4 MoEs PEPDS Survival Service Time for Long Term Interrupt Load Survival Service Time for Long Term Interrupt Load Goal = TBD		[ref 39]	Analysis		2022.11.15
S1.1.3.3 PEPDS Safety							
S1.1.3.3.1 Personnel Safety							
S1.1.3.3.1.1	PEPDS shall minimize LRU s Liftability achieving a maximum threshold of TBD.	Crew LRUs B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS LRU s Liftability LRU s Liftability Threshold = TBD	2.3 Safety 2.3.2 Liftable 5.11 Simplified LRU Replacement	[ref 50]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.3.1.2	PEPDS should minimize LRU s Liftability achieving a maximum goal of TBD.	Crew LRUs B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS LRU s Liftability LRU s Liftability Goal = TBD	2.3 Safety 2.3.2 Liftable 5.11 Simplified LRU Replacement	[ref 50]	Analysis		2022.11.15
S1.1.3.3.1.3	PEPDS shall maximize LRU s Transportability achieving a minimum threshold of TBD.	Crew LRUs B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS LRU s Transportability LRU s Transportability Threshold = TBD	2.3 Safety 2.3.2 Liftable 5.11 Simplified LRU Replacement	[ref 50]	Analysis		2022.11.15
S1.1.3.3.1.4	PEPDS should maximize LRU s Transportability achieving a minimum goal of TBD.	Crew LRUs B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS LRU s Transportability LRU s Transportability Goal = TBD	2.3 Safety 2.3.2 Liftable 5.11 Simplified LRU Replacement	[ref 50]	Analysis		2022.11.15
S1.1.3.3.1.5	PEPDS shall maximize Thermal Safety achieving a minimum threshold of TBD.	B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS Thermal Safety Thermal Safety Threshold = TBD	2.3 Safety 2.3.1 Thermally Touchable 3.1 Serial Thermal Management	[ref 24]	Analysis		2022.11.15
S1.1.3.3.1.6	PEPDS should maximize Thermal Safety achieving a minimum goal of TBD.	B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS	2.3 Safety 2.3.1 Thermally Touchable 3.1 Serial Thermal Management	[ref 24]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Thermal Safety Thermal Safety Goal = TBD					
S1.1.3.3.1.7	PEPDS shall maximize Electrical Safety achieving a minimum threshold of TBD.	B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS Electrical Safety Electrical Safety Threshold = TBD	2.3 Safety 2.3.3 Electrically Insulated	[ref 36]	Analysis		2022.11.15
S1.1.3.3.1.8	PEPDS should maximize Electrical Safety achieving a minimum goal of TBD.	B4.3 Safety MoEs Personnel Safety MoPs B4 MoEs PEPDS Electrical Safety Electrical Safety Goal = TBD	2.3 Safety 2.3.3 Electrically Insulated	[ref 36]	Analysis		2022.11.15
S1.1.3.3.2 System Safety							
S1.1.3.3.2.1	PEPDS shall maximize Tolerance to Environmental Loads achieving a minimum threshold of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Tolerance to Environmental Loads Tolerance to Environmental Loads Threshold = TBD	3.1 Serial Thermal Management	[ref 24]	Analysis		2022.11.15
S1.1.3.3.2.2	PEPDS should maximize Tolerance to Environmental Loads achieving a minimum goal of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Tolerance to Environmental Loads Tolerance to Environmental Loads Goal = TBD	3.1 Serial Thermal Management	[ref 24]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.1.3.3.2.3	PEPDS shall minimize Mean Time to Detect Cybersecurity Intrusion achieving a maximum threshold of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Mean Time to Detect Cybersecurity Intrusion CyberMTTD Threshold = TBD	3.3.2 Cyber Security 5.8 Automated Self-check	[ref 50]	Analysis		2022.11.15
S1.1.3.3.2.4	PEPDS should minimize Mean Time to Detect Cybersecurity Intrusion achieving a maximum goal of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Mean Time to Detect Cybersecurity Intrusion CyberMTTD Goal = TBD	3.3.2 Cyber Security 5.8 Automated Self-check	[ref 50]	Analysis		2022.11.15
S1.1.3.3.2.5	PEPDS shall minimize Mean Time to Resolve Cybersecurity Intrusion achieving a maximum threshold of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Mean Time to Resolve Cybersecurity Intrusion CyberMTTR Threshold = TBD	3.3.2 Cyber Security	[ref 24]	Analysis		2022.11.15
S1.1.3.3.2.6	PEPDS should minimize Mean Time to Resolve Cybersecurity Intrusion achieving a maximum goal of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Mean Time to Resolve Cybersecurity Intrusion CyberMTTR Goal = TBD	3.3.2 Cyber Security	[ref 24]	Analysis		2022.11.15
S1.1.3.3.2.7	PEPDS shall minimize Mean Time to Contain Cybersecurity Intrusion achieving a maximum threshold of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Mean Time to Contain Cybersecurity Intrusion	3.3.2 Cyber Security	[ref 24]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		CyberMTTC Threshold = TBD					
S1.1.3.3.2.8	PEPDS should minimize Mean Time to Contain Cybersecurity Intrusion achieving a maximum goal of TBD.	B4.3 Safety MoEs B4 MoEs System Safety MoPs PEPDS Mean Time to Contain Cybersecurity Intrusion CyberMTTC Goal = TBD	3.3.2 Cyber Security	[ref 24]	Analysis		2022.11.15
S1.2 Capability Requirements							
S1.2.1 Control Capability Requirements							
S1.2.1.1 Control Capability Generic Requirements							
S1.2.1.1.1	The Control Capability shall control capabilities through Commands based on the Control Strategy.	W2.1 Control PEPDS W2.1.2 Control PEPDS Capabilities Issue Prioritized Commands Map Control Strategy onto PEPDS Actions Control Strategy Commands Control Capability		[ref 52]	Analysis		2022.11.15
S1.2.1.1.2	The Control Capability shall send Feedback with PEPDS status to Ship Control and the Crew.	W2.1 Control PEPDS W2.1.1 Control Information Report on PEPDS Crew Ship Control Feedback Control Capability PEPDS		[ref 52]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.2.1.1.3	PEPDS Feedback shall provide a projection of intended automatic choices to the Crew.	W2.1 Control PEPDS W2.1.1 Control Information Report on PEPDS Crew Feedback PEPDS		[ref 52] [ref 54]	Analysis		2022.11.15
S1.2.1.2 Control Capability Innovative Requirements							
S1.2.1.2.3	The Control Capability shall analyze capability needs based on capability Feedback to Determine Course of Action.	W2.1 Control PEPDS W2.1.1 Control Information Analyze Capability Needs Determine Course of Action Feedback Control Capability	5.7 Adaptive Controls	[ref 52]	Analysis		2022.11.15
S1.2.1.2.4	The Control Capability shall Determine Course of Action based on the Control Strategy, Commands from Ship Control and Crew, analysis of capability needs, power source supply, and power load demand.	W2.1 Control PEPDS W2.1.1 Control Information Analyze Capability Needs Analyze Power Source Supply Analyze Power Load Demands Determine Course of Action Crew Onboard Power Sources Offboard Power Systems Onboard Power Loads Ship Control Control Strategy Commands Feedback Control Capability PEPDS	5.7 Adaptive Controls	[ref 52]	Analysis		2022.11.15
S1.2.1.2.1	The Control Capability's course of action shall be any independent or coordinated use of PEPDS Capabilities.	W2.1 Control PEPDS W2.1.1 Control Information Determine Course of Action W2.1.2 Control PEPDS Capabilities	5.5 Integrated Control	[ref 48] [ref 47]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		PEPDS Control Capability					
S1.2.1.2.6	The Control Capability shall analyze power load needs based on power load Characterization and the Control Strategy.	W2.1 Control PEPDS W2.1.1 Control Information Analyze Power Load Demands Characterization Control Strategy Control Capability	5.7 Adaptive Controls	[ref 52] [ref 58]	Analysis		2022.11.15
S1.2.1.2.5	The Control Capability shall update the Control Strategy based on Crew Commands, Ship Control Commands, analyzing Capability Needs, power source supply, and power load demand.	W2.1 Control PEPDS W2.1.1 Control Information Analyze Capability Needs Analyze Power Source Supply Analyze Power Load Demands Update Control Strategy Crew Onboard Power Sources Offboard Power Systems Onboard Power Loads Ship Control Control Strategy Commands Control Capability	5.7 Adaptive Controls	[ref 52] [ref 58]	Analysis		2022.11.15
S1.2.1.2.2	The Control Capability shall Issue Prioritized Commands to the capabilities.	W2.1 Control PEPDS W2.1.2 Control PEPDS Capabilities Issue Prioritized Commands Commands Control Capability	5.5 Integrated Control	[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.1.2.7	The Control Capability shall ensure system stability during normal operations while meeting all demands for Electrical Power.	W2.1 Control PEPDS Electric Systems Electrical Power Control Capability	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15
S1.2.1.2.8	The Control Capability shall direct PEPDS operations to ensure system stability by accommodating pulse loads.	W2.1 Control PEPDS Offboard Power Systems Onboard Power Loads Control Capability PEPDS	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.2.1.2.9	The Control Capability shall direct PEPDS operations to ensure system stability by accommodating mismatched loads.	W2.1 Control PEPDS Offboard Power Systems Onboard Power Loads Control Capability PEPDS	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15
S1.2.1.2.10	The Control Capability shall direct PEPDS operations to ensure system stability by accommodating stochastic loads.	W2.1 Control PEPDS Offboard Power Systems Onboard Power Loads Control Capability PEPDS	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15
S1.2.1.2.11	The Control Capability shall direct PEPDS operations to ensure system stability by accommodating large loads.	W2.1 Control PEPDS Offboard Power Systems Onboard Power Loads Control Capability PEPDS	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15
S1.2.1.2.12	The Control Capability shall direct PEPDS operations to ensure system stability while servicing and shedding loads.	W2.1 Control PEPDS W2.1.2 Control PEPDS Capabilities Command Service Loads Command Shed Loads Offboard Power Systems Onboard Power Loads Control Capability PEPDS	5.7 Adaptive Controls 5.2 Load Interface Design	[ref 52]	Analysis		2022.11.15
S1.2.1.2.13	The Control Capability shall direct PEPDS operations to ensure system stability while accessing and de-accessing sources.	W2.1 Control PEPDS W2.1.2 Control PEPDS Capabilities Command Access Source Power Command De-access Source Power Offboard Power Systems Onboard Power Sources Control Capability PEPDS	5.7 Adaptive Controls	[ref 52]	Analysis		2022.11.15
S1.2.1.2.15	The Control Capability shall direct PEPDS operations to ensure system stability by	W2.1 Control PEPDS Offboard Power Systems Onboard Power Sources	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
	accommodating startup surge power.	Control Capability PEPDS Electrical Power					
S1.2.1.2.14	The Control Capability shall direct PEPDS operations to ensure system stability by accommodating mismatched sources.	W2.1 Control PEPDS Offboard Power Systems Onboard Power Sources Control Capability PEPDS	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15
S1.2.1.2.16	The Control Capability shall direct PEPDS operations to ensure system stability according to priorities from an assessment of PEPDS state and Crew Commands.	Crew Control Capability PEPDS Feedback Commands	5.7 Adaptive Controls	[ref 51]	Analysis		2022.11.15
S1.2.1.2.17	The Control Capability shall be able to Program Communication Networks.	W2.1 Control PEPDS W2.1.1 Control Information Program Communication Networks Control Capability	5.6 Functional Control	[ref 50]	Analysis		2022.11.15
S1.2.1.2.18	The Control Capability shall be able to Program Power Networks.	W2.1 Control PEPDS W2.1.1 Control Information Program Power Networks Control Capability	5.6 Functional Control	[ref 50]	Analysis		2022.11.15
S1.2.1.2.19	The Control Capability shall be able to Program PEPDS components.	W2.1 Control PEPDS W2.1.1 Control Information Program PEPDS Components Control Capability	5.6 Functional Control	[ref 50]	Analysis		2022.11.15
S1.2.1.2.20	The Control Capability shall provide an assessment of the impact of programming communication networks, power networks, and PEPDS components based on the Control Strategy in its Feedback.	W2.1 Control PEPDS W2.1.1 Control Information Assess Impact Program PEPDS Components Program Power Networks Program Communication Networks Control Capability PEPDS Feedback Control Strategy	5.8 Automated Self-check 5.6 Functional Control	[ref 50]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.2.1.2.21	The Control Capability shall Capture and Store Data to be used in analysis for CBM+.	W2.1 Control PEPDS W2.1.1 Control Information Capture Data Store Data Control Capability	5.9 Integrated CBM+	[ref 48] [ref 47]	Analysis		2022.11.15
S1.2.1.2.22	The Control Capability shall Transmit Data to support external CBM+ activities.	W2.1 Control PEPDS W2.1.1 Control Information Transmit Data Control Capability	5.9 Integrated CBM+	[ref 48] [ref 47]	Analysis		2022.11.15
S1.2.1.2.23	The Control Capability shall Perform CBM+ analysis as instructed by the Control Strategy.	W2.1 Control PEPDS W2.1.1 Control Information Perform CBM+ Analysis Control Capability Control Strategy	5.9 Integrated CBM+	[ref 48] [ref 47]	Analysis		2022.11.15
S1.2.1.2.24	The Control Capability shall implement change to the Maintenance Strategy based on data analysis, Ship Control Maintenance Strategy, and PEPDS Control Strategy.	W2.1 Control PEPDS W2.1.1 Control Information Perform CBM+ Analysis Control Capability PEPDS Ship Control Control Strategy Commands	5.9 Integrated CBM+	[ref 48] [ref 47]	Analysis		2022.11.15
S1.2.1.2.25	The Control Capability shall execute self-learning by tracking and improving based on the Control Capability operations, Control Strategy, Feedback from PEPDS capabilities and Commands form Crew and Ship Control.	W2.1 Control PEPDS W2.1.1 Control Information Track and Improve Control Capability PEPDS Ship Control Crew Control Strategy Commands Feedback	5.9 Integrated CBM+ 5.4 Self Learning	[ref 48] [ref 47]	Analysis		2022.11.15
S1.2.1.2.26	The Control Capability should be capable of self-learning in order to improve PEPDS performance over time.	W2.1 Control PEPDS W2.1.1 Control Information Control Capability PEPDS	5.4 Self Learning	[ref 48] [ref 47]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
S1.2.2 Protection Capability Requirements							
S1.2.2.2 Protection Capability Innovative Requirements							
S1.2.2.2.1	The Protection Capability shall provide the Control Capability Feedback enabling protection related Commands.	W2.2 Protect PEPDS Send(context Protection Capability) Feedback Commands Control Capability Protection Capability	5.13 Integrated Power and Energy Power Distribution System 5.5 Integrated Control 5.7 Adaptive Controls	[ref 52]	Analysis		2022.11.15
S1.2.2.2.2	The Protection Capability shall Analyze Source and Load Interfaces Characteristics in order to detect incipient failures.	W2.2 Protect PEPDS Analyze Power Source and Load Interface Characteristics(context Protection Capability) Failure PEPDS Protection Capability	5.13 Integrated Power and Energy Power Distribution System	[ref 50]	Analysis		2022.11.15
S1.2.2.2.3	The Protection Capability shall Analyze PEPDS Performance in order to detect incipient failures.	W2.2 Protect PEPDS Analyze PEPDS Performance(context Protection Capability) Failure PEPDS Protection Capability	5.13 Integrated Power and Energy Power Distribution System	[ref 50] [ref 58]	Analysis		2022.11.15
S1.2.2.2.4	The Protection Capability shall Determine Operational Needs for Safety, Performance, and Resilience based on the Control Strategy and Commands from the Control Capability.	W2.2 Protect PEPDS Determine Operational Needs for Safety, Performance, and Resilience(context Protection Capability) Control Strategy Commands	5.13 Integrated Power and Energy Power Distribution System 5.5 Integrated Control 5.7 Adaptive Controls	[ref 52]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Control Capability Protection Capability					
S1.2.2.2.5	The Protection Capability shall perform accurate diagnosis and prognosis when a failure event occurs.	W2.2 Protect PEPDS Perform Prognosis(context Protection Capability) Perform Diagnosis(context Protection Capability) Failure Protection Capability	5.13 Integrated Power and Energy Power Distribution System 5.9 Integrated CBM+	[ref 50]	Analysis		2022.11.15
S1.2.2.2.6	The Protection Capability shall Select Protection Response based on the diagnosis and prognosis of the failure event and the need for system safety, performance, and resiliency.	W2.2 Protect PEPDS Select Protection Response(context Protection Capability) Perform Prognosis(context Protection Capability) Perform Diagnosis(context Protection Capability) Determine Operational Needs for Safety, Performance, and Resilience(context Protection Capability) Failure Protection Capability	5.13 Integrated Power and Energy Power Distribution System 5.5 Integrated Control 5.7 Adaptive Controls	[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3 Electrical Distribution Capability Requirements							
S1.2.3.1 Electrical Distribution Capability Generic Requirements							
S1.2.3.1.1	The Power Conversion Capability shall Convert Electrical Power based on Commands from the Control Capability.	W2.3 Distribute Power Convert Electrical Power Commands Electrical Distribution		[ref 50] [ref 52]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Capability Control Capability Power Conversion Capability					
S1.2.3.1.3	The Power Conversion Capability shall send Electrical Power to the Power Transportation Capability as appropriate.	W2.3 Distribute Power Electrical Power Electrical Distribution Capability Power Transportation Capability Power Conversion Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.6	The Power Conversion Capability shall receive Electrical Power from the Power Transportation Capability as appropriate.	W2.3 Distribute Power Electrical Power Electrical Distribution Capability Power Transportation Capability Power Conversion Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.9	The Power Conversion Capability shall receive Electrical Power from the Energy Storage Capability as appropriate.	W2.3 Distribute Power Electrical Power Electrical Distribution Capability Energy Storage Capability Power Conversion Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.10	The Power Conversion Capability shall send Feedback to the Control Capability.	W2.3 Distribute Power Feedback Electrical Distribution Capability Control Capability Power Conversion Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.11	The Power Conversion Capability shall send Electrical Power to the Energy Storage Capability as appropriate.	W2.3 Distribute Power Electrical Power Electrical Distribution Capability Power Conversion Capability Energy Storage Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.4	The Power Transportation Capability shall Transport Electrical Power based on	W2.3 Distribute Power Transport Electrical Power		[ref 50] [ref 52]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
	Commands from the Control Capability.	Commands Electrical Distribution Capability Control Capability Power Transportation Capability					
S1.2.3.1.7	The Power Transportation Capability shall send Feedback to the Control Capability.	W2.3 Distribute Power Feedback Electrical Distribution Capability Control Capability Power Transportation Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.2	The Energy Storage Capability shall Store Electrical Power received from the Power Conversion Capability based on Commands by the Control Capability.	W2.3 Distribute Power Store Electrical Power Commands Electrical Distribution Capability Control Capability Power Conversion Capability Energy Storage Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.5	The Energy Storage Capability shall discharge Electrical Power to the Power Conversion Capability based on Commands by the Control Capability.	W2.3 Distribute Power Electrical Power Commands Electrical Distribution Capability Control Capability Energy Storage Capability Power Conversion Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.1.8	The Energy Storage Capability shall send Feedback to the Control Capability.	W2.3 Distribute Power Feedback Electrical Distribution Capability Control Capability Energy Storage Capability		[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.3.2 Electrical							

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
Distribution Capability Innovative Requirements							
S1.2.3.2.2	The Power Conversion Capability shall Convert source Electrical Power in order to service loads from dc to dc, dc to ac, ac to dc, ac to ac at various voltages and frequencies.	W2.3 Distribute Power Convert Onboard Power Sources Offboard Power Systems Onboard Power Loads Electrical Power Electrical Distribution Capability Power Conversion Capability	5.14 Distributed Power Conversion	[ref 51]	Analysis		2022.11.15
S1.2.3.2.1	The Power Transportation Capability shall Transport Electrical Power from sources to loads, either of which may be onboard or offboard the Electric Ship.	W2.3 Distribute Power Transport Onboard Power Sources Offboard Power Systems Onboard Power Loads Electrical Power Power Transportation Capability Electrical Distribution Capability	5.2 Load Interface Design	[ref 50] [ref 52]	Analysis		2022.11.15
S1.2.4 Thermal Management Capability Requirements							
S1.2.4.1 Thermal Management Capability Generic Requirements							
S1.2.4.1.1	The Thermal Management Capability should regulate the thermal load of PEPDS capabilities to minimize the Environmental Load on PEPDS.	W2.4 Manage Thermal Load of PEPDS Regulate PEPDS Internal Thermal Load to Facilitate PEPDS Continuing Operations Environmental Load	3.1 Serial Thermal Management	[ref 11]	Analysis		2022.11.16

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		PEPDS Thermal Management Capability					
S1.2.4.1.2	The Thermal Management Capability shall regulate the thermal load of PEPDS capabilities to protect Crew.	W2.4 Manage Thermal Load of PEPDS Regulate PEPDS Internal Thermal Load to Facilitate PEPDS Continuing Operations Crew Environmental Load Personnel Safety MoPs PEPDS Thermal Management Capability	3.1 Serial Thermal Management	[ref 11] [ref 52]	Analysis		2022.11.15
S1.2.4.1.3	The Thermal Management Capability shall regulate the thermal load of PEPDS capabilities as necessary to maintain operations.	W2.4 Manage Thermal Load of PEPDS Regulate PEPDS Internal Thermal Load to Facilitate PEPDS Continuing Operations Environmental Load PEPDS Thermal Management Capability	3.1 Serial Thermal Management	[ref 11]	Analysis		2022.11.15
S1.2.4.1.5	The Thermal Management Capability shall regulate the thermal loads of PEPDS capabilities in accordance with the Commands from the Control Capability.	W2.4 Manage Thermal Load of PEPDS Regulate PEPDS Internal Thermal Load to Facilitate PEPDS Continuing Operations Environmental Load Commands PEPDS Control Capability Thermal Management Capability	3.1 Serial Thermal Management	[ref 11]	Analysis		2022.11.16
S1.2.4.1.6	The Thermal Management Capability shall send Feedback to the Control Capability.	W2.4 Manage Thermal Load of PEPDS Feedback Control Capability	3.1 Serial Thermal Management	[ref 11]	Analysis		2022.11.15

Name	Text	Refines	Derived From	Source	Verify Method	Risk	Revision Date
		Thermal Management Capability					
S1.2.4.2 Thermal Management Capability Innovative Requirements							
S1.2.4.2.1	The Thermal Management Capability should utilize the Electric Ship's environmental services to regulate the thermal load of PEPDS capabilities.	W2.4 Manage Thermal Load of PEPDS Regulate PEPDS Internal Thermal Load to Facilitate PEPDS Continuing Operations Environmental Management Services Environmental Load Thermal Management Capability	3.1 Serial Thermal Management	[ref 14]	Analysis		2022.11.15

11.2.3.6 S3 System Structure Solution Exploration

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

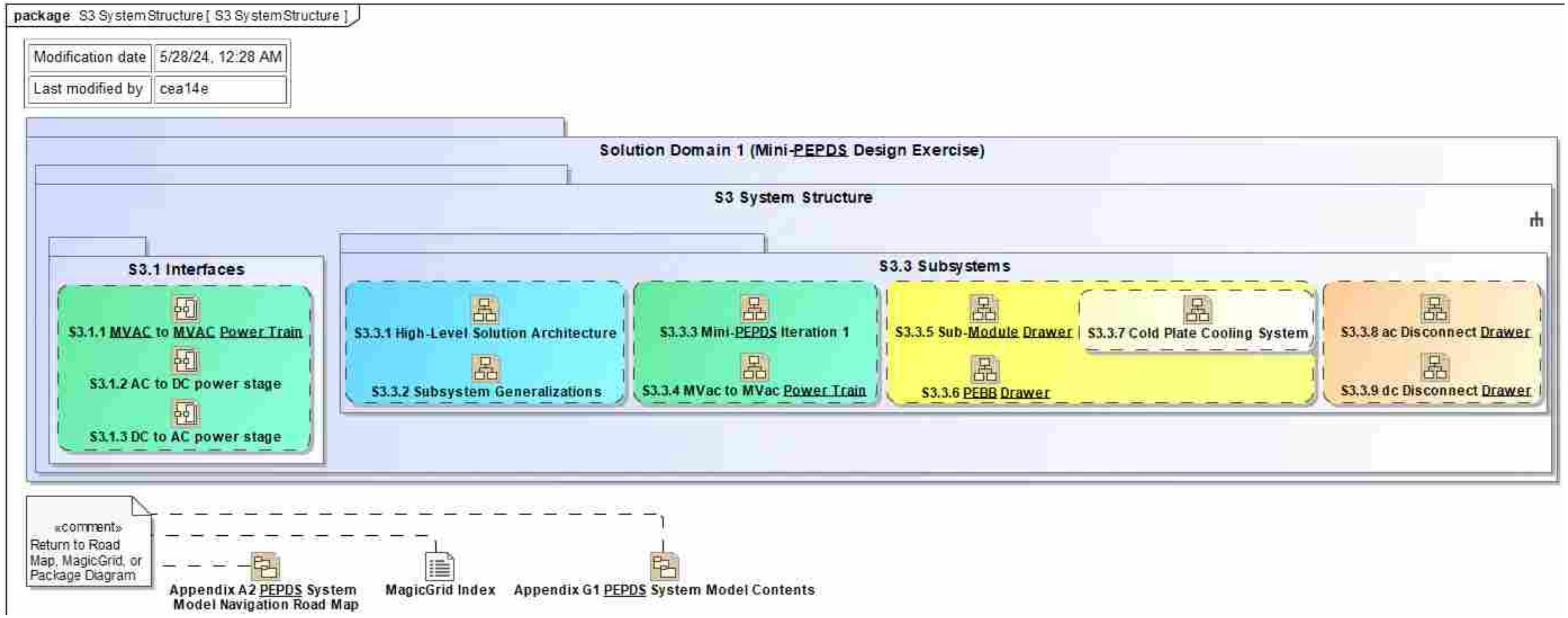


Fig. 72: S3 System Structure

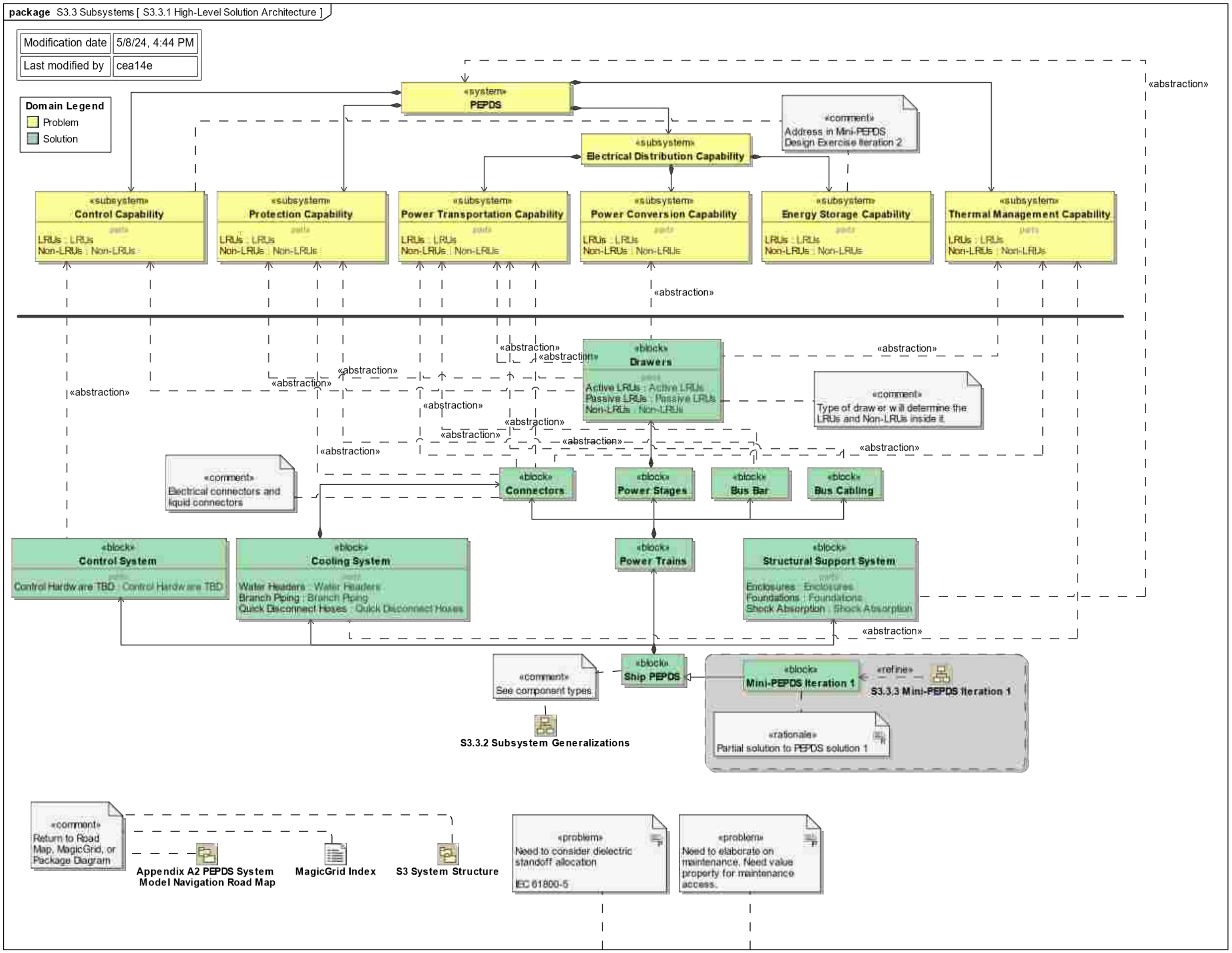


Fig. 73: S3.1.1 MVAC to MVAC Power Train

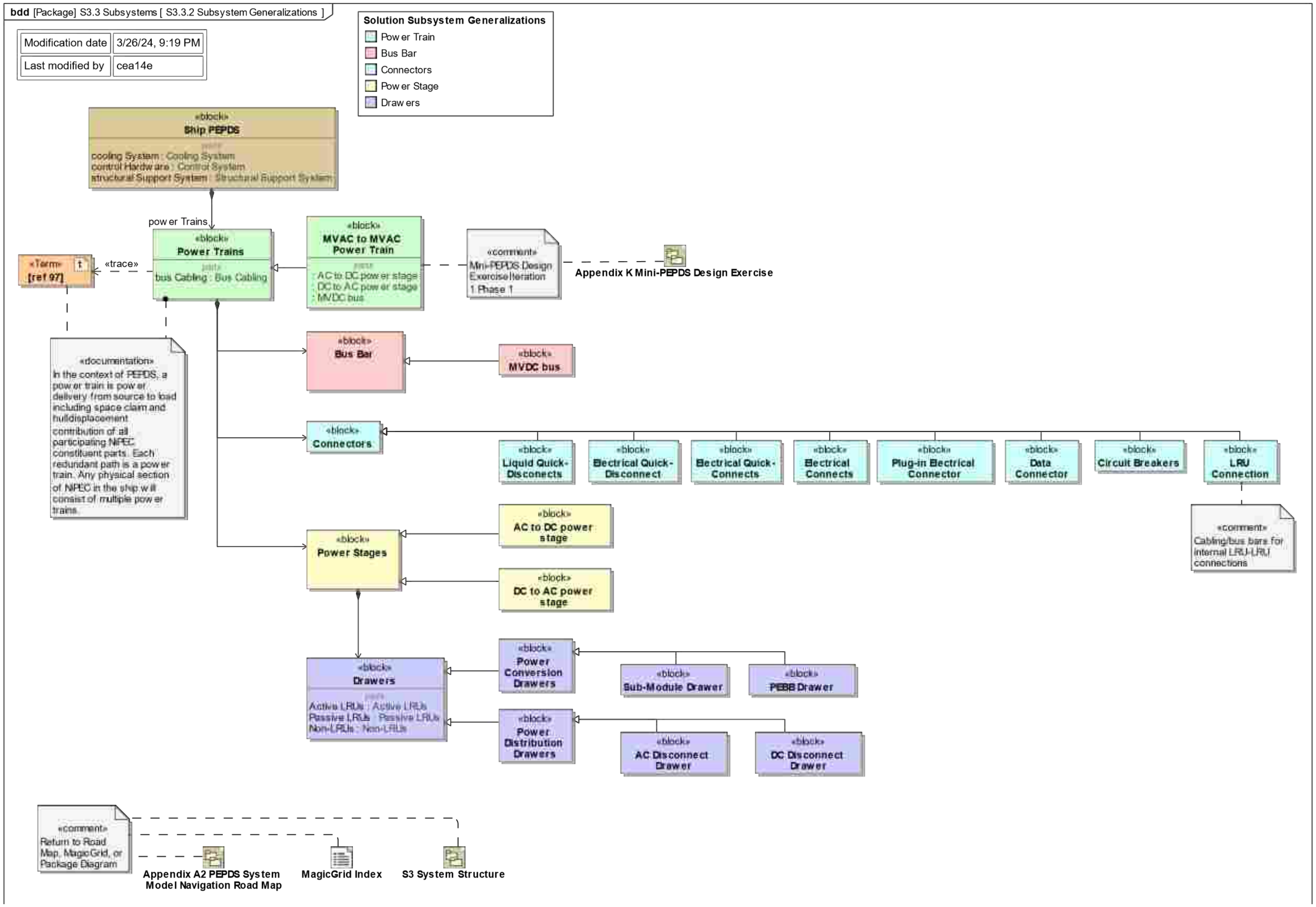


Fig. 74: S3.3.2 Subsystem Generalizations

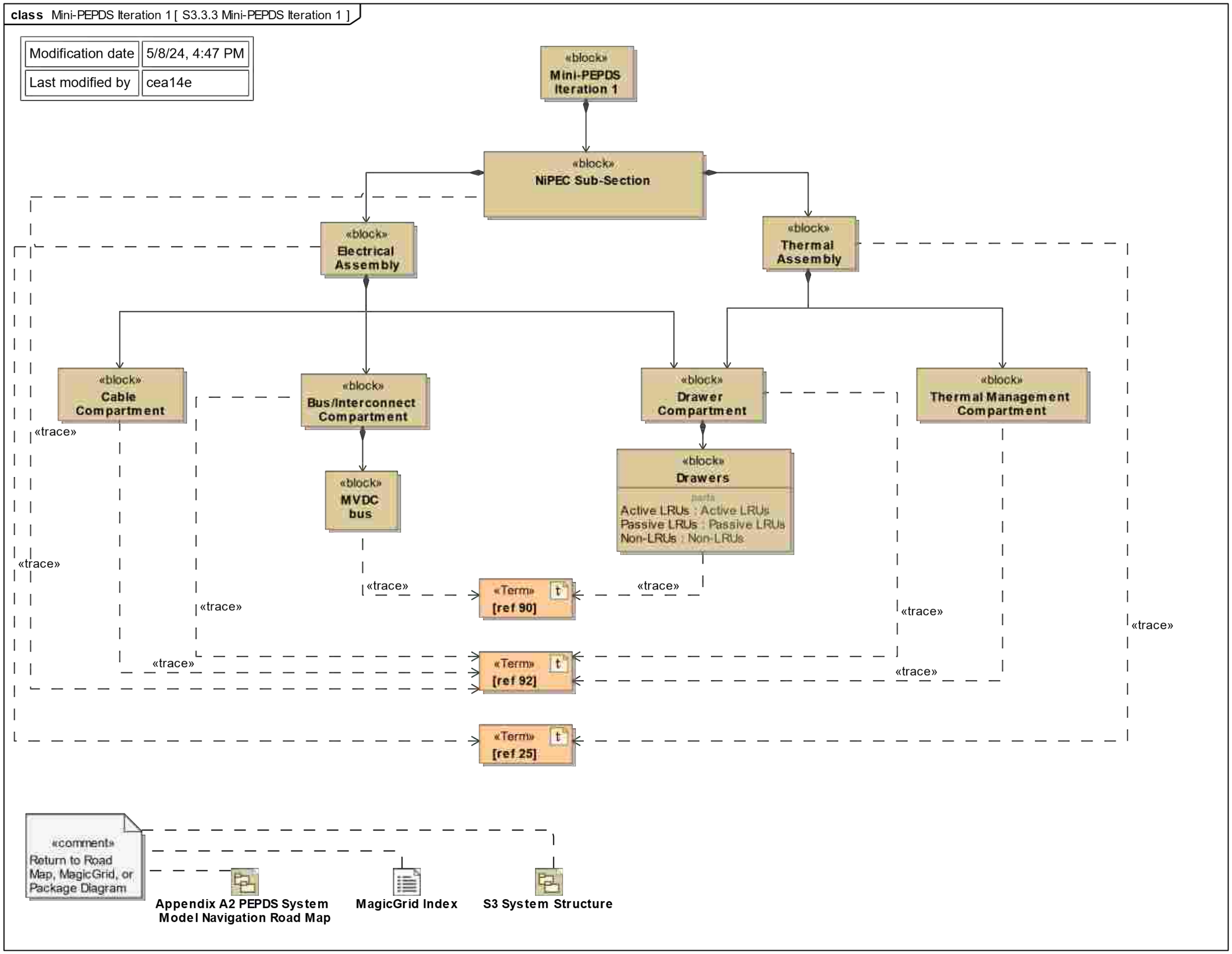


Fig. 75: S3.3.3 Mini-PEPDS Iteration 1

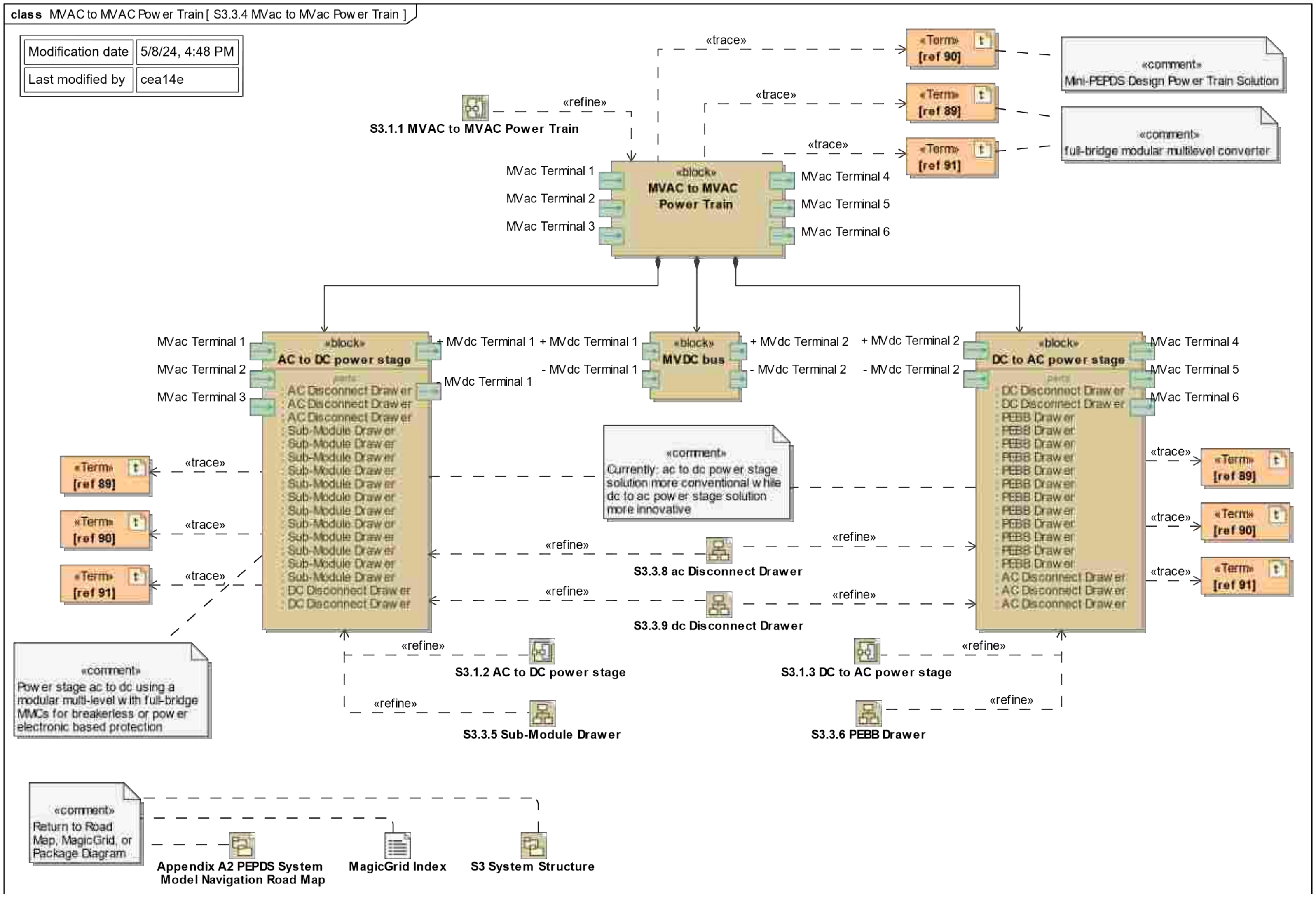
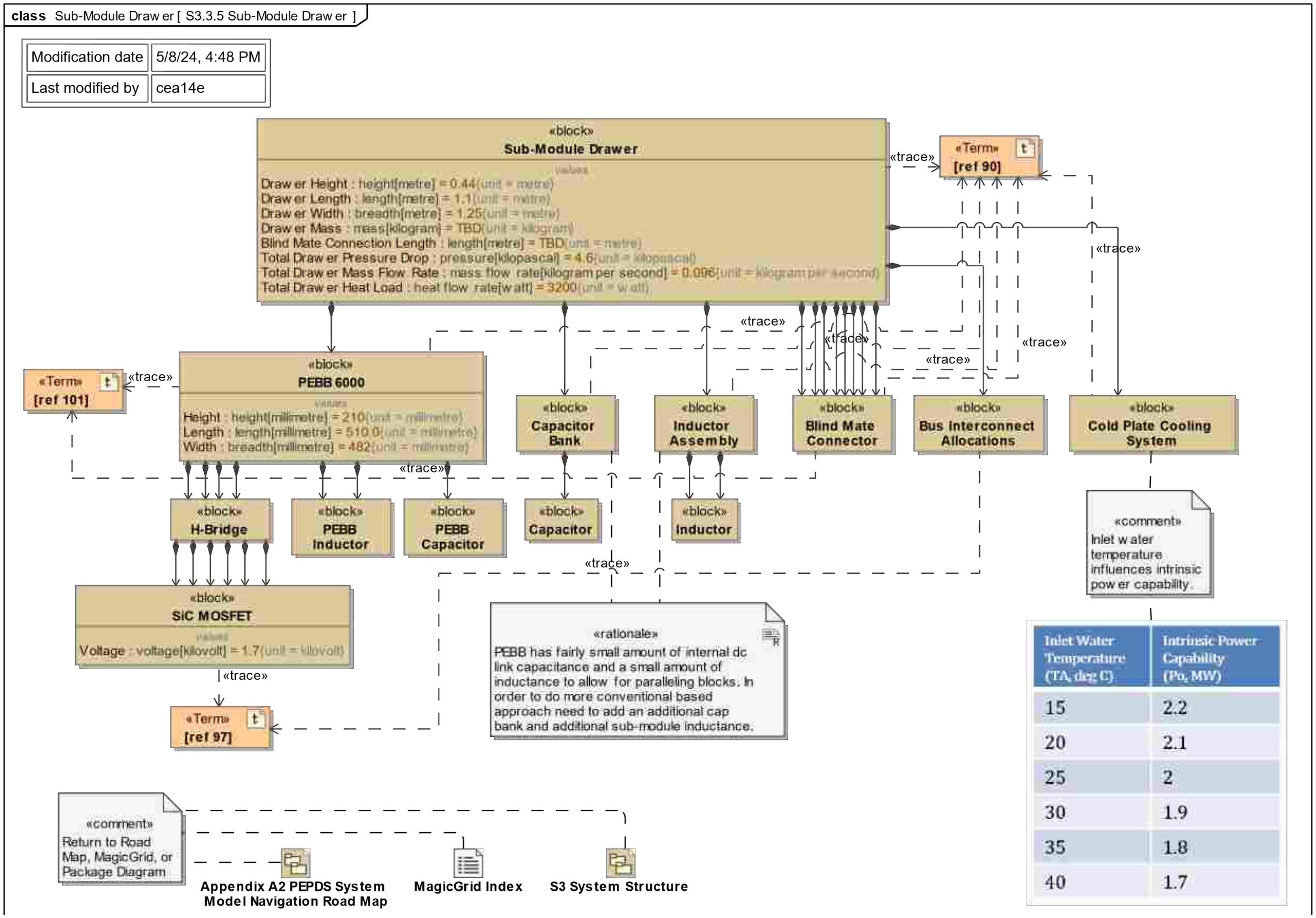


Fig. 76: S3.3.4 MVac to MVac Power Train



Inlet Water Temperature (TA, deg C)	Intrinsic Power Capability (Po, MW)
15	2.2
20	2.1
25	2
30	1.9
35	1.8
40	1.7

Fig. 77: S3.3.5 Sub-Module Drawer

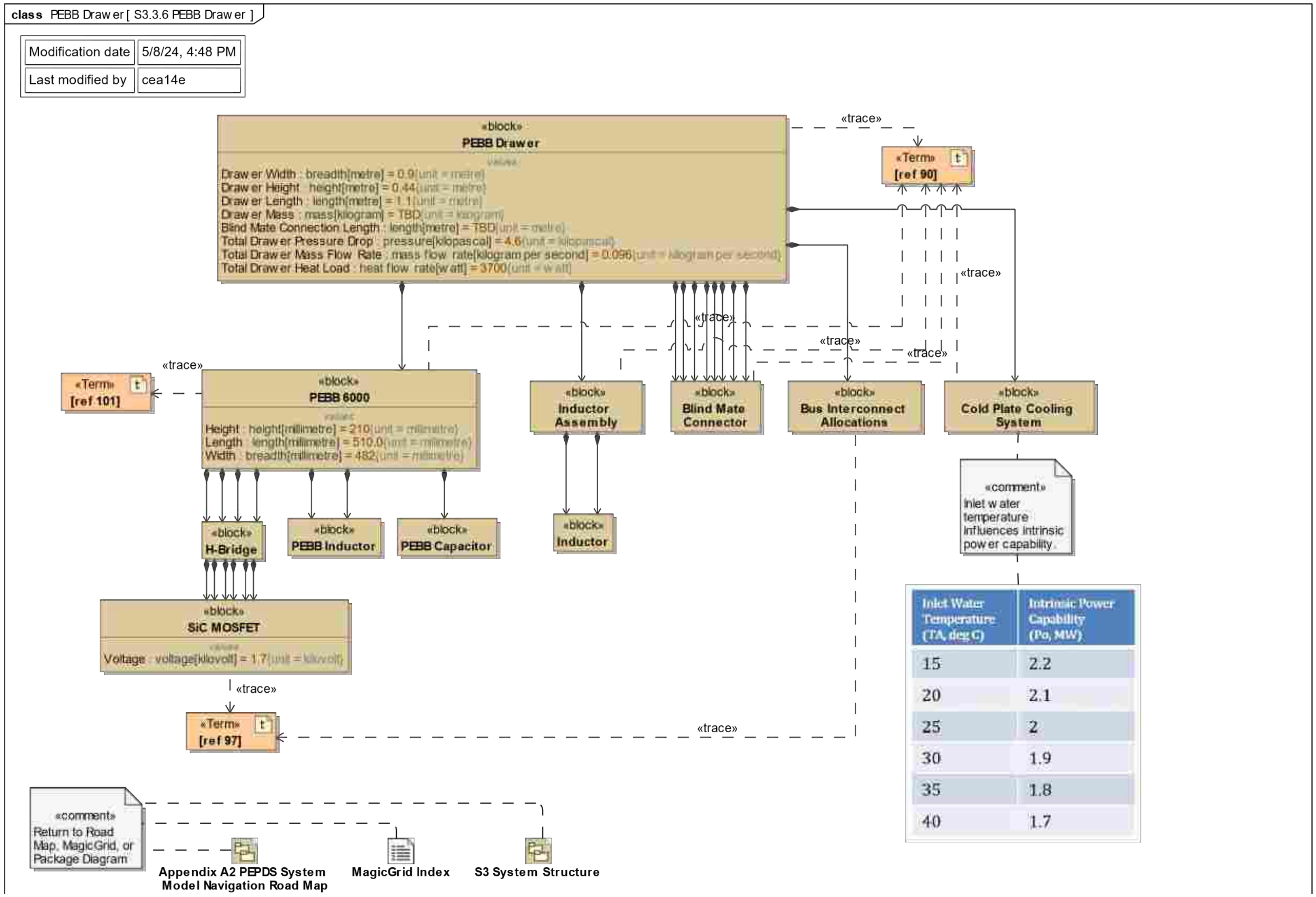


Fig. 78: S3.3.6 PEBB Drawer

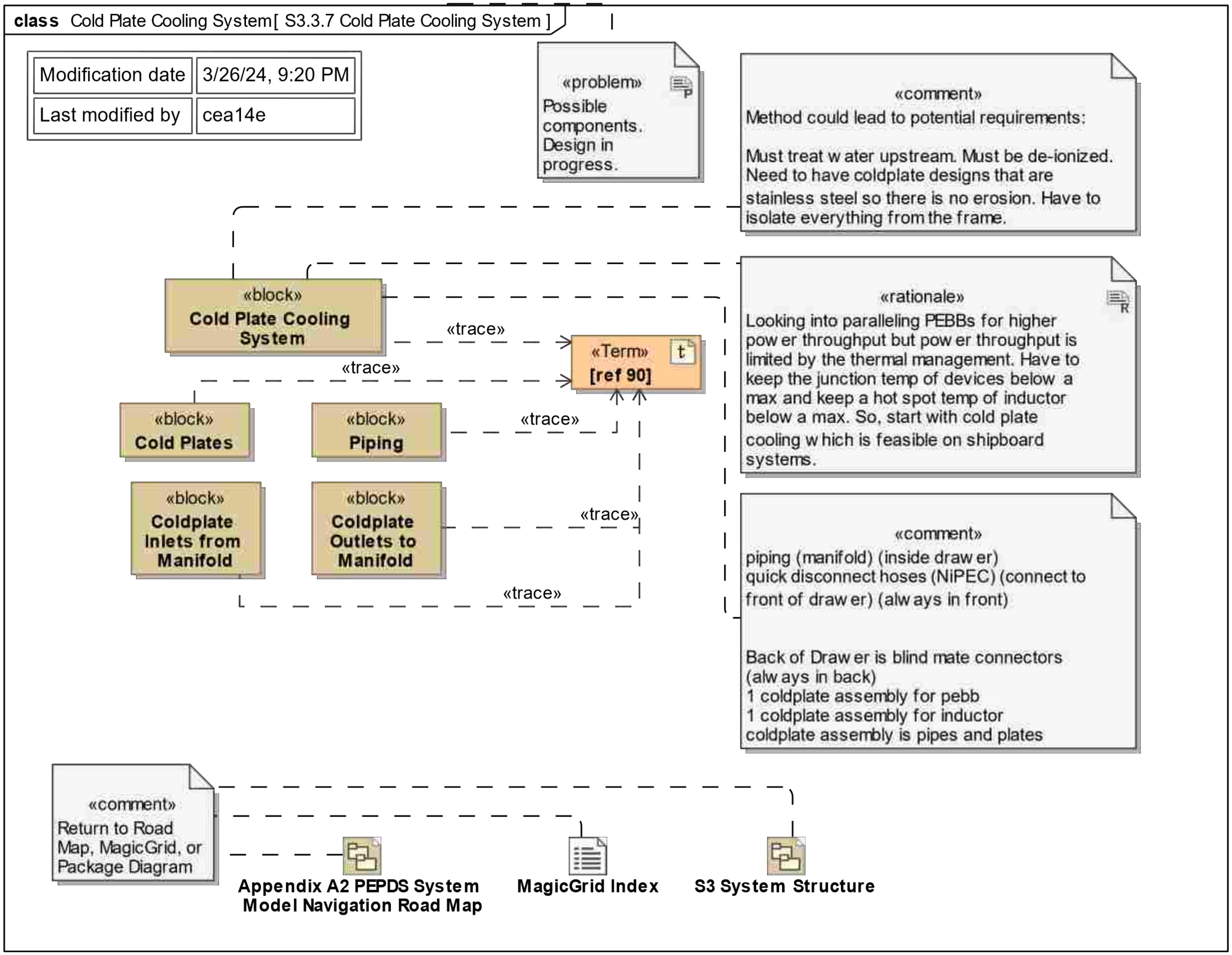


Fig. 79: S3.3.7 Cold Plate Cooling System

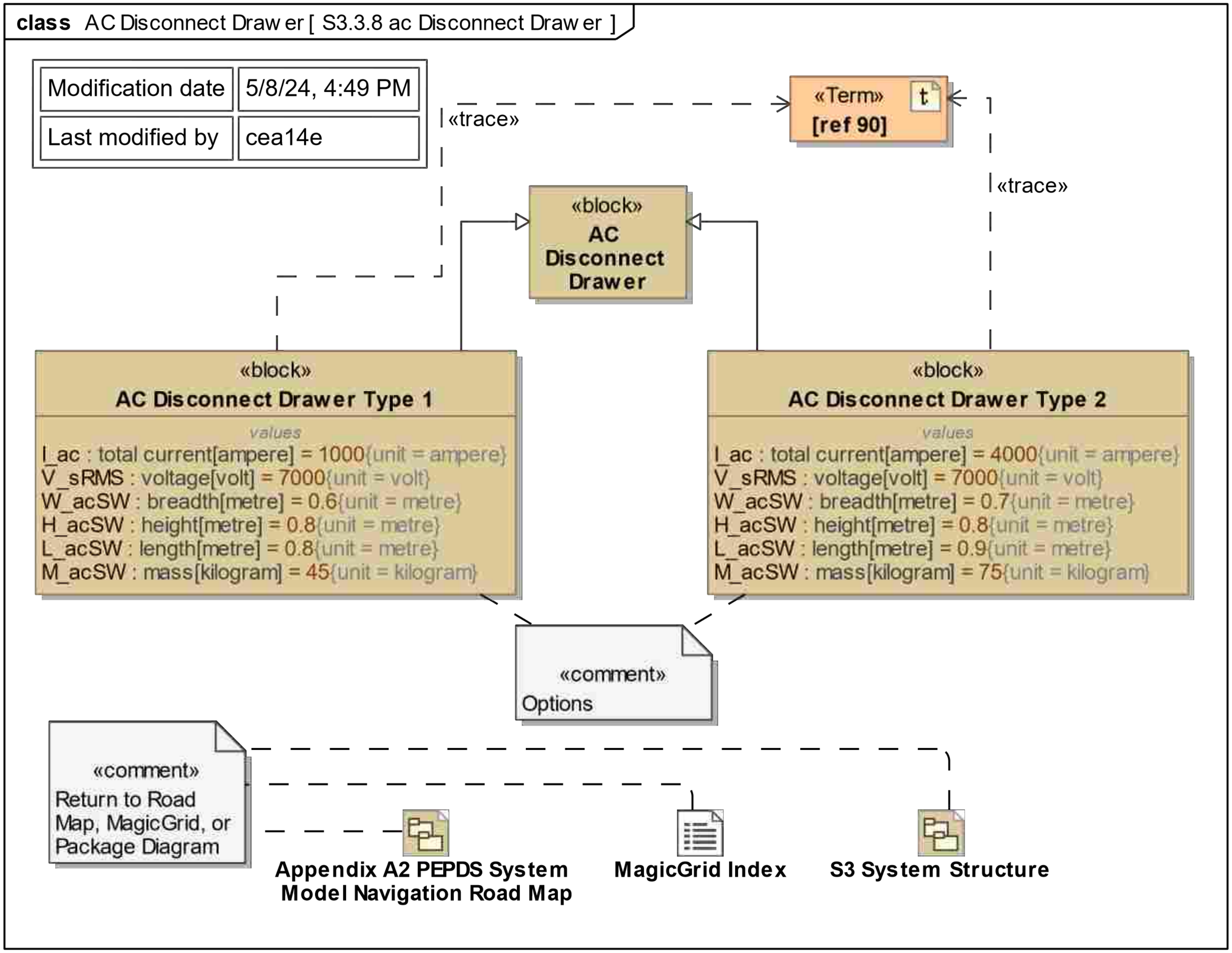


Fig. 80: S3.3.8 ac Disconnect Drawer

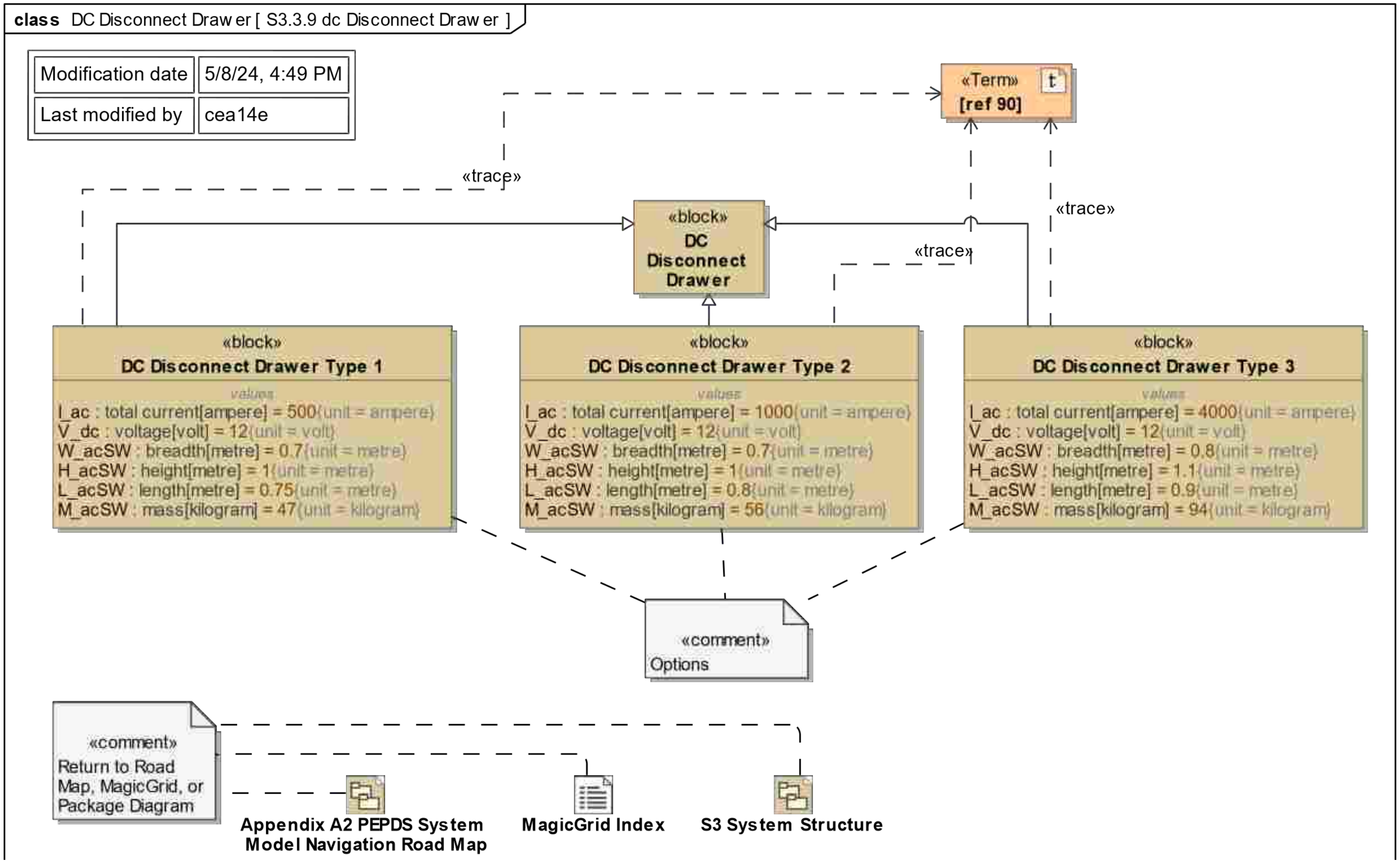


Fig. 81: S3.3.9 dc Disconnect Drawer

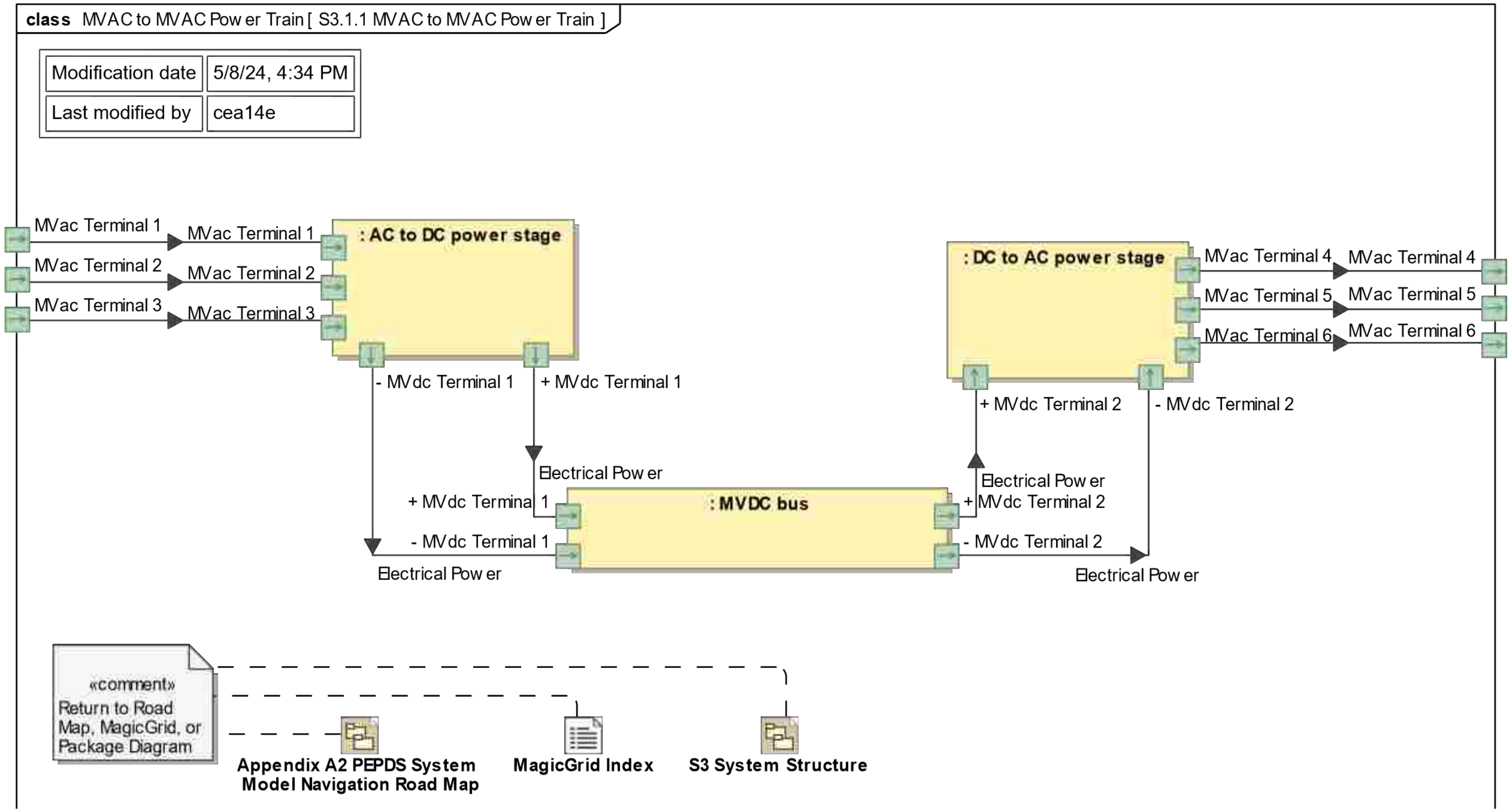


Fig. 82: S3.1.1 MVAC to MVAC Power Train

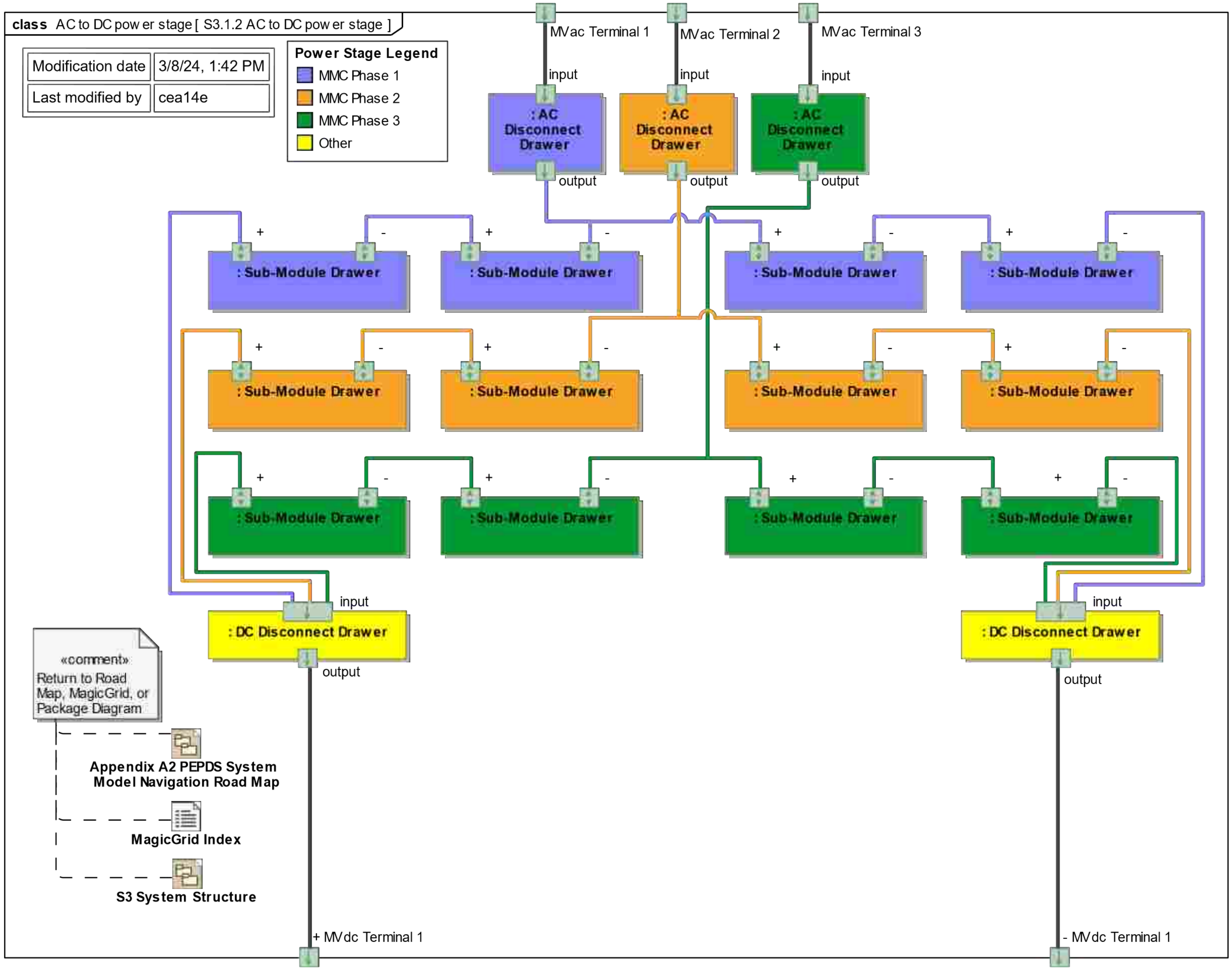


Fig. 83: S3.1.2 AC to DC power stage

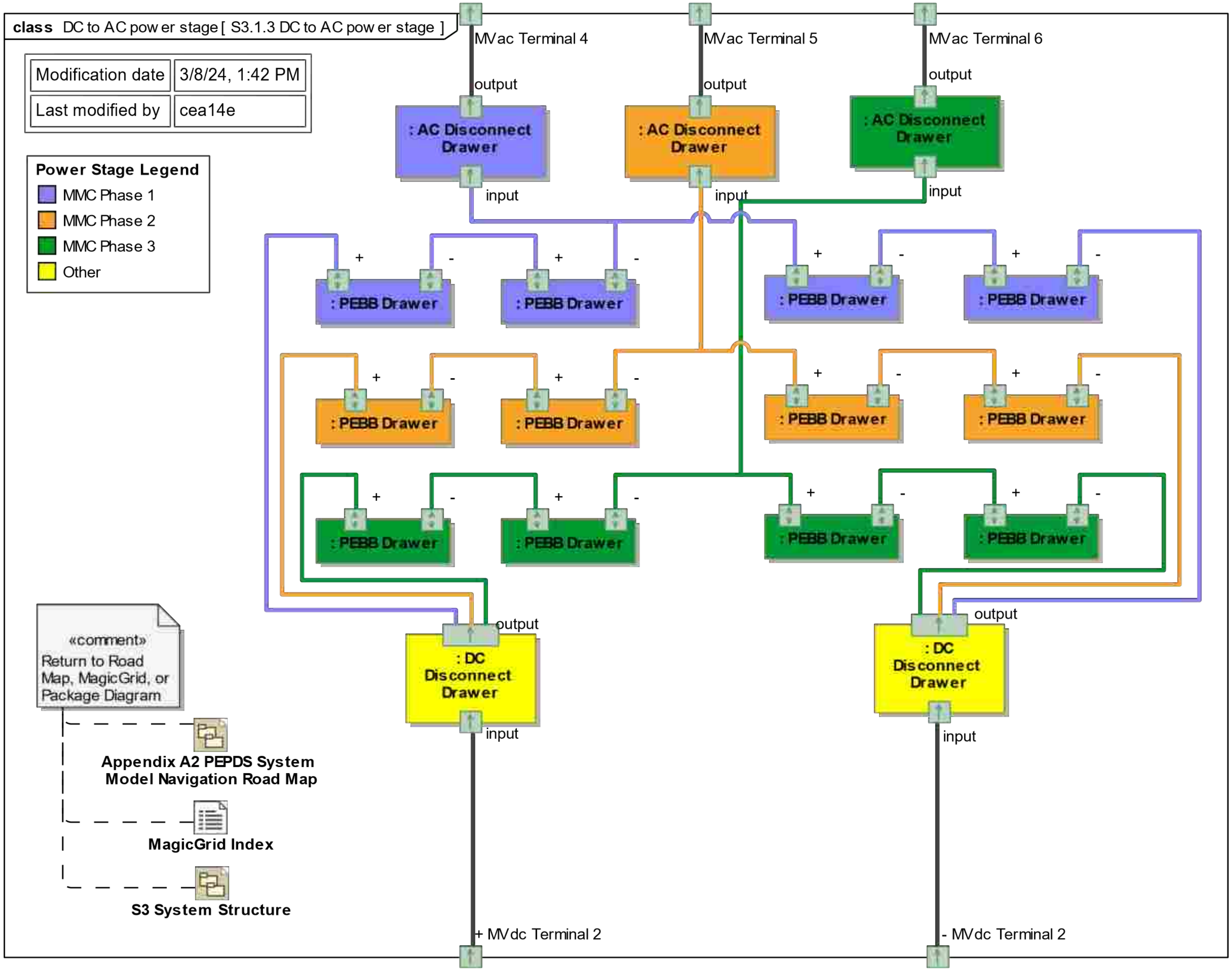


Fig. 84: S3.1.3 DC to AC power stage

11.3 System Model Appendix

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

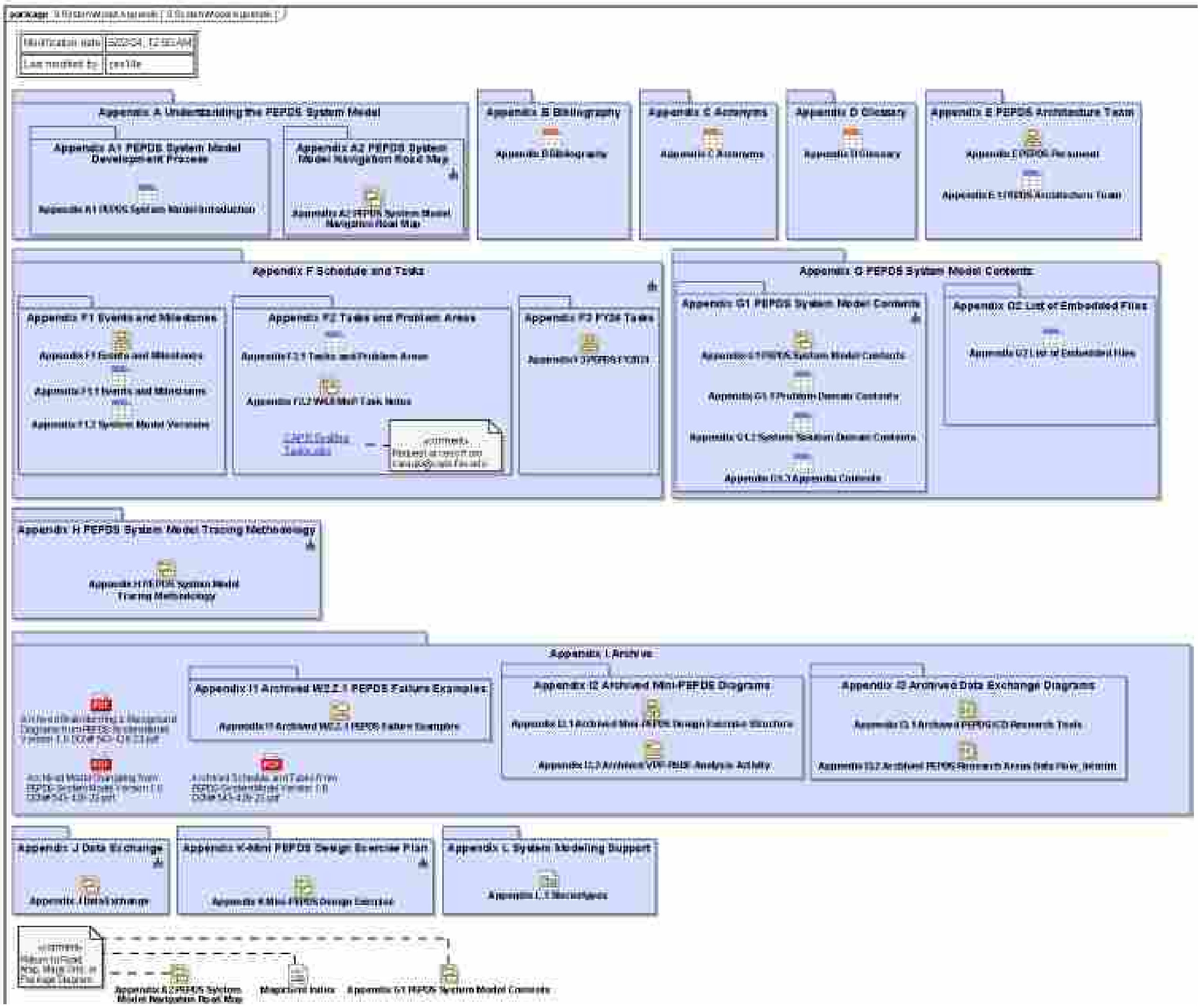


Fig. 85: 9 System Model Appendix

Table XX: Appendix A1 PEPDS System Model Introduction

Name	Question	Answer	Comment	Related Diagram	Additional Information
1	What is PEPDS?	The Power Electronic Power Distribution System (PEPDS) is a new power, energy, and control distribution concept enabled by technology development funded by the Office of Naval Research (ONR). “The goal of the PEPDS program is to achieve revolutionary changes to system design and operation by leveraging recent technological advances and developing both the applications to use them and the control and modeling capabilities needed to employ them” [ref 24]. The PEPDS development program has five (5) main areas of science and technology (S&T) development: (1) Navy Integrated Power Electronics Building Block (NiPEBB), (2) Navy Integrated Power and Energy Corridor (NiPEC), (3) Model is the Specification, (4) Control, and (5) System Simulation [ref 24].	To learn more about PEPDS and its main areas of S&T development, see the PEPDS Plan from [ref 24].		L. Petersen, C. Schegan, T. S. Ericsen, D. Boroyevich, R. Burgos, N. G. Hingorani, M. Steurer, J. Chalfant, H. Ginn, C. DiMarino, G. C. Montanari, F. Z. Peng, C. Chryssostomidis, C. Cooke, and I. Cvetkovic, “Power Electronic Power Distribution Systems (PEPDS),” Electric Ship Research & Development Consortium, USA, 2020. [Online]. Available: https://www.esrdc.com/library/pepds-plan/
2	What is the technical approach?	The technical approach for integrating this work is digital engineering grounded in model-based system engineering (MBSE). The product of this MBSE effort is the PEPDS System Model.			
3	What is digital engineering?	"Digital Engineering is an integrated digital approach that uses authoritative sources of systems’ data and models as a continuum across disciplines to support lifecycle activities from concept through disposal" [ref 114]. "The crux of digital engineering is the creation of computer readable models to represent all aspects of the system and to support all the activities for the design, development, manufacture, and operation of the system throughout its lifecycle" [ref 115]. MBSE is a subset of digital engineering [ref 115].			"Department of Defense (DoD) Digital Engineering Fundamentals," Assistant Secretary of Defense for Mission Under Secretary of Defense for Research and Engineering, March 2022. [Online] Available: https://ac.cto.mil/wp-content/uploads/2022/03/DE-Fundamentals-2022.pdf (accessed May 9, 2024). “Digital Engineering,” Guide to the System Engineering Body of Knowledge, https://sebokwiki.org/wiki/Digital_Engineering (accessed May 9, 2024).

Name	Question	Answer	Comment	Related Diagram	Additional Information
4	What is MBSE and its benefits?	MBSE is "the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases" [ref 84]. The benefits of using an MBSE approach over a traditional document-based approach are enhanced communications, reduced developmental risk, improved quality, increased productivity, and enhanced knowledge transfer [ref 82].			"Systems Engineering Vision 2020," International Council on Systems Engineering, San Diego, CA, USA, TP-2004-004-02, 2007. S. Friedenthal, A. Moore, and R. Steiner, A Practical Guide to SysML: The Systems Modeling Language, 3rd ed. Amsterdam: Morgan Kaufmann, 2014.
5	What is the PEPDS System Model?	The PEPDS System Model is a living document that will change and grow throughout the lifetime of the system. It will support system requirements, design, analysis, verification, and validation activities throughout development and later lifecycle phases [ref 84].			"Systems Engineering Vision 2020," International Council on Systems Engineering, San Diego, CA, USA, TP-2004-004-02, 2007.
6	What is the purpose of the PEPDS System Model?	Using an MBSE approach for the PEPDS development process will enhance communication, reduce developmental risk, improve quality, increase productivity, and enhance knowledge transfer [ref 84]. System designers will use the PEPDS System Model to understand the PEPDS functional architecture, propose alternative designs, select a preferred design, and build and qualify implementations. The PEPDS System Model will provide a framework for PEPDS architecture studies and enable collaborate research.			"Systems Engineering Vision 2020," International Council on Systems Engineering, San Diego, CA, USA, TP-2004-004-02, 2007.
7	What MBSE tool is used for the PEPDS System Model?	For the PEPDS System Model, the MBSE tool being used is the Cameo Enterprise Architecture software which is a product of CATIA No Magic owned by Dassault Systems. The Cameo Enterprise Architecture software is a core product for building integrated enterprise architectures meeting DoDAF, MODAF, NAF and TOGAF requirements [ref 83]. The product is based on UPDM, SysML, BPMN, SoaML, and UML modeling standards [ref 83].			"Enterprise Architecture," Integrated Enterprise Architecture (EA) Models - CATIA - Dassault Systèmes®. [Online]. Available: https://www.3ds.com/products-services/catia/products/no-magic/solutions/enterprise-architecture/#:~:text=Cameo%20Enterprise%20Architecture%20%2D%20Cameo%20Enterprise,SoaML%2C

Name	Question	Answer	Comment	Related Diagram	Additional Information
					%20and%20UML%20modeling%20 standards (accessed: 26-Aug-2022).
8	What modeling language is used for the PEPDS System Model?	The Cameo supported modeling language selected for the PEPDS System Model is SysML. "Modeling languages are specifications which provide standardized guidelines and structures for expressing system information" [ref 81]. SysML is one of the more frequently used modeling languages for MBSE and is a "graphical language that utilizes diagrams and tables in order to express system information and provides a standard set of nine diagram types which can be used to organize and express system information" [ref 81]. The information expressed via a modeling language is often organized via an architecture framework [ref 81]. The PEPDS System Model follows the MagicGrid® Framework.	To learn more about SysML elements and diagrams, see the No Magic Product Documentation "Glossary of SysML Concepts" from [ref 55].		"Glossary of SysML Concepts," No Magic Product Documentation. [Online]. Available: https://docs.nomagic.com/display/SYSMLP190/Glossary+of+SysML+concepts (accessed: 07-Mar-2023). C. Singam, "Model-Based Systems Engineering (MBSE)" in SEBoK Editorial Board, in The Guide to the Systems Engineering Body of Knowledge (SEBoK), v. 2.7, R. J. Cloutier, Ed. Hoboken, NJ: The Trustees of the Stevens Institute of Technology, 2022. [Online]. Available: https://www.sebokwiki.org/wiki/Model-Based_Systems_Engineering_(MBSE) (accessed: Mar 7, 2023).
9	What modeling framework is used in the PEPDS System Model?	The PEPDS System Model follows the MagicGrid® Framework defined by the first edition of the MagicGrid® Book of Knowledge by NoMagic, Inc. The MagicGrid® approach "includes the definition of the problem, solution, and implementation domains in the system model. They align with the processes defined by ISO/IEC/IEEE 15288 as follows: problem domain with the Stakeholder Needs Development process, solution domain with the Architecture Definition process, and implementation domain with the Design Definition process" [ref 80]. "Each domain definition includes four different aspects of the system to be considered and captured in the model. These aspects match the four pillars of the SysML, that is, requirements, behavior, structure, and parameters" [ref 80].	To learn more about the MagicGrid® Framework, see the first edition of the MagicGrid® Book of Knowledge from [ref 80]. The newest edition of the MagicGrid® Book of Knowledge can be downloaded from the Dassault Systèmes website. Take note that the PEPDS System Model follows the first edition. To assist the reader in navigating and understanding the PEPDS System Model, a road	MagicGrid Index Appendix A2 PEPDS System Model Navigation Road Map	A. Aleksandravičienė and A. Morkevičius, MagicGrid® Book of Knowledge: A Practical Guide to Systems Modeling using MagicGrid from No Magic, Kaunas, Lithuania: Vitae Litera, 2018.

Name	Question	Answer	Comment	Related Diagram	Additional Information
			map for navigating the model was created. The PEPDS System Model can be explored using the MagicGrid® Index or the road map.		
10	Who are the contributors to the PEPDS System Model?	The PEPDS Architecture Team uses the Systems Modeling Language (SysML) to develop the PEPDS System Model with the Cameo Enterprise Architecture software. Consistent with similar projects at the Naval Sea Systems Command (NAVSEA), the PEPDS System Model follows the MagicGrid® Framework.		Appendix E PEPDS Personnel	

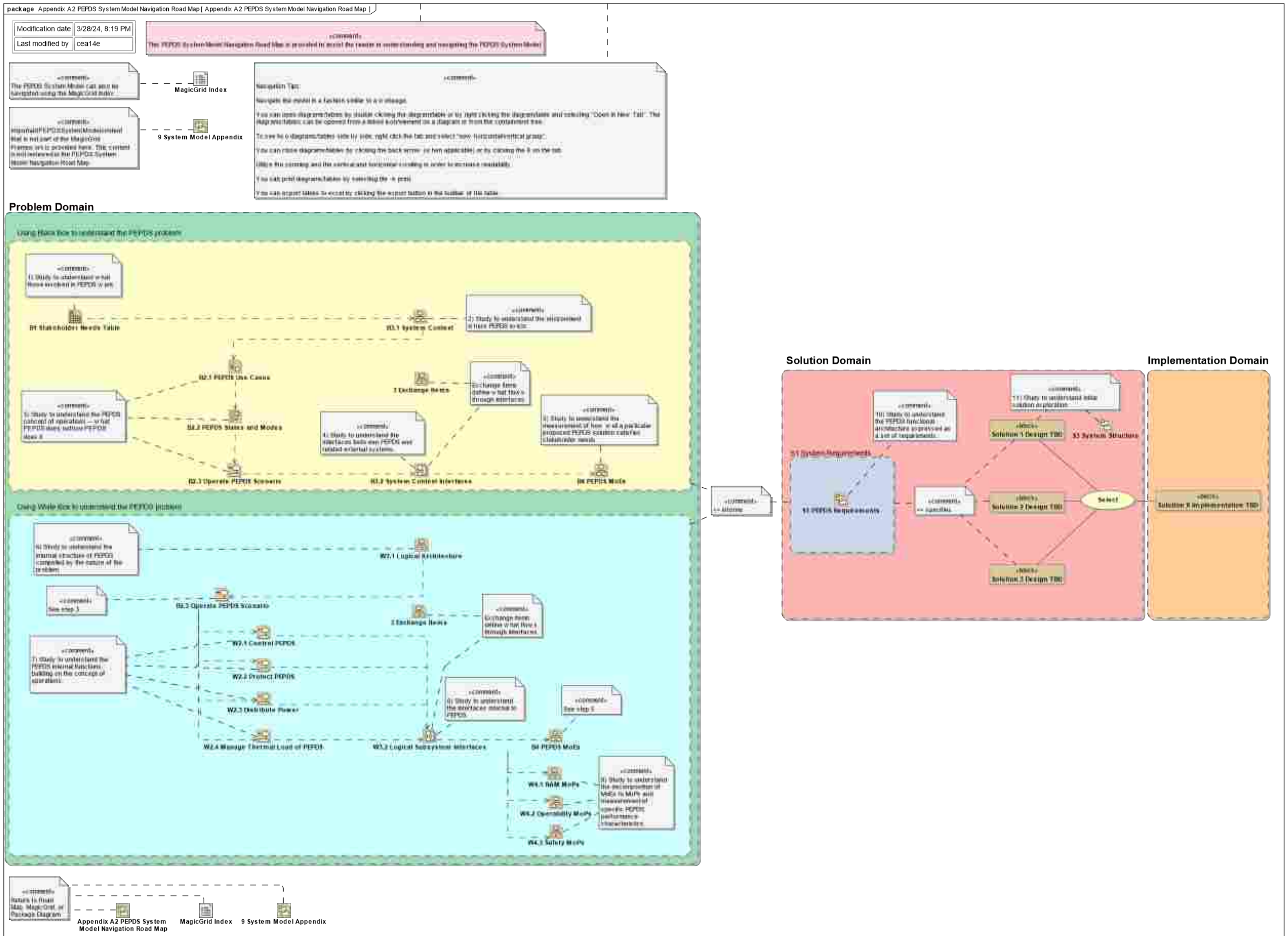


Fig. 86: Appendix A2 PEPDS System Model Navigation Road Map

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Table XXII: Appendix C Acronyms

Term	Description	References
A_i	Inherent Availability	
ACWP	Actual Cost of Work Performed	[ref 75]
ADT	Administrative Delay Time	[ref 35]
BCWP	Budgeted Cost of Work Performed	[ref 75]
BCWS	Budgeted Cost of Work Scheduled	[ref 76]
BIT	built-in test	[ref 33]
BPMN	Business Process Model and Notation	[ref 117]
CAPS	Center for Advanced Power Systems	[ref 29]
CB	Capacitor Bank	[ref 25]
CBM+	Conditioned Based Maintenance Plus	[ref 61]
CBRN	Chemical, Biological, Radiological, and Nuclear	[ref 62]
CCDC	Current Commutating Drive Circuit	[ref 25]
CHIL	Controller Hardware-in-the-Loop	[ref 24]
CPES	Center for Power Electronics Systems	
CPI	Cost Performance Index	[ref 75]
CTE	Critical Technology Element	
CTEs	Critical Technology Elements	
CV	Cost Variance	[ref 75]
CyberMTTC	Mean Time to Contain Cybersecurity Failure	[ref 63]
CyberMTTD	Mean Time to Detect Cybersecurity Failure	[ref 64]
CyberMTTR	Mean Time to Resolve Cybersecurity Failure	[ref 65]
DCX	Isolated DC-DC Converter part of iPEBB with dielectric stand-off	
DoDAF	Department of Defense Architecture Framework (USA)	[ref 116]
DRTS	Digital Real Time Simulator	[ref 24]
ECM	Energy Conversion Module	[ref 31]
EM	Energy Magazine	
EMC	Electromagnetic Compatibility	[ref 66]
EMCB	Electro-Mechanical Circuit Breaker	[ref 25]
EMI	Electromagnetic Interference	[ref 66]
ERL	Energy Routing Laboratory	
ESM	Energy Storage Module	[ref 25]
ESTS	Electric Ship Technologies Symposium	
EWS	Electronic Warfare System	[ref 26]
FA	Fan Assembly	[ref 25]

Term	Description	References
FA-1	Filter Assembly	[ref 25]
FH	Flight Hours (i.e., Functional Hours)	[ref 23]
FMS	Fast Mechanical Switch	[ref 25]
FSU	Florida State University	
FY	Fiscal Year	
FY20	Fiscal Year 2020	
FY21	Fiscal Year 2021	
FY22	Fiscal Year 2022	
FY23	Fiscal Year 2023	
FY24	Fiscal Year 2024	
HFXA	High Frequency Transformer Assembly	[ref 25]
HXA	Heat Exchanger	[ref 25]
IA	Inductor Assembly	[ref 25]
IDLH	Immediately Dangerous to Life or Health	[ref 67]
IEEE	Institute of Electrical and Electronics Engineers	
iPEBB	integrated Power Electronic Building Blocks	[ref 24]
IPEC	Integrated Power and Energy Corridor	[ref 41]
IPES	Integrated Power and Energy System	[ref 24]
LCC	Life Cycle Cost	[ref 38]
LCS	Load Commutating Switch	[ref 25]
LDT	Logistics Delay Time	[ref 35]
LMS	Logistics, Maintenance, and Support	[ref 38]
LRU	Line Replaceable Unit	[ref 6]
LRUs	Line Replaceable Units	[ref 6]
LV	Low Voltage	
MAMT	Mean Active Maintenance Time	[ref 35]
MBSE	Model-based systems engineering	
MCD	Most Common Denominator	[ref 24]
MCMT	Mean Corrective Maintenance Time	[ref 35]
MDT	Mean Downtime	[ref 35]
MIT	Massachusetts Institute of Technology	
MMC	Modular Multilevel Converter	[ref 89]
MMH	Maintenance Man Hours	[ref 23]
MODAF	Ministry of Defense Architecture Framework (UK)	[ref 116]
MoE	Measurement of Effectiveness	[ref 27]
MOHBFA	Mean Operating Hours Between False Alarm	[ref 33]
MoP	Measurement of Performance	[ref 27]

Term	Description	References
MPMT	Mean Preventative Maintenance Time	[ref 35]
MTBCF	Mean Time Between Critical Failure	[ref 33]
MTBF	Mean Time Between Failure	[ref 23]
MTBM	Mean Time Between Maintenance	[ref 33]
MTBOMF	Mean Time Between Operational Mission Failure	[ref 33]
MTBR	Mean Time Between Repair	[ref 33]
MTTR	Mean Time to Repair	[ref 24]
MV	Medium Voltage	
MVAC	Medium Voltage Alternating Current	[ref 24]
MVDC	Medium Voltage Direct Current	[ref 24]
n_F	Number of Failures	
n_maint	Number of Maintenance Actions	
n_PM	Number of Preventative Maintenance Activities	
n_R	Number of Repairs	
NAF	NATO Architecture Framework	[ref 118]
NATO	North Atlantic Treaty Organization	
NiPEBB	Navy iPEBB	[ref 71]
NiPEC	Navy integrated Power and Energy Corridor	[ref 42]
NLSw	No Load Switch/DC Disconnect	[ref 25]
Non-LRU	Non- Least Replaceable Unit	
Non-LRUs	Non- Least Replaceable Units	
NSWCPD	Naval Surface Warfare Center Philadelphia Division	
OB	Outer bridge part of iPEBB with passives and dielectric stand-off	
OBE	Overcome By Events	[ref 68]
ONR	Office of Naval Research	
PCB	Printed Circuit Board	[ref 25]
PCM	Power Conversion Module	[ref 25]
PD	PEBB Drawer	[ref 90]
PDM	Power Distribution Module	[ref 25]
PEBB	Power Electronic Building Block	[ref 24]
PEPDS	Power Electronic Power Distribution System	[ref 24]
PFD	Percent Fault Detection	[ref 33]
PFI	Percent Fault Isolation	[ref 33]
PGM	Power Generation Module	[ref 25]
PHIL	Power Hardware-in-the-Loop	[ref 24]
PMM	Propulsion Motor Module	[ref 25]
PPEL	Pulsed Power and Energy Laboratory	

Term	Description	References
PS	Power Systems	
Q1	Quarter 1	
Q2	Quarter 2	
Q3	Quarter 3	
Q4	Quarter 4	
RA	Risk Assessment	
RAM	Reliability, Availability, and Maintainability	[ref 23]
rate_CM	Corrective Maintenance Rate	[ref 35]
rate_F	Failure Rate	[ref 35]
rate_PM	Preventative Maintenance Rate	[ref 35]
RSDE	Rapid Ship Design Environment	
RTS	Real Time Simulator	[ref 24]
S&T	Science and Technology	
SD&A	Stability Design & Assessment	
Sea Grant	Sea Grant Design Laboratory	
SEES	Center for Sustainable Electrical Energy Systems	
SHIPALT	Ship Alteration	[ref 32]
SiC MOSFET	Silicon Carbide Metal-Oxide-Semiconductor Field-Effect Transistor	
SMD	Sub-Module Drawer	[ref 90]
SME	subject-matter expert	
SMEs	subject-matter experts	
SoaML	Service Oriented Architecture Modeling Language	[ref 116]
SoC	State of Charge	[ref 30]
SPI	Schedule Performance Index	[ref 76]
SRR	System Requirements Review	
SSSw	Solid State Switch	[ref 25]
SV	Schedule Variance	[ref 76]
SysEng	Systems Engineering	
SysML	Systems Modeling Language	[ref 116]
t_OH	Total Operating Hours	
t_PM	Preventative Maintenance Time	
t_R	Repair Time	
t_up	Uptime	
TBD	To Be Determined	[ref 69]
TC	Technical Candidate	
TEM	Tactical Energy Management	[ref 24]
THD	Total Harmonic Disorder	[ref 70]

Term	Description	References
TMM	Thermal Modeling and Management	
TOGAF	The Open Group Architecture Framework	[ref 119]
TPM	Technical Performance Measure	[ref 38]
TRA	Technology Readiness Assessment	
TRL	Technology Readiness Level	
TTE	Transactions on Transportation Electrification	
U.S.	United States	
UML	Unified Modeling Language	[ref 116]
UPDM	The Unified Profile for DoDAF/MODAF	[ref 116]
UPS	Uninterruptible Power Supply	[ref 28]
USC	University of South Carolina	
UTA	University of Texas at Arlington	
UWM	University of Wisconsin-Milwaukee	
VPP	Virtual Prototyping Process	
VT	Virginia Tech	

Table XXIII: Appendix D Glossary

Term	Description	Reference
Bay	A building block of equal, repeatable functionality	[ref 25]
Bays	A building block of equal, repeatable functionality	[ref 25]
Compartment	Physically defined spaces within a bay	[ref 25]
Diagnoses	see diagnosis	
Diagnosis	identification of the nature and cause of a failure	
Drawer	Drawers hold one or more LRUs and contain additional allocations for dielectric stand-off and accessibility to enable multi-use LRU concepts	[ref 25]
Electrical Load	An electrical load is an electrical component of a circuit that consumes electrical power.	
Electrical Source	An electrical source is a device that dissipates electrical power.	
Failure	Anything that degrades or disrupts the operation of the system. Response time varies. Includes Faults.	
Fault	Disruptive event to the normal operation of the system that requires immediate response of the system because of imminent danger to personnel or system inside or outside PEPDS. Is a type of Failure.	
LRU	In the context of the PEPDS System Model: 1) LRUs are easily installed, removed, and transported by a single sailor 2) LRUs have spares onboard 3) Some LRUs are reprogrammable.	[ref 46]
LRUs	see LRU	[ref 46]
Module	A structural implementation of a specific functionality	[ref 25]
Non-LRU	In the context of the PEPDS System Model: 1) Non-LRUs are not easily installed, removed, and transported by a single sailor.	[ref 46]
Non-LRUs	see Non-LRU	[ref 46]
Power Train	A cascaded connection of power stages between points of source and points of load (or feed) are referred to as a power train, or PEPDS power train. For design space exploration a PEPDS power train is represented by cuboid physical dimensions and mass, and electro-thermal performance, including switches for re-routing, electrical-thermal-structural interfaces that comprise the configuration of PEBBs/iPEBBs required to realize required source input to load output functionality of that power train. Any physical section of NiPEC in the ship will consist of multiple power trains.	[ref 97]
Power Trains	See Power Train	[ref 97]
Prognoses	see prognosis	
Prognosis	a forecast of the consequences of a failure if not addressed	
Program	see re-programmability	
Programming	see re-programmability	
Re-programmability	Changing system behavior by altering internal functions of components, e.g. through firmware or software, thereby treating components as white boxes.	
Reconfigurability	Changing system behavior by altering interconnections between components and/or selection of predefined options available for components, thereby treating components as black boxes.	

Term	Description	Reference
Reconfiguration	see reconfigurability	
Tappable	Points at which Electrical Power provided by PEPDS may be accessed.	

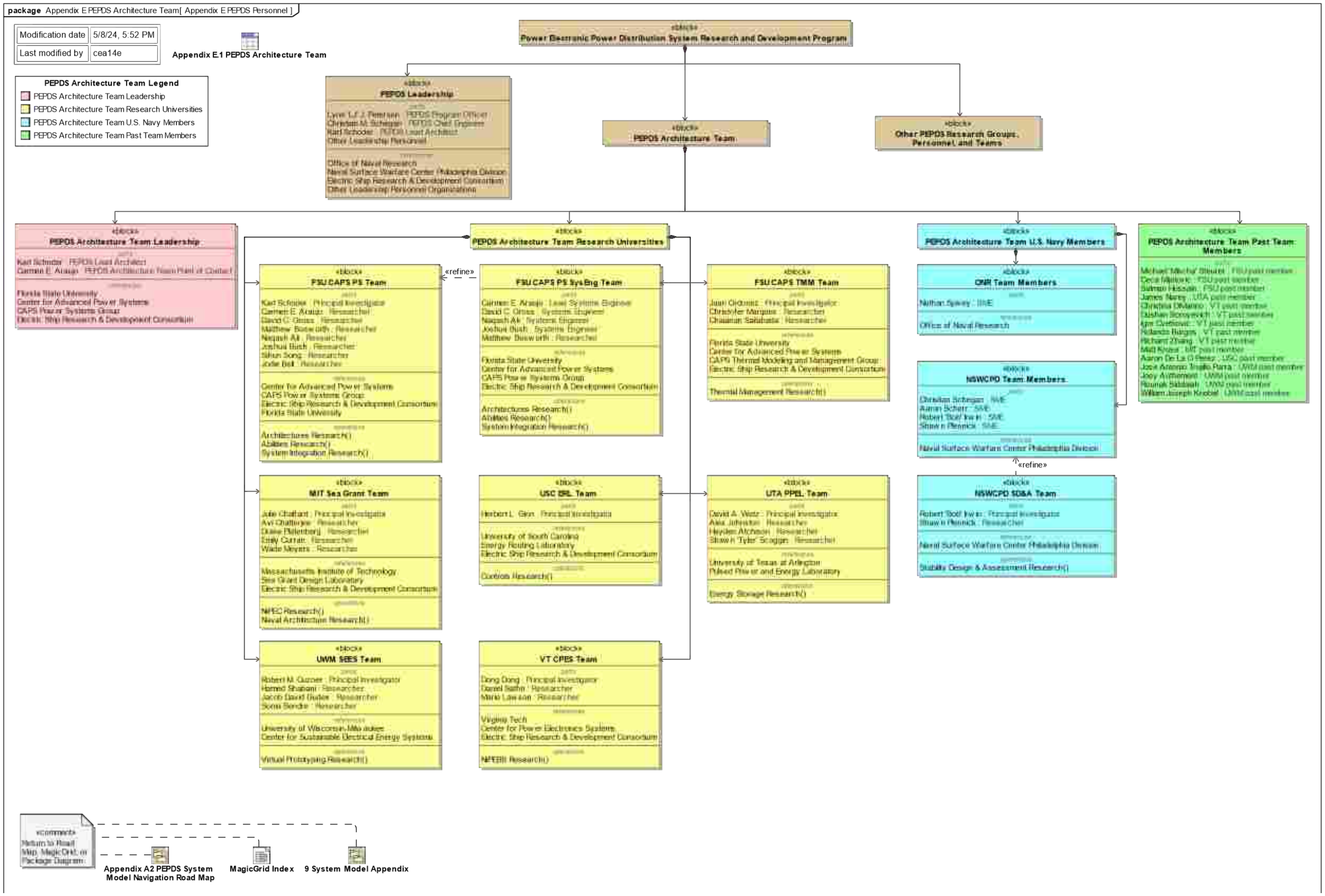

Fig. 87: Appendix E PEPDS Personnel

Table XXIV: Appendix E.1 PEPDS Architecture Team

Member Group	Name	Role	Research
PEPDS Architecture Team Leadership	Karl Schoder	PEPDS Lead Architect	
PEPDS Architecture Team Leadership	Carmen E. Araujo	PEPDS Architecture Team Point of Contact	
FSU CAPS PS Team	Karl Schoder	Principal Investigator	Architectures Research Abilities Research System Integration Research
FSU CAPS PS Team	Carmen E. Araujo	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS PS Team	David C. Gross	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS PS Team	Matthew Bosworth	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS PS Team	Naqash Ali	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS PS Team	Joshua Bush	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS PS Team	Sihun Song	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS PS Team	Jodie Bell	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS PS SysEng Team	Carmen E. Araujo	Lead Systems Engineer	Architectures Research Abilities Research

Member Group	Name	Role	Research
			System Integration Research
FSU CAPS PS SysEng Team	David C. Gross	Systems Engineer	Architectures Research Abilities Research System Integration Research
FSU CAPS PS SysEng Team	Naqash Ali	Systems Engineer	Architectures Research Abilities Research System Integration Research
FSU CAPS PS SysEng Team	Joshua Bush	Systems Engineer	Architectures Research Abilities Research System Integration Research
FSU CAPS PS SysEng Team	Matthew Bosworth	Researcher	Architectures Research Abilities Research System Integration Research
FSU CAPS TMM Team	Juan Ordonez	Principal Investigator	Thermal Management Research
FSU CAPS TMM Team	Christofer Marques	Researcher	Thermal Management Research
FSU CAPS TMM Team	Chaianan Sailabada	Researcher	Thermal Management Research
MIT Sea Grant Team	Julie Chalfant	Principal Investigator	NiPEC Research Naval Architecture Research
MIT Sea Grant Team	Avi Chatterjee	Researcher	NiPEC Research Naval Architecture Research
MIT Sea Grant Team	Drake Platenberg	Researcher	NiPEC Research Naval Architecture Research
MIT Sea Grant Team	Emily Curran	Researcher	NiPEC Research Naval Architecture Research
MIT Sea Grant Team	Wade Meyers	Researcher	NiPEC Research Naval Architecture Research

Member Group	Name	Role	Research
USC ERL Team	Herbert L. Ginn	Principal Investigator	Controls Research
UTA PPEL Team	David A. Wetz	Principal Investigator	Energy Storage Research
UTA PPEL Team	Alex Johnston	Researcher	Energy Storage Research
UTA PPEL Team	Hayden Atchison	Researcher	Energy Storage Research
UTA PPEL Team	Shawn 'Tyler' Scoggin	Researcher	Energy Storage Research
UWM SEES Team	Robert M. Cuzner	Principal Investigator	Virtual Prototyping Research
UWM SEES Team	Hamed Shabani	Researcher	Virtual Prototyping Research
UWM SEES Team	Jacob David Gudex	Researcher	Virtual Prototyping Research
UWM SEES Team	Sonia Bendre	Researcher	Virtual Prototyping Research
VT CPES Team	Dong Dong	Principal Investigator	NiPEBB Research
VT CPES Team	Daniel Sathri	Researcher	NiPEBB Research
VT CPES Team	Marie Lawson	Researcher	NiPEBB Research
ONR Team Members	Nathan Spivey	SME	
NSWCPD Team Members	Christian Schegan	SME	
NSWCPD Team Members	Aaron Scherr	SME	
NSWCPD Team Members	Robert 'Bob' Irwin	SME	
NSWCPD Team Members	Shawn Plesnick	SME	
NSWCPD SD&A Team	Robert 'Bob' Irwin	Principal Investigator	Stability Design & Assessment Research
NSWCPD SD&A Team	Shawn Plesnick	Researcher	Stability Design & Assessment Research
PEPDS Architecture Team Past Team Members	Michael 'Mischa' Steurer	FSU past member	
PEPDS Architecture Team Past Team Members	Ceca Mijatovic	FSU past member	
PEPDS Architecture Team Past Team Members	Salman Hussain	FSU past member	
PEPDS Architecture Team Past Team Members	Matt Kruse	MIT past member	
PEPDS Architecture Team Past Team Members	Aaron De La O Perez	USC past member	
PEPDS Architecture Team Past Team Members	James Narey	UTA past member	

Member Group	Name	Role	Research
PEPDS Architecture Team Past Team Members	William Joseph Koebel	UWM past member	
PEPDS Architecture Team Past Team Members	Joey Authement	UWM past member	
PEPDS Architecture Team Past Team Members	Jose Antonio Trujillo Parra	UWM past member	
PEPDS Architecture Team Past Team Members	Rounak Siddaiah	UWM past member	
PEPDS Architecture Team Past Team Members	Igor Cvetkovic	VT past member	
PEPDS Architecture Team Past Team Members	Christina DiMarino	VT past member	
PEPDS Architecture Team Past Team Members	Rolando Burgos	VT past member	
PEPDS Architecture Team Past Team Members	Dushan Boroyevich	VT past member	
PEPDS Architecture Team Past Team Members	Richard Zhang	VT past member	

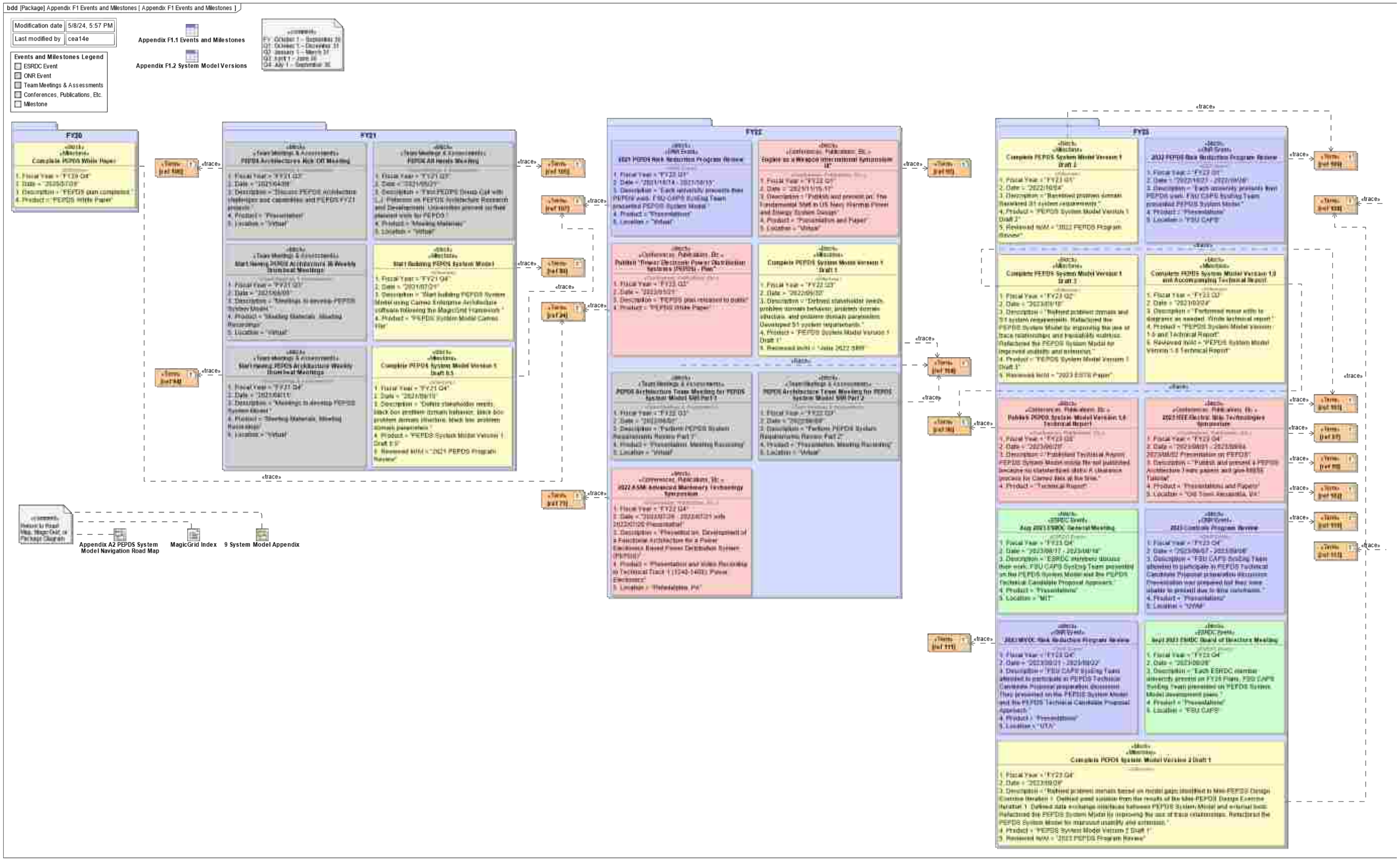

Fig. 88: Appendix F1 Events and Milestones Part 1

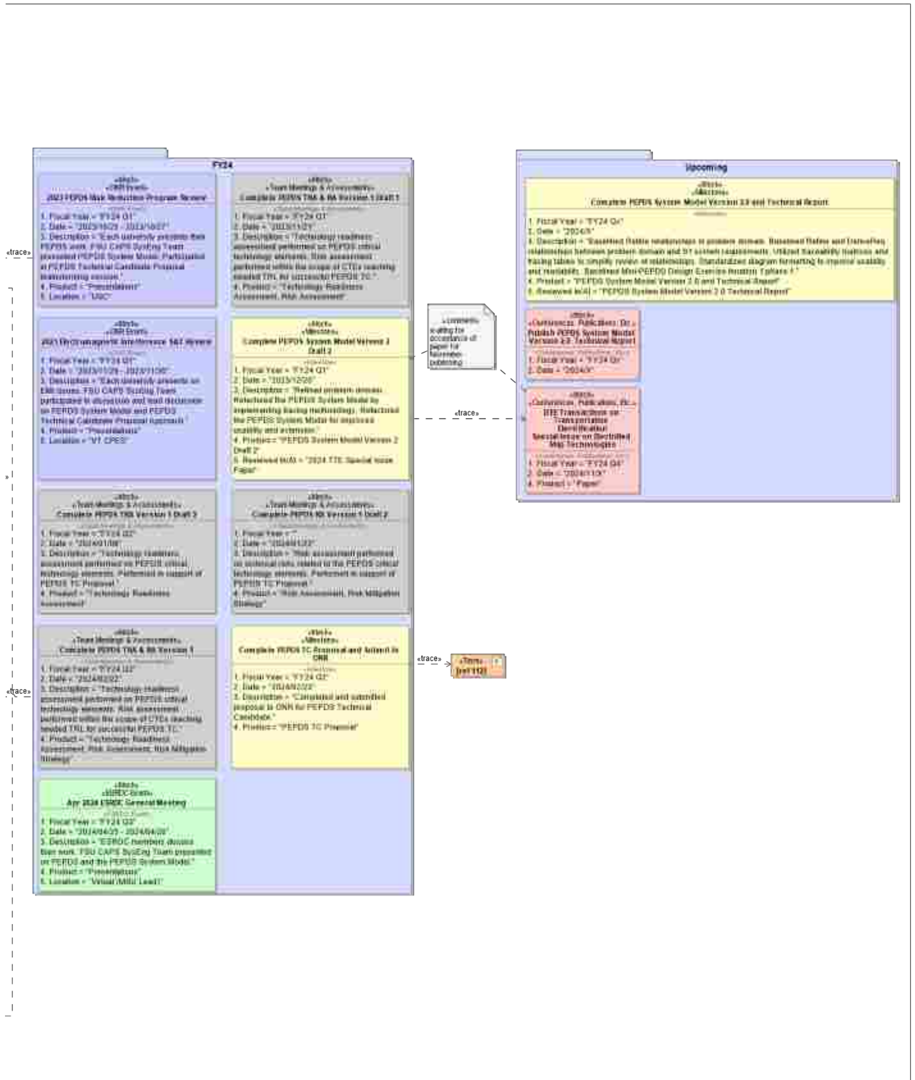

Fig. 89: Appendix F1 Events and Milestones Part 2

Table XXV: Appendix F1.1 Events and Milestones

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
Complete PEPDS White Paper	FY20	FY20 Q4	2020/07/26	PEPDS plan completed.	PEPDS White Paper		[ref 24]	L. Petersen, C. Schegan, T. S. Ericsen, D. Boroyevich, R. Burgos, N. G. Hingorani, M. Steurer, J. Chalfant, H. Ginn, C. DiMarino, G. C. Montanari, F. Z. Peng, C. Chryssostomidis, C. Cooke, and I. Cvetkovic, "Power Electronic Power Distribution Systems (PEPDS)," Electric Ship Research & Development Consortium, USA, 2020. [Online]. Available: https://www.esrdc.com/library/pepds-plan/	https://www.esrdc.com/library/pepds-plan/	Block [Class] Milestone [Element]
PEPDS Architectures Kick-Off Meeting	FY21	FY21 Q3	2021/04/08	Discuss PEPDS Architecture challenges and capabilities and PEPDS FY21 projects.	Presentation	Virtual	[ref 106]	M. Steurer, "PEPDS Architectures Kick-off Meeting" Amazon Work Docs, April 2021, [Online]. Available: https://rcpc.awsapp	https://rcpc.awsapps.com/workdocs/index.html#/document/8a5c318390303cb7bb568fde293533b2725	Block [Class] Team Meetings & Assessments [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
								s.com/workdocs/index.html#/document/8a5c318390303cb7bb568fde293533b2725fe91aa0661986c3b8f3bffdd974bd	fe91aa0661986c3b8f3bffdd974bd	
PEPDS All Hands Meeting	FY21	FY21 Q3	2021/05/21	First PEDPS Group Call with L.J. Peterson on PEPDS Architecture Research and Development. Universities present on their planned work for PEPDS.	Meeting Materials	Virtual	[ref 105]	PEPDS Team "PEPDS All Hands Meeting Presentations" Amazon Work Docs, May 2021, [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/5f4b3d69cccaf9f287ab3d52877aa1d304ef50bcf4ec3085c1ba64663c82e3b5	https://rcpc.awsapps.com/workdocs/index.html#/document/5f4b3d69cccaf9f287ab3d52877aa1d304ef50bcf4ec3085c1ba64663c82e3b5	Block [Class] Team Meetings & Assessments [Element]
Start Having PEPDS Architecture Bi-Weekly Drumbeat Meetings	FY21	FY21 Q3	2021/06/09	Meetings to develop PEPDS System Model.	Meeting Materials, Meeting Recordings	Virtual				Block [Class] Team Meetings & Assessments [Element]
Start Building PEPDS System Model	FY21	FY21 Q4	2021/07/21	Start building PEPDS System Model using Cameo Enterprise Architecture	PEPDS System Model Cameo File		[ref 80]	A. Aleksandravičienė and A. Morkevičius, MagicGrid® Book of Knowledge: A Practical Guide to Systems Modeling	https://discover.3ds.com/magicgrid-book-of-knowledge	Block [Class] Milestone [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				software following the MagicGrid Framework.				using MagicGrid from No Magic, Kaunas, Lithuania: Vitae Litera, 2018.		
Start Having PEPDS Architecture Weekly Drumbeat Meetings	FY21	FY21 Q4	2021/08/11	Meetings to develop PEPDS System Model.	Meeting Materials, Meeting Recordings	Virtual	[ref 94]	Weekly Architecture SMEs Meetings. Amazon WorkDocs. https://rcpc.awsapps.com/workdocs/index.html#/folder/6876af510d7b0907e5f4646503a78871c0d611ba5bd72a38eaf8f5fb9d90a340	https://rcpc.awsapps.com/workdocs/index.html#/folder/6876af510d7b0907e5f4646503a78871c0d611ba5bd72a38eaf8f5fb9d90a340	Block [Class] Team Meetings & Assessments [Element]
Complete PEPDS System Model Version 1 Draft 0.5	FY21	FY21 Q4	2021/09/15	Define stakeholder needs, black box problem domain behavior, black box problem domain structure, black box problem domain parameters.	PEPDS System Model Version 1 Draft 0.5		[ref 107]	M. Steurer, "PEPDS Architectures 2021 ONR PEPDS Program Review", Amazon Work Docs, Oct 2021. [Online] Available: https://rcpc.awsapps.com/workdocs/index.html#/document/02567c6e794df6a594bcd802489ac0019a7aed0f0c413a574e97720fc3f88be0	https://rcpc.awsapps.com/workdocs/index.html#/document/02567c6e794df6a594bcd802489ac0019a7aed0f0c413a574e97720fc3f88be0	Block [Class] Milestone [Element]
2021 PEPDS Risk Reduction	FY22	FY22 Q1	2021/10/14 - 2021/10/15	Each university presents their PEPDS	Presentations	Virtual	[ref 107]	M. Steurer, "PEPDS Architectures 2021 ONR PEPDS	https://rcpc.awsapps.com/workdocs/index.htm	Block [Class] ONR Event [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
Program Review				work. FSU CAPS SysEng Team presented PEPDS System Model.				Program Review", Amazon Work Docs, Oct 2021. [Online] Available: https://rcpc.awsapps.com/workdocs/index.html#/document/02567c6e794df6a594bcd802489ac0019a7aed0f0c413a574e97720fc3f88be0	l#/document/02567c6e794df6a594bcd802489ac0019a7aed0f0c413a574e97720fc3f88be0	
Engine as a Weapon International Symposium IX"	FY22	FY22 Q1	2021/11/15-17	Publish and present on: The Fundamental Shift in US Navy Warship Power and Energy System Design	Presentation and Paper	Virtual	[ref 95]	S. P. Markle, M. E. Steurer M, D. C. Gross, M. D. Bosworth, E. S. Ammeen, J. M. Voth, "The Fundamental Shift in US Navy Warship Power and Energy System Design", in Int. Maritime Eng. Sci. and Technol. (IMarEST) Engine as a Weapon (EAAW) Int. Symp. IX, Virtual, Nov 2021, doi: 10.24868/issn.2515-8171.2021.003 Available: https://www.imarest.org/events/category/categories/imarest-learned-	https://www.imarest.org/events/category/categories/imarest-learned-society/engine-as-a-weapon-international-symposium-ix	Block [Class] Conferences, Publications, Etc. [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
								society/engine-as-a-weapon-international-symposium-ix		
Publish "Power Electronic Power Distribution Systems (PEPDS) - Plan"	FY22	FY22 Q2	2022/01/21	PEPDS plan released to public	PEPDS White Paper		[ref 24]	L. Petersen, C. Schegan, T. S. Ericsen, D. Boroyevich, R. Burgos, N. G. Hingorani, M. Steurer, J. Chalfant, H. Ginn, C. DiMarino, G. C. Montanari, F. Z. Peng, C. Chryssostomidis, C. Cooke, and I. Cvetkovic, “Power Electronic Power Distribution Systems (PEPDS),” Electric Ship Research & Development Consortium, USA, 2020. [Online]. Available: https://www.esrdc.com/library/pepds-plan/	https://www.esrdc.com/library/pepds-plan/	Block [Class] Conferences, Publications, Etc. [Element]
Complete PEPDS System Model Version 1 Draft 1	FY22	FY22 Q3	2022/05/30	Defined stakeholder needs, problem domain behavior, problem	PEPDS System Model Version 1 Draft 1		[ref 104]	C. Araujo, D. C. Gross, S. Hussain, S. Song, "PEPDS System Requirements Review" Amazon Work Docs, June	https://rcpc.awsapps.com/workdocs/index.html#/document/ec66a6fc17bebea1c0	Block [Class] Milestone [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				domain structure, and problem domain parameters. Developed S1 system requirements.				2022, [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/ec66a6fc17bebea1c09823bb259889b5124082806a625b9afd4462ceeb7030c2	9823bb259889b5124082806a625b9afd4462ceeb7030c2	
PEPDS Architecture Team Meeting for PEPDS System Model SRR Part 1	FY22	FY22 Q3	2022/06/02	Perform PEPDS System Requirements Review Part 1	Presentation, Meeting Recording	Virtual	[ref 104]	C. Araujo, D. C. Gross, S. Hussain, S. Song, "PEPDS System Requirements Review" Amazon Work Docs, June 2022, [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/ec66a6fc17bebea1c09823bb259889b5124082806a625b9afd4462ceeb7030c2	https://rcpc.awsapps.com/workdocs/index.html#/document/ec66a6fc17bebea1c09823bb259889b5124082806a625b9afd4462ceeb7030c2	Block [Class] Team Meetings & Assessments [Element]
PEPDS Architecture Team Meeting for PEPDS System Model SRR Part 2	FY22	FY22 Q3	2022/06/09	Perform PEPDS System Requirements Review Part 2	Presentation, Meeting Recording	Virtual	[ref 104]	C. Araujo, D. C. Gross, S. Hussain, S. Song, "PEPDS System Requirements Review" Amazon Work Docs, June 2022, [Online]. Available: https://rcpc.awsapp	https://rcpc.awsapps.com/workdocs/index.html#/document/ec66a6fc17bebea1c09823bb259889b51240 82806a625	Block [Class] Team Meetings & Assessments [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
								s.com/workdocs/index.html#/document/ec66a6fc17bebea1c09823bb259889b5124082806a625b9afd4462ceeb7030c2	b9afd4462ceeb7030c2	
2022 ASNE Advanced Machinery Technology Symposium	FY22	FY22 Q4	2022/07/20 - 2022/07/21 with 2022/07/20 Presentation	Presented on: Development of a Functional Architecture for a Power Electronics Based Power Distribution System (PEPDS)	Presentation and Video Recording in Technical Track 1 (1240-1400): Power Electronics	Philadelphia, PA	[ref 71]	S. Song, C. Araujo, J. Bell, D. Gross, S. Hussain, M. Steurer, "Development of a Functional Architecture for a Power Electronics Based Power Distribution System (PEPDS)," Proc. Advanced Machinery Technology Symposium 2022, Philadelphia, PA, Jul. 2022. [Online]. Available: https://www.navalengineers.org/Symposia/AMTS2022/VideoProceeding. [Accessed: 22-Nov-2022].	https://www.navalengineers.org/Symposia/AMTS2022/VideoProceeding	Block [Class] Conferences, Publications, Etc. [Element]
Complete PEPDS System Model Version 1 Draft 2	FY23	FY23 Q1	2022/10/04	Baselined problem domain. Baselined S1 system	PEPDS System Model Version 1 Draft 2		[ref 109]	PEPDS Team "2022 PEPDS Program Review Presentations", Amazon Work Docs, Oct 2022.	https://rcpc.awsapps.com/workdocs/index.html#/document/4e42907f	Block [Class] Milestone [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				requirements.				[Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/4e42907f650bca60458dc5662ee21f906b2940e32bbd24278c917888c7bc1093	650bca60458dc5662ee21f906b2940e32bbd24278c917888c7bc1093	
2022 PEPDS Risk Reduction Program Review	FY23	FY23 Q1	2022/10/27 - 2022/10/28	Each university presents their PEPDS work. FSU CAPS SysEng Team presented PEPDS System Model.	Presentations	FSU CAPS	[ref 109]	PEPDS Team "2022 PEPDS Program Review Presentations", Amazon Work Docs, Oct 2022. [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/4e42907f650bca60458dc5662ee21f906b2940e32bbd24278c917888c7bc1093	https://rcpc.awsapps.com/workdocs/index.html#/document/4e42907f650bca60458dc5662ee21f906b2940e32bbd24278c917888c7bc1093	Block [Class] ONR Event [Element]
Complete PEPDS System Model Version 1 Draft 3	FY23	FY23 Q2	2023/03/10	Refined problem domain and S1 system requirements. Refactored the PEPDS System Model by improving	PEPDS System Model Version 1 Draft 3		[ref 103]	C. Araujo, D. Gross, M. Steurer, S. Song and C. Schegan, "Baselining a Functional Architecture for a Power Electronic Power Distribution System for Navy Vessels," 2023	https://ieeexplore.ieee.org/document/10220545	Block [Class] Milestone [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				the use of trace relationships and traceability matrices. Refactored the PEPDS System Model for improved usability and extension.				IEEE Electric Ship Technologies Symposium (ESTS), Alexandria, VA, USA, 2023, pp. 10-18, doi: 10.1109/ESTS56571.2023.10220545. [Online]. Available: https://ieeexplore.ieee.org/document/10220545		
Complete PEPDS System Model Version 1.0 and Accompanying Technical Report	FY23	FY23 Q2	2023/03/24	Performed minor edits to diagrams as needed. Wrote technical report.	PEPDS System Model Version 1.0 and Technical Report		[ref 96]	C. E. Araujo, D. C. Gross, M. Steurer, N. Ali. "Power Electronic Power Distribution System Architectures," FSU Center For Advanced Power Systems, Tallahassee, FL, USA, Jun. 20, 2023. [Online]. Available: https://www.esrdc.com/library/power-electronic-power-distribution-system-architectures-pepds/	https://www.esrdc.com/library/power-electronic-power-distribution-system-architectures-pepds/	Block [Class] Milestone [Element]
Publish PEPDS System Model	FY23	FY23 Q3	2023/06/20	Published Technical Report.	Technical Report		[ref 96]	C. E. Araujo, D. C. Gross, M. Steurer, N. Ali. "Power	https://www.esrdc.com/library/p	Block [Class] Conferences,

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
Version 1.0 Technical Report				PEPDS System Model mdzip file not published because no standardized distro A clearance process for Cameo files at the time.				Electronic Power Distribution System Architectures," FSU Center For Advanced Power Systems, Tallahassee, FL, USA, Jun. 20, 2023. [Online]. Available: https://www.esrdc.com/library/power-electronic-power-distribution-system-architectures-pepds/	ower-electronic-power-distribution-system-architectures-pepds/	Publications, Etc. [Element]
2023 IEEE Electric Ship Technologies Symposium	FY23	FY23 Q4	2023/08/01 - 2023/08/04 2023/08/02 Presentation on PEPDS	Publish and present 4 PEPDS Architecture Team papers and give MBSE Tutorial	Presentations and Papers	Old Town Alexandria, VA	[ref 97] [ref 99] [ref 102] [ref 103]	"R. Siddaiah, R. M. Cuzner, C. Sailabada, J. Ordonez, N. Rajagopal, C DiMarino, A. Chatterjee, J. Chalfant, ""Virtual Prototyping Process: Enabling Shipboard Sizing and Arrangement of a Power Electronics Power Distribution System,"" 2023 IEEE Electric Ship Technologies Symposium	"https://ieeexplore.ieee.org/document/10220481	Block [Class] Conferences, Publications, Etc. [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
								(ESTS), Alexandria, VA, USA, 2023, pp. 19-28, doi: 10.1109/ESTS56571.2023.10220481. [Online] Available: https://ieeexplore.ieee.org/document/10220481		
Aug 2023 ESRDC General Meeting	FY23	FY23 Q4	2023/08/17 - 2023/08/18	ESRDC members discuss their work. FSU CAPS SysEng Team presented on the PEPDS System Model and the PEPDS Technical Candidate Proposal Approach.	Presentations	MIT		H. L. Atchison, D. A. Wetz, A. N. Johnston, and S. T. Scoggin, “Empirically Based Energy Storage Sizing,” in 2023 IEEE Electric Ship Technologies Symposium (ESTS), Aug. 2023, pp. 52–57. doi: 10.1109/ESTS56571.2023.10220466. [Online]. Available: https://ieeexplore.ieee.org/document/10220466	https://ieeexplore.ieee.org/document/10220466	Block [Class] ESRDC Event [Element]
2023 Controls Program Review	FY23	FY23 Q4	2023/09/07 - 2023/09/08	FSU CAPS SysEng Team attended to participate in PEPDS Technical	Presentations	UWM	[ref 110]	R. M. Cuzner, D. C. Gross, R. Siddaiah, J. Chalfant, M. Steurer and N. Ali, ""Determining Parameter	https://ieeexplore.ieee.org/document/10220562	Block [Class] ONR Event [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				Candidate Proposal preparation discussion. Presentation was prepared but they were unable to present due to time constraints.				Objectives via Model-Based Engineering,"" 2023 IEEE Electric Ship Technologies Symposium (ESTS), Alexandria, VA, USA, 2023, pp. 274-283, doi: 10.1109/ESTS56571.2023.10220562. [Online]. Available: https://ieeexplore.ieee.org/document/10220562		
2023 MVDC Risk Reduction Program Review	FY23	FY23 Q4	2023/09/21 - 2023/09/22	FSU CAPS SysEng Team attended to participate in PEPDS Technical Candidate Proposal preparation discussion. They presented on the PEPDS System Model and the PEPDS Technical Candidate Proposal Approach.	Presentations	UTA	[ref 111]	C. Araujo, D. Gross, M. Steurer, S. Song and C. Schegan, ""Baselining a Functional Architecture for a Power Electronic Power Distribution System for Navy Vessels,"" 2023 IEEE Electric Ship Technologies Symposium (ESTS), Alexandria, VA, USA, 2023, pp. 10-18, doi: 10.1109/ESTS56571.2023.10220545. [Online].	https://ieeexplore.ieee.org/document/10220545"	Block [Class] ONR Event [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
								Available: https://ieeexplore.ieee.org/document/10220545 "		
Sept 2023 ESRDC Board of Directors Meeting	FY23	FY23 Q4	2023/09/28	Each ESRDC member university presents on FY24 Plans. FSU CAPS SysEng Team presented on PEPDS System Model development plans.	Presentations	FSU CAPS				Block [Class] ESRDC Event [Element]
Complete PEPDS System Model Version 2 Draft 1	FY23	FY23 Q4	2023/09/29	Refined problem domain based on model gaps identified in Mini-PEPDS Design Exercise Iteration 1. Defined point solution from the results of the Mini-PEPDS	PEPDS System Model Version 2 Draft 1		[ref 108]	"Controls Program Review Presentations", Amazon Work Docs, Sept 2023. [Online] Available: https://rcpc.awsapps.com/workdocs/index.html#/document/e09d3b53ef88ba0a4ed61788dcb51450222b13f28fb8ae1cb72848102b989f30	https://rcpc.awsapps.com/workdocs/index.html#/document/e09d3b53ef88ba0a4ed61788dcb51450222b13f28fb8ae1cb72848102b989f30	Block [Class] Milestone [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				Design Exercise Iteration 1. Defined data exchange interfaces between PEPDS System Model and external tools. Refactored the PEPDS System Model by improving the use of trace relationships. Refactored the PEPDS System Model for improved usability and extension.						
2023 PEPDS Risk Reduction Program Review	FY24	FY24 Q1	2023/10/25 - 2023/10/27	Each university presents their PEPDS work. FSU CAPS SysEng Team presented PEPDS	Presentations	USC	[ref 108]	"MVDC Program Review Presentations", Amazon Work Docs, Sept 2023. [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/docume	https://rcpc.awsapps.com/workdocs/index.html#/document/39b858e6bb4653a7e0b5e1764b592f5453cbee8cfd2ff	Block [Class] ONR Event [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				System Model. Participated in PEPDS Technical Candidate Proposal brainstorming session.				nt/39b858e6bb4653a7e0b5e1764b592f5453cbee8cfd2ff594037ebfec33e7d3ee	594037ebfec33e7d3ee	
Complete PEPDS TRA & RA Version 1 Draft 1	FY24	FY24 Q1	2023/11/21	Technology readiness assessment performed on PEPDS critical technology elements. Risk assessment performed within the scope of CTEs reaching needed TRL for successful PEPDS TC.	Technology Readiness Assessment, Risk Assessment					Block [Class] Team Meetings & Assessments [Element]
2023 Electromagnetic Interference S&T Review	FY24	FY24 Q1	2023/11/29 - 2023/11/30	Each university presents EMI issues. FSU CAPS SysEng Team participated in discussion	Presentations	VT CPES		PEPDS Team "2023 PEPDS Program Review Presentations", Amazon Work Docs, Oct 2023. [Online]. Available: https://rcpc.awsapp	https://rcpc.awsapps.com/workdocs/index.html#/document/b04a1c6375d5c78dd5dcfdd281eb701d2eec	Block [Class] ONR Event [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				and lead discussion on PEPDS System Model and PEPDS Technical Candidate Proposal Approach.				s.com/workdocs/index.html#/document/b04a1c6375d5c78dd5dcfdd281eb701d2eec9b052fcbf2730d951ccbc96a2017	9b052fcbf2730d951ccbc96a2017	
Complete PEPDS System Model Version 2 Draft 2	FY24	FY24 Q1	2023/12/20	Refined problem domain. Refactored the PEPDS System Model by implementing tracing methodology. Refactored the PEPDS System Model for improved usability and extension.	PEPDS System Model Version 2 Draft 2		IEEE Transactions on Transportation Electrification Special Issue on Electrified Ship Technologies	PEPDS Team "2023 PEPDS Program Review Presentations", Amazon Work Docs, Oct 2023. [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/b04a1c6375d5c78dd5dcfdd281eb701d2eec9b052fcbf2730d951ccbc96a2017	https://rcpc.awsapps.com/workdocs/index.html#/document/b04a1c6375d5c78dd5dcfdd281eb701d2eec9b052fcbf2730d951ccbc96a2017	Block [Class] Milestone [Element]
Complete PEPDS TRA Version 1 Draft 2	FY24	FY24 Q2	2024/01/08	Technology readiness assessment performed on PEPDS critical technology elements. Performed	Technology Readiness Assessment					Block [Class] Team Meetings & Assessments [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
				in support of PEPDS TC Proposal.						
Complete PEPDS RA Version 1 Draft 2	FY24		2024/01/22	Risk assessment performed on technical risks related to the PEPDS critical technology elements. Performed in support of PEPDS TC Proposal.	Risk Assessment, Risk Mitigation Strategy					Block [Class] Team Meetings & Assessments [Element]
Complete PEPDS TRA & RA Version 1	FY24	FY24 Q2	2024/02/22	Technology readiness assessment performed on PEPDS critical technology elements. Risk assessment performed within the scope of CTEs reaching needed TRL for successful PEPDS TC.	Technology Readiness Assessment, Risk Assessment, Risk Mitigation Strategy		[ref 113]			Block [Class] Team Meetings & Assessments [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
Complete PEPDS TC Proposal and Submit to ONR	FY24	FY24 Q2	2024/02/23	Completed and submitted proposal to ONR for PEPDS Technical Candidate.	PEPDS TC Proposal		[ref 112]			Block [Class] Milestone [Element]
Apr 2024 ESRDC General Meeting	FY24	FY24 Q3	2024/04/25 - 2024/04/26	ESRDC members discuss their work. FSU CAPS SysEng Team presented on PEPDS and the PEPDS System Model.	Presentations	Virtual (MSU Lead)				Block [Class] ESRDC Event [Element]
IEEE Transactions on Transportation Electrification Special Issue on Electrified Ship Technologies	Upcoming	FY24 Q4	2024/11/X		Paper			PEPDS Team "PEPDS TC Proposal TRA & RA Results Final" [Online] Available: https://rcpc.awsapps.com/workdocs/index.html#/document/7c2bc0d083568d9d6ad3dfd4044aa333cba0ace0c46b7ec84b2fa4beb89a4adc	https://rcpc.awsapps.com/workdocs/index.html#/document/7c2bc0d083568d9d6ad3dfd4044aa333cba0ace0c46b7ec84b2fa4beb89a4adc	Block [Class] Conferences, Publications, Etc. [Element]
Complete PEPDS System Model Version 2.0	Upcoming	FY24 Qx	2024/X	Baselined Refine relationships in problem	PEPDS System Model Version			"PEPDS Technical Candidate Proposal Select Slides" Feb 2024 [Online].	https://rcpc.awsapps.com/workdocs/index.htm	Block [Class] Milestone [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
and Technical Report				domain. Baselined Refine and DeriveReq relationships between problem domain and S1 system requirements. Utilized traceability matrices and tracing tables to simplify review of relationships. Standardized diagram formatting to improve usability and readability. Baselined Mini-PEPDS Design Exercise iteration 1 phase 1.	2.0 and Technical Report			Available: https://rcpc.awsapps.com/workdocs/index.html#/document/9d1ed2e3cde3692ca794710ab3f5396170c6f9a8b98027a24a0224fad18a4a93	l#/document/9d1ed2e3cde3692ca794710ab3f5396170c6f9a8b98027a24a0224fad18a4a93	
Publish PEPDS System Model Version 2.0	Upcoming	FY24 Qx	2024/X							Block [Class] Conferences, Publications, Etc. [Element]

Name	Fiscal Year	Fiscal Year & Quarter	Date	Description	Product	Location	Traced Item	Reference	Link	Stereotype
Technical Report										

Table XXVI: Appendix F1.2 System Model Versions

Product	Completion Date	Description	Reviewed In/At	Traced Item
PEPDS System Model Cameo File	2021/07/21	Start building PEPDS System Model using Cameo Enterprise Architecture software following the MagicGrid Framework.		A. Aleksandravičienė and A. Morkevičius, MagicGrid® Book of Knowledge: A Practical Guide to Systems Modeling using MagicGrid from No Magic, Kaunas, Lithuania: Vitae Litera, 2018.
PEPDS System Model Version 1 Draft 0.5	2021/09/15	Define stakeholder needs, black box problem domain behavior, black box problem domain structure, black box problem domain parameters.	2021 PEPDS Program Review	M. Steurer, "PEPDS Architectures 2021 ONR PEPDS Program Review", Amazon Work Docs, Oct 2021. [Online] Available: https://rcpc.awsapps.com/workdocs/index.html#/document/02567c6e794df6a594bcd802489ac0019a7aed0f0c413a574e97720fc3f88be0
PEPDS System Model Version 1 Draft 1	2022/05/30	Defined stakeholder needs, problem domain behavior, problem domain structure, and problem domain parameters. Developed S1 system requirements.	June 2022 SRR	C. Araujo, D. C. Gross, S. Hussain, S. Song, "PEPDS System Requirements Review" Amazon Work Docs, June 2022, [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/ec66a6fc17bebea1c09823bb259889b5124082806a625b9afd4462ceeb7030c2
PEPDS System Model Version 1 Draft 2	2022/10/04	Baselined problem domain. Baselined S1 system requirements.	2022 PEPDS Program Review	PEPDS Team "2022 PEPDS Program Review Presentations", Amazon Work Docs, Oct 2022. [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/4e42907f650bca60458dc5662ee21f906b2940e32bbd24278c917888c7bc1093
PEPDS System Model Version 1 Draft 3	2023/03/10	Refined problem domain and S1 system requirements. Refactored the PEPDS System Model by improving the use of trace relationships and traceability matrices. Refactored the PEPDS System Model for improved usability and extension.	2023 ESTS Paper	C. Araujo, D. Gross, M. Steurer, S. Song and C. Schegan, "Baselining a Functional Architecture for a Power Electronic Power Distribution System for Navy Vessels," 2023 IEEE Electric Ship Technologies Symposium (ESTS), Alexandria, VA, USA, 2023, pp. 10-18, doi: 10.1109/ESTS56571.2023.10220545. [Online]. Available: https://ieeexplore.ieee.org/document/10220545
PEPDS System Model Version 1.0 and Technical Report	2023/03/24	Performed minor edits to diagrams as needed. Wrote technical report.	PEPDS System Model Version 1.0 Technical Report	C. E. Araujo, D. C. Gross, M. Steurer, N. Ali. "Power Electronic Power Distribution System Architectures," FSU Center For Advanced Power Systems, Tallahassee, FL, USA, Jun. 20, 2023. [Online]. Available:

Product	Completion Date	Description	Reviewed In/At	Traced Item
				https://www.esrdc.com/library/power-electronic-power-distribution-system-architectures-pepds/
PEPDS System Model Version 2 Draft 1	2023/09/29	Refined problem domain based on model gaps identified in Mini-PEPDS Design Exercise Iteration 1. Defined point solution from the results of the Mini-PEPDS Design Exercise Iteration 1. Defined data exchange interfaces between PEPDS System Model and external tools. Refactored the PEPDS System Model by improving the use of trace relationships. Refactored the PEPDS System Model for improved usability and extension.	2023 PEPDS Program Review	PEPDS Team "2023 PEPDS Program Review Presentations", Amazon Work Docs, Oct 2023. [Online]. Available: https://rcpc.awsapps.com/workdocs/index.html#/document/b04a1c6375d5c78dd5dcfdd281eb701d2eec9b052fcbf2730d951ccbc96a2017
PEPDS System Model Version 2 Draft 2	2023/12/20	Refined problem domain. Refactored the PEPDS System Model by implementing tracing methodology. Refactored the PEPDS System Model for improved usability and extension.	2024 TTE Special Issue Paper	
PEPDS System Model Version 2.0 and Technical Report	2024/X	Baselined Refine relationships in problem domain. Baselined Refine and DeriveReq relationships between problem domain and S1 system requirements. Utilized traceability matrices and tracing tables to simplify review of relationships. Standardized diagram formatting to improve usability and readability. Baselined Mini-PEPDS Design Exercise iteration 1 phase 1.	PEPDS System Model Version 2.0 Technical Report	

Table XXVII: Appendix F2.1 Tasks and Problem Areas

Owner	Annotated Element	Body	To Do
1 Problem Domain	1 Problem Domain	Need to utilize implied relations throughout problem domain	Version 3 task
3 Exchange Items	3 Exchange Items	Is tracing complete? Compare with diagrams that use the exchange items. Should refine relationships be added?	On hold
Appendix F Schedule and Tasks		Conform to standards	On hold
Appendix F Schedule and Tasks		Define trade study approach in PEPDS system model	Version 3 task
Appendix F Schedule and Tasks		Elaborate on supportability - defining scenarios	Version 3 task
Appendix F Schedule and Tasks		Elaborate on supportability - Failure Modes Effects and Criticality Analysis (FMECA)	Version 3 task
Appendix F Schedule and Tasks		Elaborate on supportability - model resiliency	Version 3 task
Appendix F Schedule and Tasks		Elaborate verification for solutions	On Hold
Appendix F Schedule and Tasks		Refactor PEPDS System Model to increase accuracy of SysML execution and prepare for simulation within Cameo software	Ongoing
Appendix I1 Archived W2.2.1 PEPDS Failure Examples		1 Differentiate Internal and External Failures. 2. Add failures at terminal. (Inter-zonal faults/failure) (Damage failures) 3. Differentiate between instant events and emergent failures over time. 4. Boundary cases of failures in response to external malicious impacts and system's internal response to it. 5. Create a Hierarchy of failures. 6. Define Failures (internal) and Faults (External event/Malicious). 7. Fault triggers a loss of capability (off-nominal state).	Part of FMECA in Version 3
Appendix I1 Archived W2.2.1 PEPDS Failure Examples		Build a hierarchy.	Part of FMECA in Version 3
Appendix J Data Exchange	Appendix J Data Exchange	Establish connection to external tools	Ongoing
Appendix J Data Exchange	Appendix J Data Exchange	Establish connection to external tools - MATLAB Simulink	Ongoing
Appendix J Data Exchange	Appendix J Data Exchange	Establish connection to external tools - Python	Ongoing

Owner	Annotated Element	Body	To Do
Appendix J Data Exchange	Appendix J Data Exchange	Establish connection to external tools - S3D	Ongoing
Appendix J Data Exchange	Appendix J Data Exchange	Establish connection to virtual prototyping framework	Ongoing
Appendix J Data Exchange	Appendix J Data Exchange	Investigate external tools that need to connect to PEPDS System Model	Ongoing
Appendix J.2 Research Tools	in Digital Twin implementations code =	Elaborate	On hold
Appendix K-Mini PEPDS Design Exercise Plan	Appendix K1.3 Improve System Model Activities	Needs Revision	Version 3 task
B1 Stakeholder Needs	B1 Stakeholder Needs Table	Needs updated as needed based on tracing results. Should reconsider names of stakeholder needs. Needs reviewed and re-baselined.	Version 3 task
B1 Stakeholder Needs	Appendix B Bibliography	Trace innovative stakeholder needs to references	Version 3 task
B2 Use Cases	B2.3 Operate PEPDS Scenario	How can this be improved?	Version 3 task
B2.1 PEPDS Use Cases	Maintain PEPDS	Missing elaboration	Version 3 task
B2.1 PEPDS Use Cases	5.1 Ease of Installation as a Unit B2.1 PEPDS Use Cases	Should ShipAlt and shipyard be added into the use cases?	Version 3 task
B2.1 PEPDS Use Cases	Replace LRUs	Should this be changed to maintaining hardware?	Version 3 task
B2.1 PEPDS Use Cases	Program	Should this be changed to maintaining software?	Version 3 task
B2.1 PEPDS Use Cases	3.3 Controllable	Elaborate and clarify	Version 3 task
B4 Measurements of Effectiveness	B4 Measures of Effectiveness Tracing	How can we show implied refine requirement text? Need to utilize implied relationships to reduce human error opportunities.	Version 3 task
B4 Measurements of Effectiveness	B4 Measurements of Effectiveness W4 Measurements of Performance	Needs revised based on Mini-PEPDS and SME input	Version 3 task
B4 Measurements of Effectiveness	B4 PEPDS MoEs W4 Measurements of Performance	Use threshold and objective rather than goal	Version 3 task
Cold Plate Cooling System	S3.3.7 Cold Plate Cooling System	Possible components. Design in progress.	Version 3 task
Mini-PEPDS Design	S3.3.1 High-Level Solution Architecture	Need to consider dielectric standoff allocation IEC 61800-5	Version 3 task
Mini-PEPDS Design	S3.3.1 High-Level Solution Architecture	Need to elaborate on maintenance. Need value property for maintenance access.	Version 3 task

Owner	Annotated Element	Body	To Do
PEPDS Research Tools	energy Sizing Tool : 9 System Model Appendix::Appendix J Data Exchange::Appendix J.2 Research Tools::Energy Sizing Tool (UTA)	Dr. Cuzner's email about no input required from Energy Sizing for the first iteration of Mini-PEPDS if only a single Power Train is to be implemented.	Version 3 task
W2.1.1 Control Information	W2.1.1.3 Execute CBM+:W2.1.1.3 Execute CBM+	Reassess approach. Should this be in protection? Lacks clarity.	Version 3 task
W4 Measurements of Performance	Threshold = 0.995 Goal = 1.0	Check RAM-C	Version 3 task
W4 Measurements of Performance	Resiliency	Incorrect Placement Reliability nominal Resiliency is off nominal	Version 3 task
W4 Measurements of Performance	W4 Measurements of Performance	Look for MoPs here https://ieeexplore.ieee.org/document/10220472 J. C. Ordonez, C. Sailabada, J. Chalfant, C. Chryssostomidis, C. Li, K. Luo, E. Santi, B. Tian, A. Biglo, N. Rajagopal, J. Stewart, C. DiMarino. "Thermal Management Approaches for Power Electronic Building Blocks and Power Corridors," 2023 IEEE Electric Ship Technologies Symposium (ESTS), Alexandria, VA, USA, 2023, pp. 418-426, doi: 10.1109/ESTS56571.2023.10220472.	Potential MOPs per JPB: Thermal Management MOP: Heat dissipation (pg. 2 fig. 3). (Appears to be the highest level while still a quantified, relevant value)
W4 Measurements of Performance		New formatting needs implemented onto other MoPs. Will be addressed in PEPDS System Model Version 3. Postponed to Version 3 because significant work will be done on other MoPs including additions, deletions, re-categorizations, and re-defining.	Version 3 task
W4 Measurements of Performance	W4 Measurements of Performance	Watch https://www.youtube.com/watch?v=NPRqmScSYTA	On hold

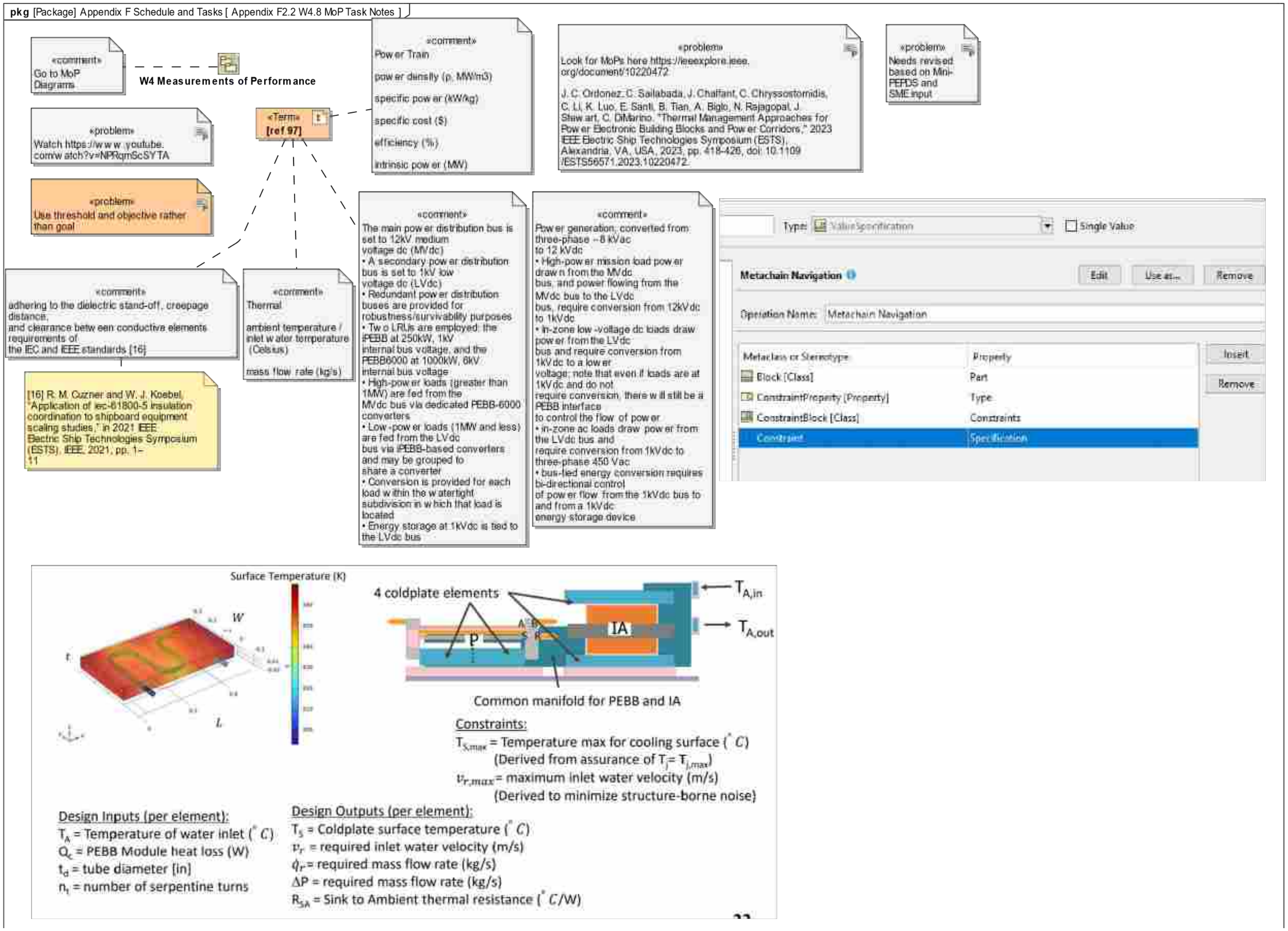

Fig. 90: Appendix F2.2 W4.8 MoP Task Notes

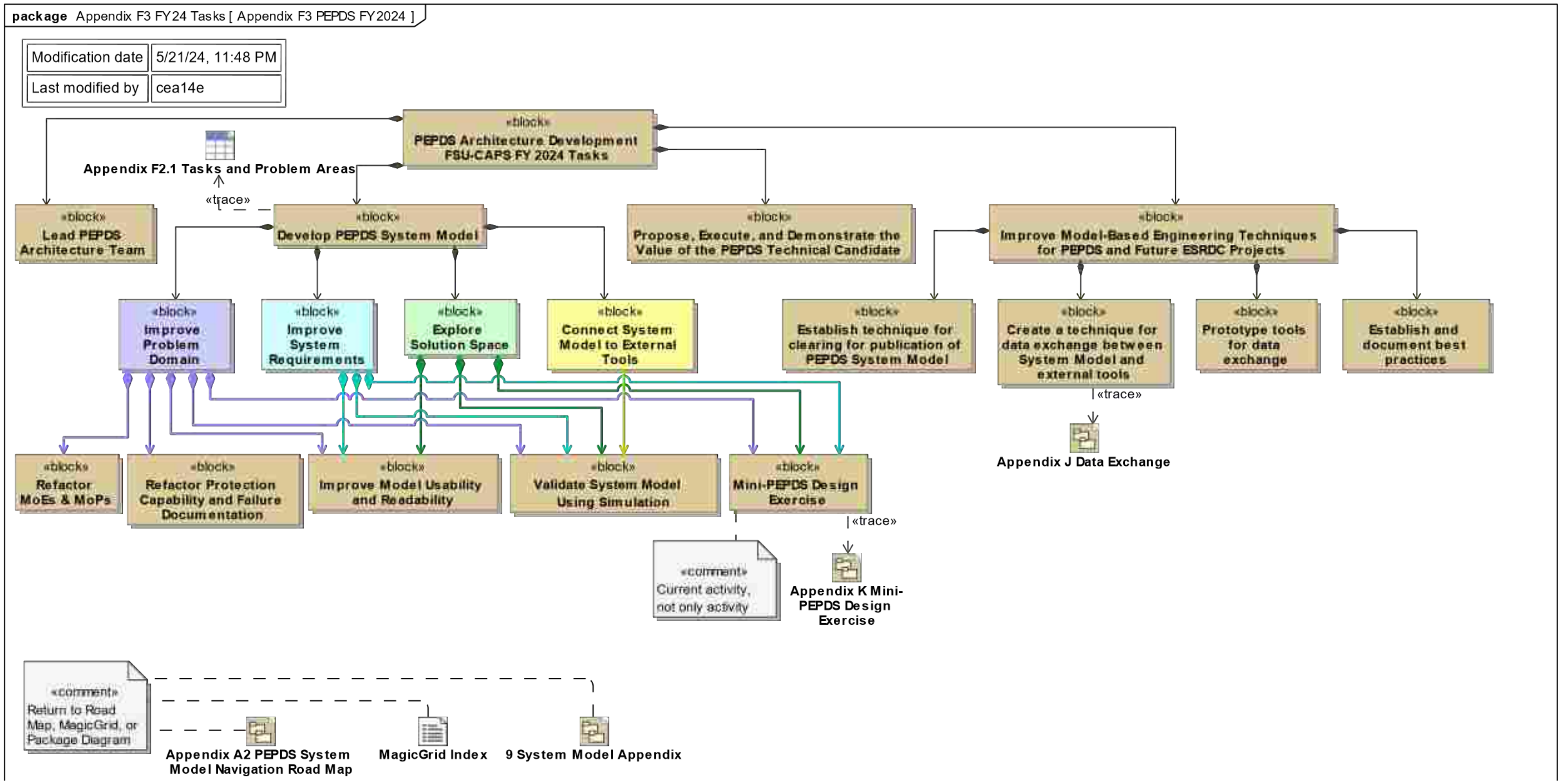

Fig. 91: Appendix F3 PEPDS FY2024

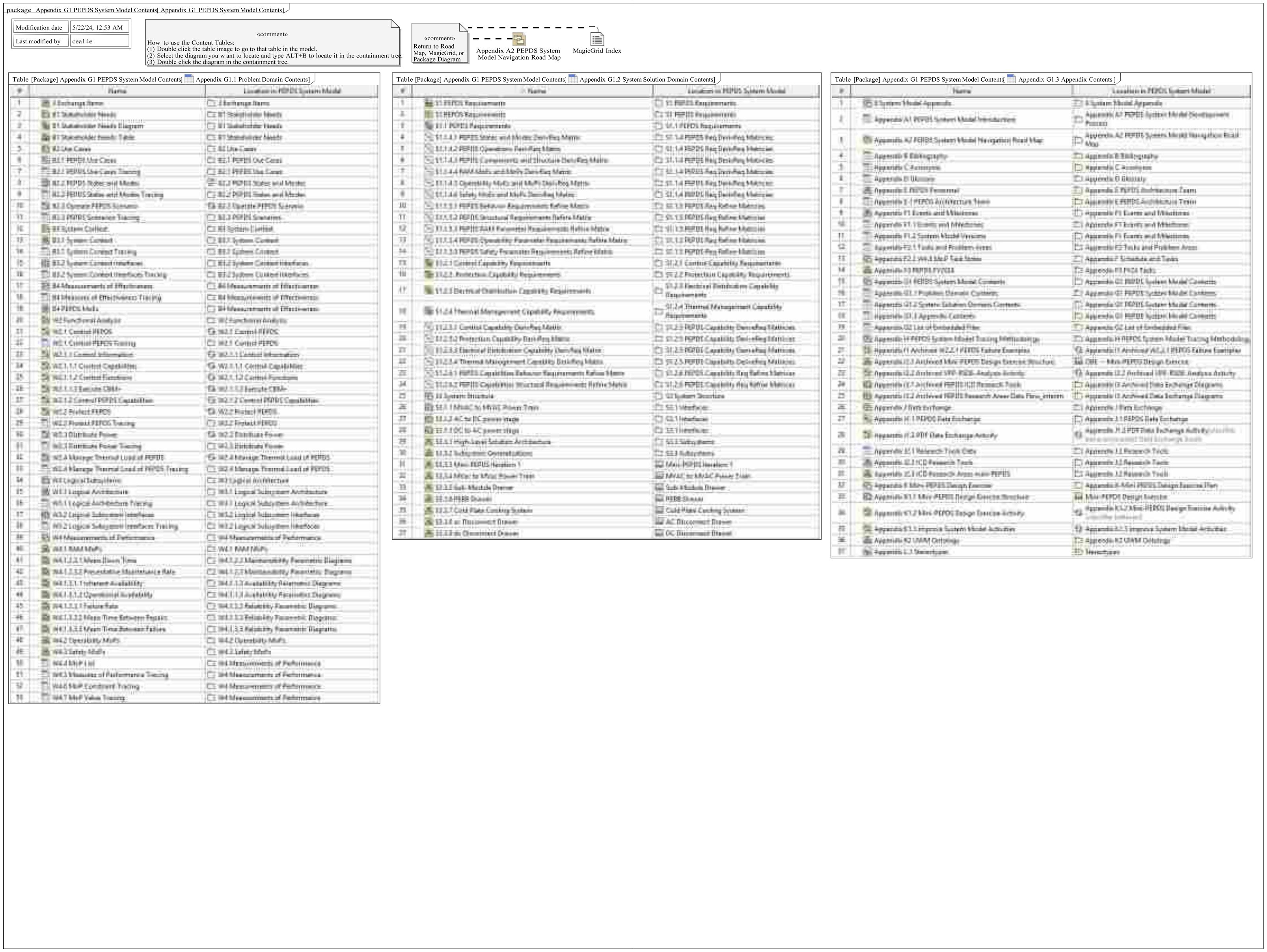

Fig. 92: Appendix G1 PEPDS System Model Contents

Table XXVIII: Appendix G1.1 Problem Domain Contents

Name	Location in PEPDS System Model
3 Exchange Items	3 Exchange Items
B1 Stakeholder Needs	B1 Stakeholder Needs
B1 Stakeholder Needs Diagram	B1 Stakeholder Needs
B1 Stakeholder Needs Table	B1 Stakeholder Needs
B2 Use Cases	B2 Use Cases
B2.1 PEPDS Use Cases	B2.1 PEPDS Use Cases
B2.1 PEPDS Use Cases Tracing	B2.1 PEPDS Use Cases
B2.2 PEPDS States and Modes	B2.2 PEPDS States and Modes
B2.2 PEPDS States and Modes Tracing	B2.2 PEPDS States and Modes
B2.3 Operate PEPDS Scenario	B2.3 Operate PEPDS Scenario
B2.3 PEPDS Scenarios Tracing	B2.3 PEPDS Scenarios
B3 System Context	B3 System Context
B3.1 System Context	B3.1 System Context
B3.1 System Context Tracing	B3.1 System Context
B3.2 System Context Interfaces	B3.2 System Context Interfaces
B3.2 System Context Interfaces Tracing	B3.2 System Context Interfaces
B4 Measurements of Effectiveness	B4 Measurements of Effectiveness
B4 Measures of Effectiveness Tracing	B4 Measurements of Effectiveness
B4 PEPDS MoEs	B4 Measurements of Effectiveness
W2 Functional Analysis	W2 Functional Analysis
W2.1 Control PEPDS	W2.1 Control PEPDS
W2.1 Control PEPDS Tracing	W2.1 Control PEPDS
W2.1.1 Control Information	W2.1.1 Control Information
W2.1.1.1 Control Capabilities	W2.1.1.1 Control Capabilities
W2.1.1.2 Control Functions	W2.1.1.2 Control Functions
W2.1.1.3 Execute CBM+	W2.1.1.3 Execute CBM+
W2.1.2 Control PEPDS Capabilities	W2.1.2 Control PEPDS Capabilities
W2.2 Protect PEPDS	W2.2 Protect PEPDS
W2.2 Protect PEPDS Tracing	W2.2 Protect PEPDS
W2.3 Distribute Power	W2.3 Distribute Power
W2.3 Distribute Power Tracing	W2.3 Distribute Power
W2.4 Manage Thermal Load of PEPDS	W2.4 Manage Thermal Load of PEPDS
W2.4 Manage Thermal Load of PEPDS Tracing	W2.4 Manage Thermal Load of PEPDS
W3 Logical Subsystems	W3 Logical Architecture
W3.1 Logical Architecture	W3.1 Logical Subsystem Architecture

Name	Location in PEPDS System Model
W3.1 Logical Architecture Tracing	W3.1 Logical Subsystem Architecture
W3.2 Logical Subsystem Interfaces	W3.2 Logical Subsystem Interfaces
W3.2 Logical Subsystem Interfaces Tracing	W3.2 Logical Subsystem Interfaces
W4 Measurements of Performance	W4 Measurements of Performance
W4.1 RAM MoPs	W4.1 RAM MoPs
W4.1.2.3.1 Mean Down Time	W4.1.2.3 Maintainability Parametric Diagrams
W4.1.2.3.2 Preventative Maintenance Rate	W4.1.2.3 Maintainability Parametric Diagrams
W4.1.3.1.1 Inherent Availability	W4.1.1.3 Availability Parametric Diagrams
W4.1.3.1.2 Operational Availability	W4.1.1.3 Availability Parametric Diagrams
W4.1.3.3.1 Failure Rate	W4.1.3.3 Reliability Parametric Diagrams
W4.1.3.3.2 Mean Time Between Repairs	W4.1.3.3 Reliability Parametric Diagrams
W4.1.3.3.3 Mean Time Between Failure	W4.1.3.3 Reliability Parametric Diagrams
W4.2 Operability MoPs	W4.2 Operability MoPs
W4.3 Safety MoPs	W4.3 Safety MoPs
W4.4 MoP List	W4 Measurements of Performance
W4.5 Measures of Performance Tracing	W4 Measurements of Performance
W4.6 MoP Constraint Tracing	W4 Measurements of Performance
W4.7 MoP Value Tracing	W4 Measurements of Performance

Table XXIX: Appendix G1.2 System Solution Domain Contents

Name	Location in PEPDS System Model
S1 PEPDS Requirements	S1 PEPDS Requirements
S1 PEPDS Requirements	S1 PEPDS Requirements
S1.1 PEPDS Requirements	S1.1 PEPDS Requirements
S1.1.4.1 PEPDS States and Modes DerivReq Matrix	S1.1.4 PEPDS Req DerivReq Matrices
S1.1.4.2 PEPDS Operations DerivReq Matrix	S1.1.4 PEPDS Req DerivReq Matrices
S1.1.4.3 PEPDS Components and Structure DerivReq Matrix	S1.1.4 PEPDS Req DerivReq Matrices
S1.1.4.4 RAM MoEs and MoPs DerivReq Matrix	S1.1.4 PEPDS Req DerivReq Matrices
S1.1.4.5 Operability MoEs and MoPs DerivReq Matrix	S1.1.4 PEPDS Req DerivReq Matrices
S1.1.4.6 Safety MoEs and MoPs DerivReq Matrix	S1.1.4 PEPDS Req DerivReq Matrices
S1.1.5.1 PEPDS Behavior Requirements Refine Matrix	S1.1.5 PEPDS Req Refine Matrices
S1.1.5.2 PEPDS Structural Requirements Refine Matrix	S1.1.5 PEPDS Req Refine Matrices
S1.1.5.3 PEPDS RAM Parameter Requirements Refine Matrix	S1.1.5 PEPDS Req Refine Matrices
S1.1.5.4 PEPDS Operability Parameter Requirements Refine Matrix	S1.1.5 PEPDS Req Refine Matrices
S1.1.5.5 PEPDS Safety Parameter Requirements Refine Matrix	S1.1.5 PEPDS Req Refine Matrices
S1.2.1 Control Capability Requirements	S1.2.1 Control Capability Requirements
S1.2.2. Protection Capability Requirements	S1.2.2 Protection Capability Requirements
S1.2.3 Electrical Distribution Capability Requirements	S1.2.3 Electrical Distribution Capability Requirements
S1.2.4 Thermal Management Capability Requirements	S1.2.4 Thermal Management Capability Requirements
S1.2.5.1 Control Capability DerivReq Matrix	S1.2.5 PEPDS Capability DeriveReq Matrices
S1.2.5.2 Protection Capability DerivReq Matrix	S1.2.5 PEPDS Capability DeriveReq Matrices
S1.2.5.3 Electrical Distribution Capability DerivReq Matrix	S1.2.5 PEPDS Capability DeriveReq Matrices
S1.2.5.4 Thermal Management Capability DerivReq Matrix	S1.2.5 PEPDS Capability DeriveReq Matrices
S1.2.6.1 PEPDS Capabilities Behavior Requirements Refine Matrix	S1.2.6 PEPDS Capability Req Refine Matrices
S1.2.6.2 PEPDS Capabilities Structural Requirements Refine Matrix	S1.2.6 PEPDS Capability Req Refine Matrices
S3 System Structure	S3 System Structure
S3.1.1 MVAC to MVAC Power Train	S3.1 Interfaces
S3.1.2 AC to DC power stage	S3.1 Interfaces
S3.1.3 DC to AC power stage	S3.1 Interfaces
S3.3.1 High-Level Solution Architecture	S3.3 Subsystems
S3.3.2 Subsystem Generalizations	S3.3 Subsystems
S3.3.3 Mini-PEPDS Iteration 1	Mini-PEPDS Iteration 1
S3.3.4 MVac to MVac Power Train	MVAC to MVAC Power Train
S3.3.5 Sub-Module Drawer	Sub-Module Drawer
S3.3.6 PEBB Drawer	PEBB Drawer
S3.3.7 Cold Plate Cooling System	Cold Plate Cooling System

Name	Location in PEPDS System Model
S3.3.8 ac Disconnect Drawer	AC Disconnect Drawer
S3.3.9 dc Disconnect Drawer	DC Disconnect Drawer

Table XXX: Appendix G1.3 Appendix Contents

Name	Location in PEPDS System Model
9 System Model Appendix	9 System Model Appendix
Appendix A1 PEPDS System Model Introduction	Appendix A1 PEPDS System Model Development Process
Appendix A2 PEPDS System Model Navigation Road Map	Appendix A2 PEPDS System Model Navigation Road Map
Appendix B Bibliography	Appendix B Bibliography
Appendix C Acronyms	Appendix C Acronyms
Appendix D Glossary	Appendix D Glossary
Appendix E PEPDS Personnel	Appendix E PEPDS Architecture Team
Appendix E.1 PEPDS Architecture Team	Appendix E PEPDS Architecture Team
Appendix F1 Events and Milestones	Appendix F1 Events and Milestones
Appendix F1.1 Events and Milestones	Appendix F1 Events and Milestones
Appendix F1.2 System Model Versions	Appendix F1 Events and Milestones
Appendix F2.1 Tasks and Problem Areas	Appendix F2 Tasks and Problem Areas
Appendix F2.2 W4.8 MoP Task Notes	Appendix F Schedule and Tasks
Appendix F3 PEPDS FY2024	Appendix F3 FY24 Tasks
Appendix G1 PEPDS System Model Contents	Appendix G1 PEPDS System Model Contents
Appendix G1.1 Problem Domain Contents	Appendix G1 PEPDS System Model Contents
Appendix G1.2 System Solution Domain Contents	Appendix G1 PEPDS System Model Contents
Appendix G1.3 Appendix Contents	Appendix G1 PEPDS System Model Contents
Appendix G2 List of Embedded Files	Appendix G2 List of Embedded Files
Appendix H PEPDS System Model Tracing Methodology	Appendix H PEPDS System Model Tracing Methodology
Appendix I1 Archived W2.2.1 PEPDS Failure Examples	Appendix I1 Archived W2.2.1 PEPDS Failure Examples
Appendix I2.1 Archived Mini-PEPDS Design Exercise Structure	OBE -- Mini-PEPDS Design Exercise
Appendix I2.2 Archived VPP-RSDE-Analysis Activity	Appendix I2.2 Archived VPP-RSDE-Analysis Activity
Appendix I3.1 Archived PEPDS ICD Research Tools	Appendix I3 Archived Data Exchange Diagrams
Appendix I3.2 Archived PEPDS Research Areas Data Flow_interim	Appendix I3 Archived Data Exchange Diagrams
Appendix J Data Exchange	Appendix J Data Exchange
Appendix J1.1 PEPDS Data Exchange	Appendix J.1 PEPDS Data Exchange
Appendix J1.2 PDF Data Exchange Activity	Appendix J1.2 PDF Data Exchange Activity(classifier behavior)(context Data Exchange Asset)
Appendix J2.1 Research Tools Data	Appendix J.2 Research Tools
Appendix J2.2 ICD Research Tools	Appendix J.2 Research Tools
Appendix J2.3 ICD Research Areas mini-PEPDS	Appendix J.2 Research Tools
Appendix K Mini-PEPDS Design Exercise	Appendix K-Mini PEPDS Design Exercise Plan
Appendix K1.1 Mini-PEPDS Design Exercise Structure	Mini-PEPDS Design Exercise
Appendix K1.2 Mini-PEPDS Design Exercise Activity	Appendix K1.2 Mini-PEPDS Design Exercise Activity(classifier behavior)

Name	Location in PEPDS System Model
Appendix K1.3 Improve System Model Activities	Appendix K1.3 Improve System Model Activities
Appendix K2 UWM Ontology	Appendix K2 UWM Ontology
Appendix L.1 Stereotypes	Stereotypes

Table XXXI: Appendix G2 List of Embedded Files

Location in PEPDS System Model	Name	Source
Appendix I Archive	Archived Brainstorming & Background Diagrams from PEPDS System Model Version 1.0 DCN# 543-426-23.pdf	Select pages from "C35_0543-426-23_Technical_Report_of_PEPDS_System_Model_Version_1.0.pdf"
Appendix I Archive	Archived Model Changelog from PEPDS System Model Version 1.0 DCN# 543-426-23.pdf	Select pages from "C35_0543-426-23_Technical_Report_of_PEPDS_System_Model_Version_1.0.pdf"
Appendix I Archive	Archived Schedule and Tasks from PEPDS System Model Version 1.0 DCN# 543-426-23.pdf	Select pages from "C35_0543-426-23_Technical_Report_of_PEPDS_System_Model_Version_1.0.pdf"
W2.2 Protect PEPDS	PEPDS FMECA.xlsx	

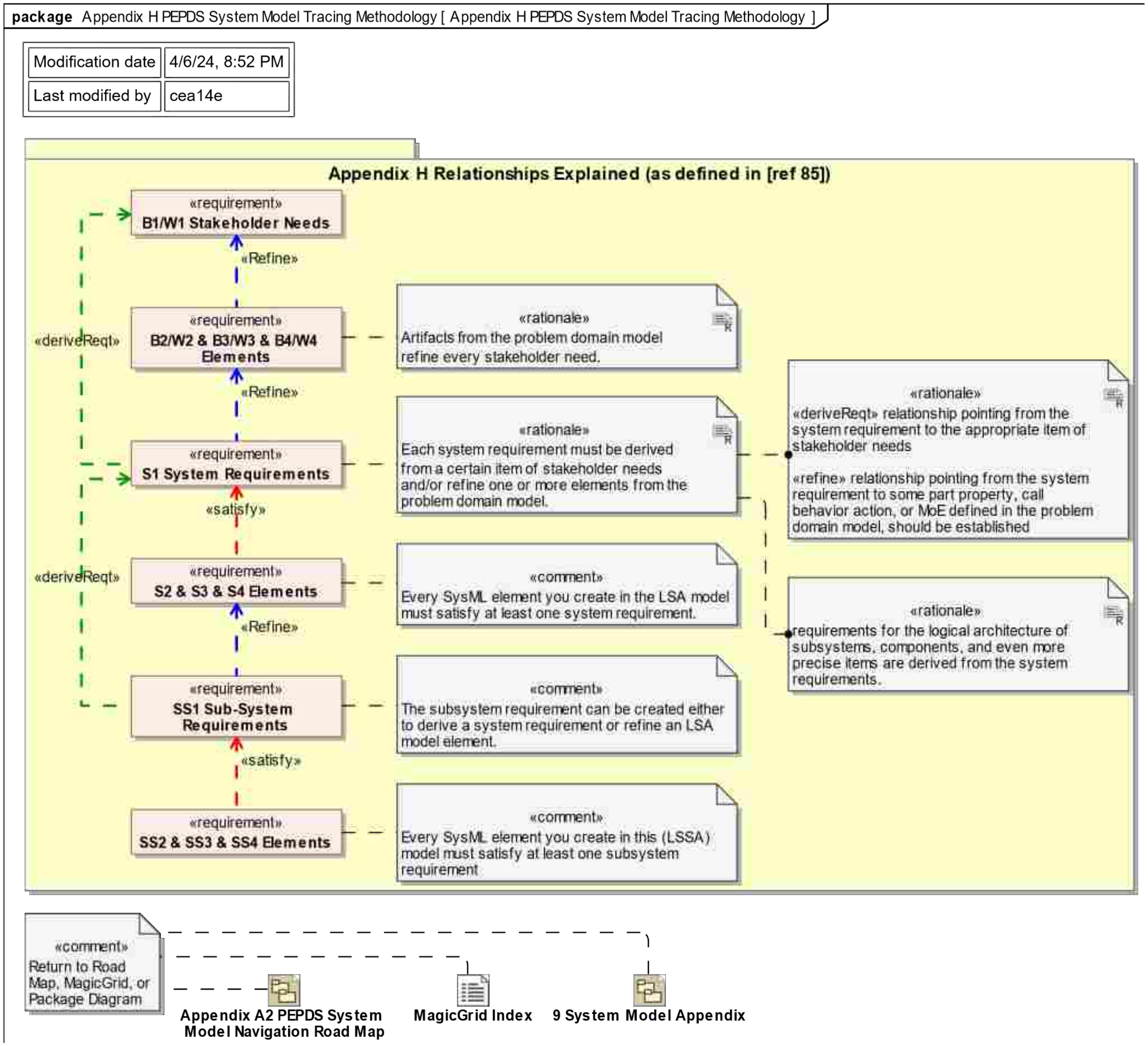

Fig. 93: Appendix H PEPDS System Model Tracing Methodology

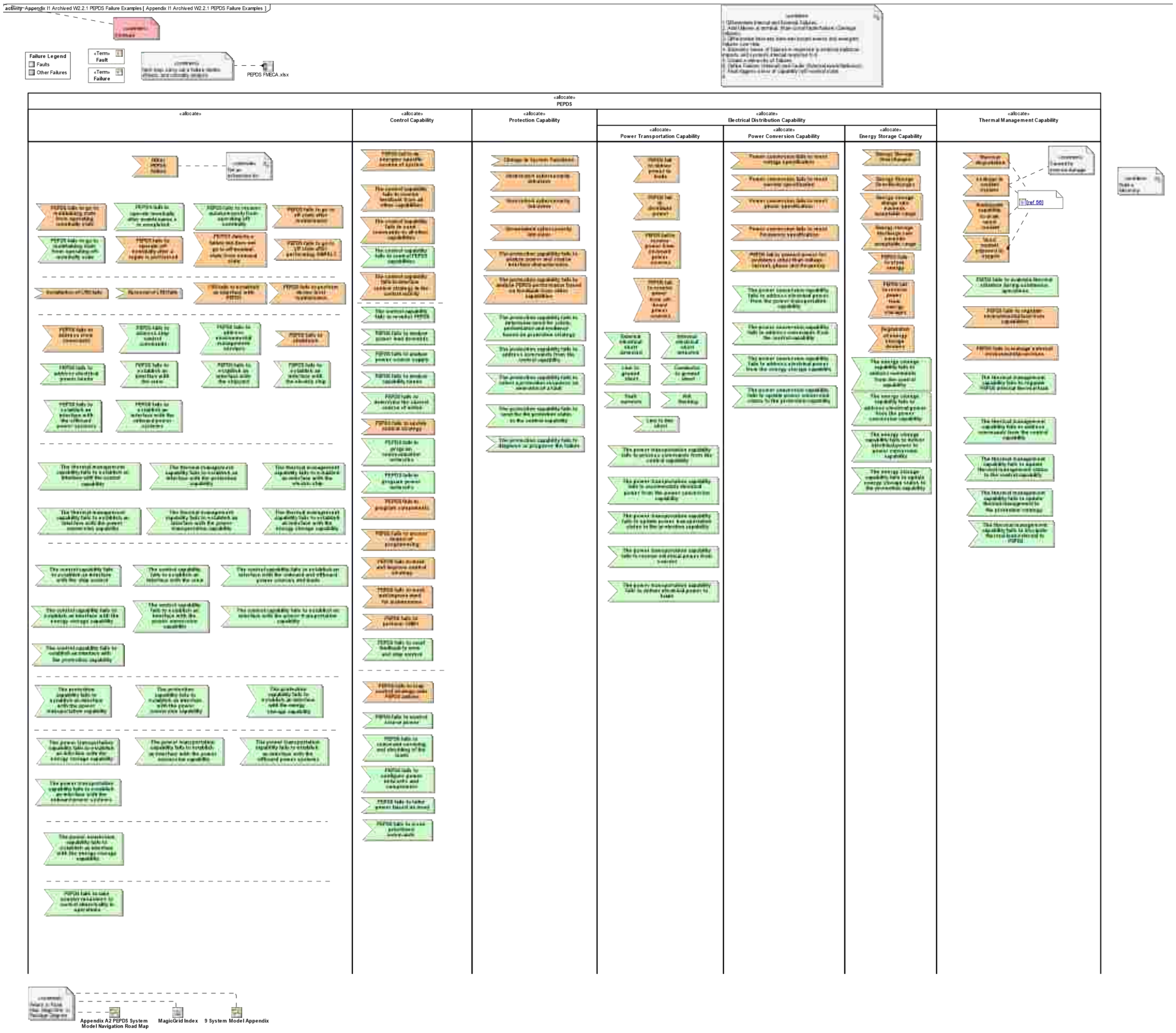

Fig. 94: Appendix I1 Archived W2.2.1 PEPDS Failure Examples

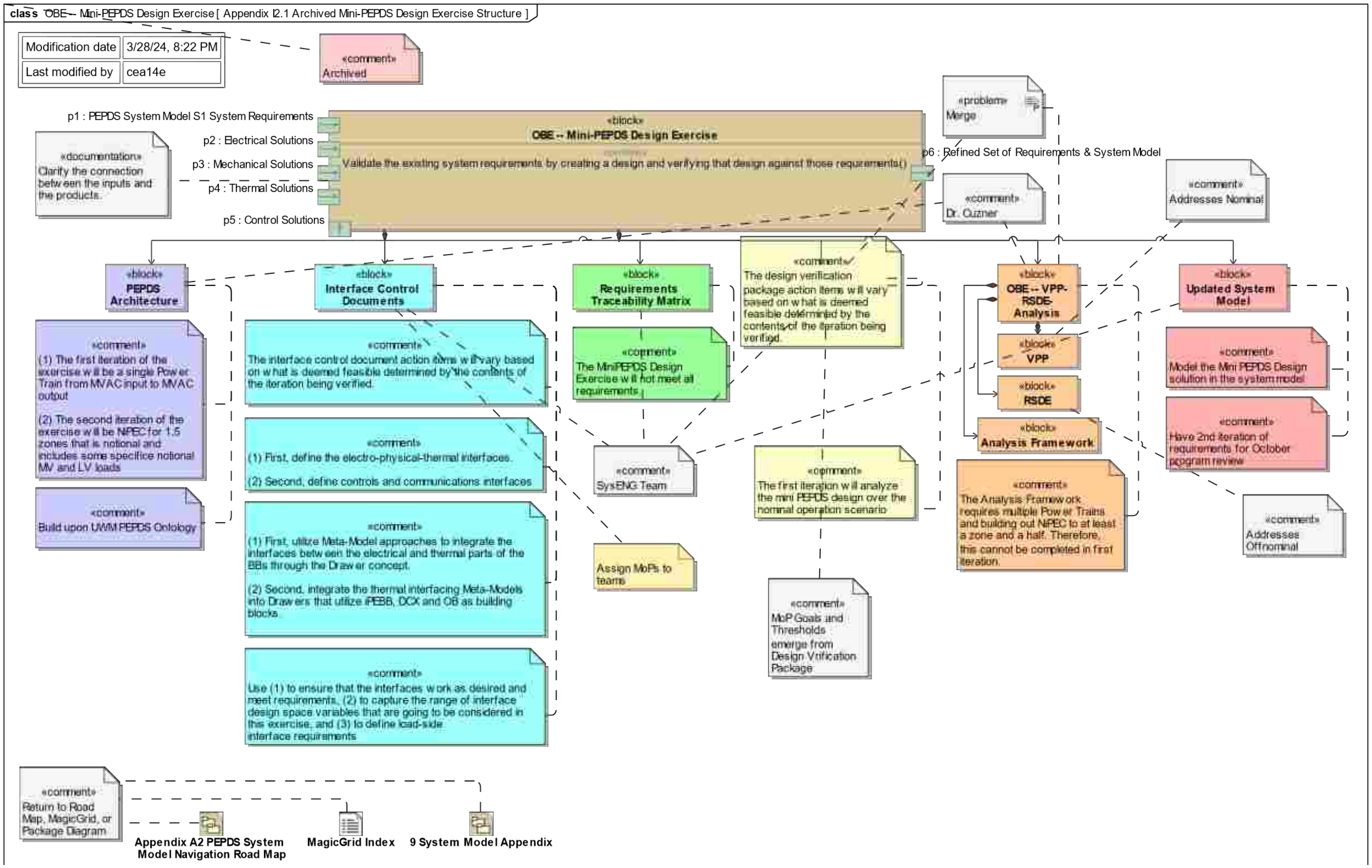

Fig. 95: Appendix I2.1 Archived Mini-PEPDS Design Exercise Structure

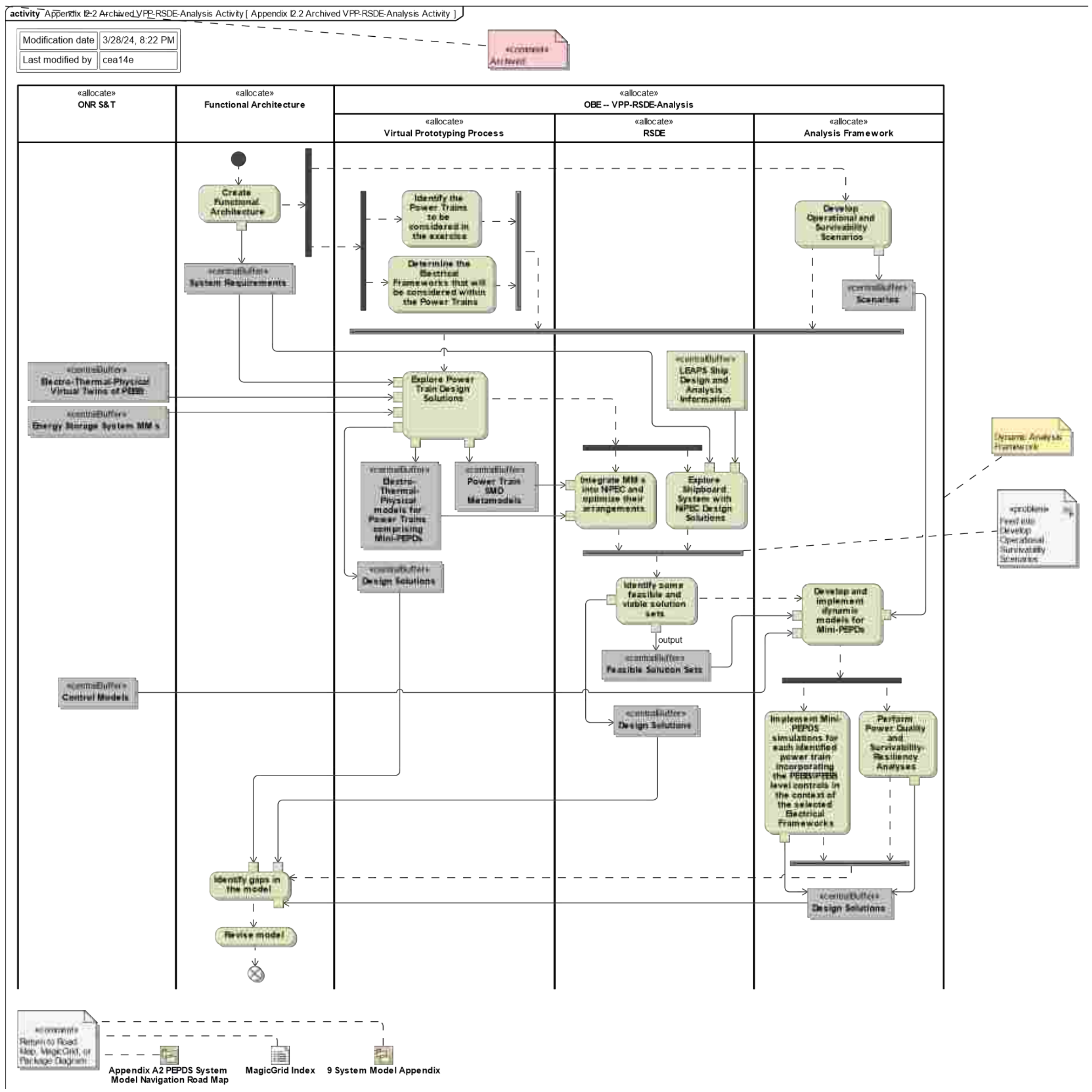

Fig. 96: Appendix I2.2 Archived VPP-RSDE-Analysis Activity

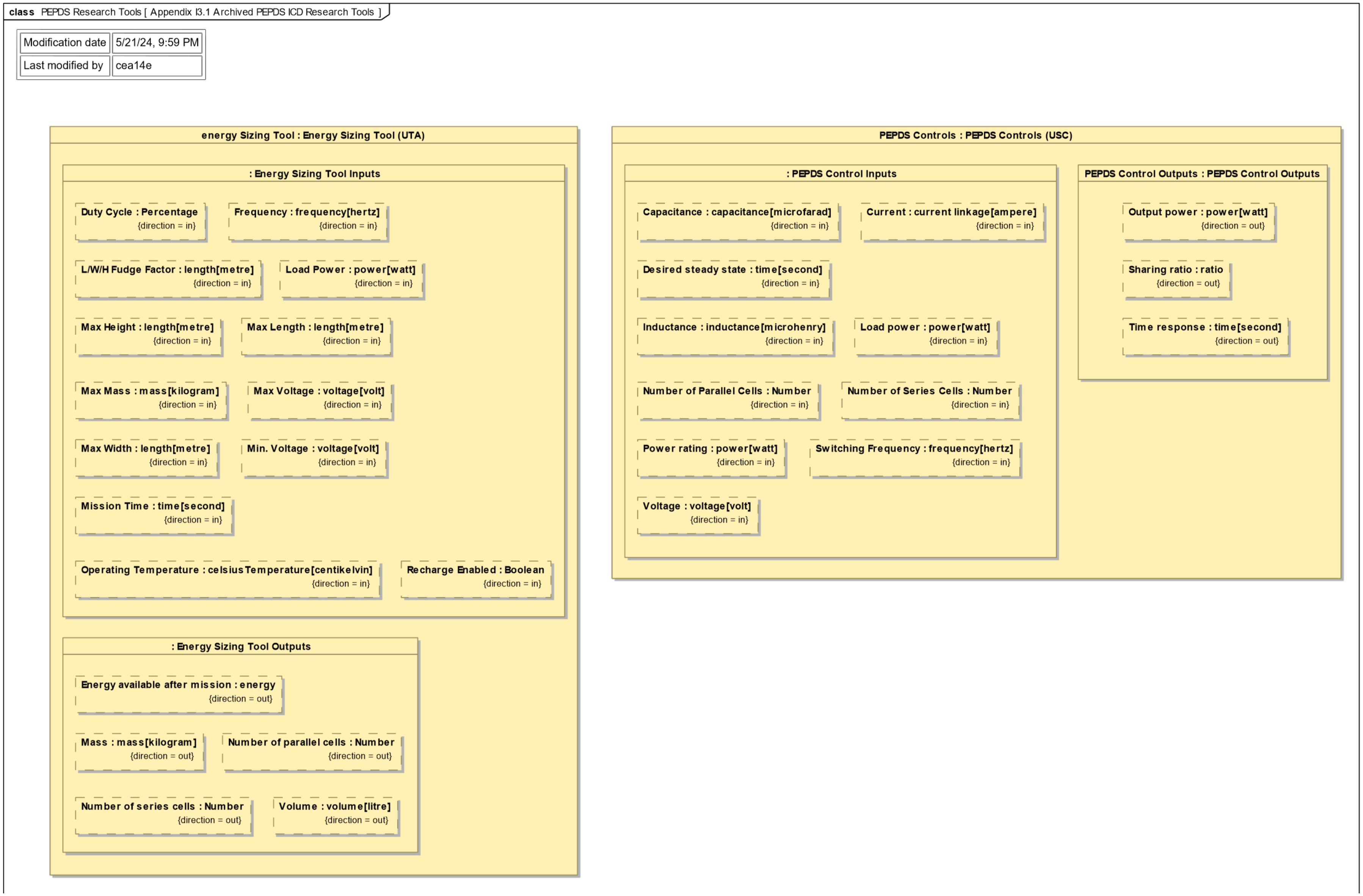

Fig. 97: Appendix I3.1 Archived PEPDS ICD Research Tools

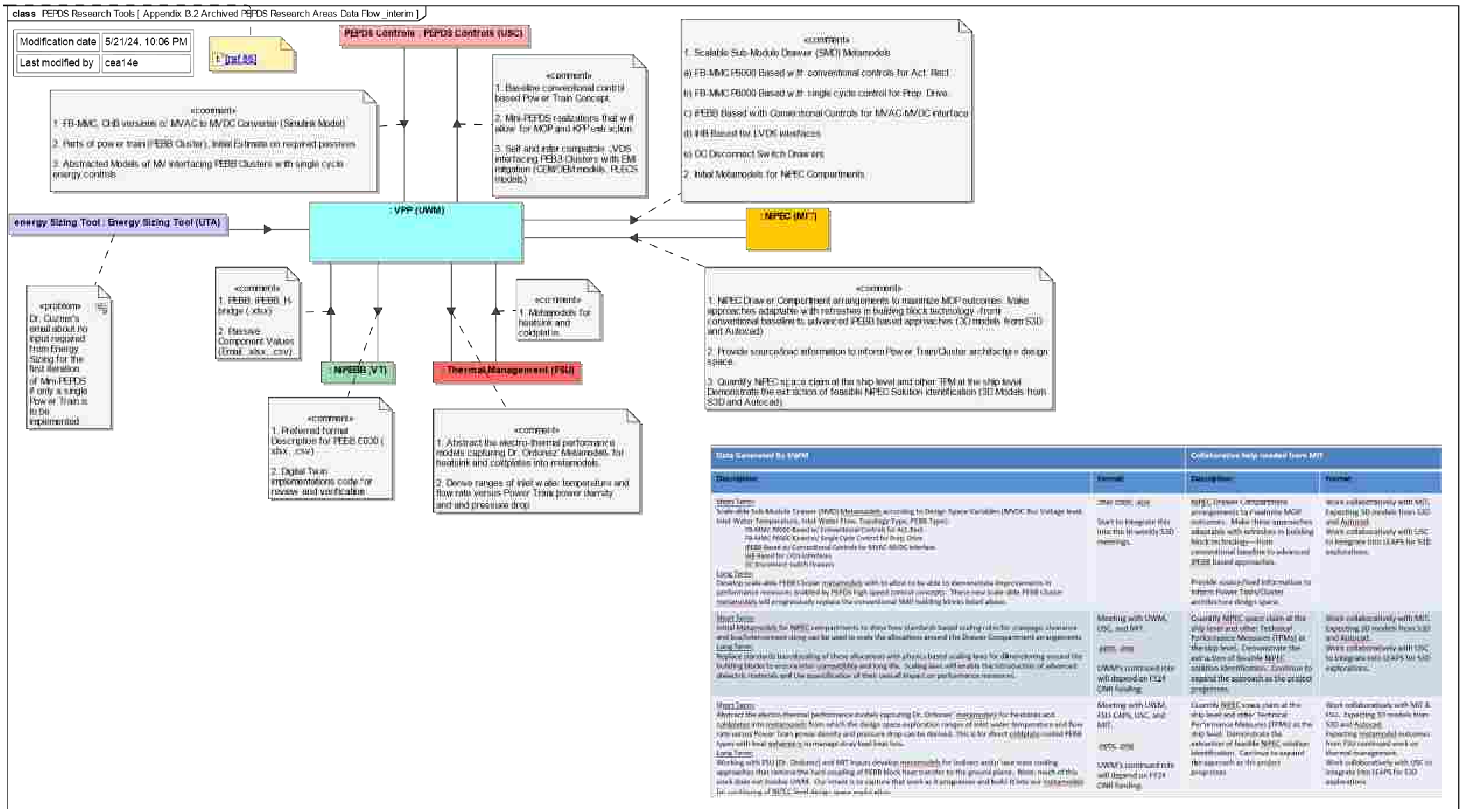

Fig. 98: Appendix I3.2 Archived PEPDS Research Areas Data Flow_interim

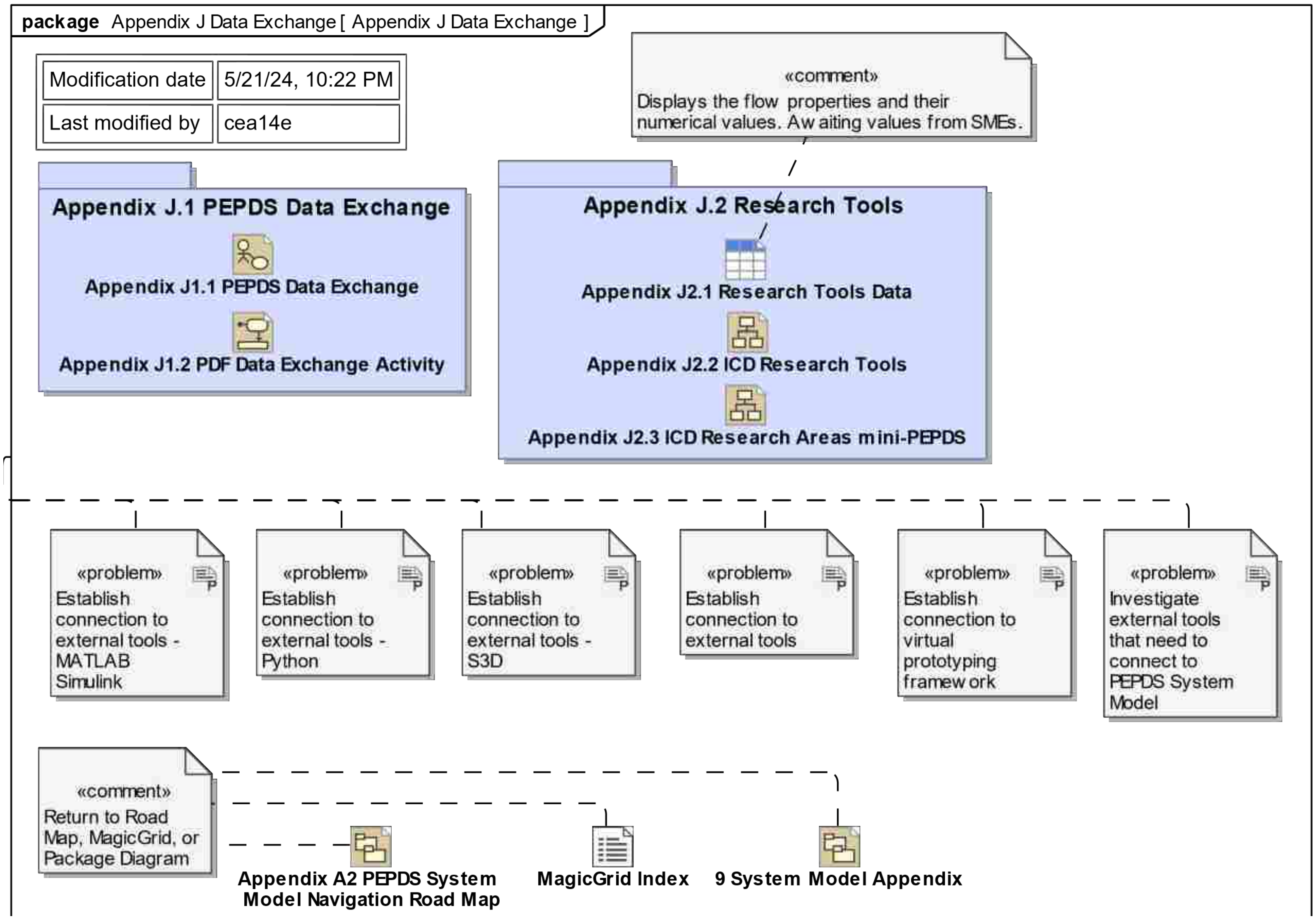

Fig. 99: Appendix J Data Exchange

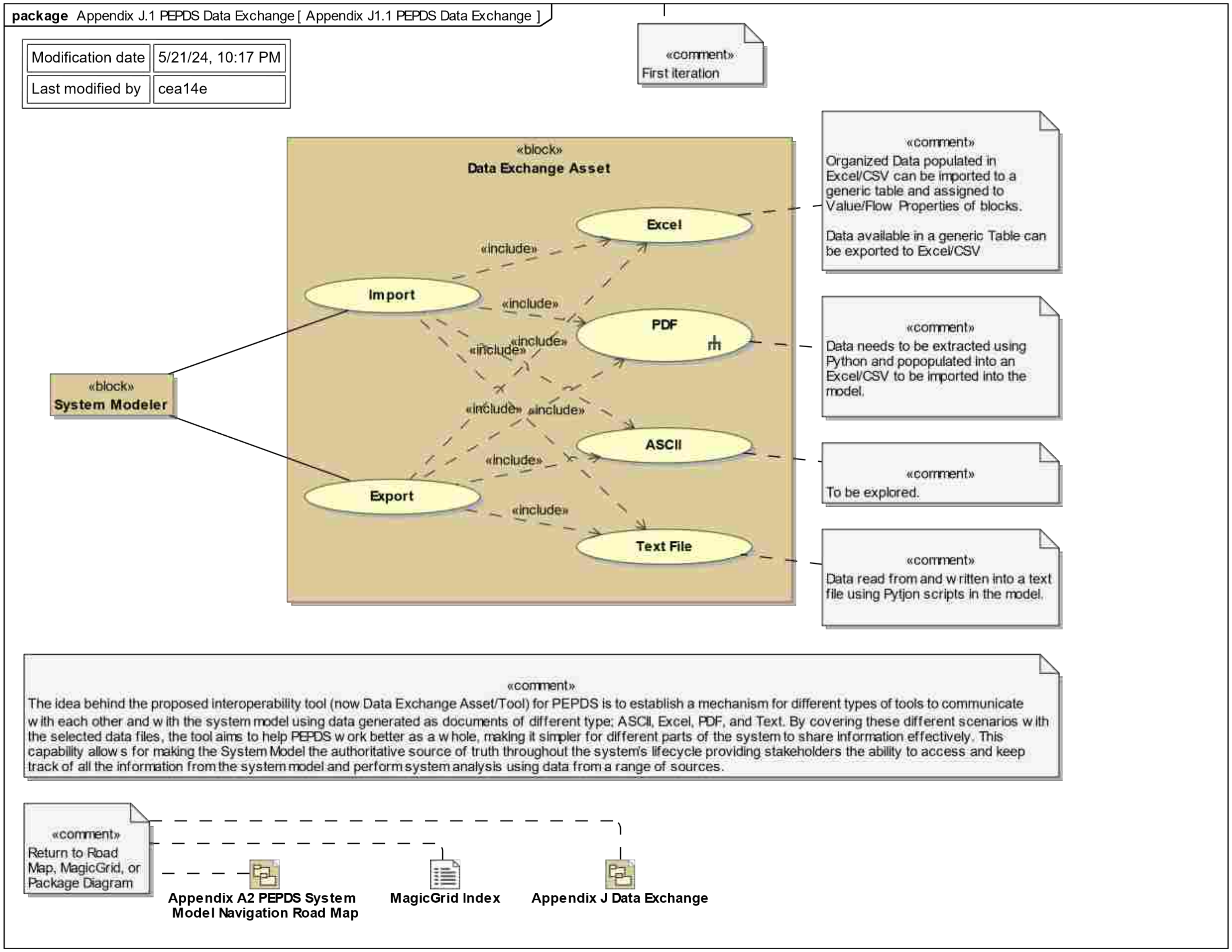

Fig. 100: Appendix J1.1 PEPDS Data Exchange

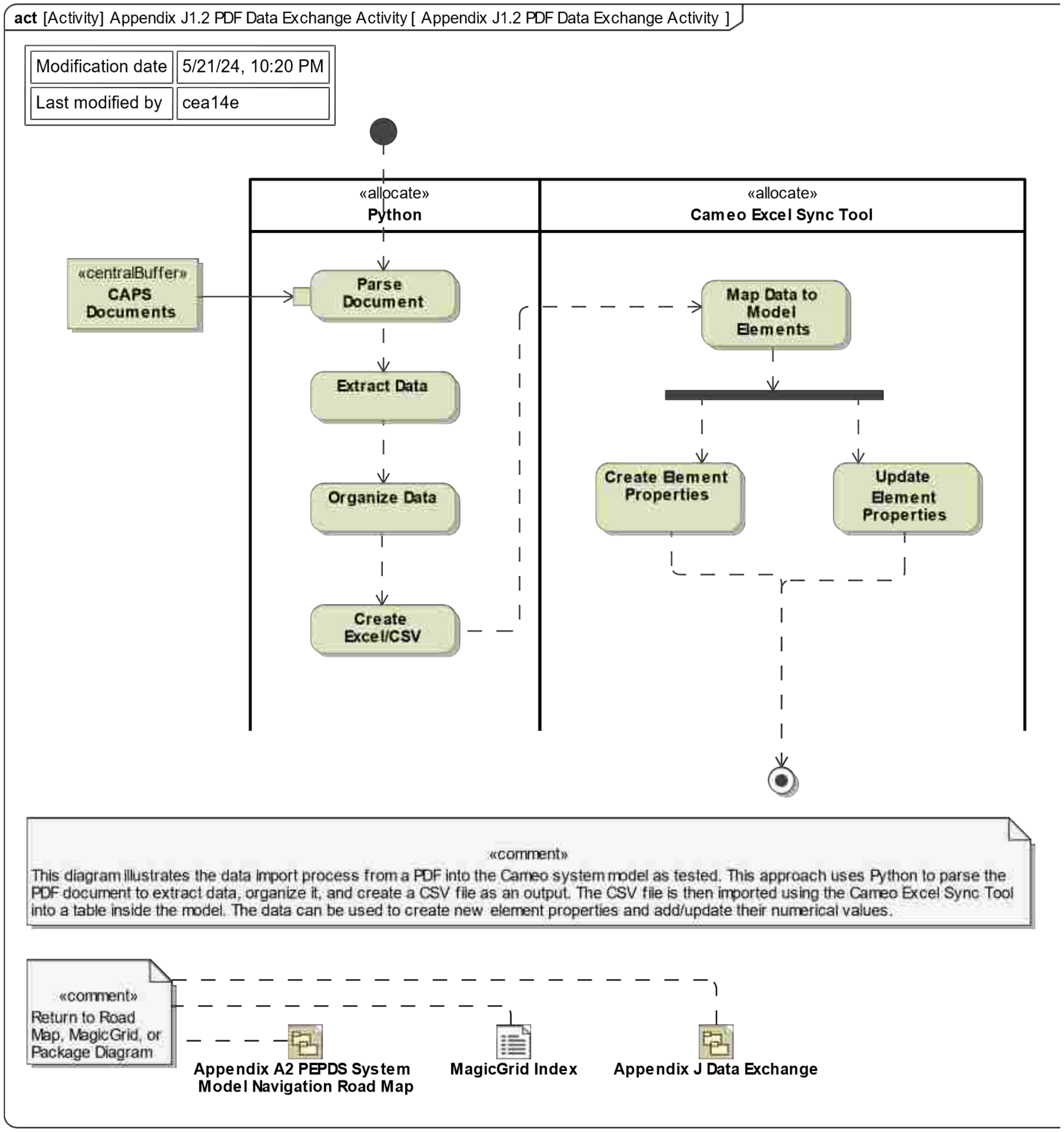

Fig. 101: Appendix J1.2 PDF Data Exchange Activity

Table XXXII: Appendix J2.1 Research Tools Data

Owner	Name	Default Value
Energy Sizing Tool Inputs	Duty Cycle	
Energy Sizing Tool Inputs	Frequency	
Energy Sizing Tool Inputs	L/W/H Fudge Factor	
Energy Sizing Tool Inputs	Load Power	
Energy Sizing Tool Inputs	Max Height	
Energy Sizing Tool Inputs	Max Length	
Energy Sizing Tool Inputs	Max Mass	
Energy Sizing Tool Inputs	Max Voltage	
Energy Sizing Tool Inputs	Max Width	
Energy Sizing Tool Inputs	Min. Voltage	
Energy Sizing Tool Inputs	Mission Time	
Energy Sizing Tool Inputs	Operating Temperature	
Energy Sizing Tool Inputs	Recharge Enabled	false
Energy Sizing Tool Outputs	Energy available after mission	
Energy Sizing Tool Outputs	Mass	
Energy Sizing Tool Outputs	Number of parallel cells	
Energy Sizing Tool Outputs	Number of series cells	
Energy Sizing Tool Outputs	Volume	
NiPEBB	Digital Twin implementations code	
NiPEBB	Preferred format Description for PEBB 6000	
NiPEBB	Passive Component Values	
NiPEBB	PEBB, iPEBB, H-bridge	
NiPEC	Initial Metamodels for NiPEC Compartments.	
NiPEC	Scalable Sub-Module Drawer Metamodels	
NiPEC	NiPEC Drawer Compartment arrangements	
NiPEC	Quantify NiPEC space claim	
NiPEC	source/load information	
PEPDS Control Inputs	Capacitance	
PEPDS Control Inputs	Current	
PEPDS Control Inputs	Desired steady state	
PEPDS Control Inputs	Inductance	
PEPDS Control Inputs	Load power	
PEPDS Control Inputs	Number of Parallel Cells	
PEPDS Control Inputs	Number of Series Cells	
PEPDS Control Inputs	Power rating	

Owner	Name	Default Value
PEPDS Control Inputs	Switching Frequency	
PEPDS Control Inputs	Voltage	
PEPDS Control Outputs	Output power	
PEPDS Control Outputs	Sharing ratio	
PEPDS Control Outputs	Time response	
PEPDS Controls	Baseline conventional control-based Power Train Concept.	
PEPDS Controls	Mini-PEPDS realizations that will allow for MOP and KPP extraction.	
PEPDS Controls	Self and inter compatible LVDC interfacing PEBB Clusters with EMI mitgation_CEM/DEM models, PLECS models.	
PEPDS Controls	Abstracted Models of MV interfacing PEBB Clusters with single cycle energy controls.	
PEPDS Controls	FB-MMC, CHB versions of MVAC to MVDC Converter_Simulink Model	
PEPDS Controls	Parts of power train_PEBB Clusters, Initial Estimate on required passives.	
Thermal Management	Abstract the electro-thermal performance models	
Thermal Management	Ranges of inlet water temperature and flow rate	
Thermal Management	Metamodels for heatsink and coldplates.	

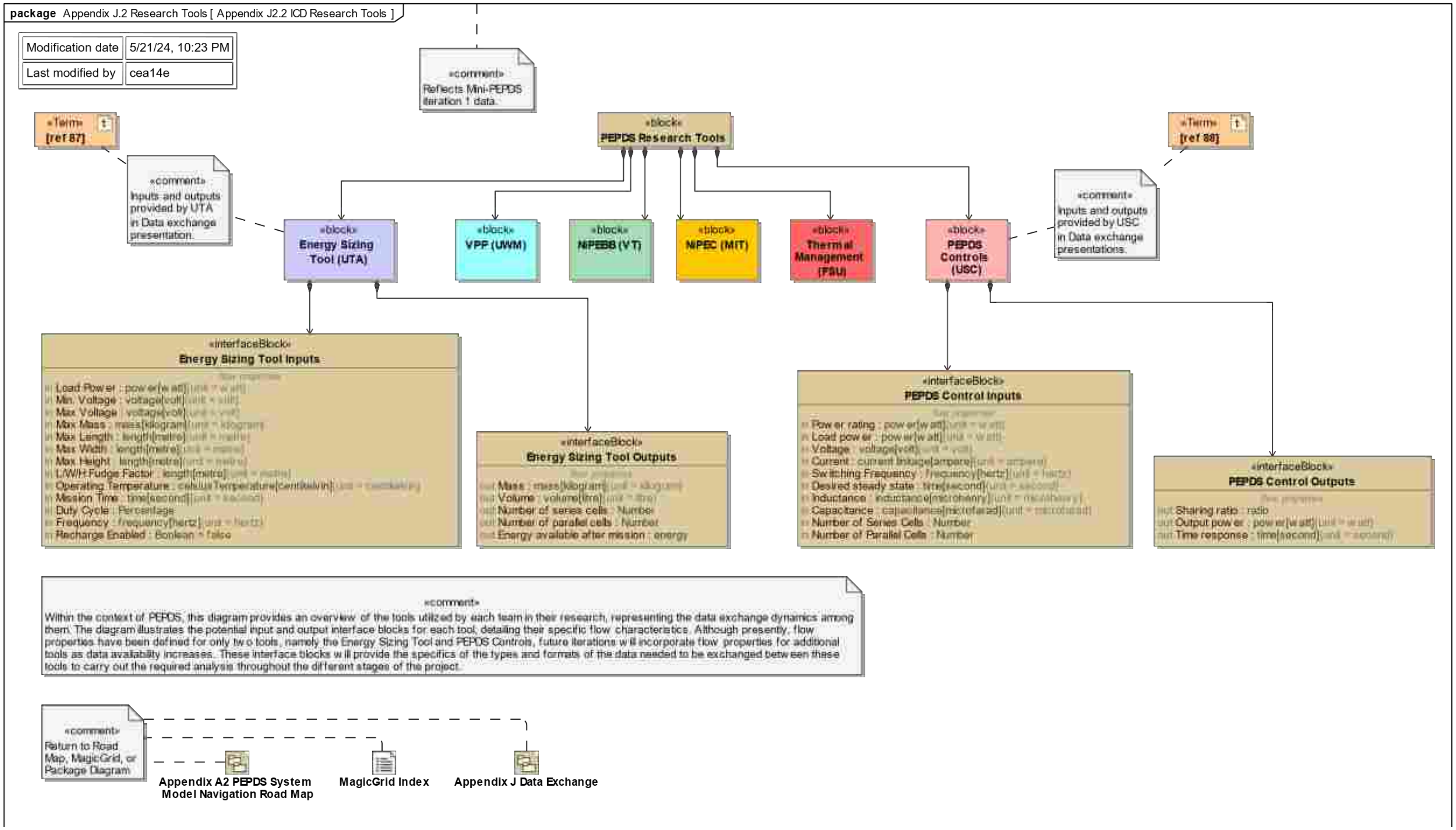

Fig. 102: Appendix J2.2 ICD Research Tools

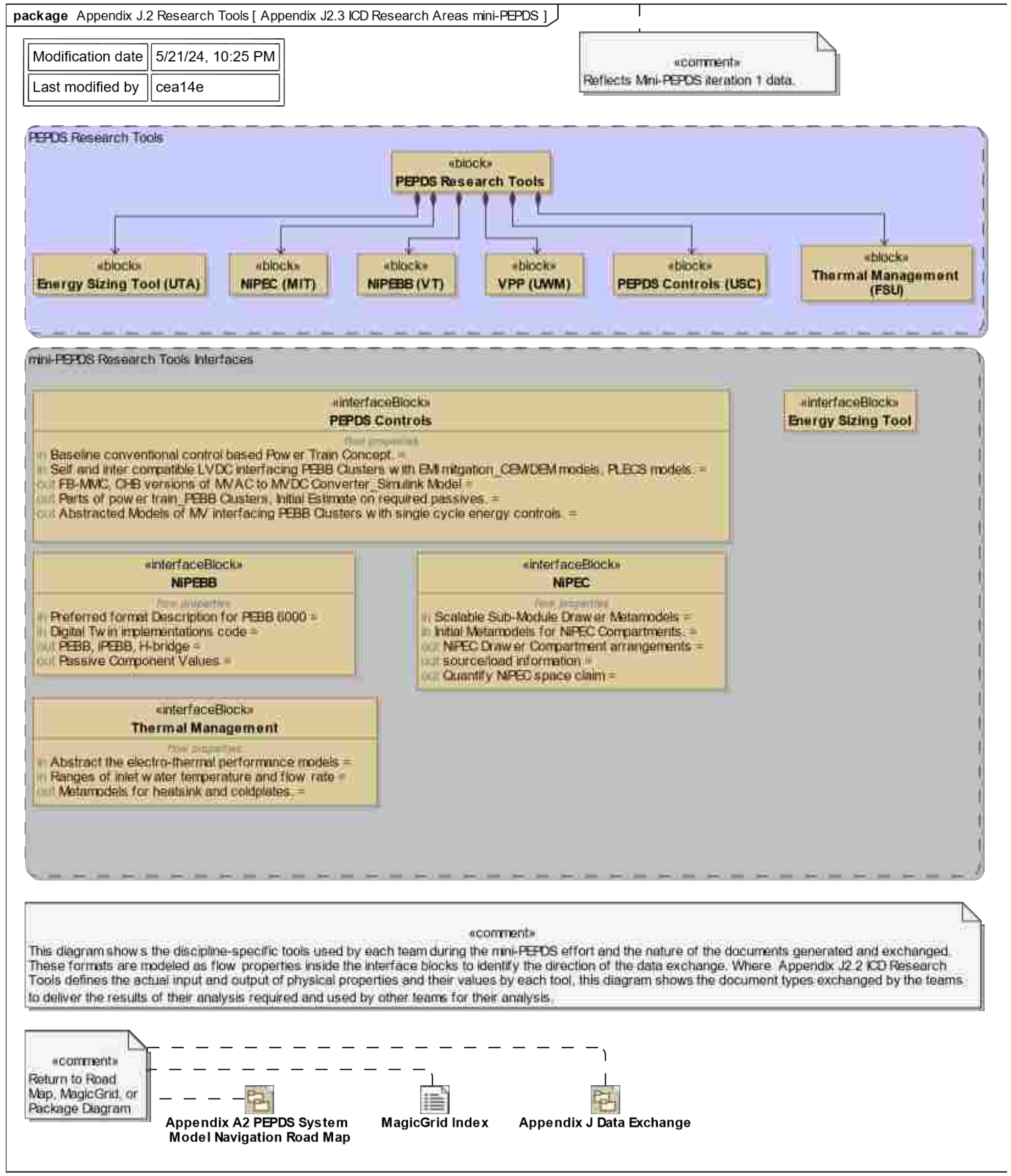

Fig. 103: Appendix J2.3 ICD Research Areas mini-PEPDS

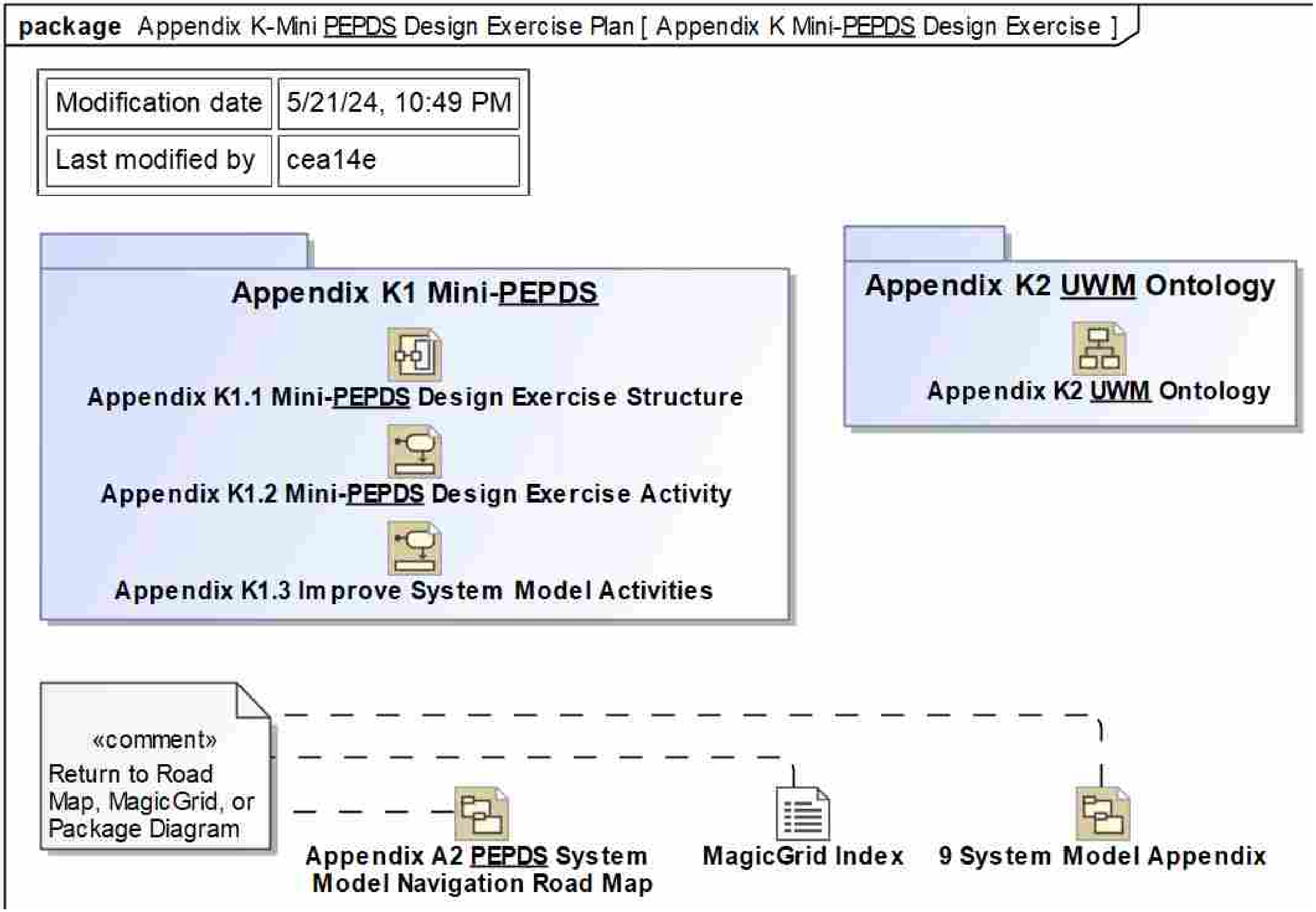

Fig. 104: Appendix K Mini-PEPDS Design Exercise

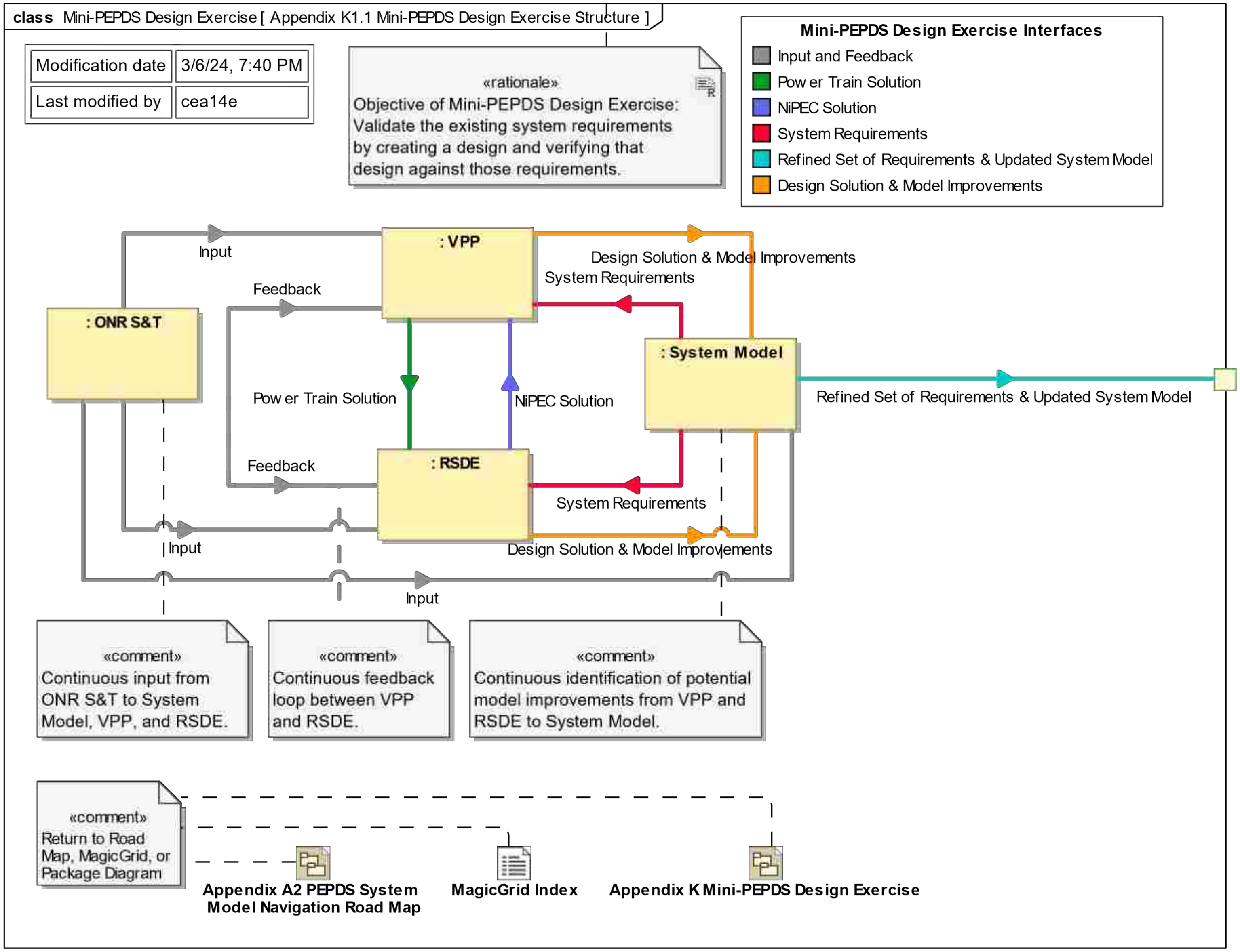

Fig. 105: Appendix K1.1 Mini-PEPDS Design Exercise Structure

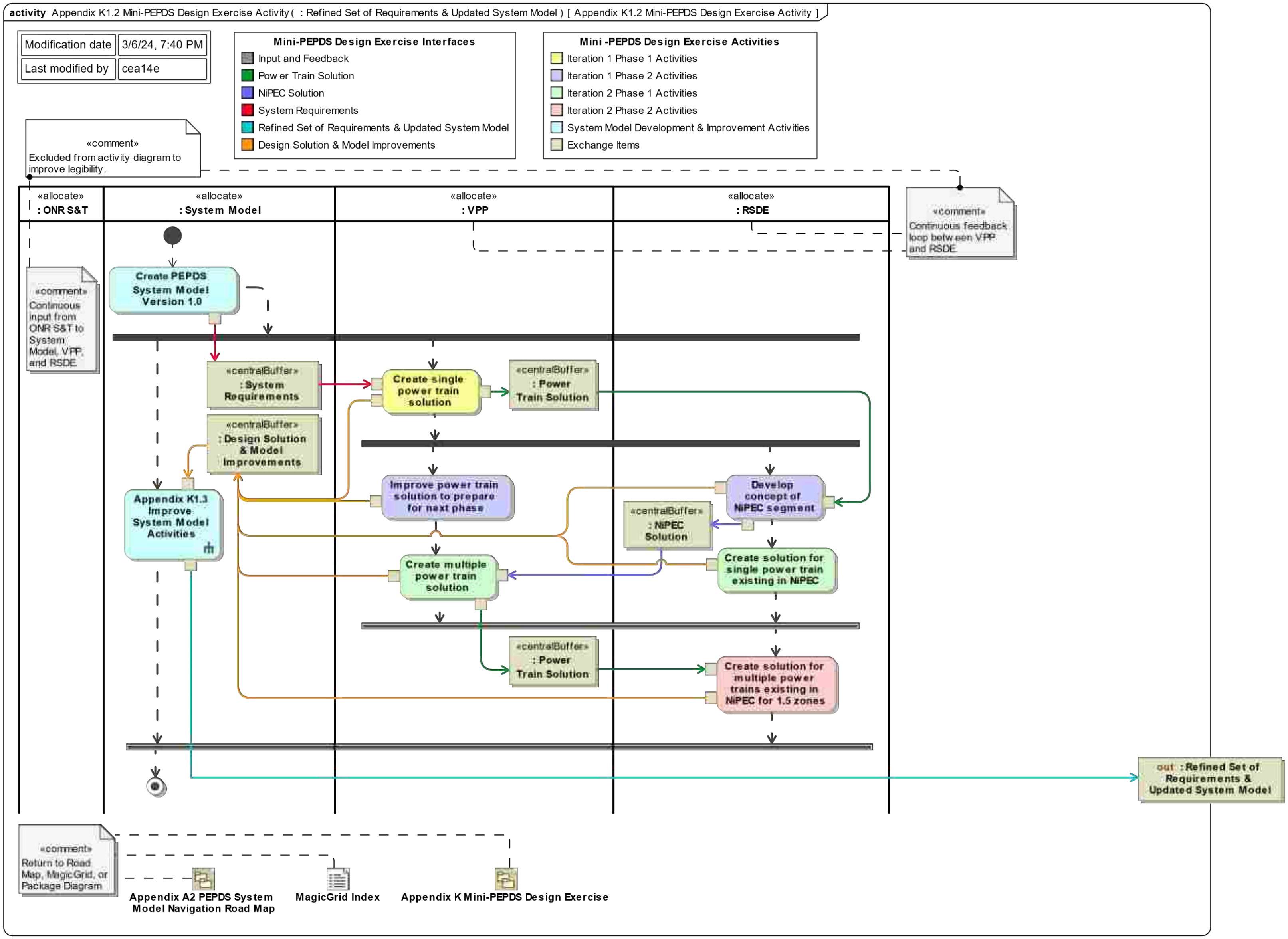

Fig. 106: Appendix K1.2 Mini-PEPDS Design Exercise Activity

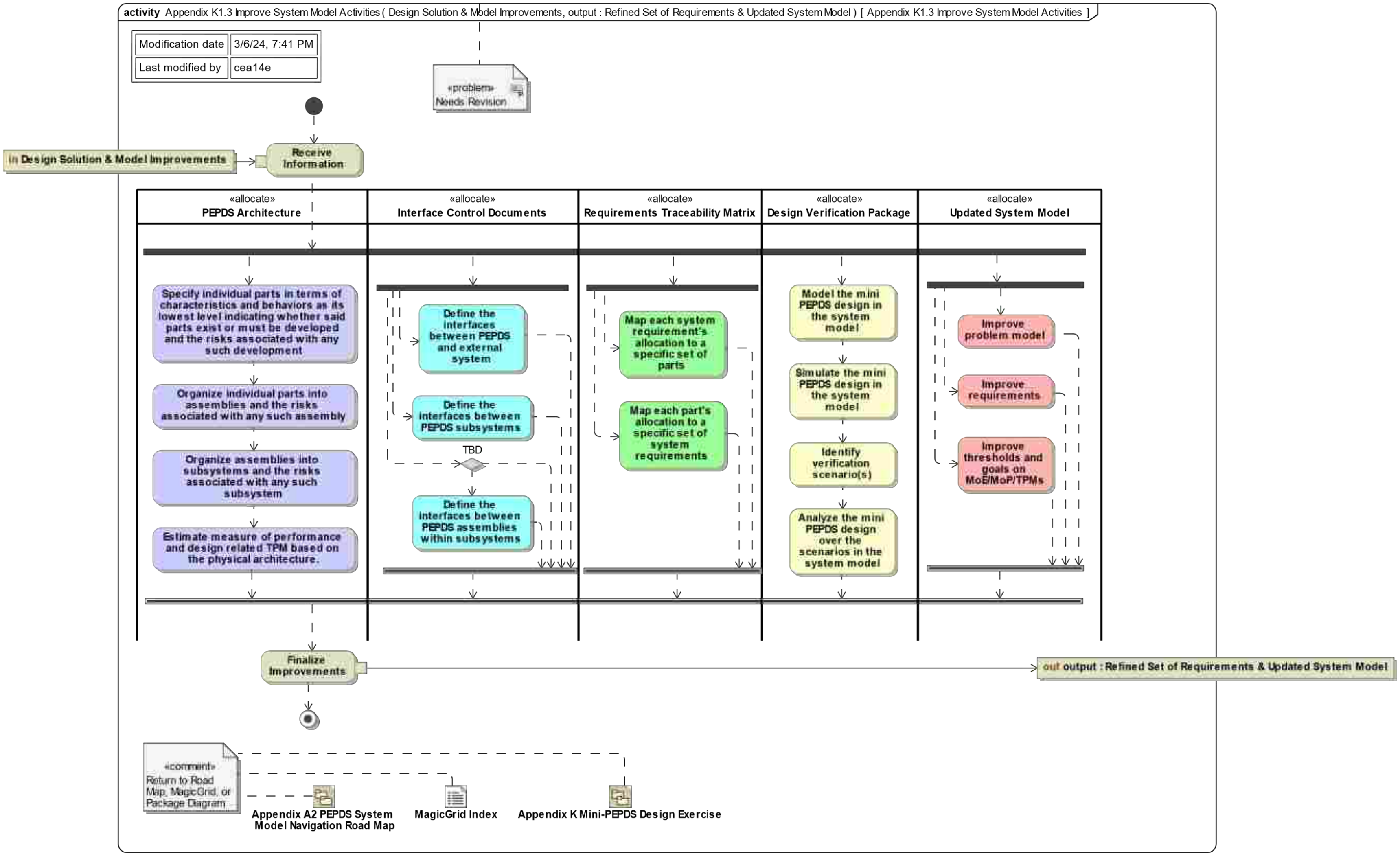

Fig. 107: Appendix K1.3 Improve System Model Activities

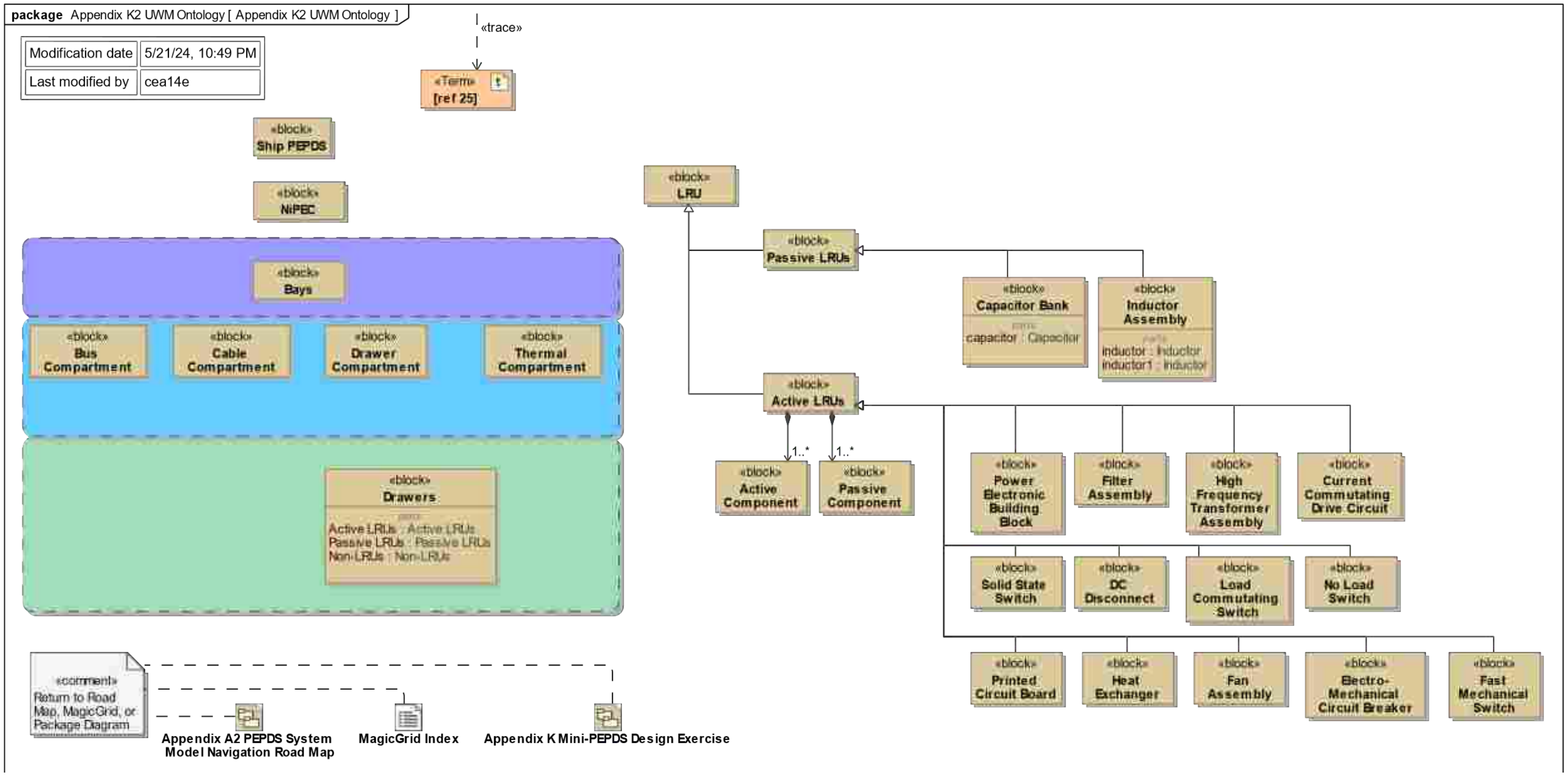

Fig. 108: Appendix K2 UWM Ontology

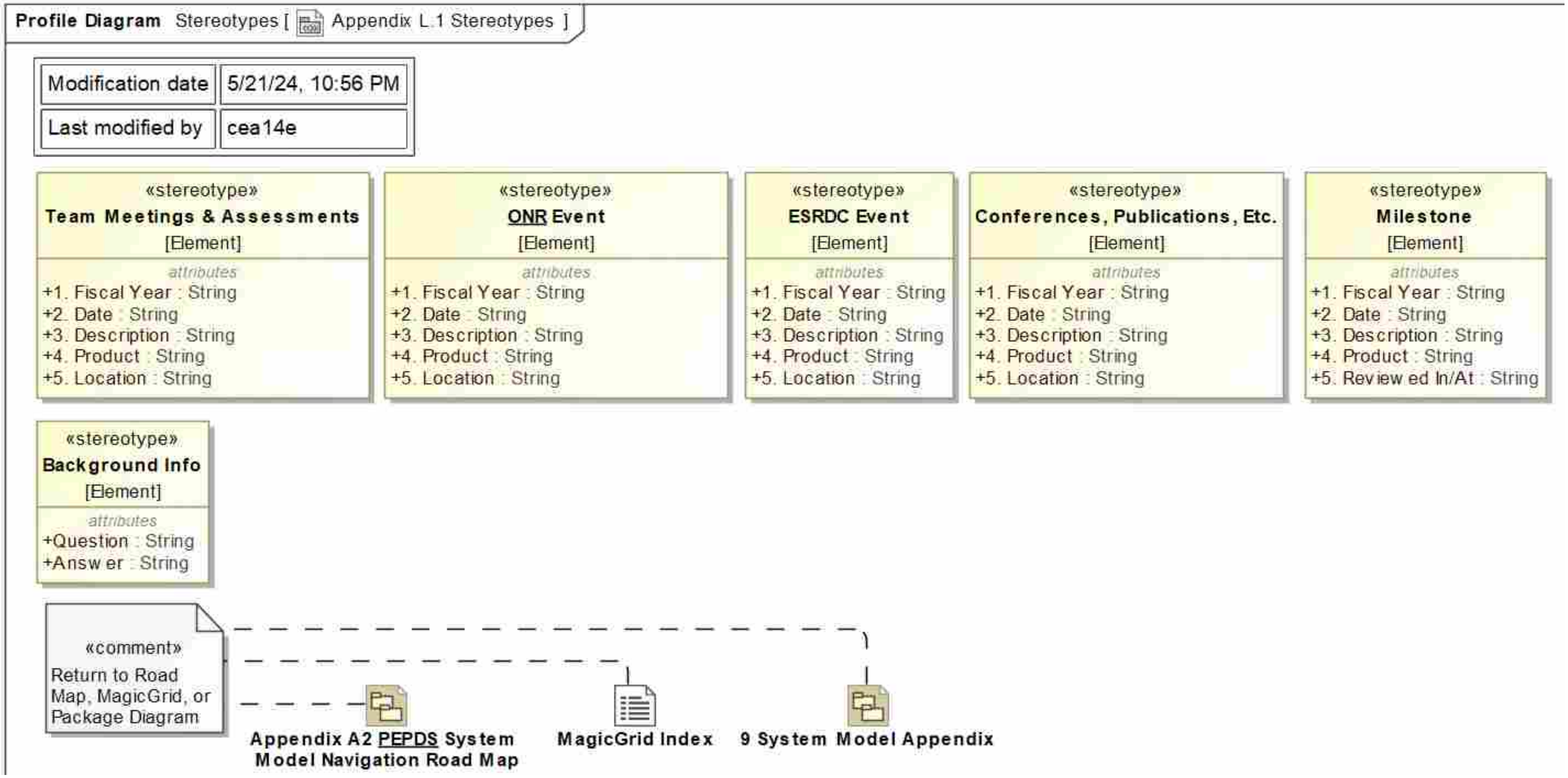

Fig. 109: Appendix L.1 Stereotypes

11.4 MagicGrid® Index Package Diagrams

Link to return to section 11 Appendix B: PEPDS System Model Contents start.

11.4.1 MagicGrid Index®

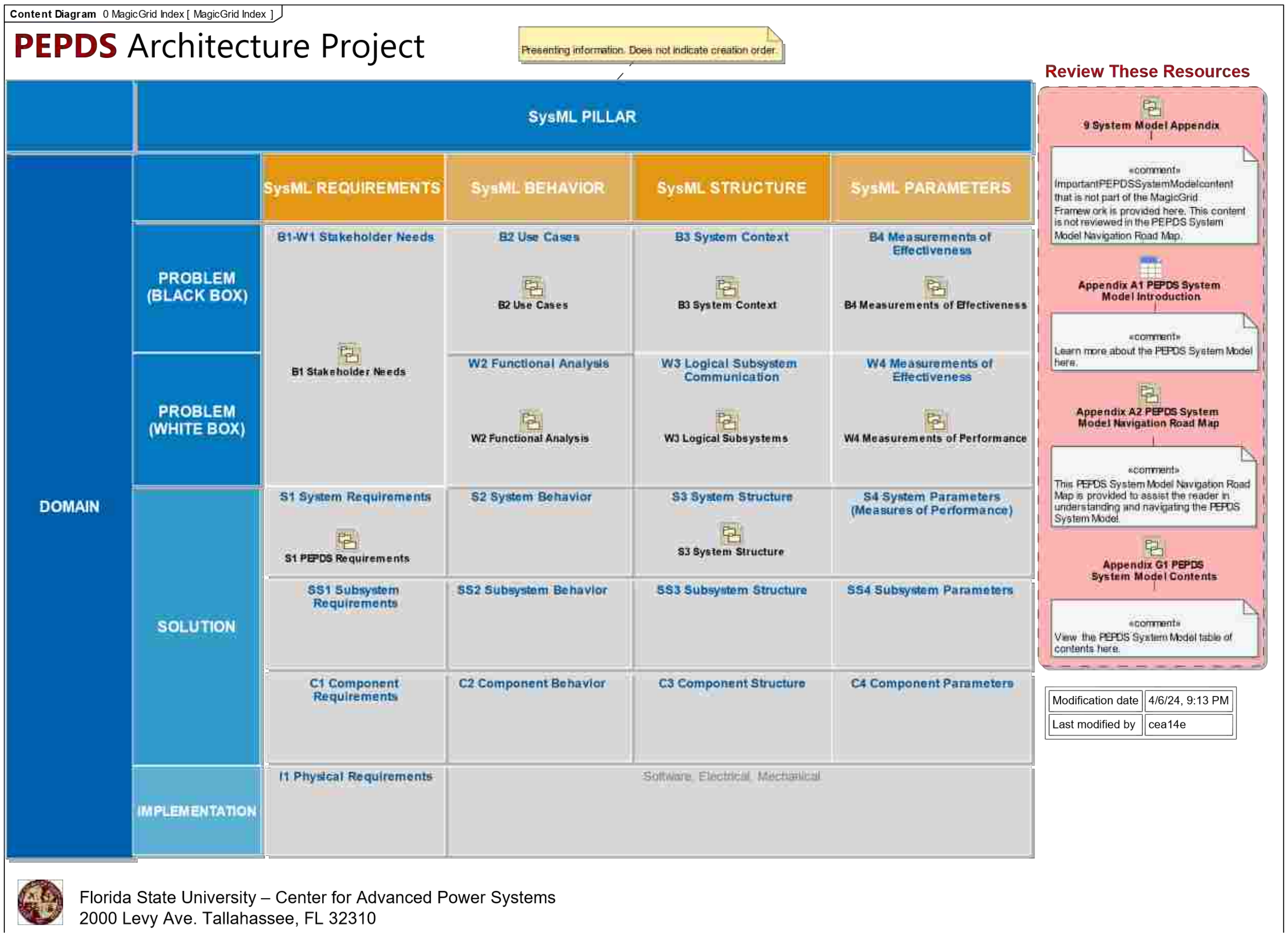

Fig. 110: MagicGrid® Index

11.4.2 MagicGrid® Index Package Diagrams for Problem Domain Requirements

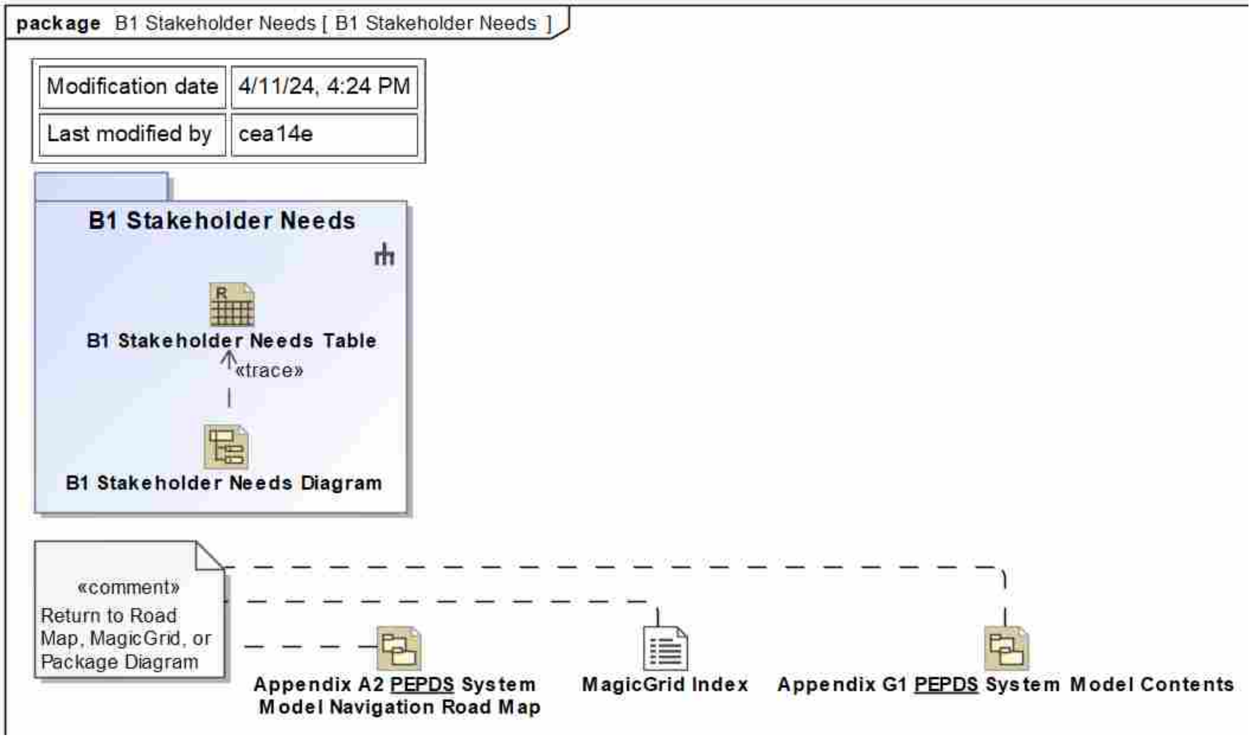

Fig. 111: B1 Stakeholder Needs Package Diagram

11.4.3 MagicGrid® Index Package Diagrams for Problem Domain Behavior

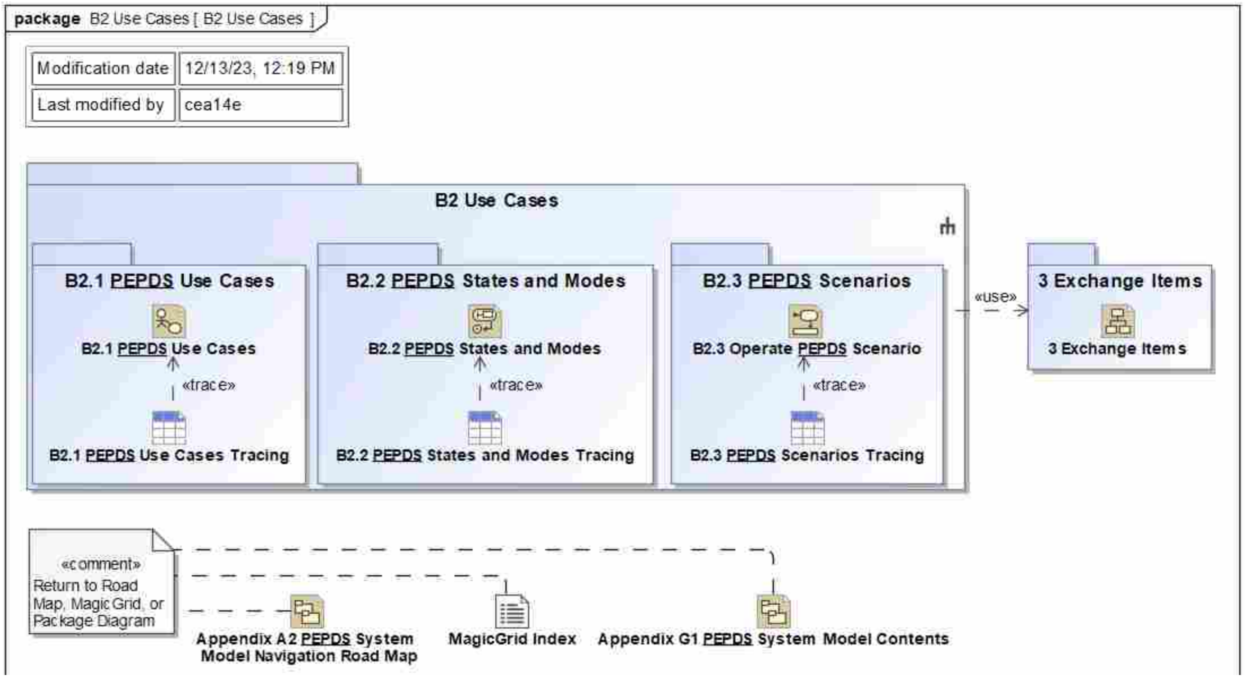

Fig. 112: B2 Use Cases Package Diagram

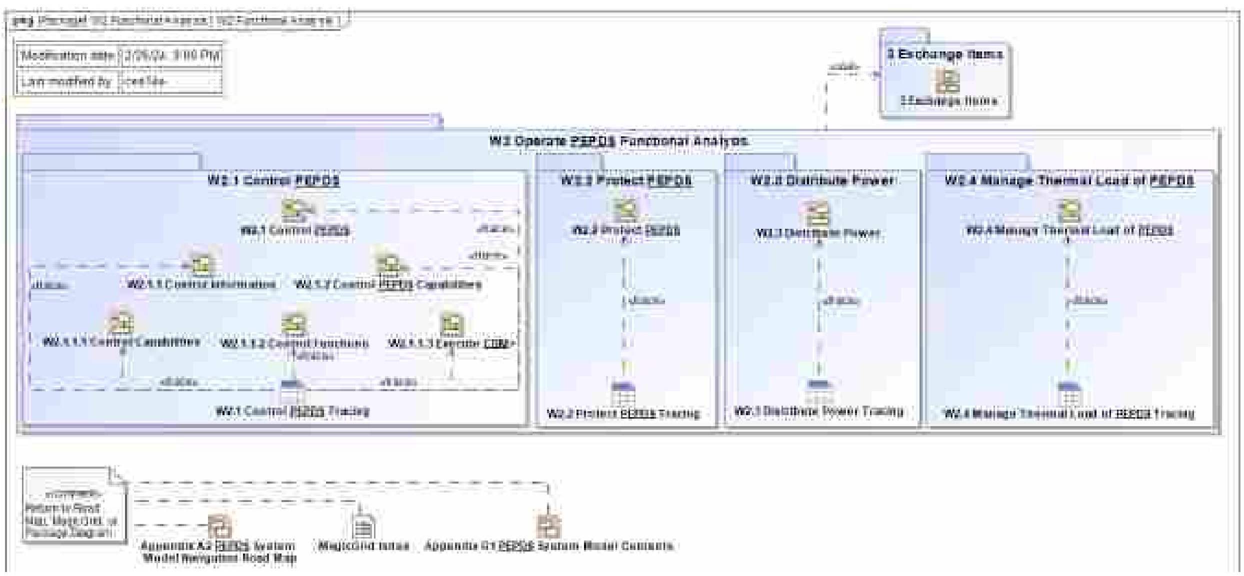

Fig. 113: W2 Functional Analysis Package Diagram

11.4.4 MagicGrid® Index Package Diagrams for Problem Domain Structure

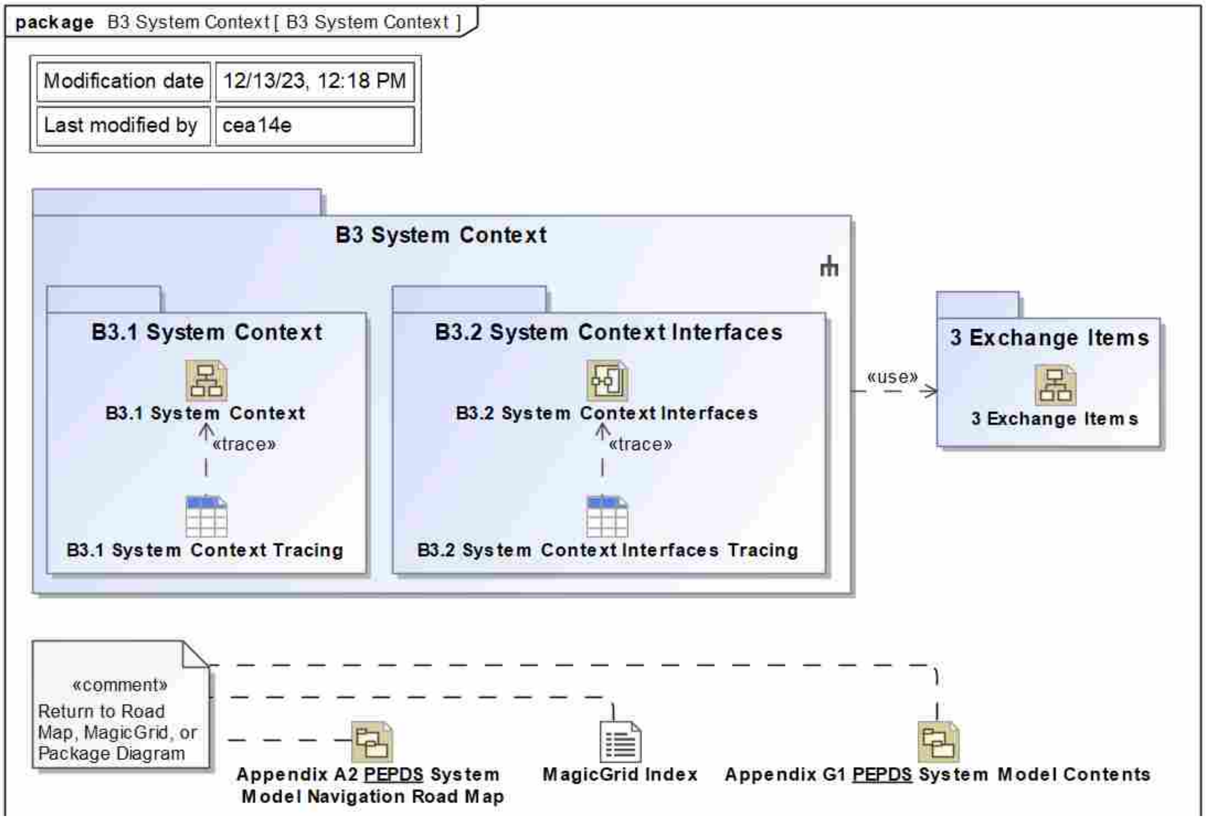

Fig. 114: B3 System Context

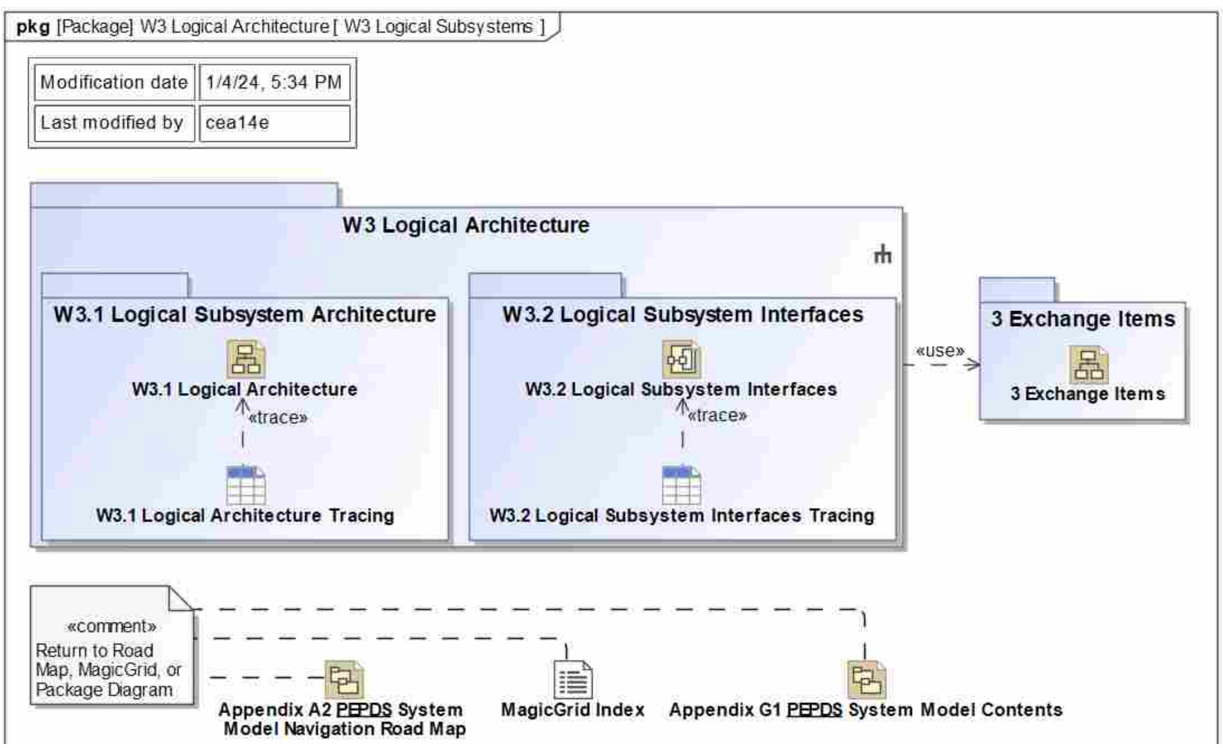

Fig. 115: W3 Logical Subsystems

11.4.5 MagicGrid® Index Package Diagrams for Problem Domain Parameters

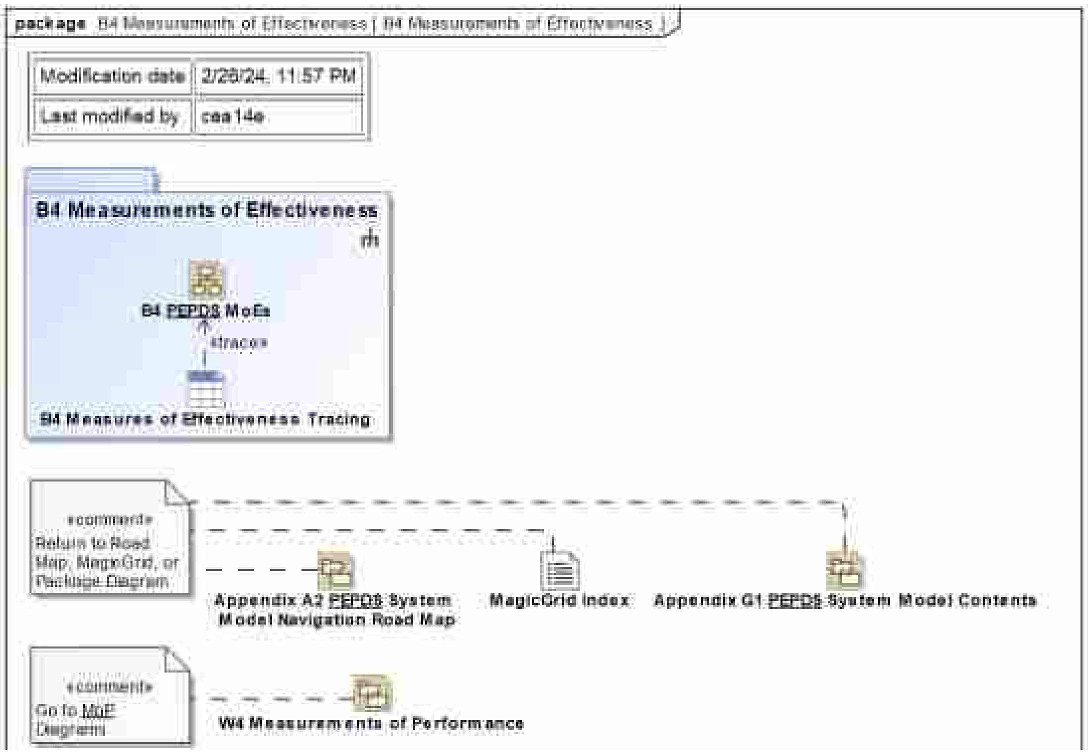

Fig. 116: B4 Measurements of Effectiveness Package Diagram

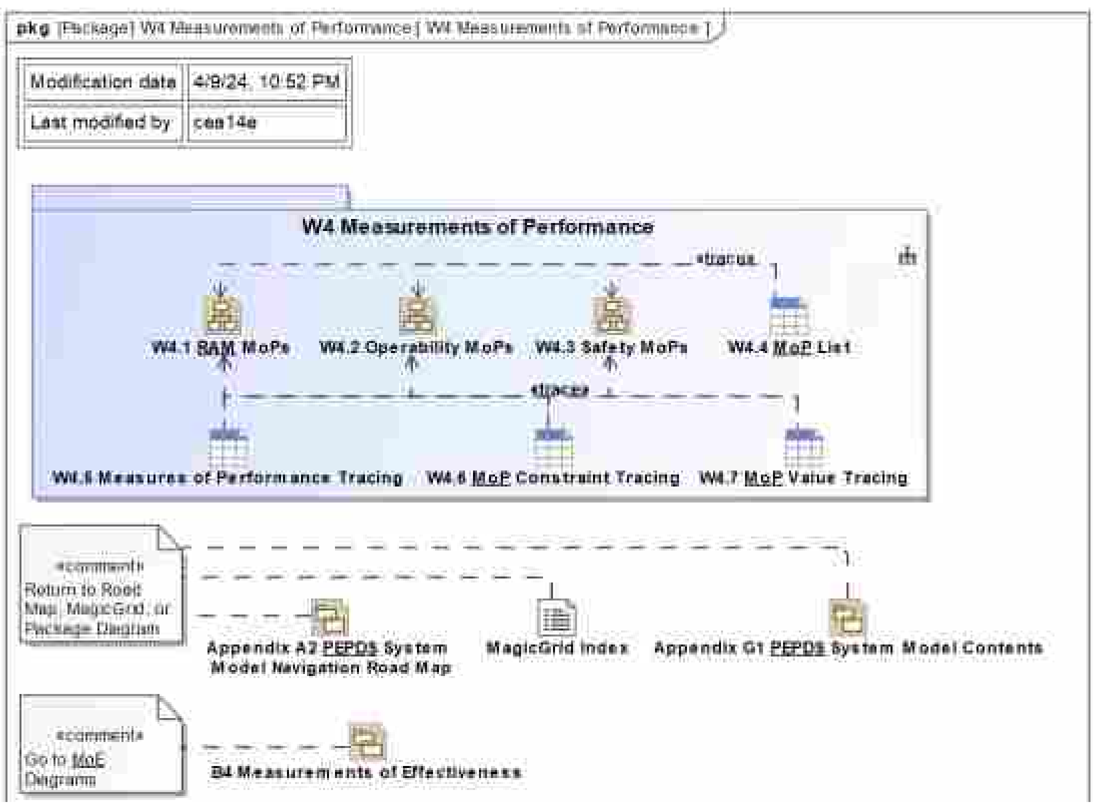

Fig. 117: W4 Measurements of Performance Package Diagram

11.4.6 MagicGrid® Index Package Diagrams for Solution Domain Requirements

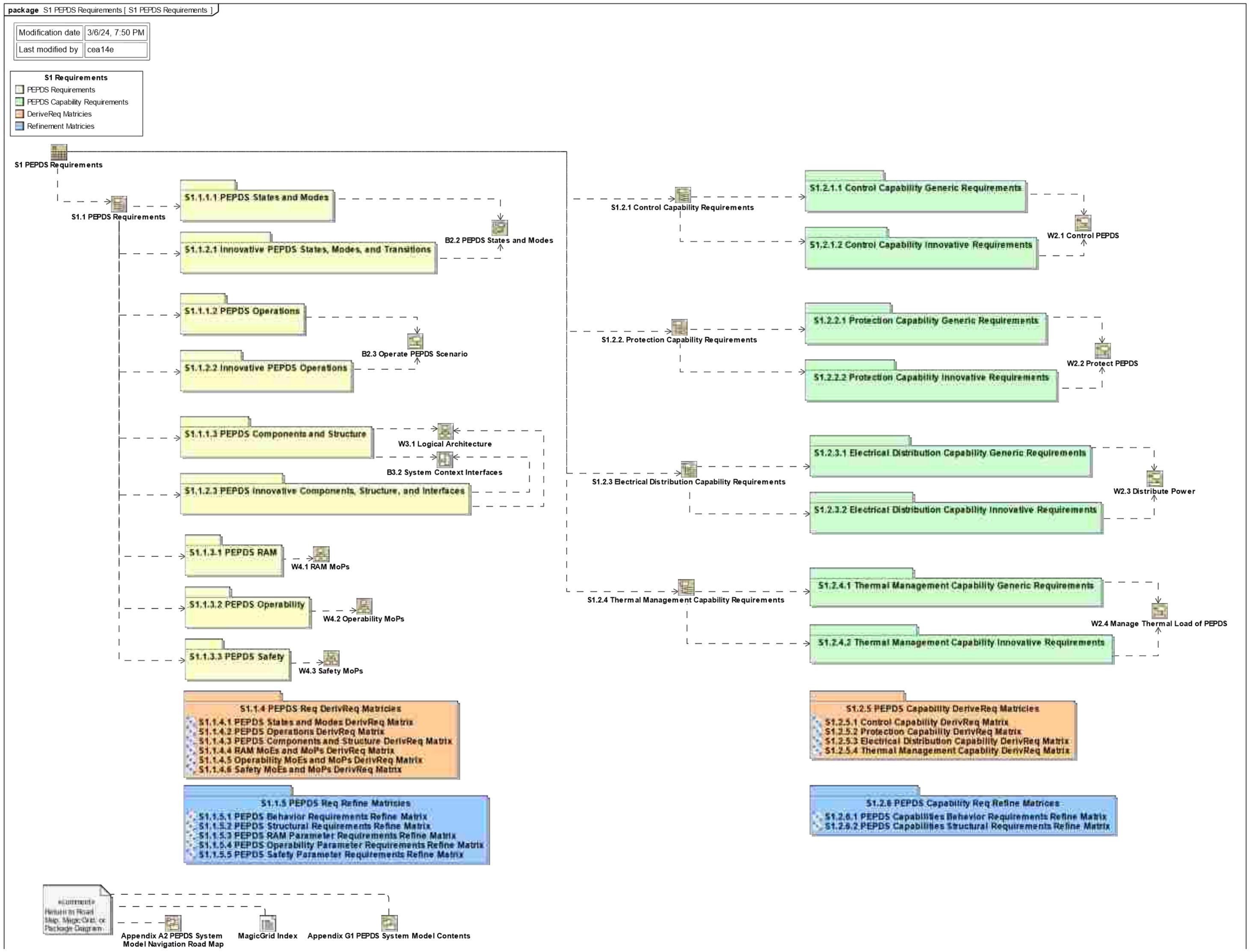

Fig. 118: S1 PEPDS Requirements Package Diagram

11.4.7 MagicGrid® Index Package Diagrams for Solution Domain Structure

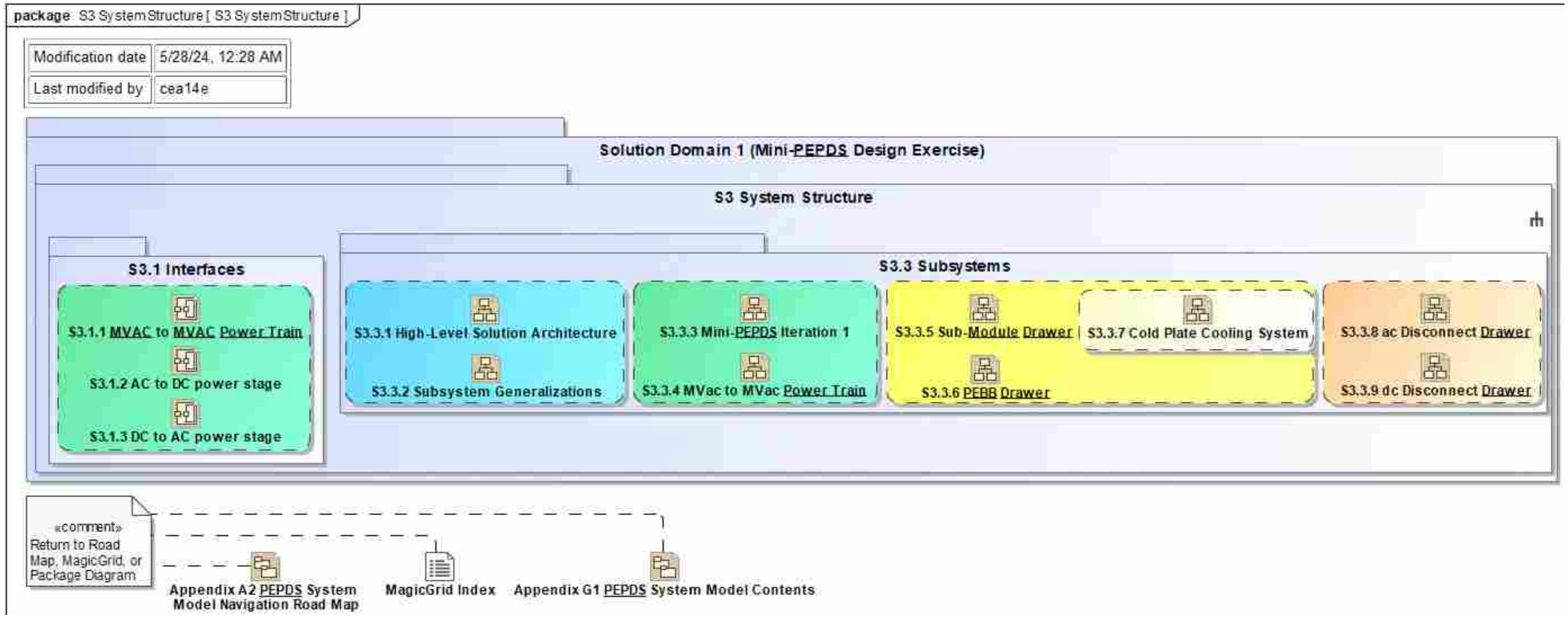

Fig. 119: S3 System Structure Package Diagram

11.4.8 MagicGrid® Index Package Diagrams for System Model Appendix

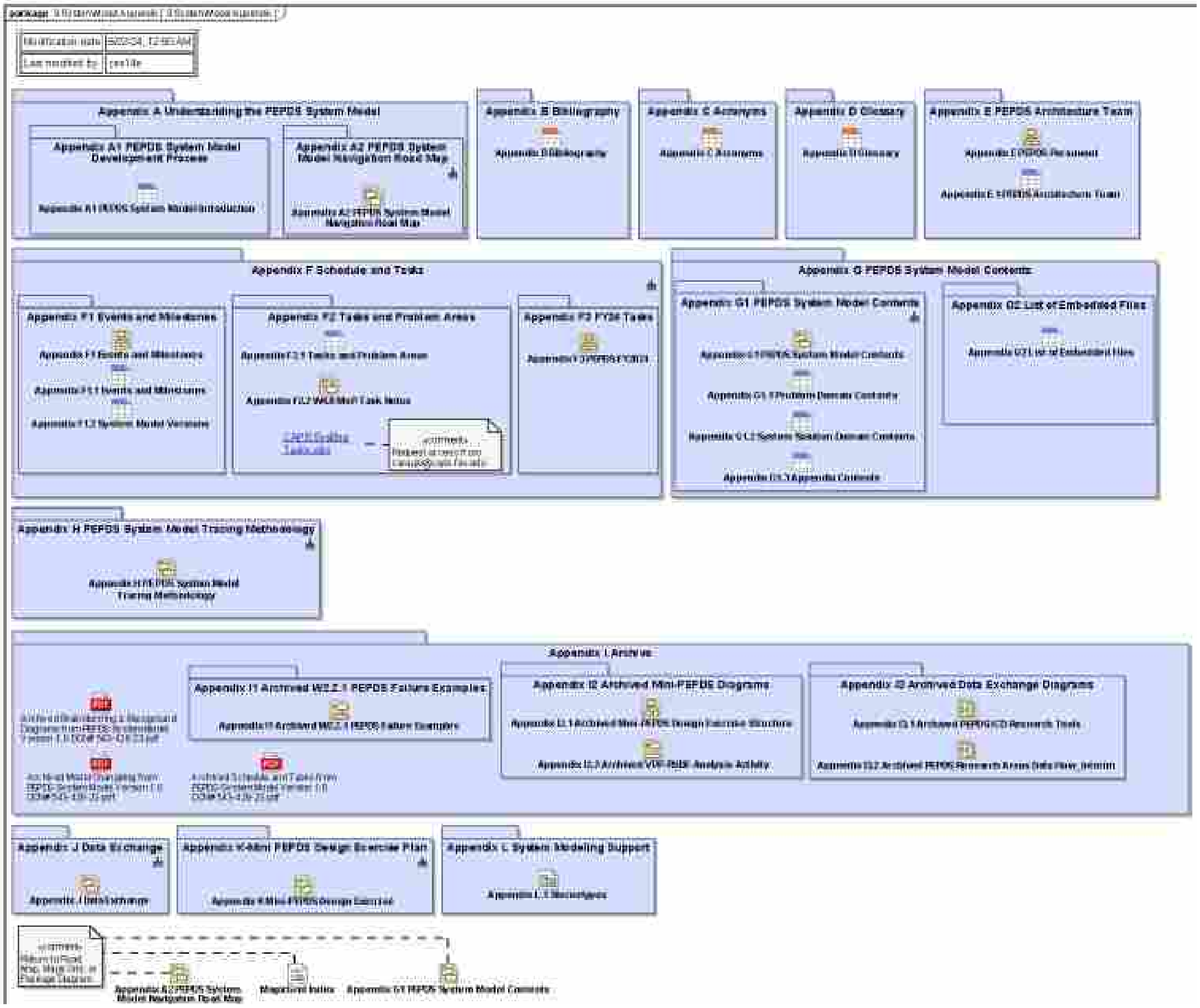

Fig. 120: System Model Appendix Package Diagram