National Aeronautics and Space Administration

NASA MBSE Implementation

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NASA Systems Engineering

MODEL BASED SYSTEMS ENGINEERING

MBSE

What is MBSE?

- INCOSE definition of MBSE
  - Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation, beginning in the conceptual design phase and continuing throughout development and later life cycle phases (Systems Engineering Vision 2020, INCOSE-TP-2004-004-02).

INCOSE
International Council on Systems Engineering

- MBSE is not a new process being added to the existing SE processes.

MBSE *is* systems engineering through the use of models.

MBSE Infusion And Modernization Initiative

FY16: **Learn & Align**

FY17: **Learn & Apply**

FY18 & FY19: **Develop Recognized Core Capability**

FY20: **Targeted Deployment**

MBSE Vision

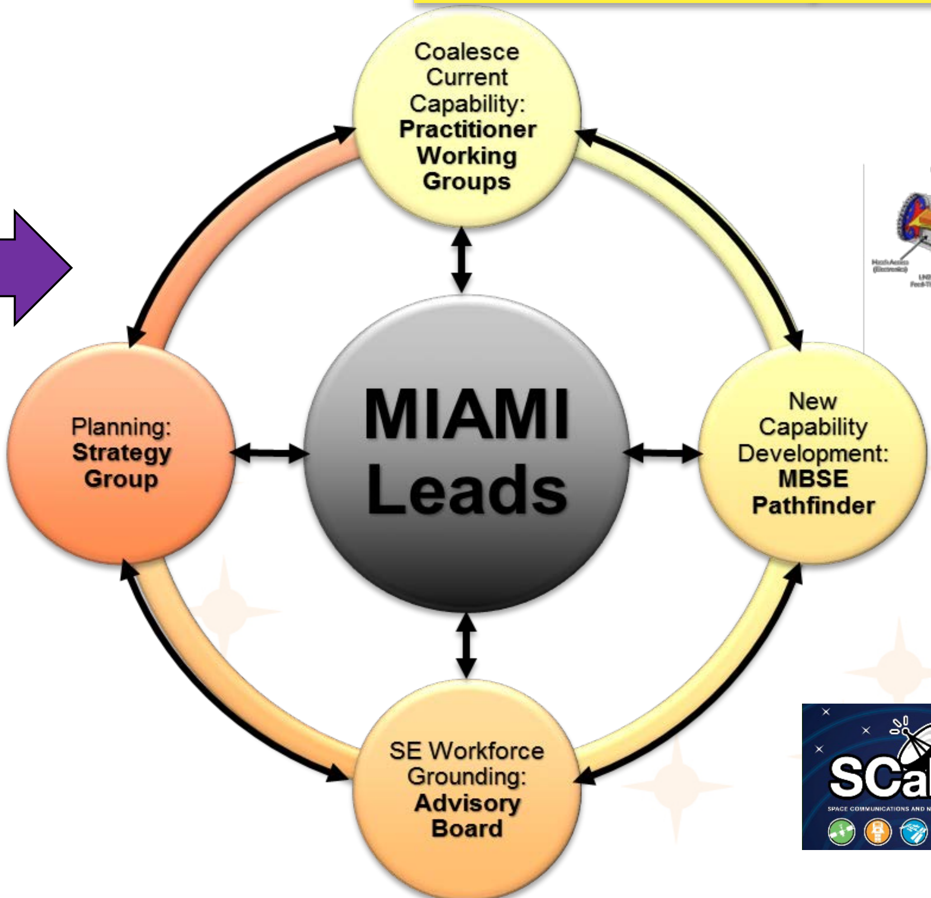
MBSE Roadmap

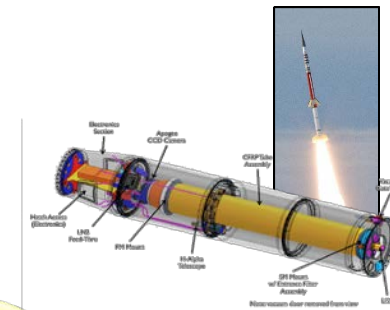
Systems Modeling WG

Systems Analysis and Data Visualization WG

Infra-structure and Ecosystem WG

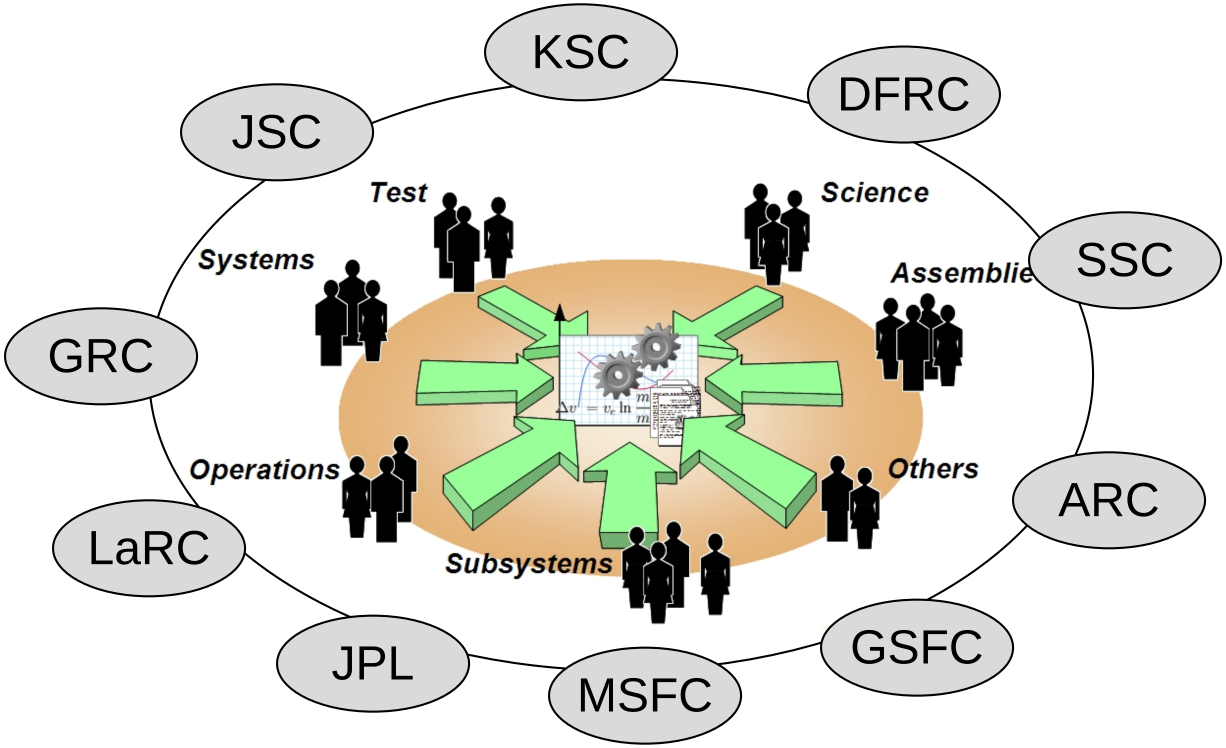
Digital Practitioner Community





MBSE Agency Collaboration

"A fully operational model-centric infrastructure that enables integration of physical models with domain discipline analytical models, simulations and cost models to support activities throughout lifecycle from concept through disposal"



- Shared system model is explicit, available, durable and authoritative
- System design kept current with 2-way information exchange with discipline models
- Agency-wide modeling standards facilitate multi-center collaboration

MSFC MBSE Advocacy

- Primarily utilizing MagicDraw 19.0 Service Pack 2 as the MBSE pathfinding tool throughout the Agency
- Marshall Space Flight Center (MSFC) is focusing on small wins by infusing MBSE through Tech Excellence (TE) projects
- Project scope is centered around lifecycle deliverables
- Process of Establishing common framework

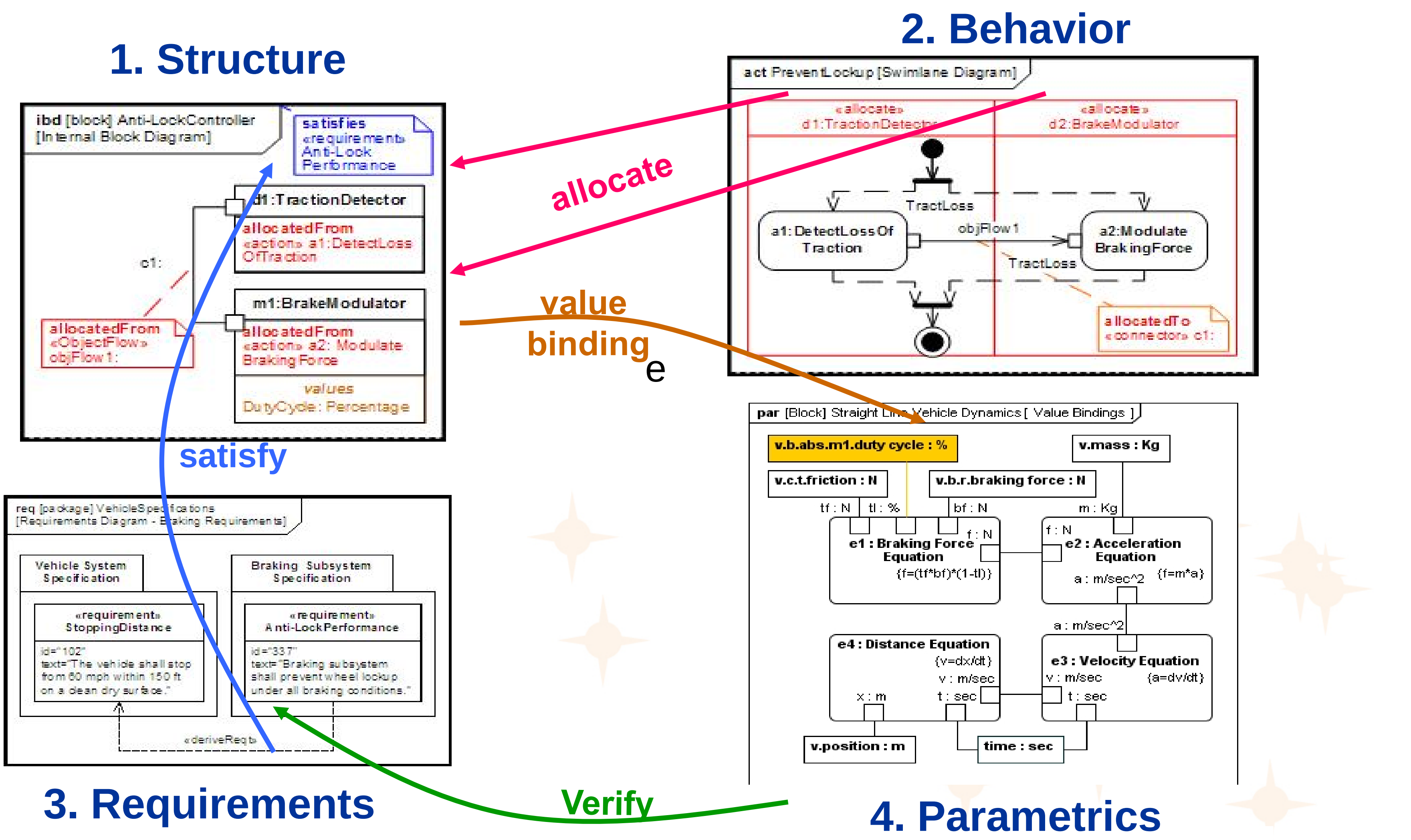
MagicGrid 101

- The MagicGrid approach is based on the framework, which can be represented as a Zachman style matrix (link below), and is designed to guide the engineers through the modeling process and answer their questions, like “how to organize the model?”, “what is the modeling workflow?”, “what model artifacts should be produced in each step of that workflow?”, “how these artifacts are linked together?”, and so on.
- The 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. Each domain is represented as a separate row of the MagicGrid framework.
- https://www.zachman.com/about-the-zachman-framework
- http://www.15288.com/about_standards.php

MagicGrid 101 Cont.

			Pillar			
Layer of Abstraction			Requirements	Behavior	Structure	Parametrics
	Specification	Concept	Stakeholder Needs	Use Cases	System Context	Measurements of Effectiveness
		Problem	System Requirements	Functional Analysis	Logical Subsystems Communication	
	Design	Solution	Component Requirements	Component Behavior	Component Structure	Component Parameters

SysML 4 Pillars

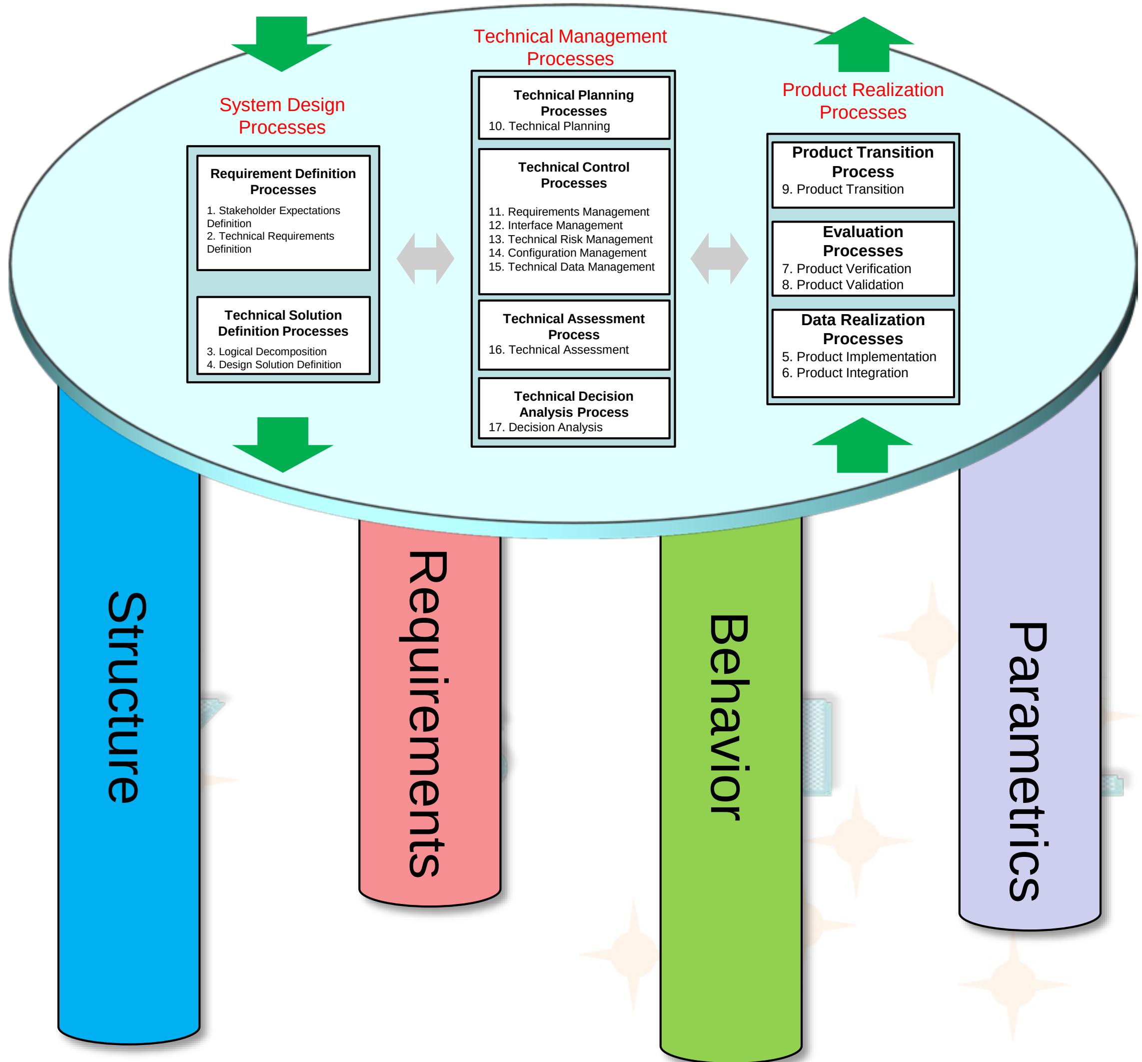


NASA MBSE 4 Pillar SE Integration

GATE PRODUCTS:
eg.NPR 7123.1B

NASA Evolution

Beginner: 4 Pillar basics
Intermediate: Integrating 4 Pillars (OOSEM)
Advanced: Model what's needed for products!!
FY20+: *Generate tailored NASA-standard profiles, artifacts and views*



MSFC MBSE Architecture Approach

- Model
  - Relations
  - 1 Problem Domain
    - Black Box
    - White Box
  - 2 Solution Domain
    - 1 System Requirements
    - 3 System Structure
    - 4 System Parameters
  - 2.1 Subsystem 1 Solution Domain
    - 2 Subsystem Behavior
    - 3 Subsystem Structure
  - 2.2 Subsystem 2 Solution Domain
    - 2 Subsystem Behavior
    - 3 Subsystem Structure
  - 3 System Configuration
    - 1 System Requirements
    - 3 System Structure
    - 4 System Parameters
  - 4 Implementation Domain
  - Index
- Code Engineering Sets

Stakeholder Expectations Definition Process

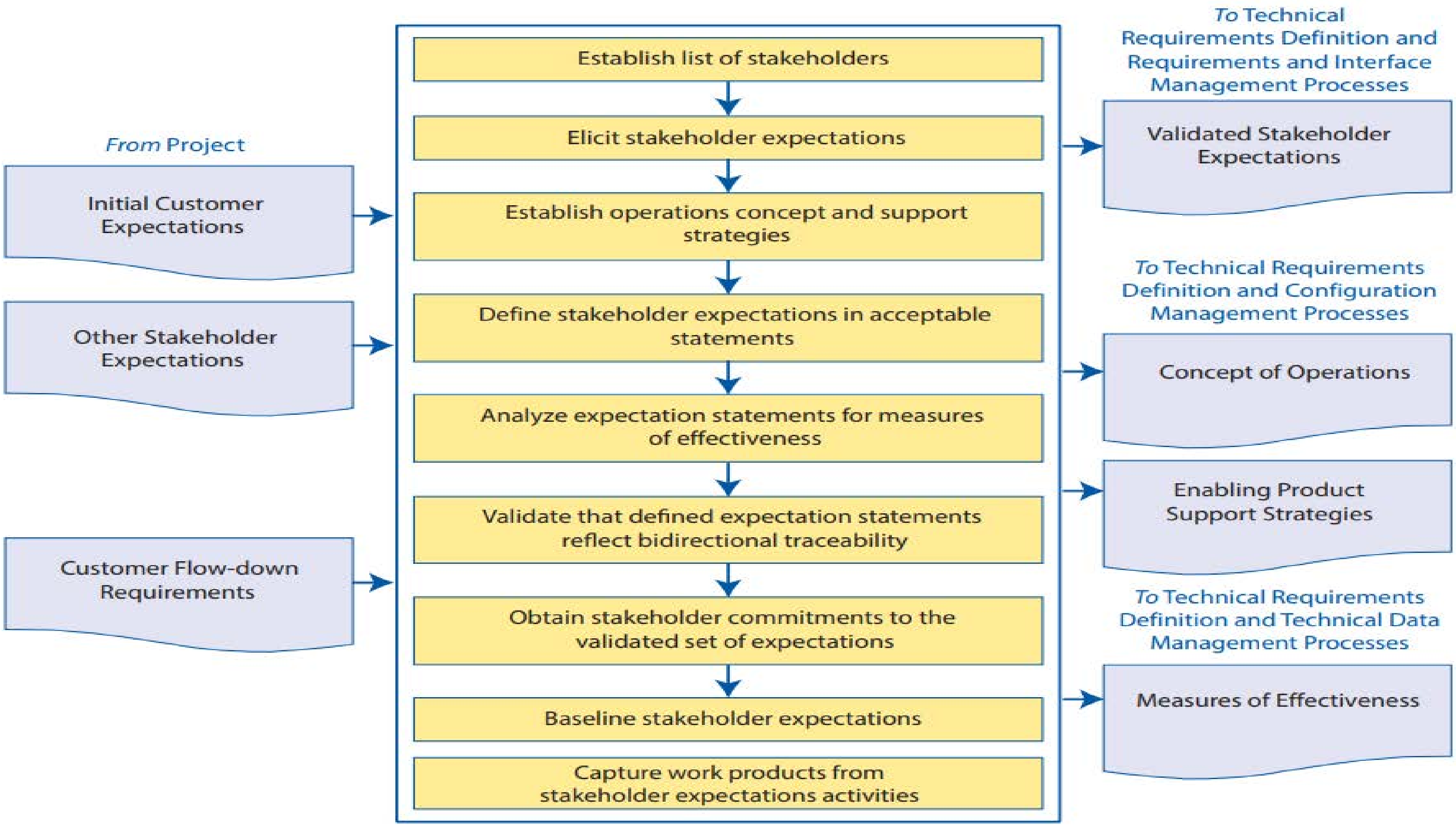
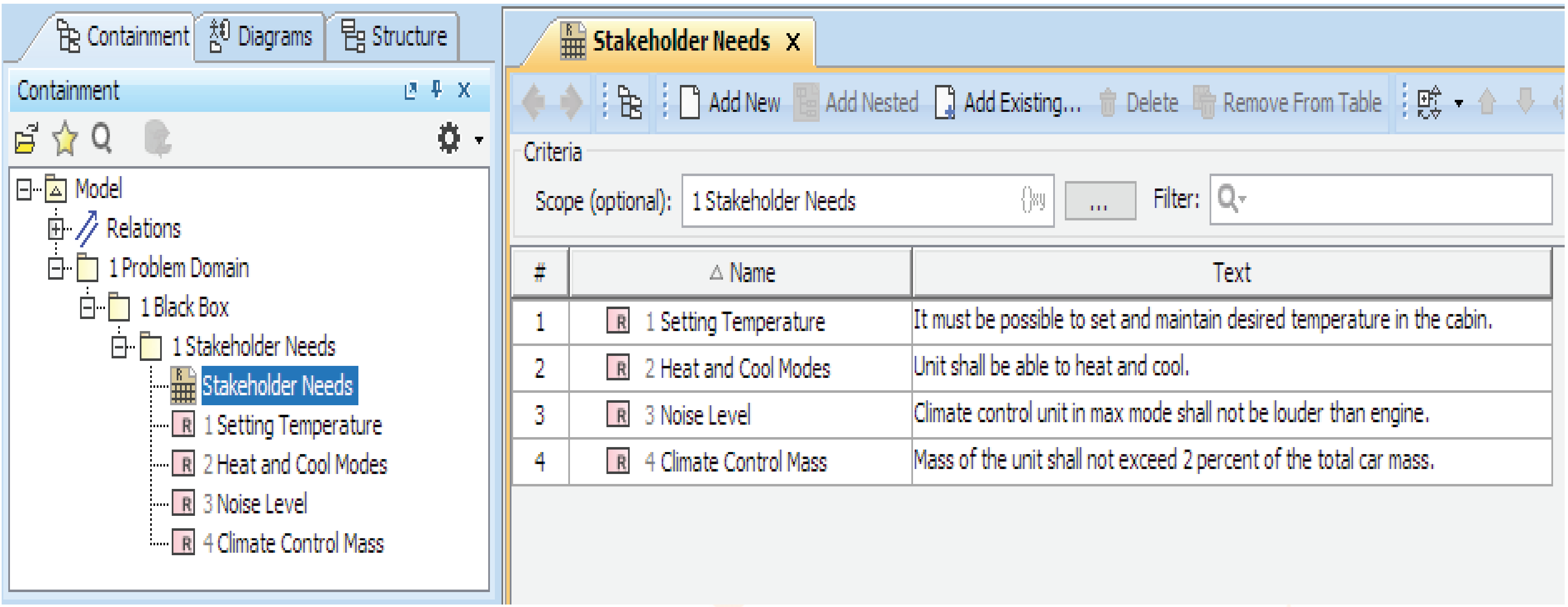


FIGURE 4.1-1 Stakeholder Expectations Definition Process

MSFC MBSE Architecture Approach

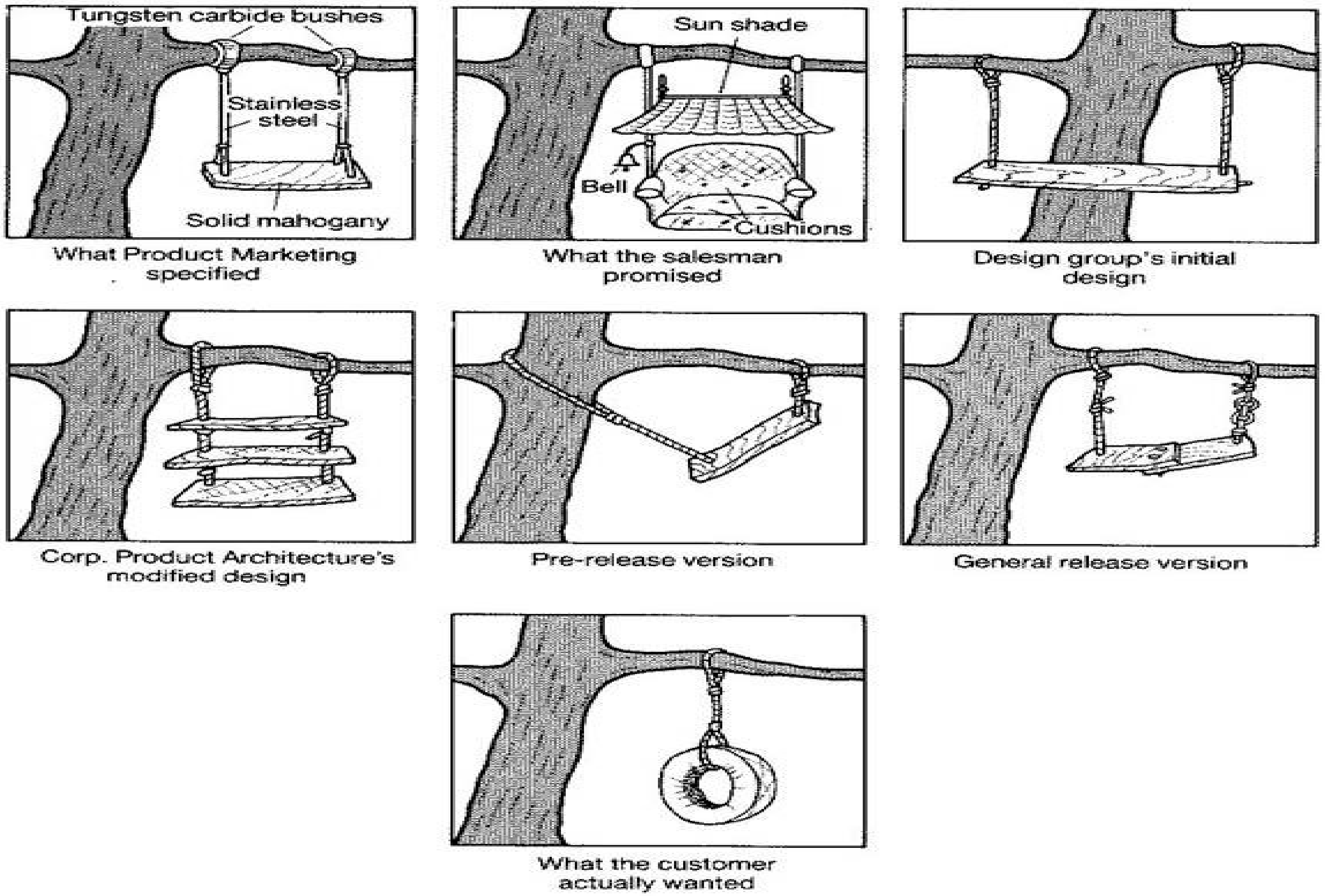


SE Product Maturity

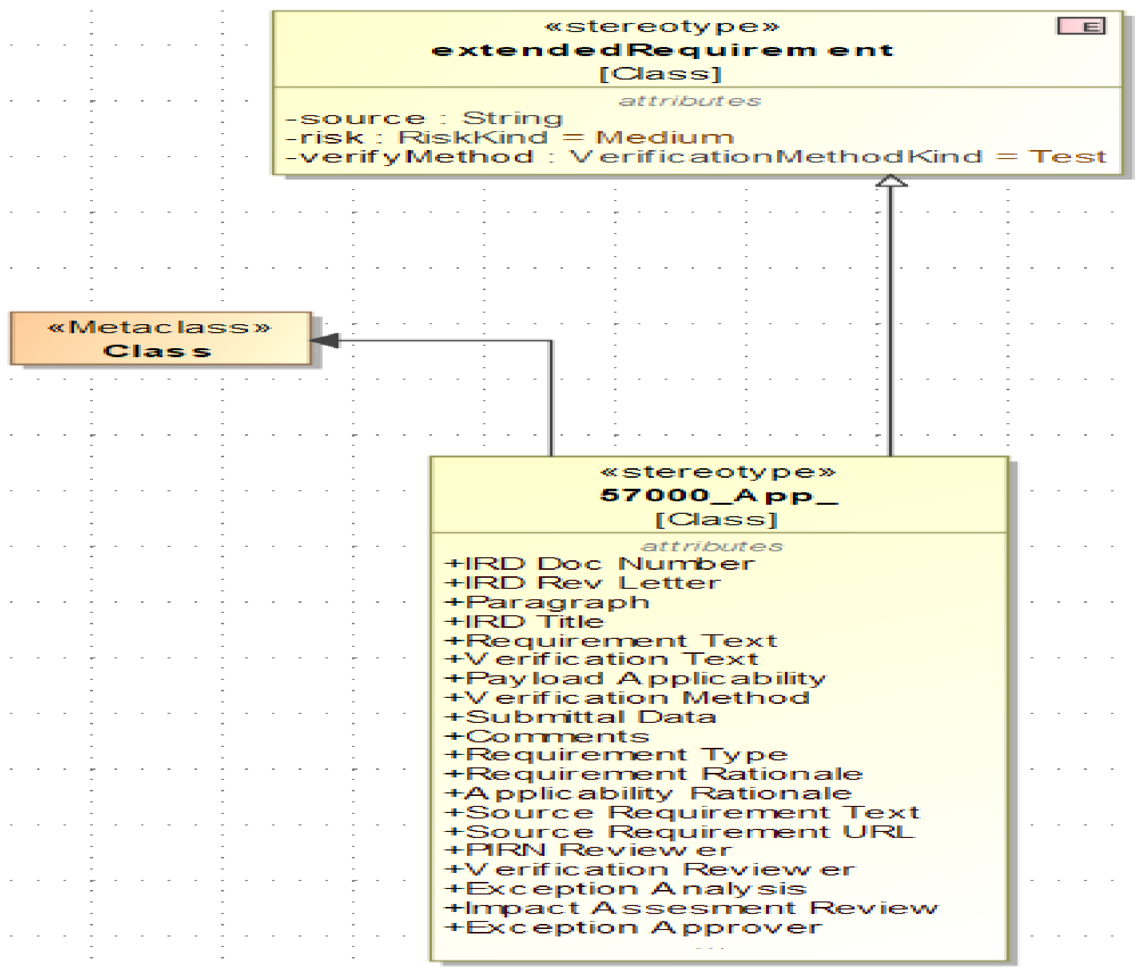
TABLE 3.0-1 SE Product Maturity from NPR 7123.1

Products										
	Formulation				Implementation					
Uncoupled/ Loosely Coupled	KDP 0		KDP I	Periodic KDPs						
Tightly Coupled Programs	KDP 0			KDP I	KDP II		KDP III		Periodic KDPs	
Projects and Single Project Programs	Pre-Phase A	Phase A		Phase B	Phase C		Phase D		Phase E	Phase F
	KDP A	KDP B		KDP C	KDP D		KDP E		KDP F	
	MCR	SRR	MDR/SDR	PDR	CDR	SIR	ORR	FRR	DR	DRR
Stakeholder identification and	**Baseline	Update	Update	Update						
Concept definition	**Baseline	Update	Update	Update	Update					
Measure of effectiveness definition	**Approve									
Cost and schedule for technical	Initial	Update	Update		Update	Update	Update	Update	Update	Update
SEMP[1]	Preliminary	**Baseline	**Baseline	Update	Update	Update				
Requirements	Preliminary	**Baseline	Update	Update	Update					
Technical Performance Measures definition			**Approve							
Architecture definition			**Baseline							
Allocation of requirements to next lower level			**Baseline							
Required leading indicator trends			**Initial	Update	Update	Update				
Design solution definition			Preliminary	**Preliminary	**Baseline	Update	Update			
Interface definition(s)			Preliminary	Baseline	Update	Update				
Implementation plans (Make/code, buy, reuse)			Preliminary	Baseline	Update					
Integration plans			Preliminary	Baseline	Update	**Update				
Verification and validation plans	Approach		Preliminary	Baseline	Update	Update				
Verification and validation results						**Initial	**Preliminary	**Baseline		
Transportation criteria and instructions					Initial	Final	Update			
Operations plans				Baseline	Update	Update	**Update			
Operational procedures					Preliminary	Baseline	**Update	Update		
Certification (flight/use)							Preliminary	**Final		
Decommissioning plans				Preliminary	Preliminary	Preliminary	**Baseline	Update	**Update	
Disposal plans				Preliminary	Preliminary	Preliminary	**Baseline	Update	Update	**Update

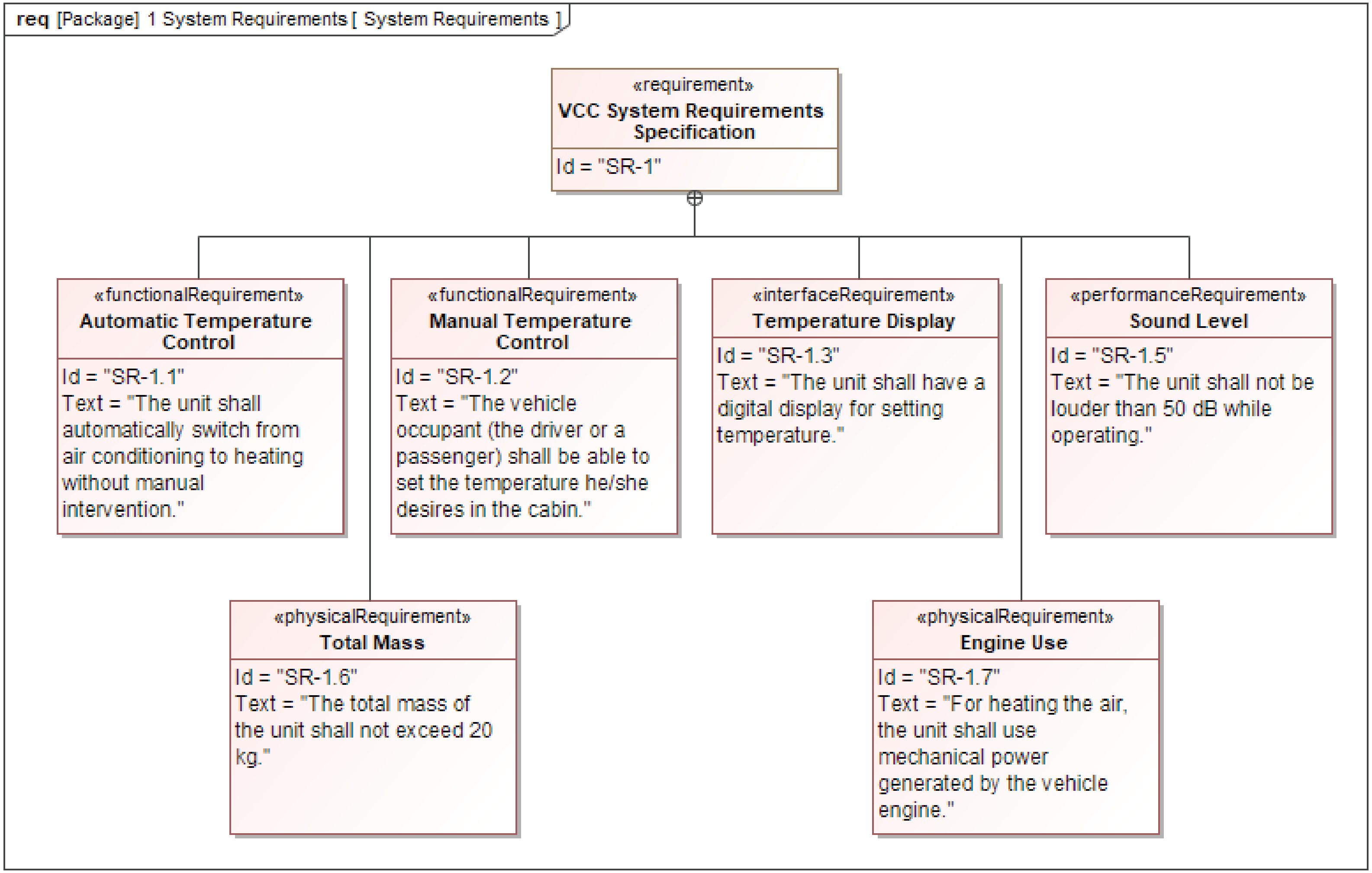
Requirement Challenges



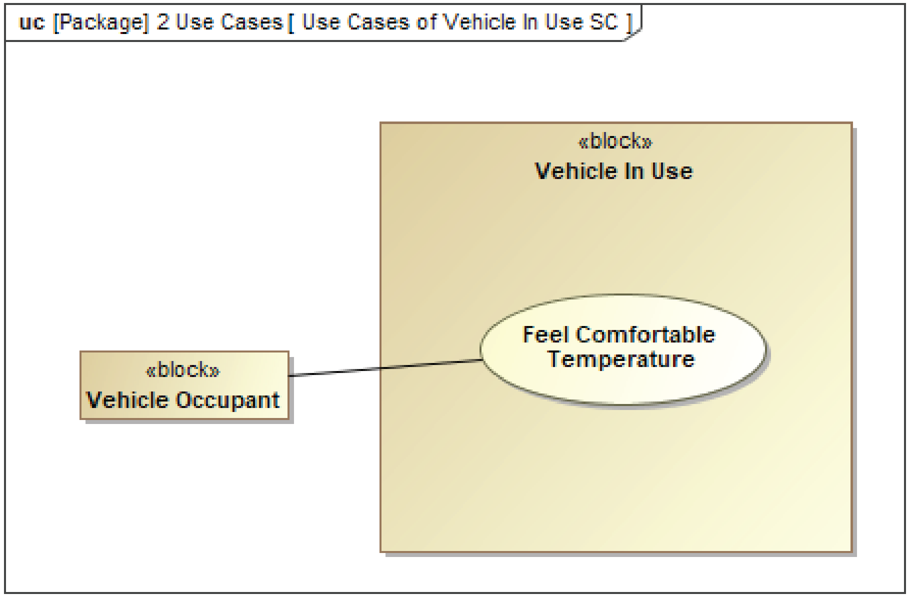
Requirement Extendibility



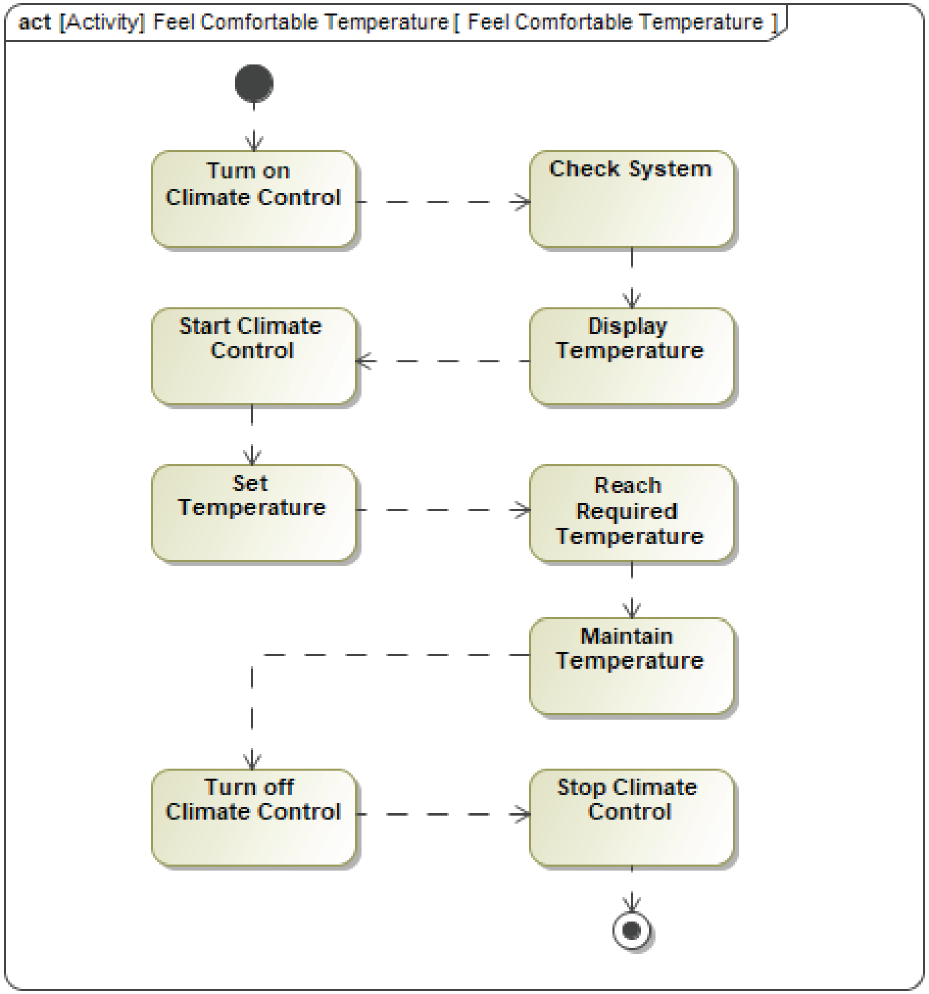
Requirement Development



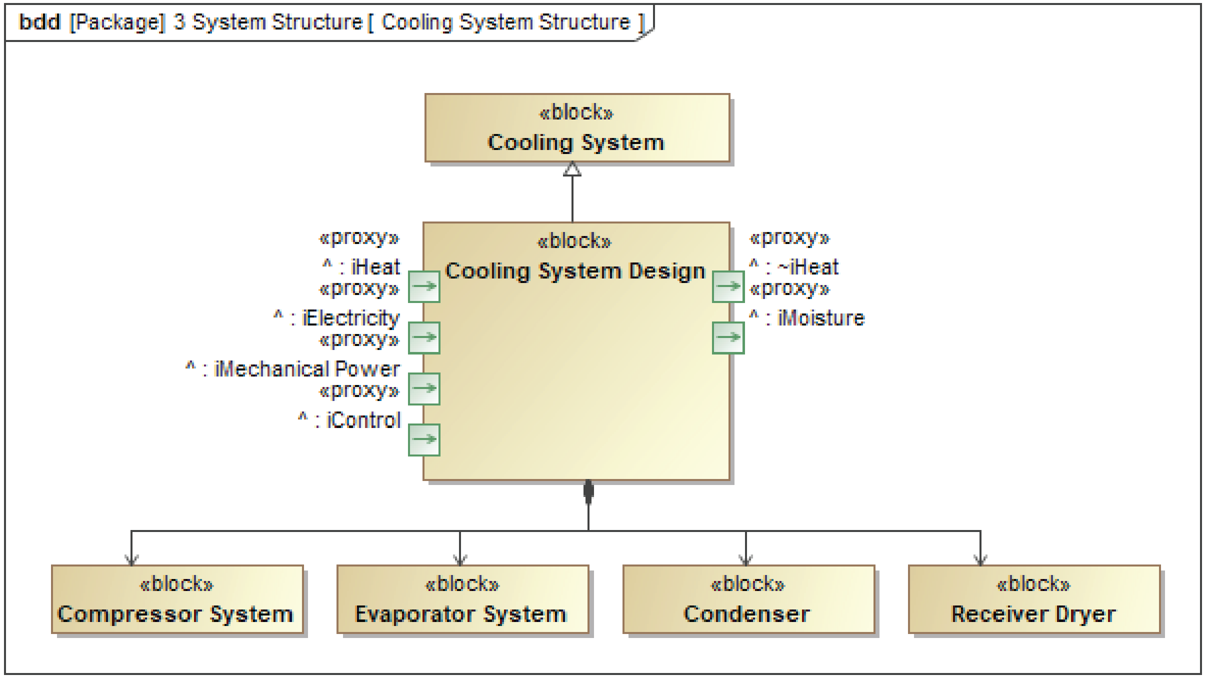
Requirement Derivation Process



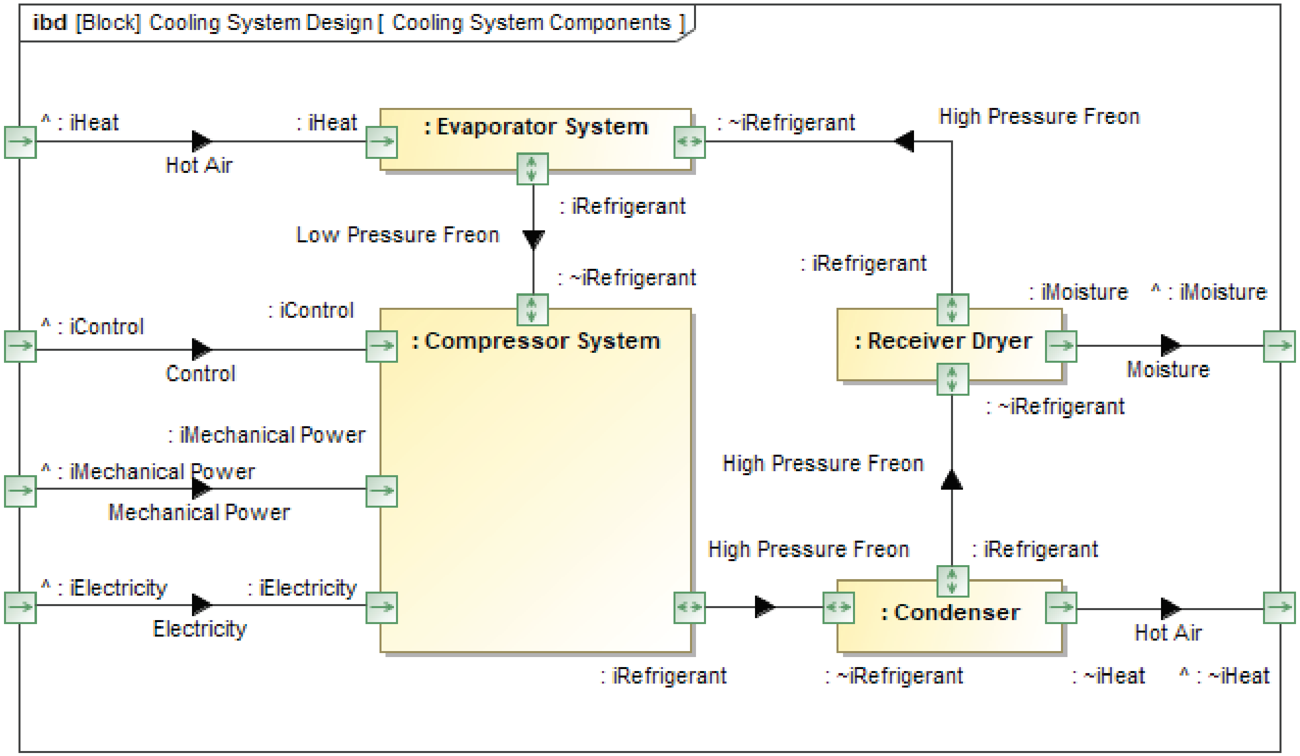
Activity Implementation



Requirement Derivation Process



Requirement Derivation Process



Requirement Derivation Process

Criteria

Element Type: Connector ... Context: Climate Control Unit ... Filter:

#	Part A	Port A	Port A Features	Port B	Port B Features	Part B
1	: Control System	inout p4 : I/O	in Control out Status	inout p4 : ~I/O	out Control in Status	: UI System
2	: Control System	inout p5 : I/O	in Control out Status	inout p5 : ~I/O	out Control in Status	: Heating System
3	: Control System	inout p6 : I/O	in Control out Status	inout p6 : ~I/O	out Control in Status	: Cooling System
4	Climate Control Unit	inout p1 : Air	inout Air Flow	inout p1 : Air	inout Air Flow	: Cooling System
5	Climate Control Unit	inout p1 : Air	inout Air Flow	inout p1 : Air	inout Air Flow	: Heating System
6	Climate Control Unit	inout p2 : I/O	in Control out Status	inout p2 : I/O	in Control out Status	: UI System
7	Climate Control Unit	in p3 : Energy	in Electrical Power in Mechanical Power	in p3 : Energy	in Electrical Power in Mechanical Power	: Control System
8	Climate Control Unit	in p3 : Energy	in Electrical Power in Mechanical Power	in p3 : Energy	in Electrical Power in Mechanical Power	: Cooling System
9	Climate Control Unit	in p3 : Energy	in Electrical Power in Mechanical Power	in p3 : Energy	in Electrical Power in Mechanical Power	: Heating System
10	Climate Control Unit	in p3 : Energy	in Electrical Power in Mechanical Power	in p3 : Energy	in Electrical Power in Mechanical Power	: UI System

Use Case Refinement

Legend
- ↗ Refine
- ⇢ Refine (Implied)

	2 White Box	2 Functional Ana	Cool	Heat	Prepare System	Reach Required Temperatur	Transfer Data	3 Logical Architecture	1 Interf	Air	Energy	I/O	2 Logical Sul	Control System	Cooling System	Heating System	UI System	Climate Control Unit	4 Measu	MoE	/Sound Level : dBA	/Total Mass : mass[kilogram]
1 System Requirements			2	2	2	2	1			2	1	1		2	4	4	2	4			1	1
SR-1 VCC System Requirements Specification																						
SR-1.1 Automatic Temperature Control	8	4	↗	↗	↗	↗		4	1	↗			2		⇢	⇢		⇢				
SR-1.2 Manual Temperature Control	8	4	↗	↗	↗	↗		4	1	↗			2		⇢	⇢		⇢				
SR-1.3 Temperature Display	7	1					↗	6	1			↗	4	⇢	⇢	⇢	⇢	⇢				
SR-1.5 Sound Level																			1		↗	
SR-1.6 Total Mass																			1			↗
SR-1.7 Engine Use	6							6	1		↗		4	⇢	⇢	⇢	⇢	⇢				

Requirement to Design Trace

Legend
↗ Satisfy

1 System Requirements
SR-1 VCC System Re

VCCS Configuration [3 System Structure]		SR-1.1 Automatic Temperature Control	SR-1.2 Manual Temperature Control	SR-1.3 Temperature Display	SR-1.5 Sound Level	SR-1.6 Total Mass	SR-1.7 Engine Use
		9	9	2	1	3	1
: Control System Design	2	↗	↗				
: Cooling System Design	2	↗	↗				
: Heating System Design	2	↗	↗				
: Sensors System Design	2	↗	↗				
: Total Mass	1					↗	
: UI System Design	1			↗			
/soundLevel : dBA	1				↗		
/totalMass : mass[kilogram]	1					↗	
in p1 : iHeat	2	↗	↗				
in p2 : iElectricity	3	↗	↗	↗			
in p3 : iMechanical Power	3	↗	↗				↗
mass : mass[kilogram]	1					↗	
out p4 : ~iHeat	2	↗	↗				
out p6 : iMoisture	2	↗	↗				

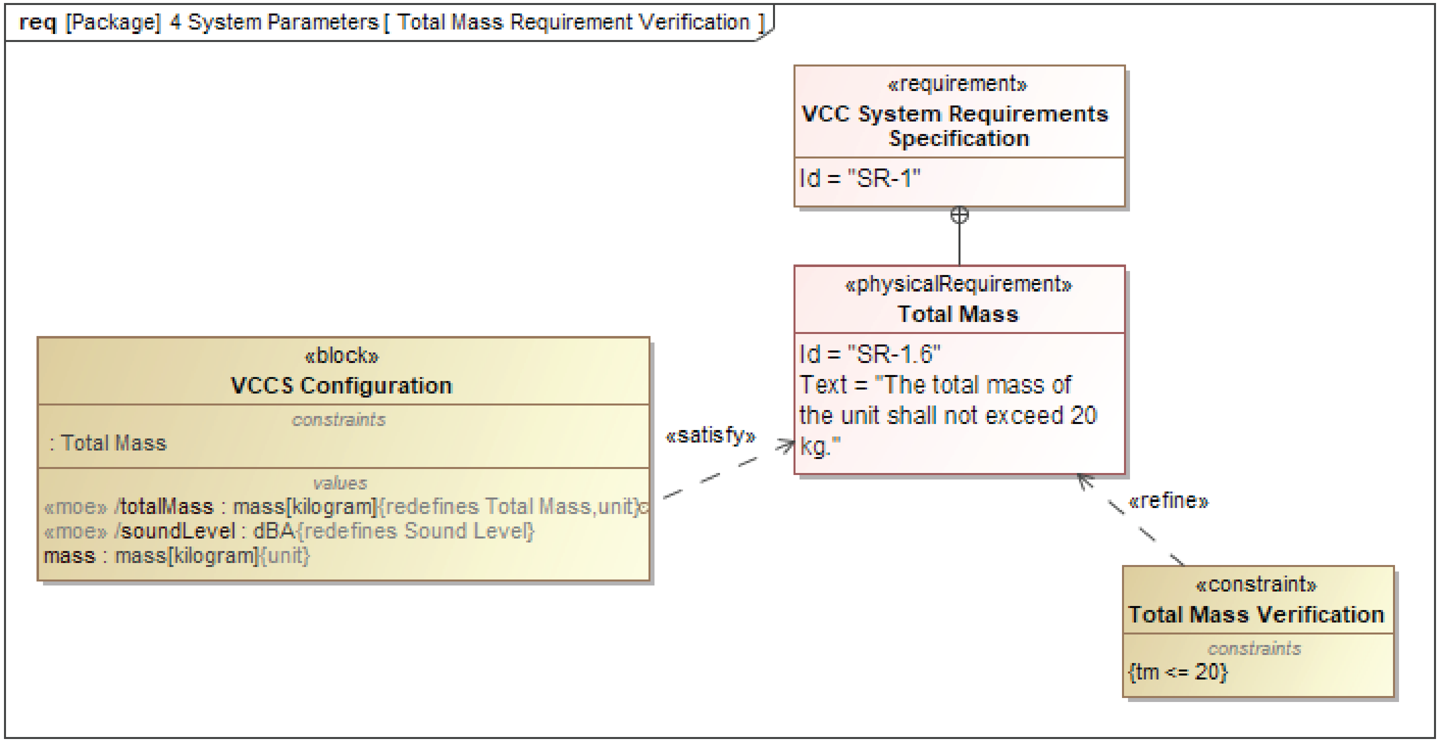
Stakeholder Need Trace

Legend

↗ Refine

		1 Stakeholder Ne / SN-1 User N	SN-1.1 Setting Temperature	SN-1.2 Heat and Cool Modes	SN-1.3 Noise Level	SN-1.4 Climate Control Mass
2 Functional Analysis			4	2		
Cool	1			↗		
Display Data	1		↗			
Heat	1			↗		
Prepare System	1		↗			
Reach Required Temperature	1		↗			
Transfer Data	1		↗			
4 Measurements of Effectiveness					1	1
MoEs Holder					1	1
/Sound Level : dBA	1				↗	
/Total Mass : mass[kilogram]	1					↗

Mass Roll Up

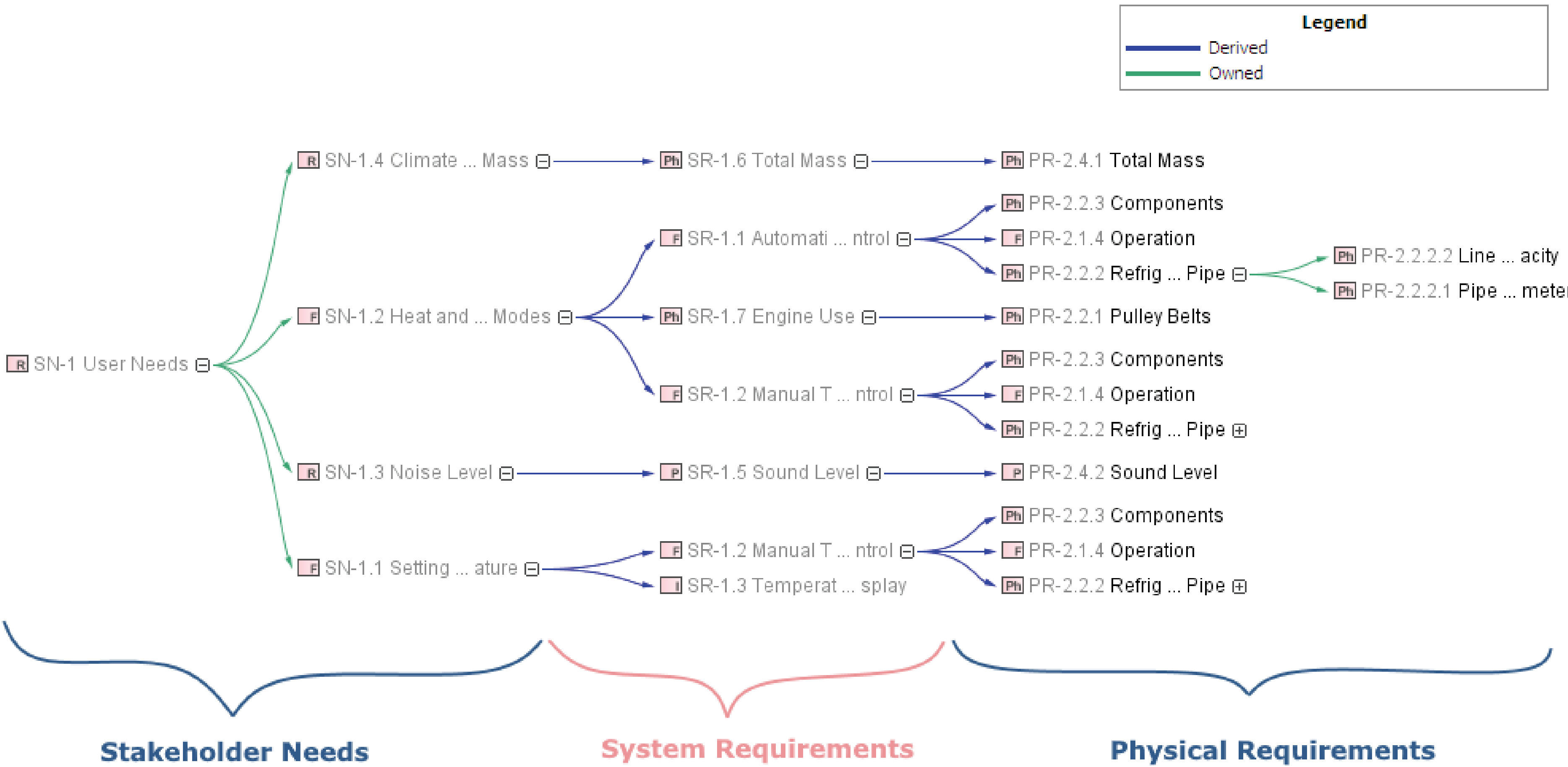


req [Package] 4 System Parameters [Total Mass Requirement Verification]
«requirement»
VCC System Requirements Specification
Id = "SR-1"
«physicalRequirement»
Total Mass
Id = "SR-1.6"
Text = "The total mass of the unit shall not exceed 20 kg."
«block»
VCCS Configuration
constraints
: Total Mass
values
«moe» /totalMass : mass[kilogram]{redefines Total Mass,unit}
«moe» /soundLevel : dBA{redefines Sound Level}
mass : mass[kilogram]{unit}
«satisfy»
«refine»
«constraint»
Total Mass Verification
constraints
{tm <= 20}

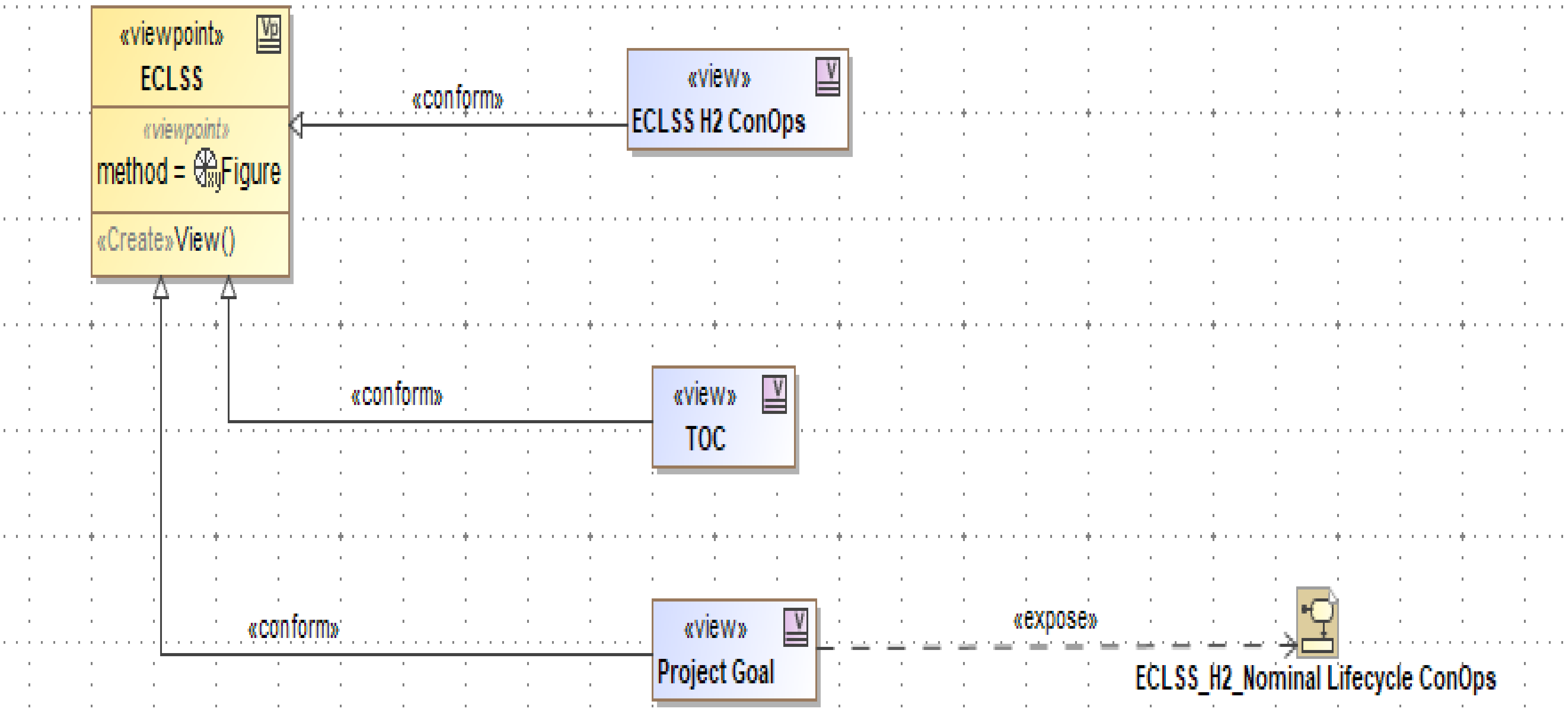
Mass Rollup Requirement Verification

Name	Value
ECLSS_H2_Technology_Demonstration_System {totalMass <= 500.0}	ECLSS_H2_Technology_Demonstration_System@3839f730
mass : Real [1]	0.0000
/totalMass : Real	501.0000
: Gas Manifold {subsets subMass} {totalMass <= 500.0}	Gas Manifold@411c1368
: Manual Flow Valve {subsets subMass} {totalMass <= 500.0}	Manual Flow Valve@7884afa3
mass : Real [1]	0.0000
/totalMass : Real	250.0000
sum : total {totalMass = mass + sum(subMass.totalMass)}	total@275f742e
: Flow Meter {subsets subMass} {totalMass <= 500.0}	Flow Meter@65097727
mass : Real [1]	251.0000
/totalMass : Real	251.0000
sum : total {totalMass = mass + sum(subMass.totalMass)}	total@4f681329
: Pressure Relief Valve {subsets subMass} {totalMass <= 500.0}	Pressure Relief Valve@43f893e1
: A/D Conv, PCDU {subsets subMass} {totalMass <= 500.0}	A/D Conv, PCDU@7a84d3cf
: Heater Zone 1 {subsets subMass} {totalMass <= 500.0}	Heater Zone 1@4af8ca6a
: Heater Zone 2 {subsets subMass} {totalMass <= 500.0}	Heater Zone 2@7cc944f4
: Sensor Elec. {subsets subMass} {totalMass <= 500.0}	Sensor Elec.@6ccf0733
: Sensor Elec. {subsets subMass} {totalMass <= 500.0}	Sensor Elec.@418c082c
: Sensor Elec. {subsets subMass} {totalMass <= 500.0}	Sensor Elec.@115c7c55
: Sensor Elec. {subsets subMass} {totalMass <= 500.0}	Sensor Elec.@b3c1d54

Traceability



Views and Viewpoints



HTML Document Generation

ECLSS Concept of Operations

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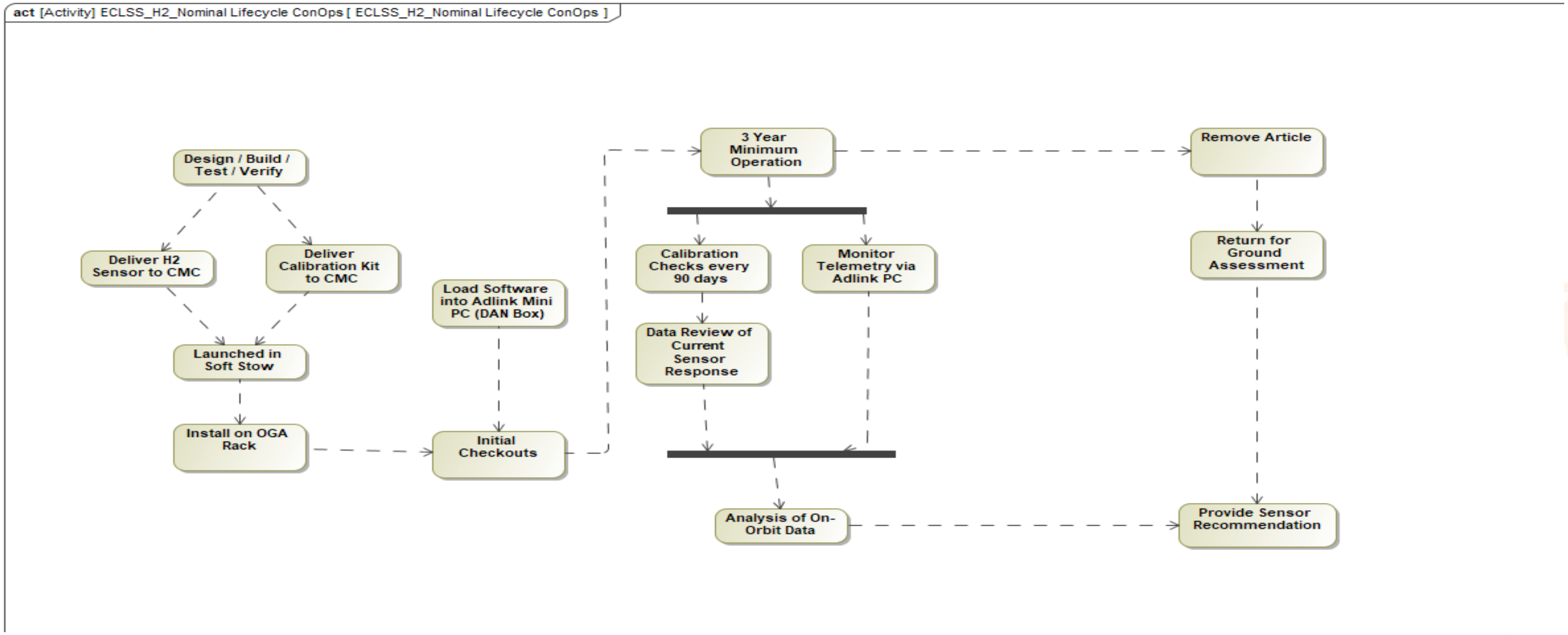
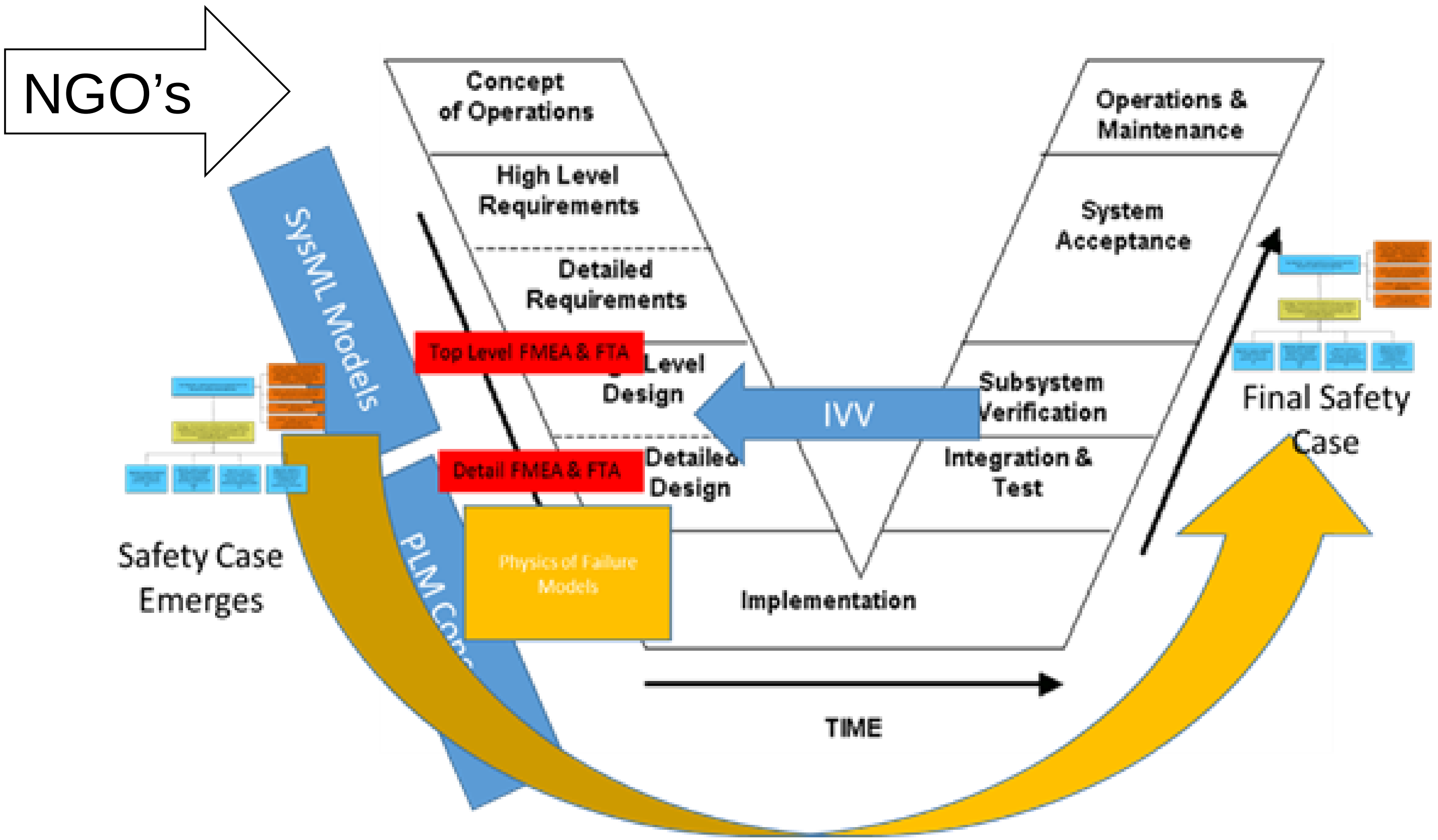
Chapter 2. Project Goal

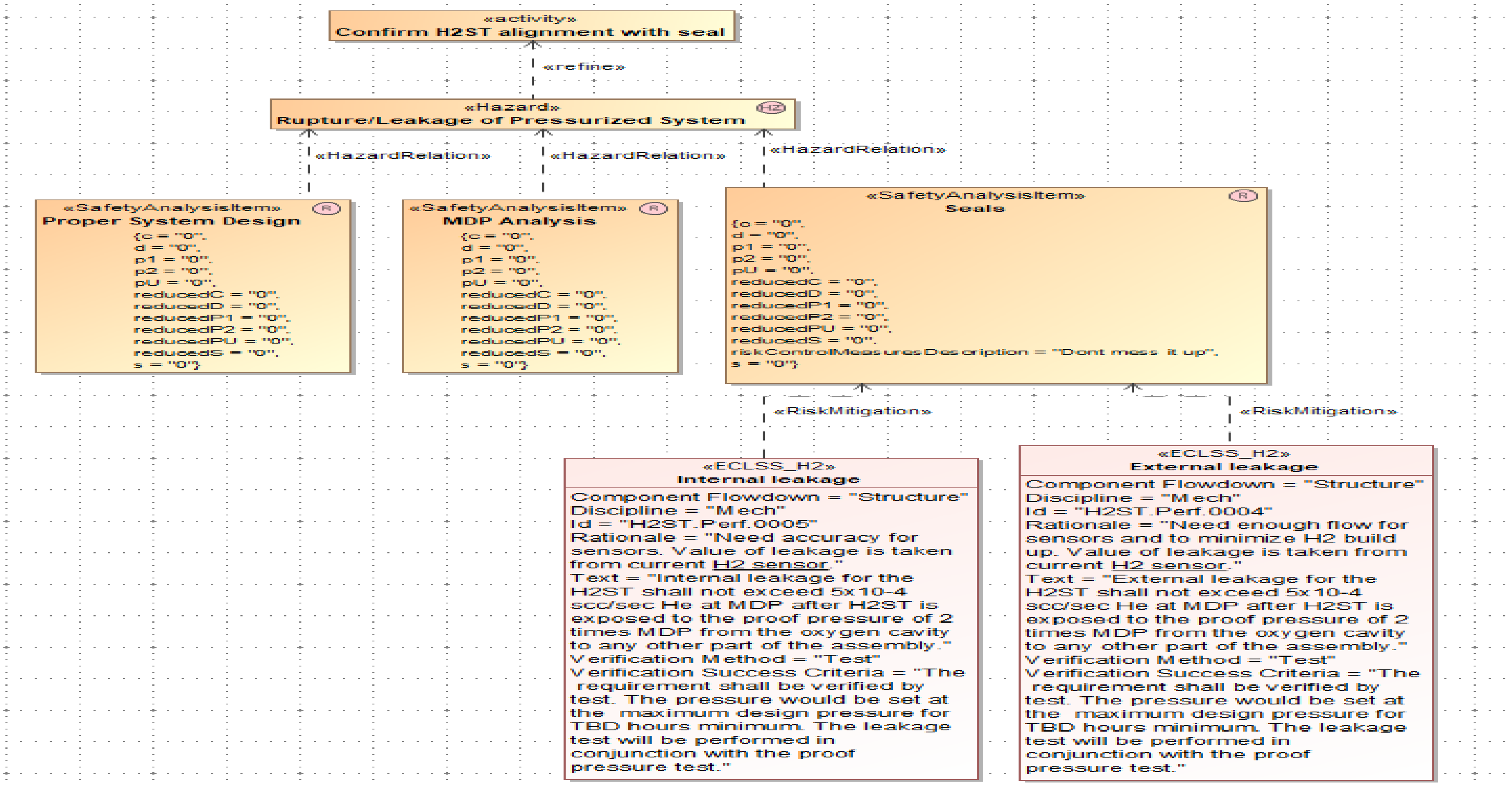


MBMA Integration



MBMA Pathfinding

- Pathfinding approach with MagicDraw Plugin Cameo Safety and Reliability



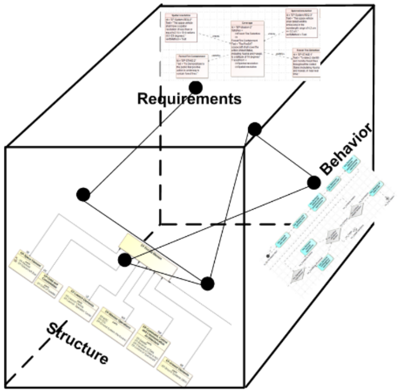
NASA Future MBSE Work

- Pilot Patterns for deploying a Scalable Architecture
- Develop Profile (and patterns) for generating a complete set of tailorable 7123 products, artifacts and views
- Explore end verification and validation approaches.
- Research Configuration and Data Management approaches.
- Further investigation into PLM tools for complete Digital Thread
- Pilot Patterns for implementing S&MA Comprehensive Project Risk Management
- Exploring Teamwork Cloud Environment centered around Cameo Collaboration

CLM Takeaways Using MBSE

- **Improved Communications**
  - Graphical elements
  - Consistent definitions
  - Collaborative infrastructure
  - Authoritative data

- **Managing a Complex System**
  - View multiple perspectives
  - Analyze change impacts
  - Evaluate system for consistency, accuracy, and completeness
  - Simulate the functionality of the system
  - Integrate with other disciplines



- **Enhanced Knowledge Transfer**
  - Store models and model elements in a library
  - Reduced start-up time
  - Consistent information between projects and between project lifecycle phases
  - Iterative and multi-level modeling

- **Reduced Time**
- **Reduced Cost**
- **Reduced Risk**
- **but…Requires up-front investment**

Questions?

- **Any Questions or go backs?**

* Details can be found in backup charts

MBSE Trace to NPR 7123 17 SE Processes