Model-Based Reviews for Systems

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Introduction

- As we conceive, acquire, develop, deploy, and operate space systems in a **digitally integrated** manner, our approach to milestone reviews will be different than in times past
- This Model-Based Reviews tutorial is broken into three parts
  - *Reviews in a Lifecycle-Managed Digital Engineering Environment (Fredda Lerner)*
  - *Model-Based Review Planning (Greg Mowles)*
  - *Model-Based Review Execution (Kevin Sanchez)*
- Unless otherwise noted, we will be discussing reviews at the system level vs. mission level, but there are many parallels

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Reviews in a Lifecycle-Managed Digital Engineering Ecosystem

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System of Systems Engineering

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This Chart Deck is Unclassified in its Entirety

Purpose and Goals of this Training

- The ***purpose*** of this training segment is to provide an overview of system lifecycle (read: Acquisition lifecycle) review execution when they are supported, to the greatest extent practicable, by models, and, to the least extent practicable, by documents

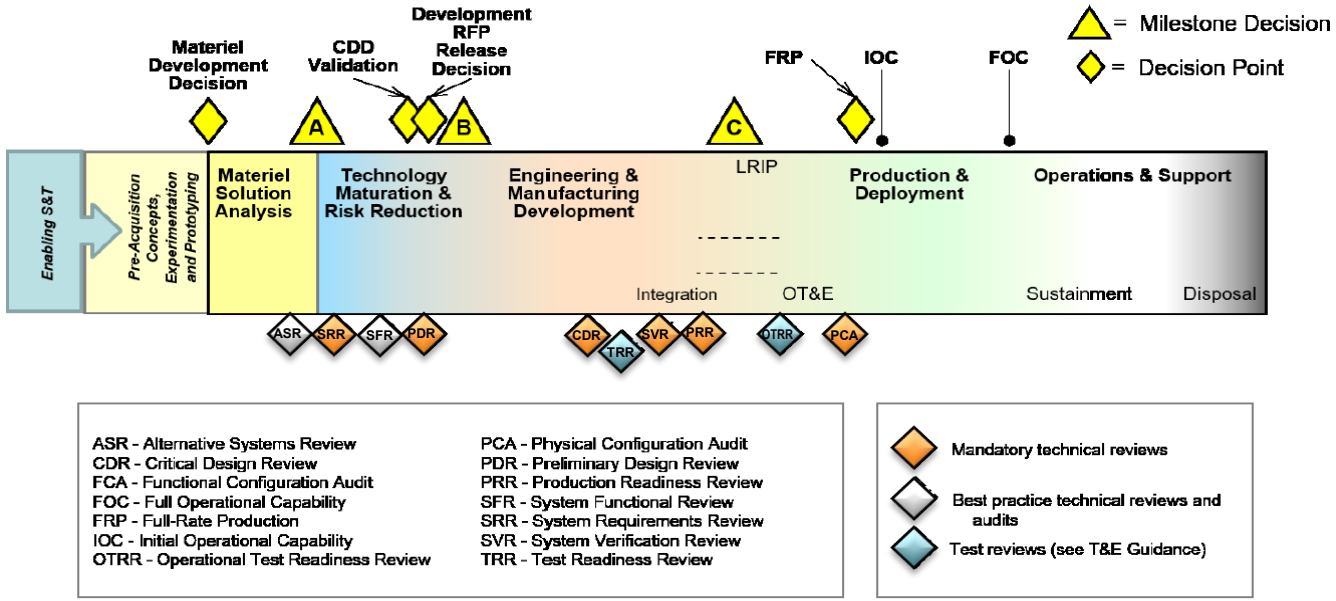
- The ***key goals*** of this training is to ensure that Acquisition lifecycle event participants, regardless of role, team, or level of authority in the lifecycle, understand
  - *The Acquisition lifecycle as defined in the references*
  - *The Acquisition lifecycle systems engineering (SE) to include descriptive data models in persistent technical reviews (TRs) that define progressive system maturity levels*

References:

- ***ISO IEC IEEE 15288:201x(E) [August 2014], Systems and Software Engineering – System Life Cycle Processes***
- ***ISO IEC IEEE 21839 [July 2019], Systems and software engineering – System of systems (SoS) considerations in life cycle stages of a system***
- ***ISO IEC IEEE 21840 [December 2019], Systems and software engineering – Guidelines for the utilization of ISO/IEC/IEEE 15288 in the context of system of systems (SoS)***
- ***ISO IEC IEEE 2184 [July 2019], Systems and software engineering – Taxonomy of systems of systems***
- ***DoD Systems Engineering Guidebook, February 2022***
- ***DoDI 5000.88, Engineering Defense Systems, November 2020***

Background: The Acquisition Life Cycle

- A system is a continuous dynamic entity that progresses through stages of maturity in time
- Architecture Adaptive Framework (AAF) defines the relative lifecycle timeline and its persistent events
  - *A system life cycle framework is an abstract representation of system of interest (SOI) or program maturity stages*
  - *Technical reviews (TRs), as shown below by , define maturity at specific points in a program and SOI lifecycle*
- The timeline is not to scale: although the sequence of TRs and events are persistent, their actual occurrence varies because the size and scope of each SOI or program expands and contracts the AAF timeline



The AAF governs the document-based process and the model-based and authoritative sources of truth (ASOT) data artifact-based process

About the (Repetitive) Technical Reviews

…in document-based and model-based technical reviews

- There are 3 overarching participant roles
  - ***The government program management office (PMO)***
    - Defines acceptance criteria for each maturity stage TR, e.g., contract data requirements list (CDRL) items, documents, data, etc.
      - *For each TR, the program manager determines acceptance criteria*
      - *Acceptance criteria are specified in contract language*
    - Ensures that previous maturity stage TR acceptance criteria are successfully met and its artifacts are available
    - Oversees risk management
    - Selects independent review team (IRT) members who are subject matter experts (SMEs) in program-relevant content
    - Reviews contractor-adjudicated artifacts and decides to approve, approve with liens, or disapprove
  - ***Each IRT member***
    - Reviews contractor artifacts that respond to acceptance criteria
    - Inputs his/her/their comments in a comment resolution matrix (CRM) for contractor adjudication
  - ***The contractor(s)***
    - Develops artifacts in response to the government PMO's acceptance criteria
    - Tracks and buys down risks
    - Submits artifacts to IRT members for review
    - Adjudicates IRT members' comments – may or may not incorporate them (requires explanation) – and submits to PMO for decision
    - Develops a mitigation plan for each "Approve with Lien" PMO decision and must work off in tandem with next maturity phase
    - Hosts TR and presents adjudicated artifacts at maturity stage review for government decision

Artifacts are the Difference Between Document-Based and Model-Based Reviews

Artifacts of evidence of

- Document based reviews' artifacts are developed as static and disconnected documents
- All artifacts can be independently developed
- Relationships between artifacts and artifact contents are implied and verified through implication

- Requires more "up front" work for data connectivity
- Builds models that are extensible, curated, and open
- Presents model views that are intuitively obvious
- Is governed by an overarching model that defines traceability and "interconnect-ability"
- Uses models to define digital twins that interconnect descriptive data elements in Authoritative Sources of Truth (ASOT) curated containers
- Uses data that evolve and change over the time of the Acquisition lifecycle

Document-Based Acquisition Lifecycle Review

Reviewing documents without alignment to acceptance criteria

- **Engineering execution and artifact preparation**
  - *Government PMO ensures all entrance criteria artifacts are available to start TR execution*
  - *Government PMO specifies exit criteria document artifacts, e.g., contract data requirements list (CDRL) items that are prescriptive and stand-alone*
  - *In a waterfall process, contractor(s) develops document artifacts*
- **Execution with discrete review period prior to TR**
  - *Review cannot start until documents are complete – often 30-60 days prior to TR (depending on SOI/program size)*
  - *IRT members comment on document-based artifacts and not on how well they address maturity with respect to (WRT) acceptance criteria*
  - *Contractor reviews IRT comments and adjudicates, as applicable*
- **Artifact approval at TR**
  - *Contractor(s) develop (often voluminous) chart deck*
  - *Contractor(s) host/lead TR which can span many days*
  - *Government PMO "grade" document artifacts*
    - Document artifacts are approved
    - Requirements approved as baseline and under configuration management control

Does document artifacts approval = acceptance criteria maturity?

Digital Engineering-Based Model-Enabled Acquisition Lifecycle Review

Reviewing models and data as a continuum and in the context of acceptance criteria

- **Engineering execution and artifact preparation**
  - *Government ensures previous maturity phase acceptance criteria data and model artifacts are available at start of execution of current maturity stage*
  - *Government ensures maturity level acceptance criteria are unambiguous and fully defined in contract language; documents, if needed, are specified in CDRL items*
  - *In a hybrid/agile process punctuated with incremental reviews, contractor(s) develop*
    - Models, data, authoritative sources of truth (ASOT) sources to address acceptance criteria – without work stoppage
    - Document templates to be populated by models and data IAW CDRL items
- **Execution interspersed with periodic/incremental mid-phase sub-reviews culminating with TR**
  - *Periodic reviews are conducted within each maturity phase to incrementally review contractors' models and data responses to acceptance criteria artifacts as they evolve/mature*
  - *IRT members participate in periodic reviews and comment on evolving/maturing data and model responses*
    - CRM is on on-line database which provides real time comment adjudication and transparency
    - Significantly fewer issues require adjudication at TR because they are adjudicated throughout the process
- **Artifact approval at TR**
  - *Government reviews responses to each acceptance criteria*
  - *Shorter TR with fewer charts*
  - *Models and requirements approved as baseline and under CM control*

Is an Organization Ready to Execute a Successful DE-Based Review?

- DE- and model-based reviews are high risk because they require significant change to be successful.

- Although the roles are not different, some key responsibilities are different.
- Although the Acquisition lifecycle is not new, how it is executed is different.
- Although an IRT is not new, how it executes is different

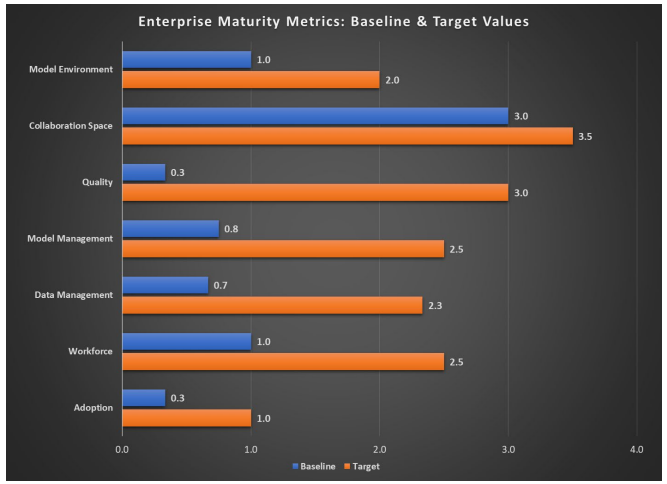
- Before an organization determines that it wants to start DE-based reviews, the organization needs to assess itself to determine where it is on the DE-readiness/model review spectrum
- Success requires that an organization must be evolved enough to ensure DE success

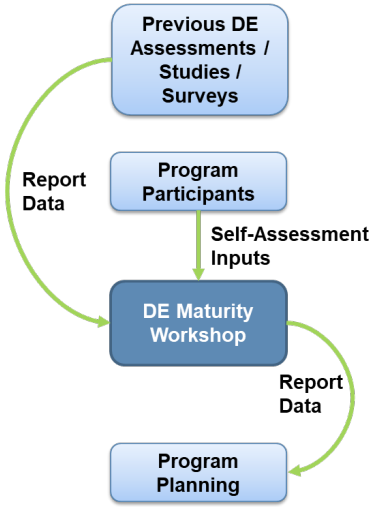
- If the organization is not evolved enough, it can use its assessment to develop a road map to success.

Use the DE Maturity Readiness Assessment

Digital Engineering Maturity Assessment Tools Overview

- **Available Tool Options For Digital Engineering Assessment and Planning of Model Based Reviews**
  - ***DE/MBSE Maturity Self-Assessments***
    - **INCOSE** Model Based Capabilities Assessment
    - **DAF** Digital Transformation Digital Engineering Maturity Metrics
      - ***Aerospace*** *DE Maturity Self-Assessment Facilitated Workshop*
  - ***System Engineering Milestone Review Evolution Roadmap***
- **Assessment Tools Provide:**
  - ***Identification*** *of current DE maturity level, desired maturity level, and gap to bridge*
  - ***Metrics*** *for tracking status of DE maturity evolution*
  - ***Justification*** *to inform organization's decision-making on DE planning (products, priorities, resources, etc)*





Category	Metric	Component	Component Baseline	Component Target	Weight (1-10, 10 = most important, 0 for N/A)	Weighted Effort Needed
Infrastructure	Modeling Environment	Access and Governance	2	3	1	2%
		Interoperability	0	1	1	2%
	Collaboration	Capability	3	4	1	2%
		Security	3	3	1	0%
Modeling / Analysis	Quality	Authoritative Sources of Truth (ASOT)	1	2	1	2%
		Metrics	0	4	5	38%
		Model-Based Verification and Validation (V&V)	0	3	1	6%
Process / Policy	Model Management	Digital Management Strategy	1	3	1	4%
		Model-Based Systems Engineering	0	1	10	19%
		Configuration Management	2	3	1	2%
		Process Verification and Validation (V&V)	0	3	1	6%
	Data Management	Innovative Technical Processes	0	1	1	2%
		Technical Management Processes	1	4	1	6%
		Analysis, User Interface (UI) and Visualization	1	2	1	2%
Workforce / Culture	Workforce	Digital User Skills	2	3	1	2%
		Common Digital Understanding	0	2	1	4%
	Adoption	Digital Artifact Use	1	2	1	2%
		Reference Architecture Incorporation	0	0	1	0%
		Milestone, Program, and Technical Reviews; Audits	0	1	1	2%

Assessment Tools Can Benefit Traditional Government Acquisition Programs At Any Stage of Digital Maturity

Model-Based Review Digital Engineering Maturity Assessment

- **How to apply DE maturity assessment to Model Based Review planning:**
  - *Assess current baseline maturity and identify desired target maturity of **"Milestone, Program, and Technical Reviews; Audits" component***
  - *In addition, assess the same for **other DE maturity components that are applicable** to the Model Based Review planning. Examples:*
    - Tool Access and Governance – Review tool interface and access
    - Collaboration Capability – Reviewer comment submission and tracking capabilities
    - Digital User Skills – Participant training
    - Digital Artifact Use – Format of review deliverables

Component	Maturity Level Description				
	Level 0	Level 1	Level 2	Level 3	Level 4
Milestone, Program, and Technical Reviews; Audits	Reviews are not model based. Reviews and audits are set by calendar date against a contract event such as contract award. Digital artifacts are not planned for use to satisfy entry/exit criteria.	Enterprise organizations do not coordinate on common review criteria application and tailoring, and the use of digital artifacts as deliverables (via contract language). Occasionally models record the acceptance of items through reviews of model content/data in a modeling environment to allow stakeholders to ensure that the review is complete based on exit criteria.	Enterprise organizations infrequently coordinate on common review criteria application and tailoring, and the use of digital artifacts as deliverables (via contract language) but they are aware of the requirements of others. Frequently models record the acceptance of items through reviews of model content/data in a modeling environment to allow stakeholders to ensure that the review is complete based on exit criteria.	Enterprise organizations frequently coordinate on common review criteria application and tailoring, and the use of digital artifacts as deliverables (via contract language). Models record the acceptance of items through reviews of model content/data in an integrated digital environment to allow stakeholders to ensure that the review is complete based on exit criteria.	Enterprise organizations coordinate on common review criteria application and tailoring, and the use of digital artifacts as deliverables (via contract language). Models automatically record acceptance through frequent reviews of model content/data in an integrated digital environment to allow stakeholders to ensure that the review is complete based on criteria.

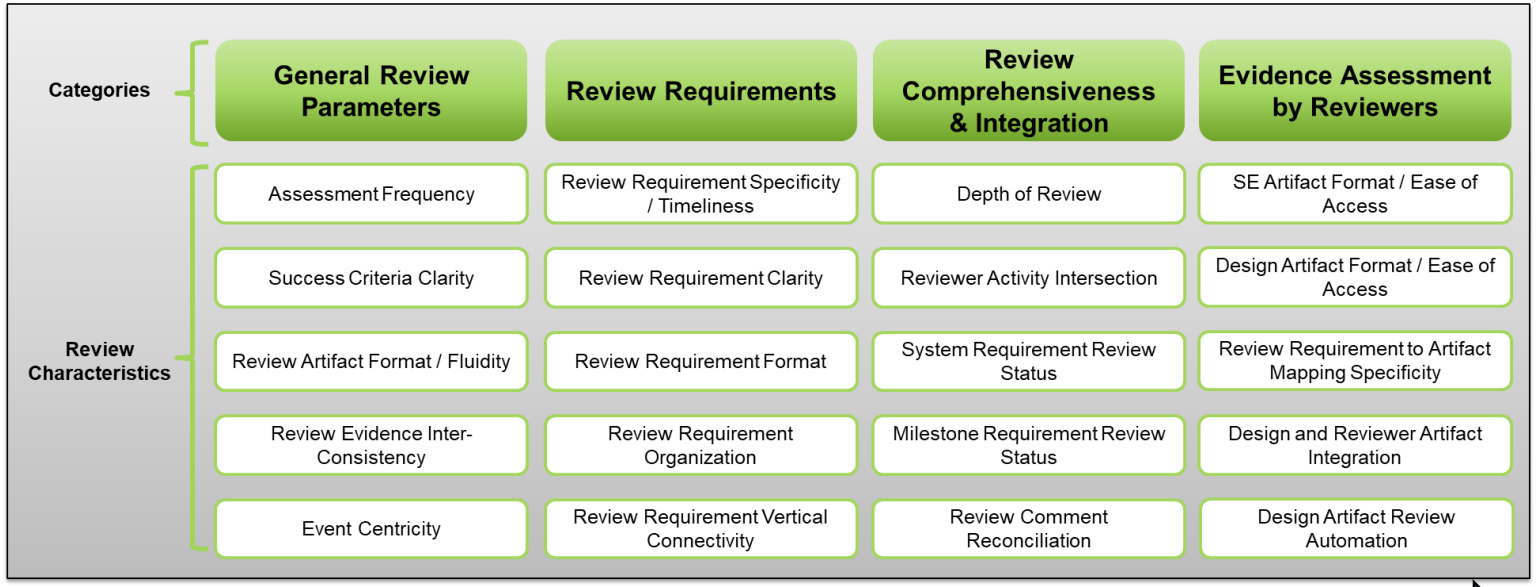
Category	Metric	Component
Infrastructure	Model Environment	Tool Access and Governance
		Interoperability
	Collaboration	Capability
		Security
Modeling / Analysis	Quality	Authoritative Sources of Truth (ASOT)
		Metrics
		Model-Based Verification and Validation (V&V)
Process / Policy	Model Management	Digital Management Strategy
		Model-Based Systems Engineering
		Configuration Management
		Process Verification and Validation (V&V)
	Data Management	Innovative Technical Processes
		Technical Management Processes
		Analysis, User Interface (UI) and Visualization
Workforce / Culture	Workforce	Digital User Skills
		Common Digital Understanding
	Adoption	Digital Artifact Use
		Reference Architecture Implementation
		Milestone, Program, and Technical Reviews; Audits

DE Maturity Assessment Tools Can Be Tailored to Focus on Model Based Reviews

System Engineering Milestone Review Evolution

Characteristics & Roadmap

- **Key characteristics of System Engineering Milestone Reviews can be selected and prioritized to define a roadmap to achieve desired level of maturity**
- **Roadmap supports assessment of current state and future state planning for Model Based Reviews**



Traditional Review State	Near-Future State	Far-Future State
Assessment Frequency - Discrete events separated by many months, resulting in substantial risk of delay in discovering defects and providing feedback	Frequent assessment of readiness driven by semi-automated identification of general areas requiring re-review, reducing delays in discovering defects and providing feedback, supporting iterative development	Continuous, proactive assessment driven by automated identification of specific areas requiring re-review, minimizing delays in discovering defects and providing feedback, fully supporting Agile/DevOps programs
Success Criteria Clarity - Success criteria are coarse, resulting in frequent disconnects between contractor, government, and individual reviewers	Success criteria defined with sufficient granularity and clarity to minimize disconnects between contractor, govt, and reviewers	Model-based success criteria facilitate automated traceability and dashboards to continually assess review maturity
Review Artifact Format/Fluidity - Program needs to freeze development work to have the time to create unique review artifacts	Review artifacts are largely the same artifacts being used to inform and document the development effort	Review artifacts are the actual models and data being used in the development effort, so the contractor can continue to work unabated

Milestone Review Transformation Roadmap Can Be Used to Track Evolution Maturity

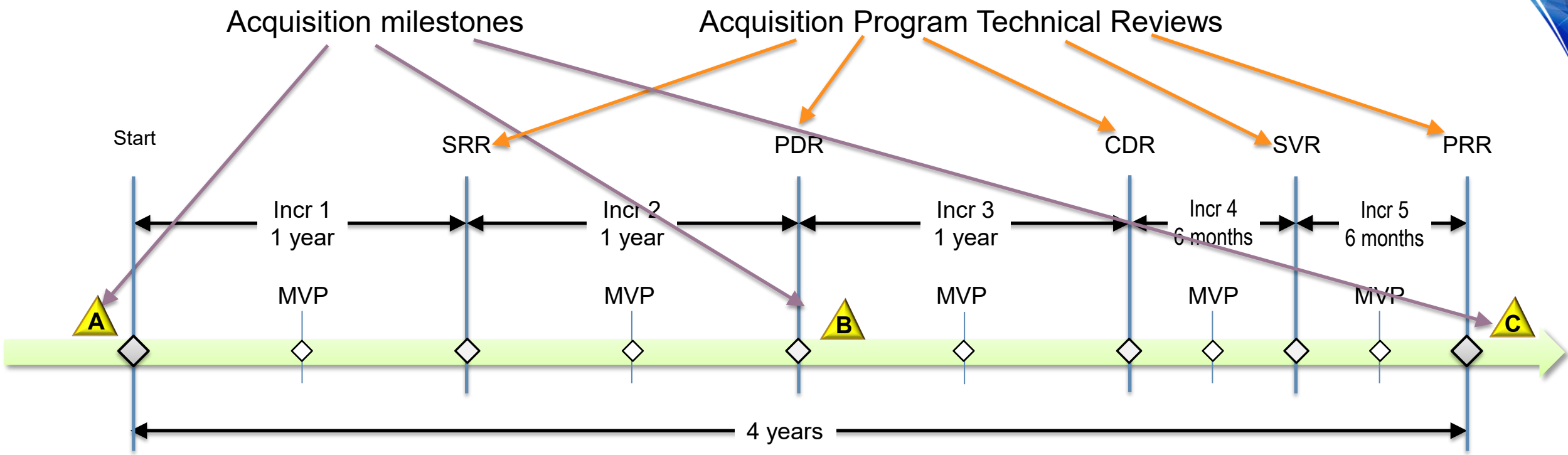
Models and Data in a Successful Review

Successful TR execution requires underpinned models with purpose

- To execute a successful model-based TR in the Acquisition lifecycle context, the models and data must be purposely traceable and “connect-able”
- Because a key outcome of every TR are traceable requirements, the overarching program model must define traceability in 3 dimensions
  - *Vertically traceable to ensure integration up, down, and through a program*
  - *Horizontally traceable to ensure addressing impacts as well as integration across related systems in a SOI or portfolio*
  - *Temporal traceability to ensure version and CM baseline control over time – at the very least, each TR will generate a new baseline*
- Connect-ability means that models must be built so that they can be understood and reconstructed anyone anywhere
  - *Using neutral standards, SysML, UAF, etc.*
  - *Use design templates applicable parts of models and data can connect with the least difficulty*

SE Process Hybrid/Agile Execution – Milestones A - C

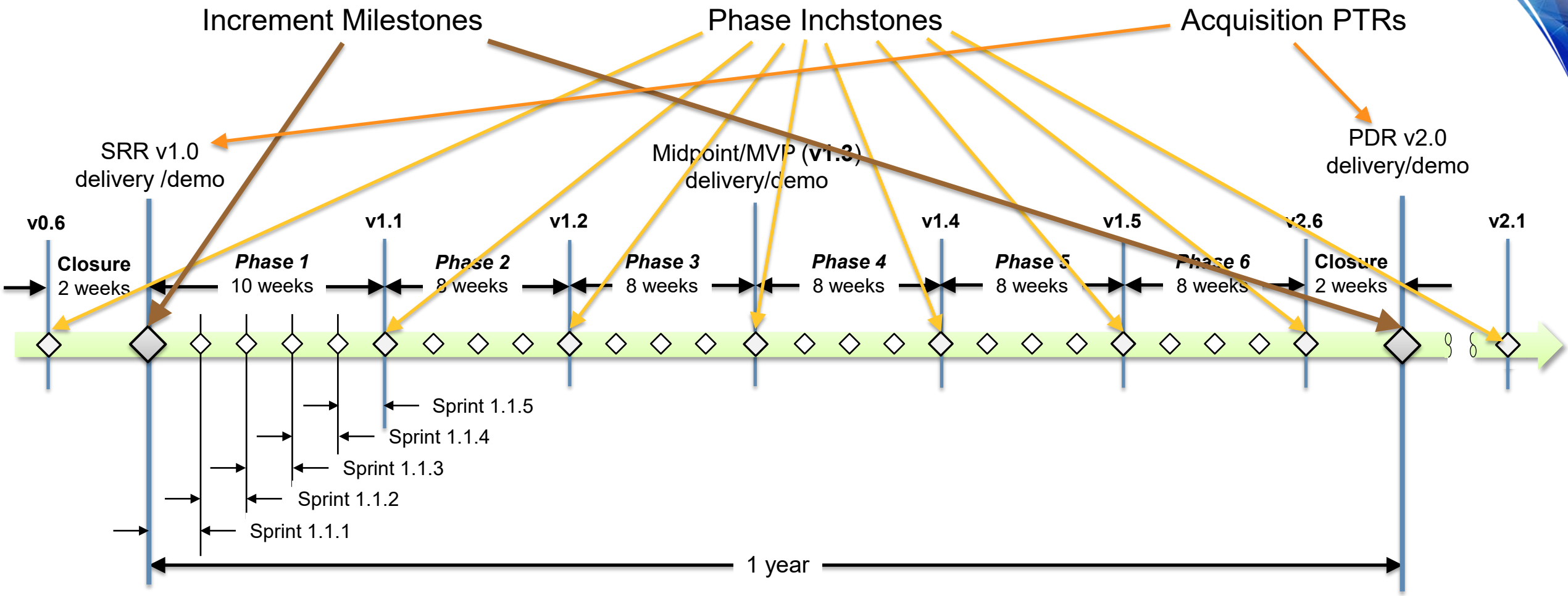
Increments 1-6 correspond to 6 program reviews



- This pathfinder is assumed to be a generic medium/large major capability acquisition where Increments 1, 2, 3 are 1 year each and Increments 4 and 5 are 6 months each
- Increment 1 closes with a SRR PTR
- Increment 2 closes with a PDR PTR
- Increment 3 closes with a CDR PTR
- Increment 4 closes with a SVR PTR
- Increment 5 closes with a PRR PTR

Acquisition Milestone Event Execution with Models and Data

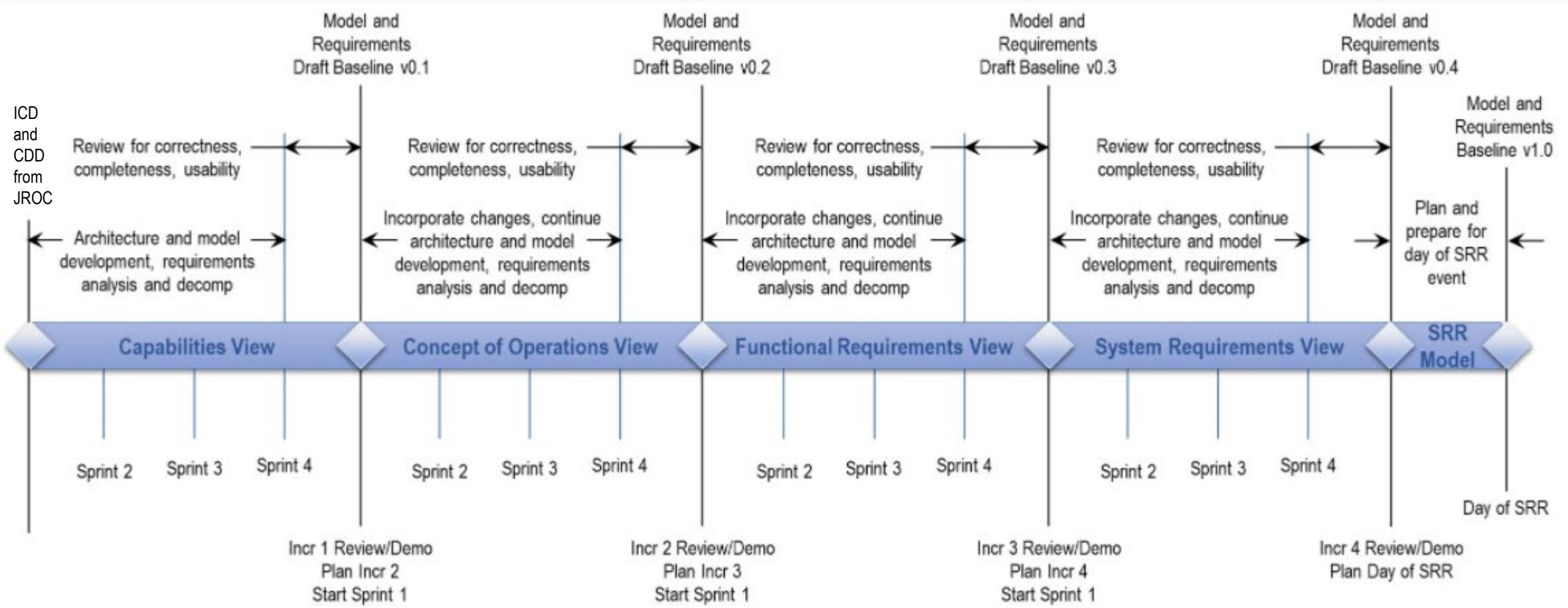
Exemplar: PDR Execution



- Each phase
  - *Concludes with an "Inchstone" event and is identified as vX.Y where X is the previous PTR version # (for Inchstone events leading to SRR, X = 0) and Y is the current phase #*
  - *Delivers a minimum viable product (MVP) at the midpoint of its execution*

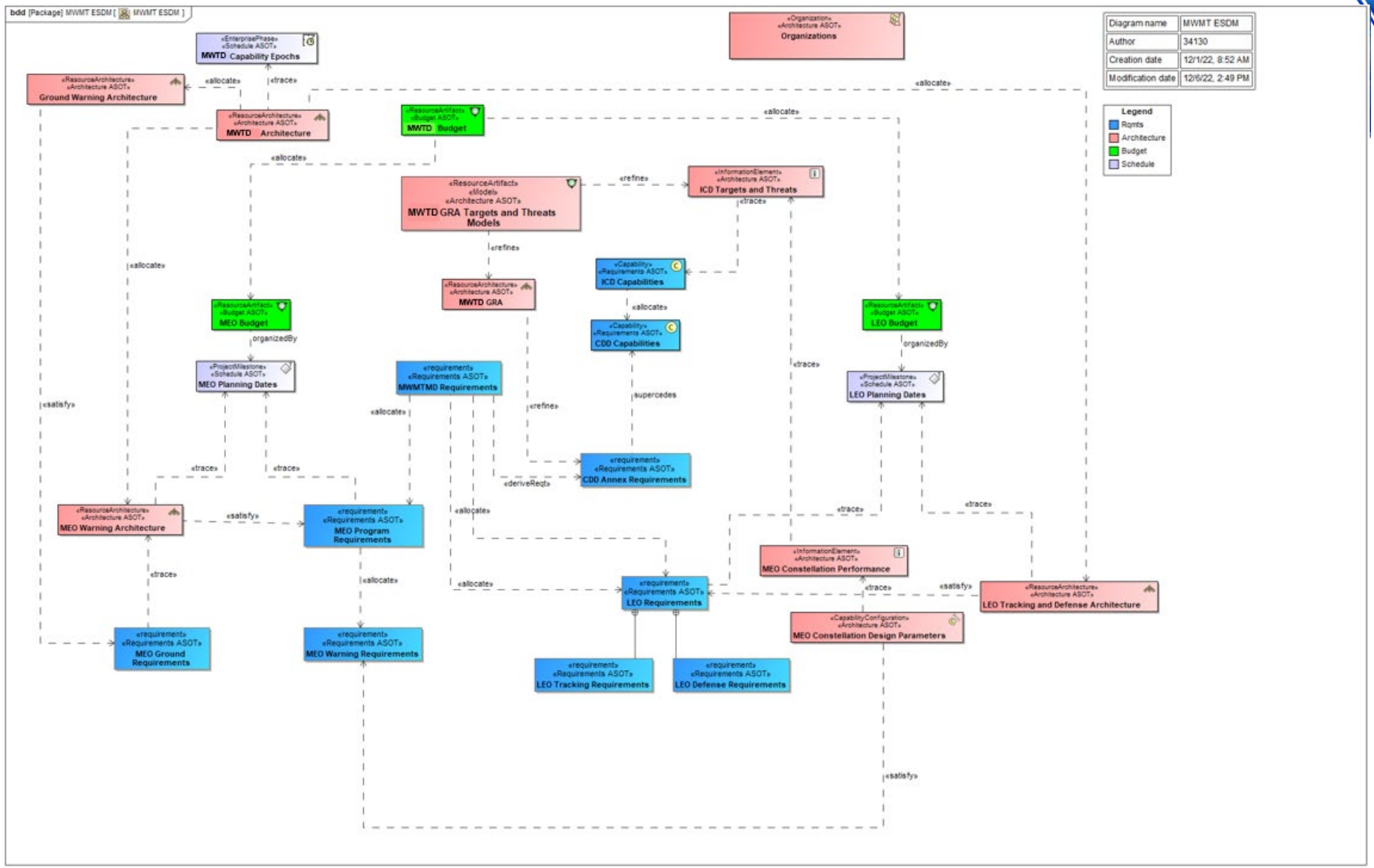
Example: Continuous Review

SRR Example with 8-month development



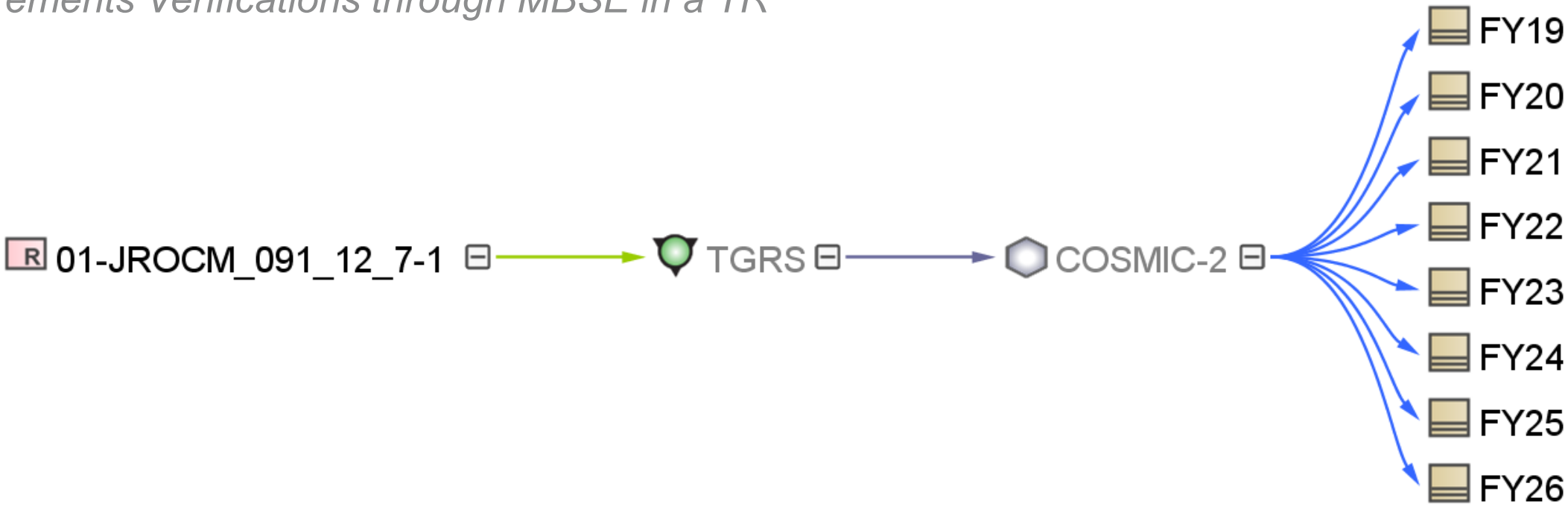
Example of Extensible Traceability Concept Model

- ESDM is the overarching reference model whose purpose is to ensure end-to-end traceability
- Assumptions:
  - *Each ASOT is "locally" curated, that is, managed by those who are the data originators*
  - *All applicable data are accessible thru ASOTs*
  - *Interconnection between data elements in disparate ASOTs are possible through use of open standard interfaces*
  - *Applicable data elements in disparate ASOTs can be passively inter-connected per the Enterprise Interconnection Model (EIM)*



MBSE – Temporal Gap Analysis Equatorial Ionospheric Scintillation

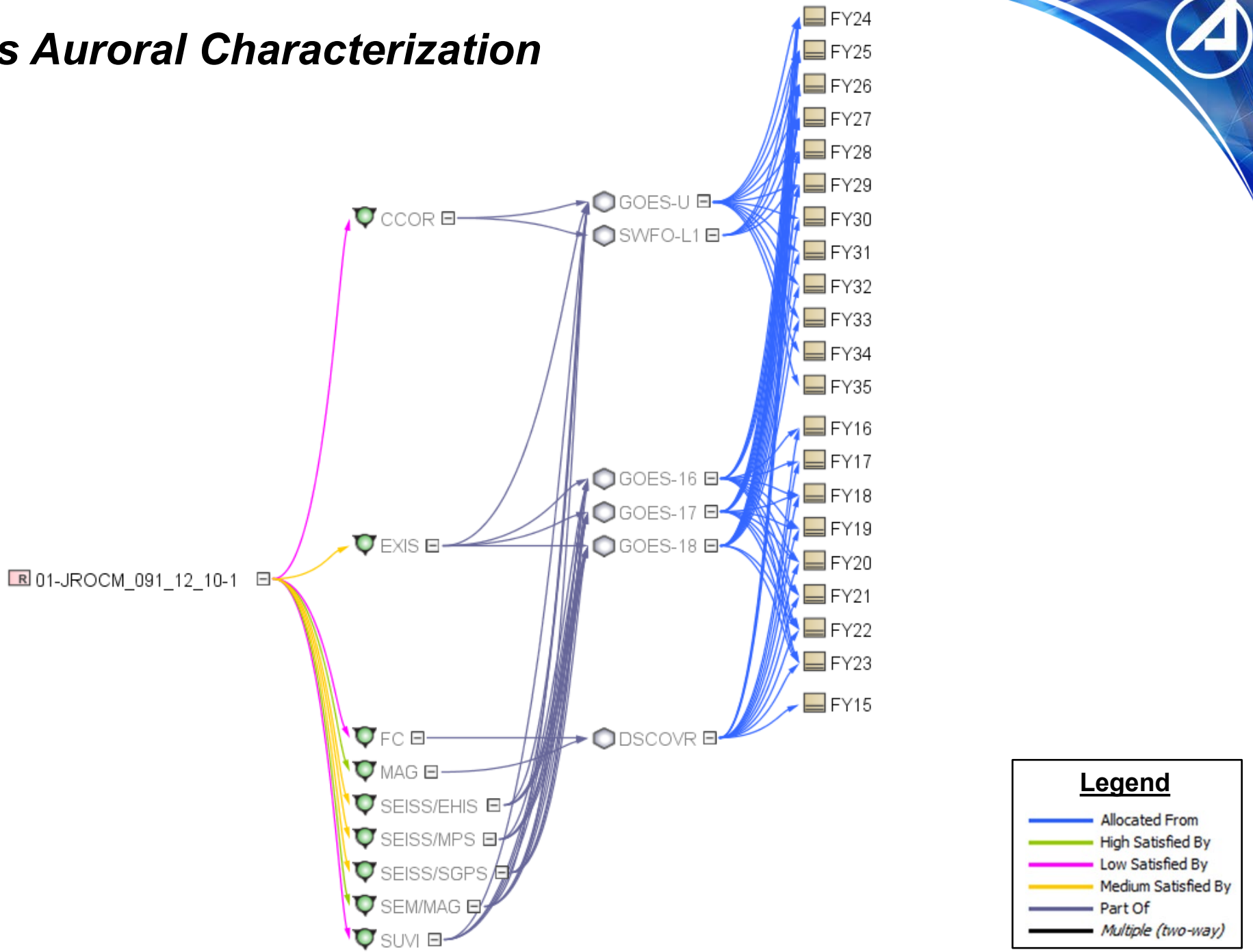
Requirements Verifications through MBSE in a TR



- TGRS measures ion density and scintillation but while it is sort of remotely sensed, it is doing it in the same fashion as a SATCOM signal, for example, would travel.
- It could also be only ‘partial’ because there is no long term plan to replace COSMIC-2.

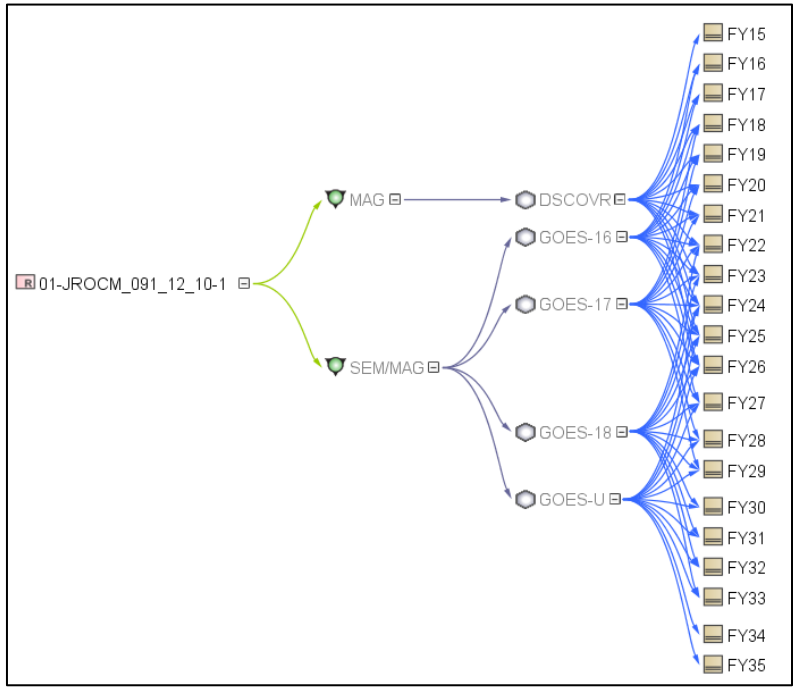
MBSE – Gap Analysis Auroral Characterization

- Low - CCOR, SUVI, FC
- Med - EXIS, SEISS
- Hi - MAG

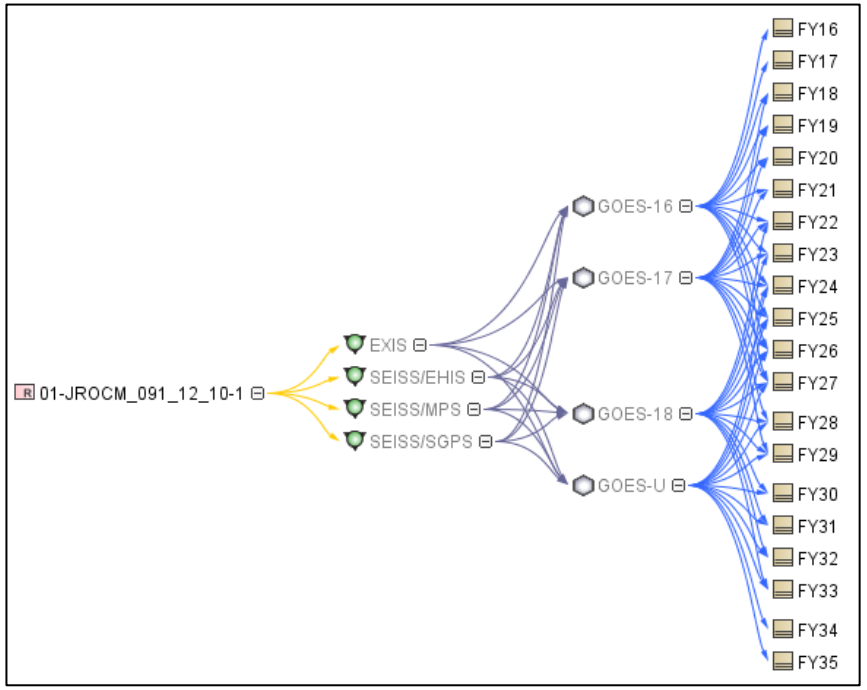


MBSE – Gap Analysis Auroral Characterization (Detail View)

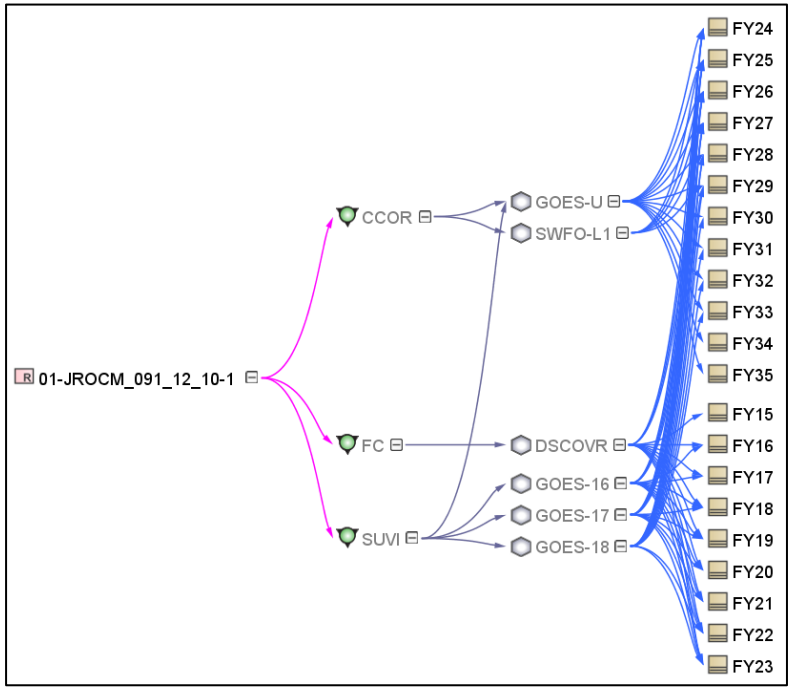
High



Medium

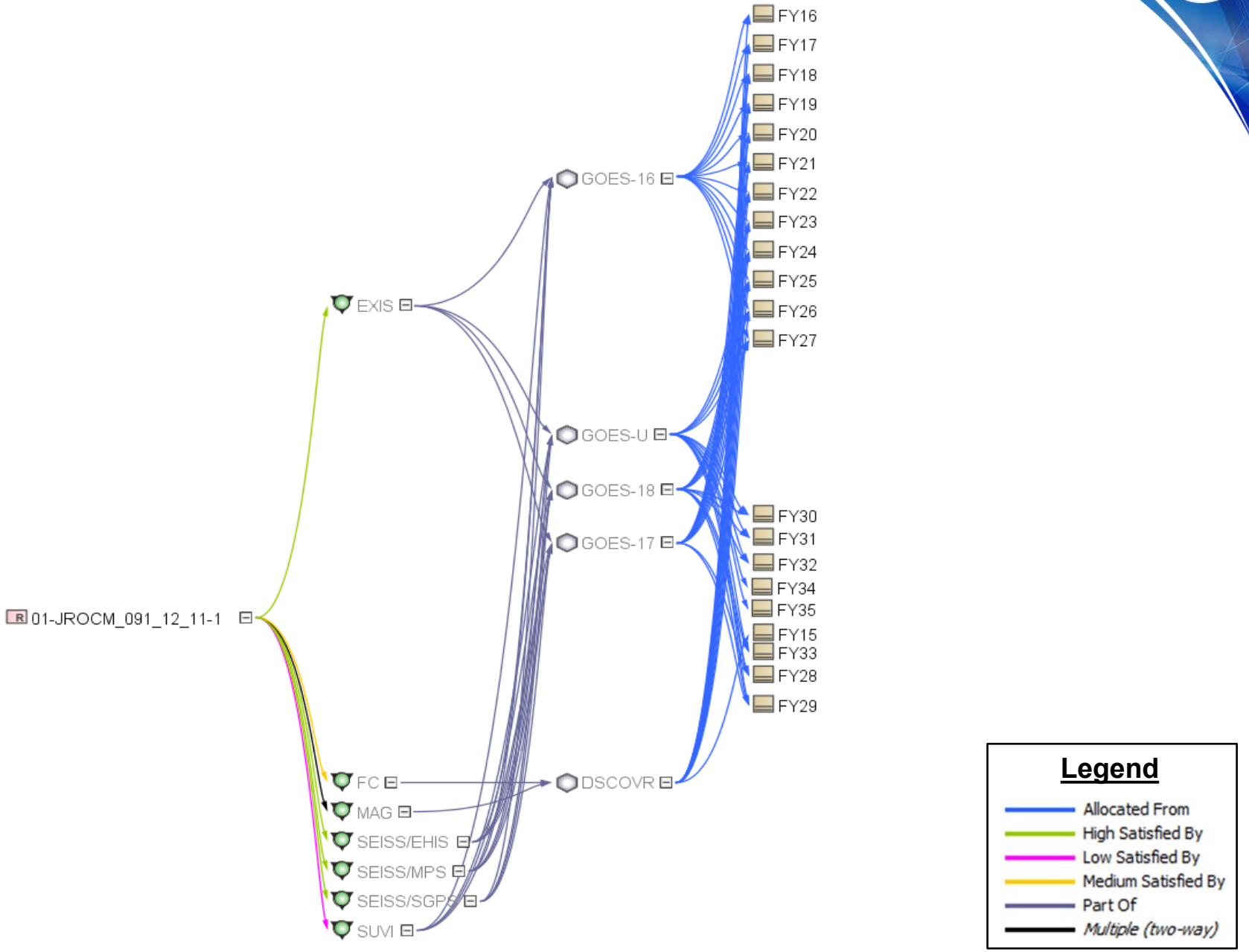


Low



MBSE– Gap Analysis Energetic Charged Particle Characterization

- Low - SUVI
- Med - FC, MAG
- Hi – MAG, EXIS, SEISS



Final Thoughts…

There are technical and socio-technical components – and all must be addressed for success

- Executing Acquisition lifecycle technical reviews in the digital engineering context requires
  - *Descriptive data to build models*
  - *Comprehensively executing systems engineering and architecture – there are no short cuts or workarounds*
  - *Building overarching models whose purpose is traceability and connect-ability*
  - *Building in top-down/bottom-up vertical traceability, horizontal traceability, and temporal traceability*
  - *Temporal traceability, that is, managing and executing change control and CM of data, models, and ASOTs is much more complex than CM of requirements only in a document-based Acquisition lifecycle*
  - *Building models that are digital twins to programs or parts of programs and interconnect data IAW use cases that define the programs*
- Participating in Acquisition lifecycle technical reviews in the digital engineering context requires
  - *Understanding hybrid/agile process execution that enables incremental and additive sub-reviews rendering actual TR execution as a much faster and focused event*
  - *Understanding data and models are in a time continuum that change and evolve as time progresses*
  - *Understanding **how** and **why** the process has changed*
  - *Understanding that models and data in the time continuum delivers **real time** enterprise situational awareness – which is not possible in a document-based Acquisition lifecycle*
  - *Understanding that IRT members' roles change the most so model views be as intuitively obvious as possible to ensure IRT members' engagement*
  - *Understanding that up-front/non-recurring work, that is, transitioning from a document-based to a model- and data-based process*
    - Delivers down-stream benefits
    - Must be executed so that the process can move forward as an Acquisition lifecycle process in a DE context
  - *Understanding that authority to proceed (ATP) model-based Acquisition lifecycle management will require not only technical approval but also approval through non-technical organizations to include policy, contracts, finance, etc.*

Lessons Learned

- This process is very different than document-based
  - *IRT members can focus on reviewing artifacts and models – they no longer need to spend days/weeks of review time figuring out how the artifact documents are related because they are related through models "behind the curtain"*
  - *Training is important so participants know what to do and when to do it*
- Model views to IRT members must be intuitive: IRT members/SMEs do not want or need to be taught how to develop or understand models or modeling languages
- Entering data into a comment resolution matrix (CRM) must be intuitive; adjudication progress of comments must available real time
- Reviewing can occur incrementally because the data and models evolve over time
- Review event day can be a non-event
- Anticipate pushback

The hardest part of incorporating model-based reviews is helping the IRT members overcome their resistance to change

Model-Enabled SRR GUI Demonstration


Questions?

Model-Based Review Planning

Myron Hecht
Digital Systems Engineering Department

25 February 2025

Objectives

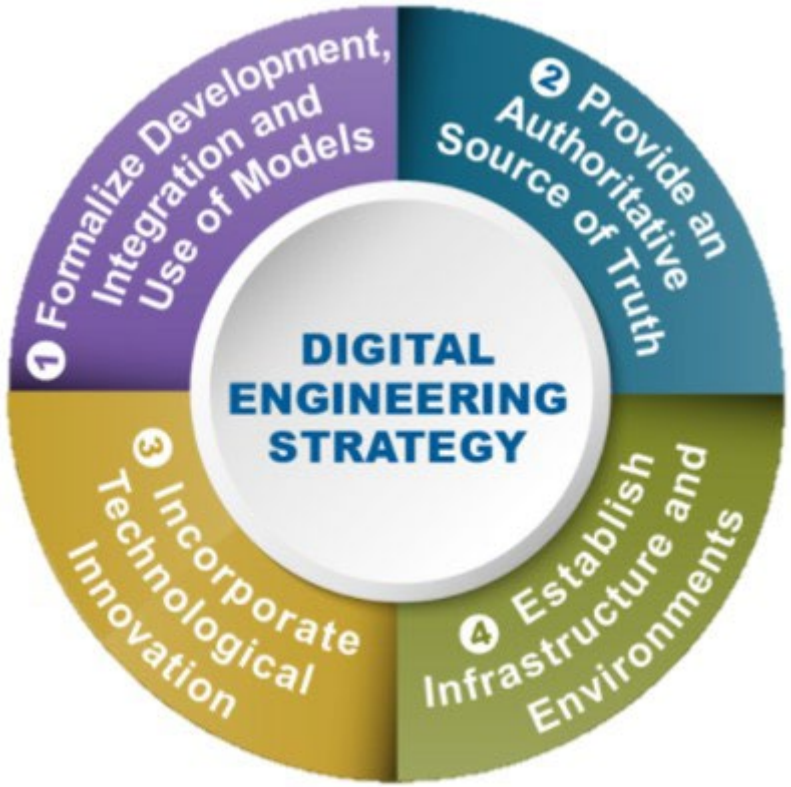
- *Identify SysML model artifacts that help satisfy review criteria*
- *Create views that support milestone reviews*
- *Understand the role of CDRLs as it relates to incorporating artifacts vice documents*
- *Discuss planning for milestone reviews*

Impact of Model-Based Reviews

Advantages

- MBSE supports overall Digital Engineering strategy
  - *Integrate models*
  - *Provide ASOTs (Authoritative Sources of Truth)*
- Potential to save time and effort (less time spent as PowerPoint rangers)
- Living model. Artifacts are fresh, not static “snapshots”
- Artifact data from “authoritative source of truth”
- Better communication. Common picture of the system. Less ambiguity and more consistency.
- Identifies risks early before they become issues
- Digital thread provides data interconnectivity across disciplines and throughout lifecycle

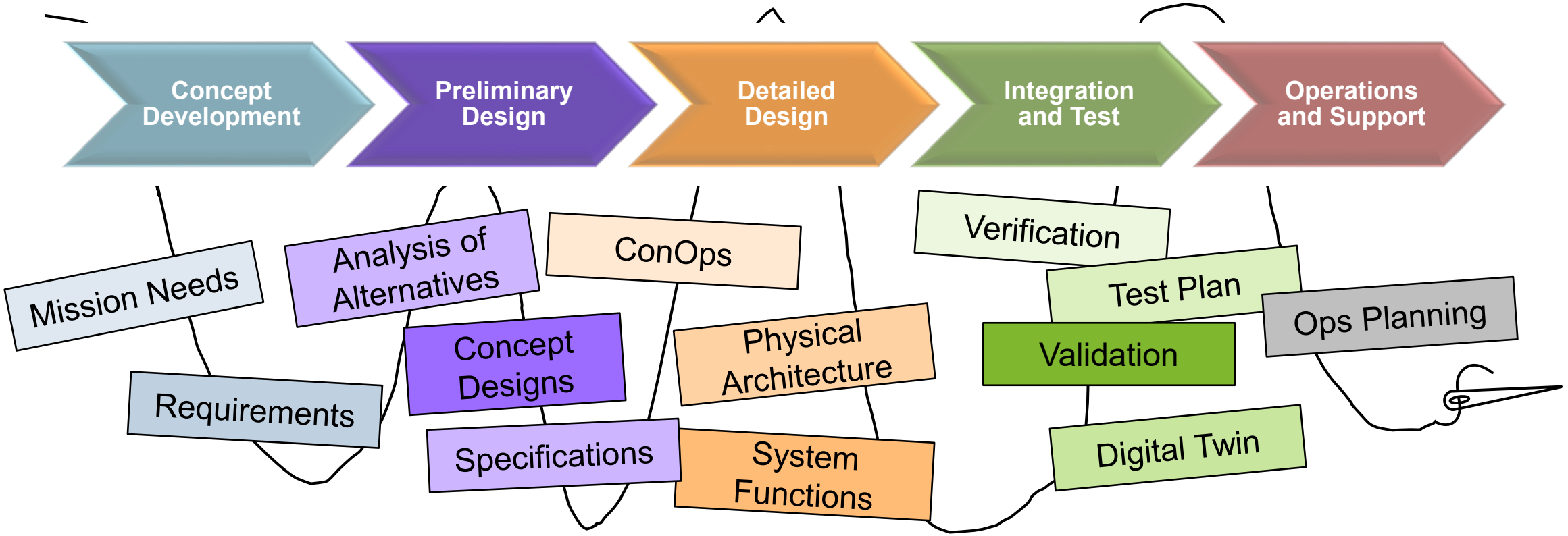
Digital Engineering
Engineering approach using an integrated digital framework connecting models and data across disciplines



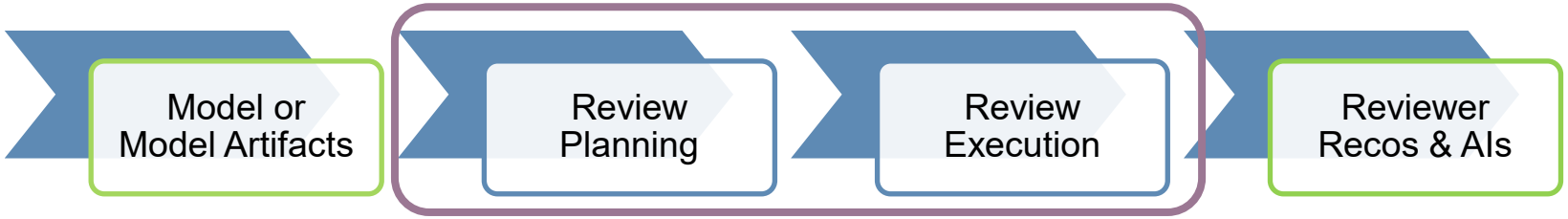
Ref: Digital Engineering Transformation Across the Department of Defense

Digital Thread

- What is a digital thread, and how does it help with model-based reviews?
- A Digital Thread is a set of **digital artifacts** whose consistency is actively managed over the **product life cycle**
  - *Ref: AIAA, Digital Thread: Definition, Value, and Reference Model*



Model-Based Review Process



Inputs

- Review sources (e.g., IEEE 15288.2)
- Traditionally, document-based artifacts address review criteria
- In model-based approach, the artifacts are models, or derivatives of models vs. static documents
- Models may or may not conform to established standard or mandated form
- These may be provided by Contractor or Government

Review Process

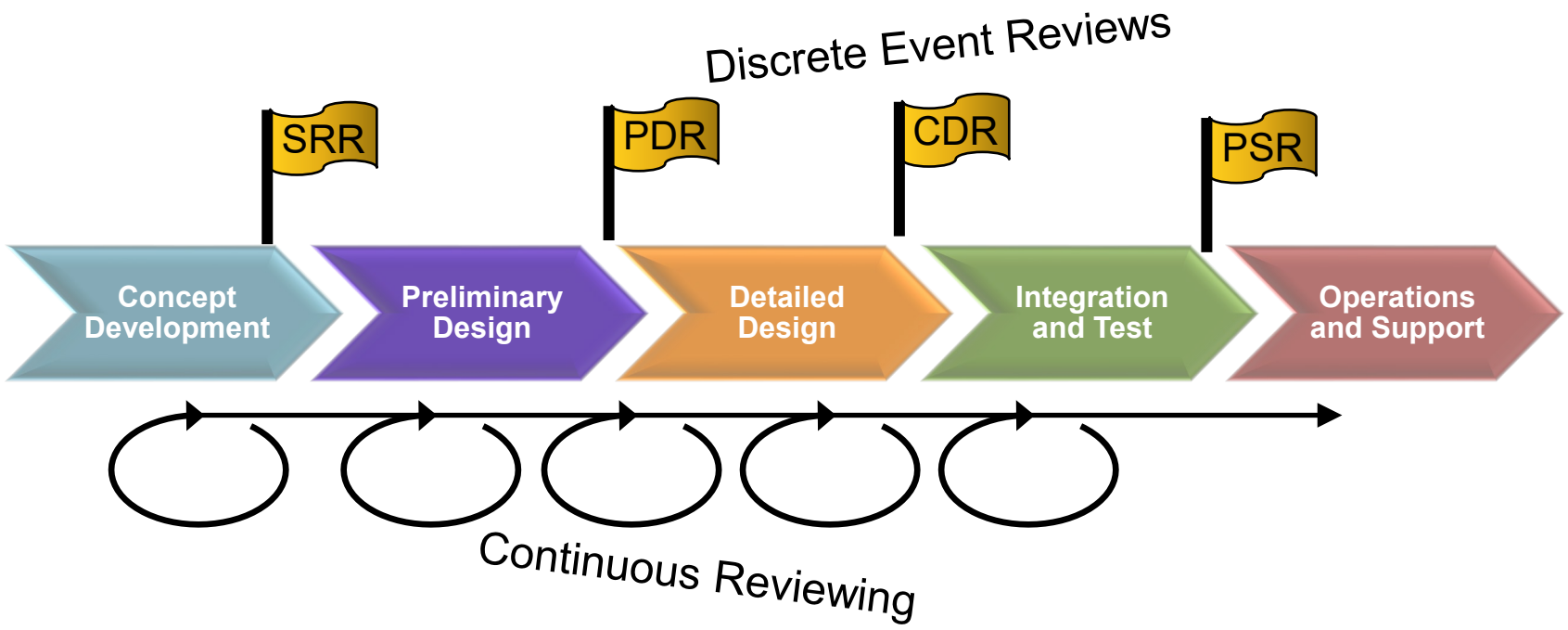
- Review *Planning* and *Execution*
- SMEs review models and model artifacts provided
- Check that contractor-provided artifacts meet entrance and exit criteria set forth by government
- Refs: IEEE 15288.2, SMC-S-021, Defense Acquisition Guidebook

Outputs

- Reviewers provide comments, recommendations and action items (AIs)
- Decision Authorities make decisions based on these
- If approach is continuous review process, then recos can be incorporated more quickly

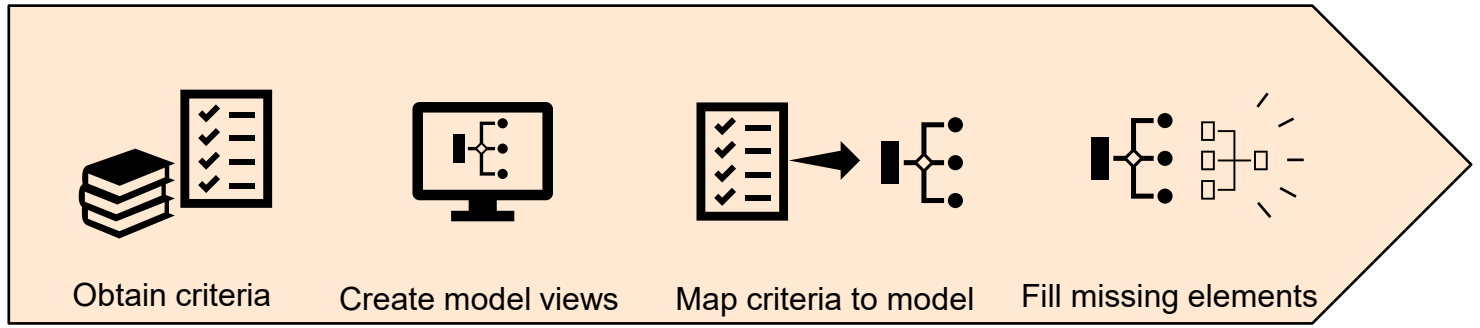
Review Approaches

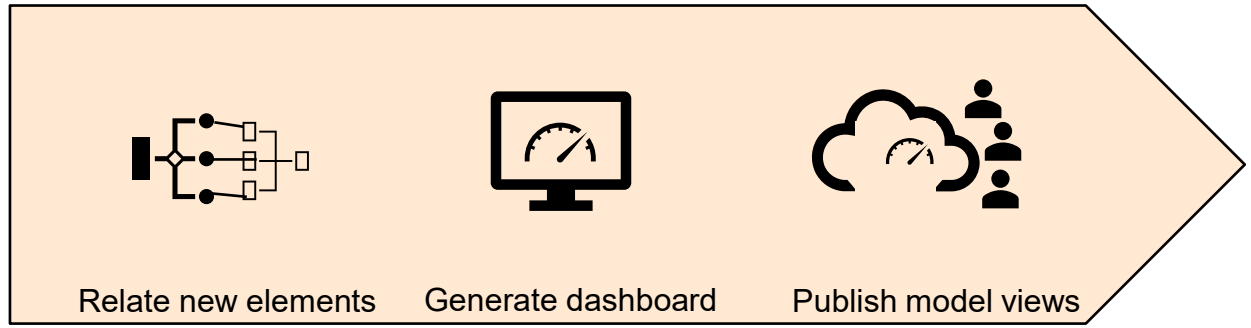
- Discrete event-based reviews
  - *Planners assemble documents to present to reviewers*
- Continuous process approach
  - *Takes advantage of "living" models that can be constantly reviewed and updated*
- Hybrid approach … a little bit of both



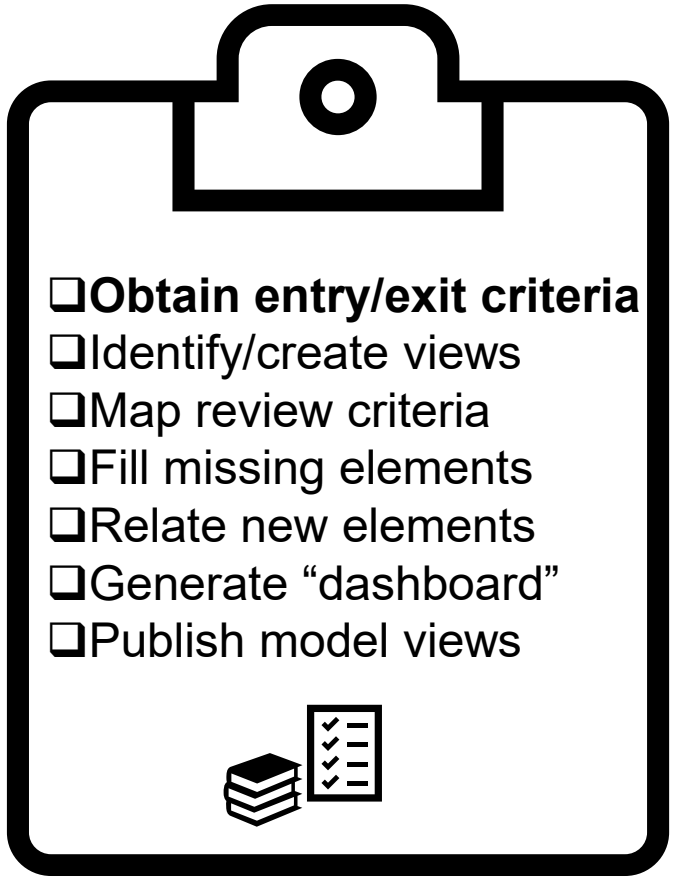
Model-Based Review Planning Process

- ❑ *Obtain entry and exit criteria from source docs*
- ❑ *Identify/create views in model that support criteria evaluation*
- ❑ *Map review criteria to supporting model views*
- ❑ *Create or import missing elements*
- ❑ *Relate new elements with rest of the model*
- ❑ *Generate review "dashboard"*
- ❑ *Publish model views*



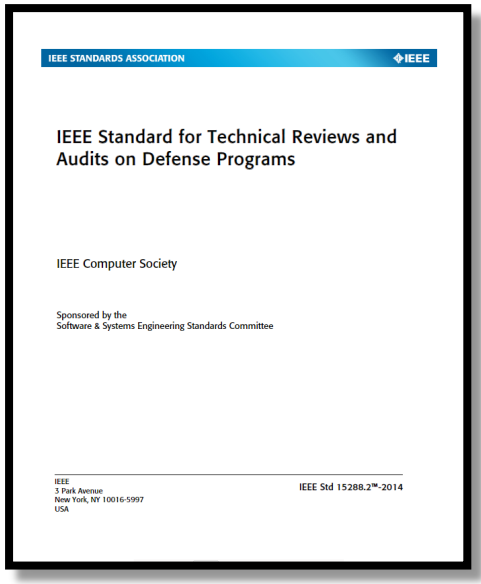


Obtain Entry and Exit Criteria from Source Documents



Obtain Entry and Exit Criteria from Source Documents

- Identify entry and exit criteria checklist items from relevant sources (e.g. ISO 15288.2)
- Criteria may be tailored to fit program
- Example:



Req's are consistent, feasible, traceable, and verifiable

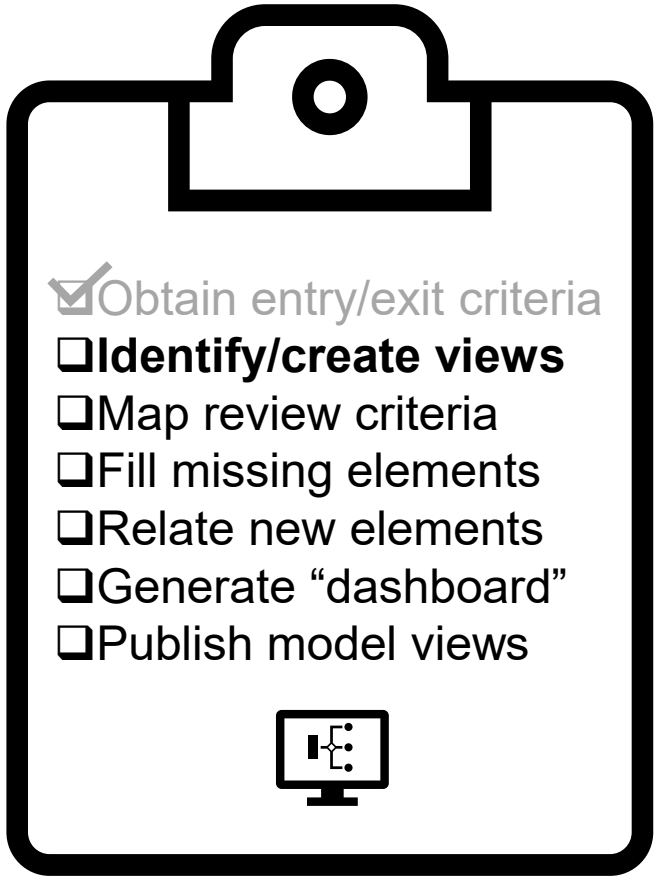
Technical req's are allocated to specifications

Req's are established within the framework of a system logical and functional architecture

IEEE/15288.2

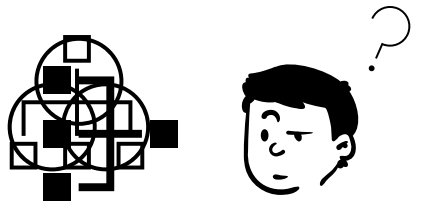
Tailored exit criteria for SRR

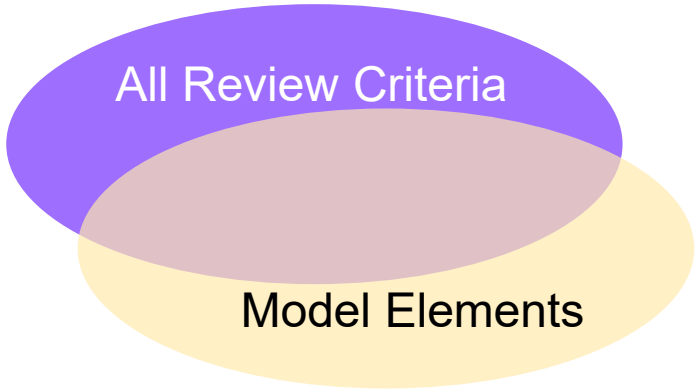
Identify or Create Views in Model that Support Criteria Evaluation

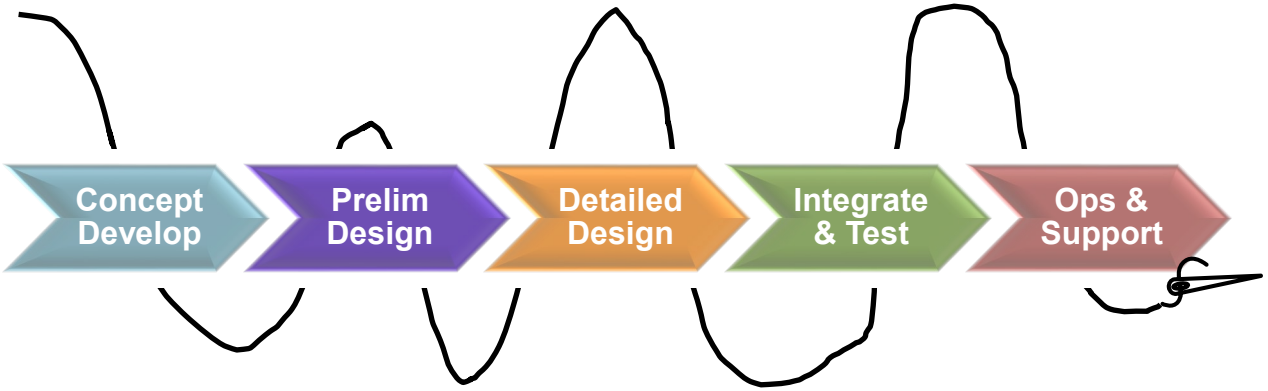


Identify or Create Views in Model that Support Criteria Evaluation

- Requires understanding of model structure, including elements and relationships (metamodel)
  - *System Models are often provided by others to the review team*
    - May not have been specified in CDRLs
    - If the System Model does not address review criteria, then reviewers will need to pair with modelers to develop a Review Model.
- Determine which criteria should be addressed by model artifacts
  - *Not all review criteria addressed by the SysML model*
  - *Include links to artifacts that are not captured in model*
  - *Option: Create criteria elements in model*
- Digital Thread – Import relevant data from data ASOTs into model. Example:
  - *Key performance parameter data generated from analysis tools that verify requirements*



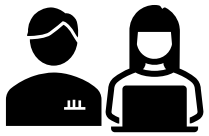


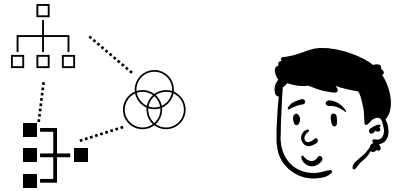


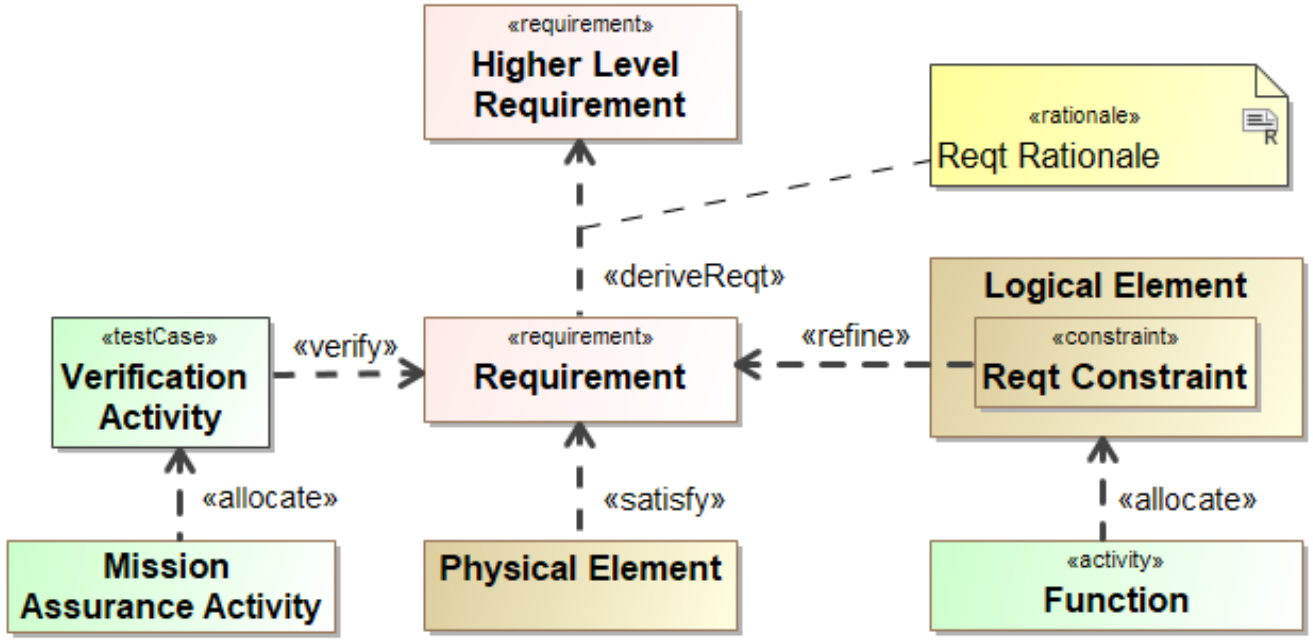
Identify or Create Views in Model that Support Criteria Evaluation

Model Structure - Metamodel

- Metamodel
  - *Shows model elements and relationships between them … a relationship map*
- What about when the Model Provider does not have a metamodel and does not connect elements?
    - Reviewers work with modelers to create a reviewer metamodel that captures the ontology
- The act of rigorously modeling itself helps identify gaps and risks
  - *Developing the model is part of the review process!*
  - *Reviewers and modelers should work together on this*



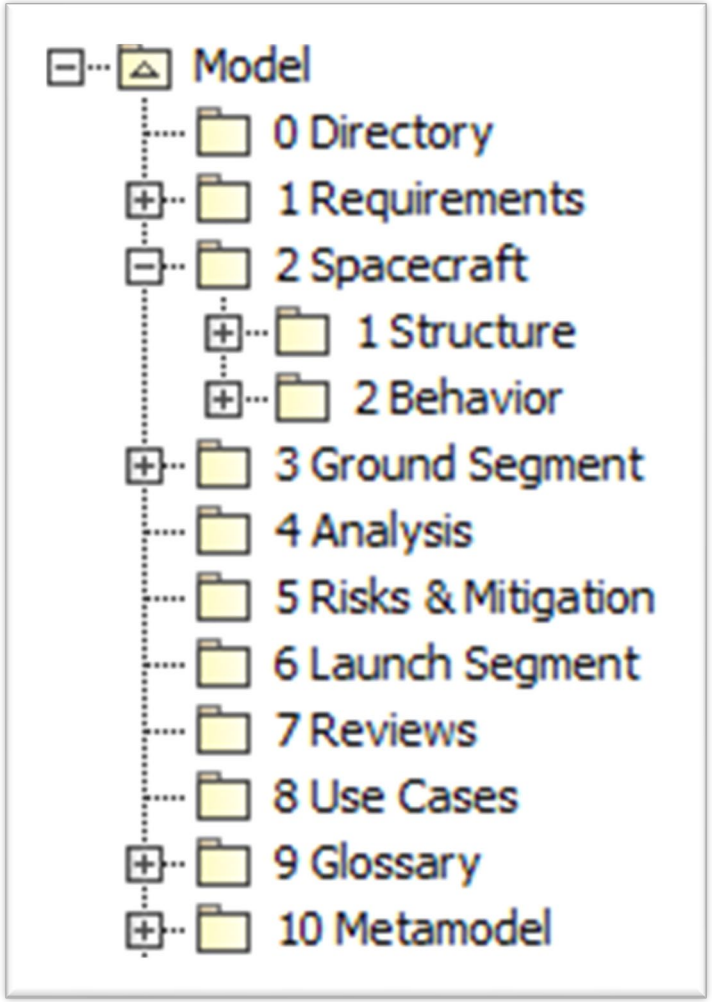




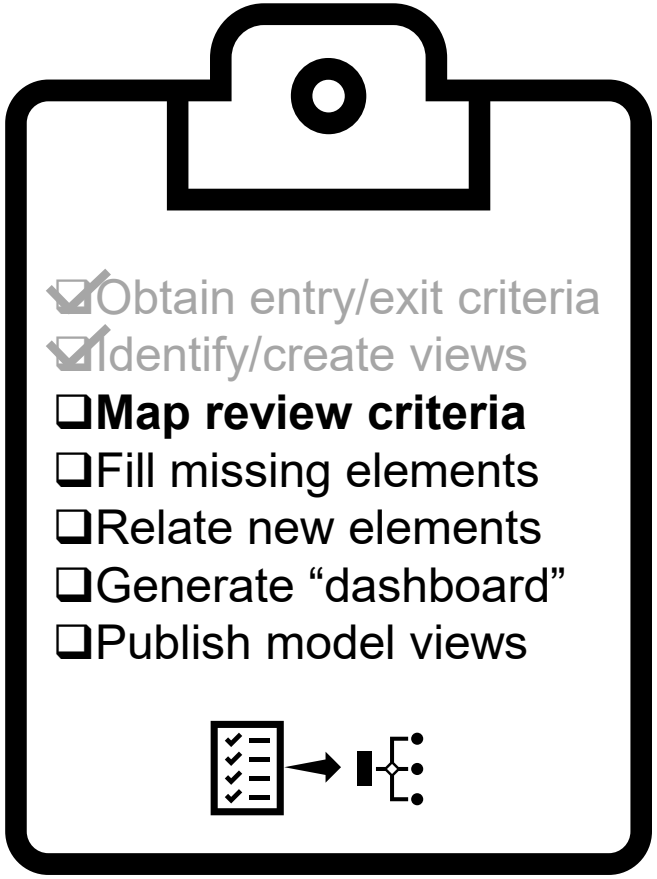
Identify or Create Views in Model that Support Criteria Evaluation

Model Structure – Package Structure

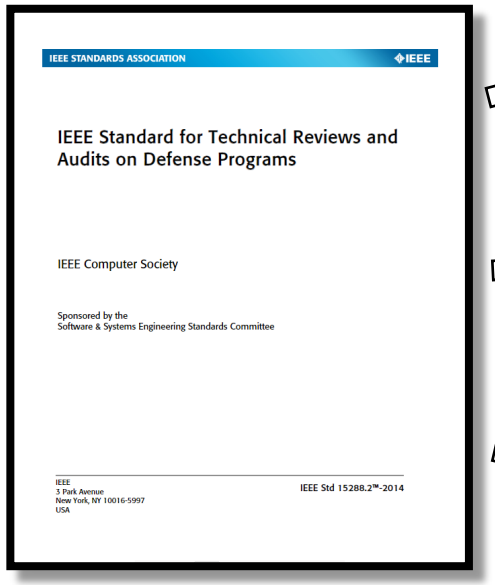
- Containment Tree
  - *Organized "folders" (packages)*
    - Helps you navigate the model
- Main difference with File Explorer folders is that packages are actual model elements
  - *These contain elements that can be dragged into diagrams directly and linkages are automatically made*
  - *Changes made to elements in these packages propagate throughout model and all the diagrams*
    - … and vice versa
- It may be useful to create a "Reviews" package that contains custom views addressing entry and exit criteria



Map Review Criteria to Supporting Model Views



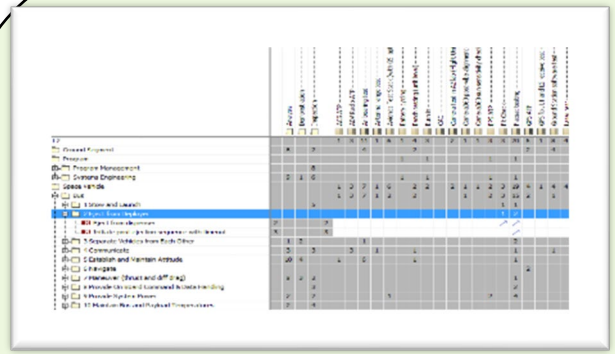
Map Review Criteria to Supporting Model Views



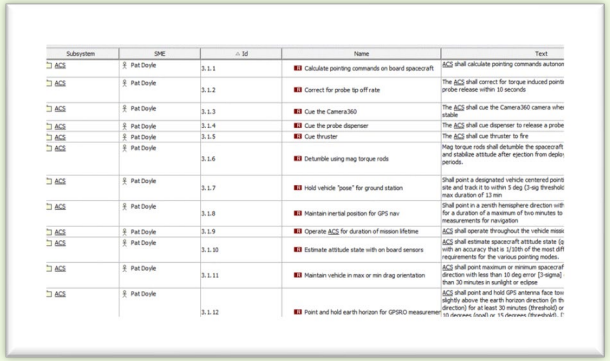
Source document

- Requirements are consistent, feasible, traceable, and verifiable
- Technical requirements are allocated to specifications
- Requirements are established within the framework of a system logical and functional architecture

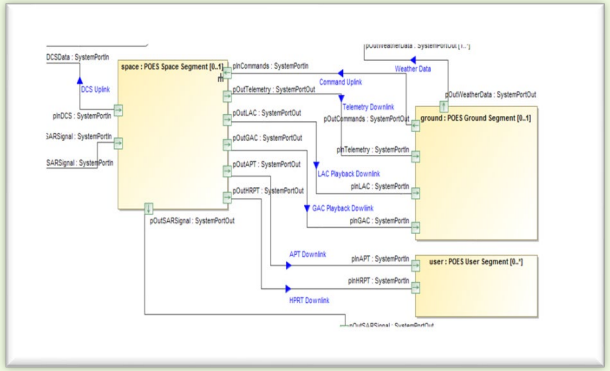
Review criteria



- Requirements Dependency Matrices
- Verification Matrix



Requirements Tables with Allocation Elements



- Satisfaction matrix
- System architecture diagram
- Requirements package

Model Views

Map Review Criteria to Supporting Model Views

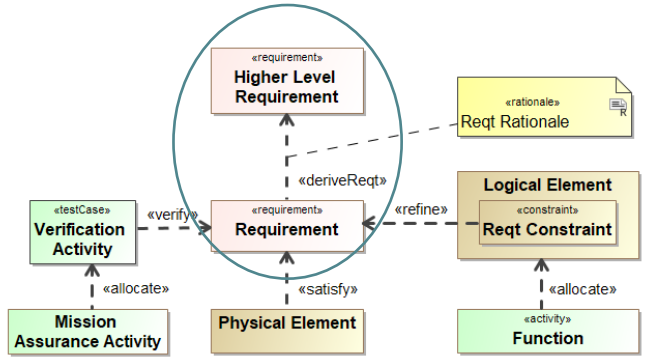
Example: Requirements Traceability

- One exit criterion for a System Requirements Review states that

> Requirements are consistent, feasible, traceable, and verifiable

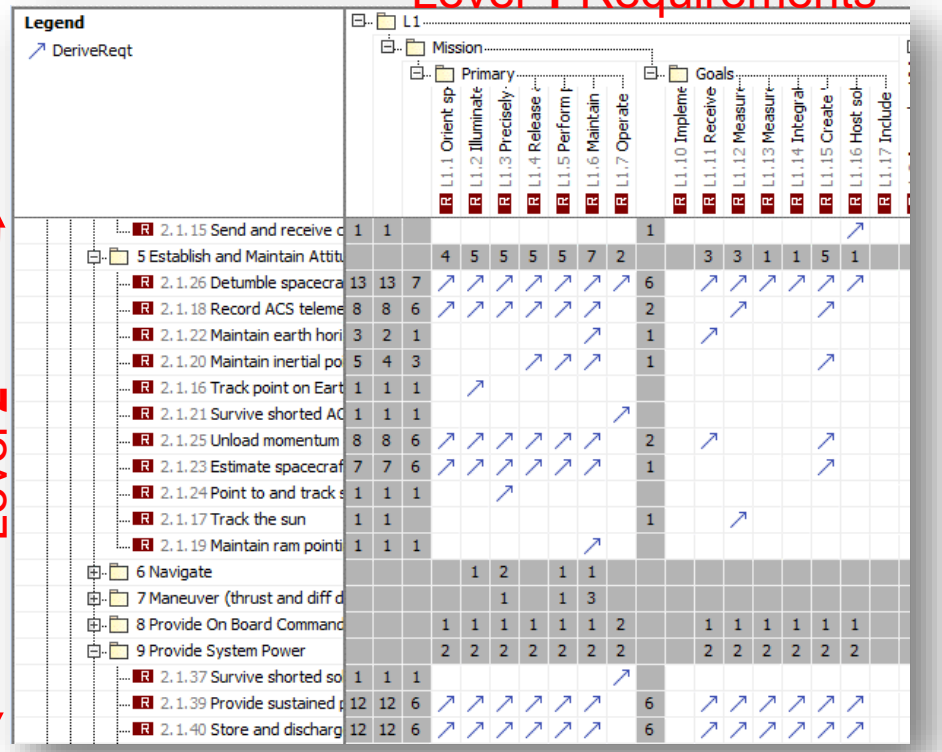
- To address “traceability”, our review model contains requirements traceability matrices that capture this (L1-L2 requirements matrix shown)

- Other diagrams and artifacts would address requirements verification, consistency, and feasibility

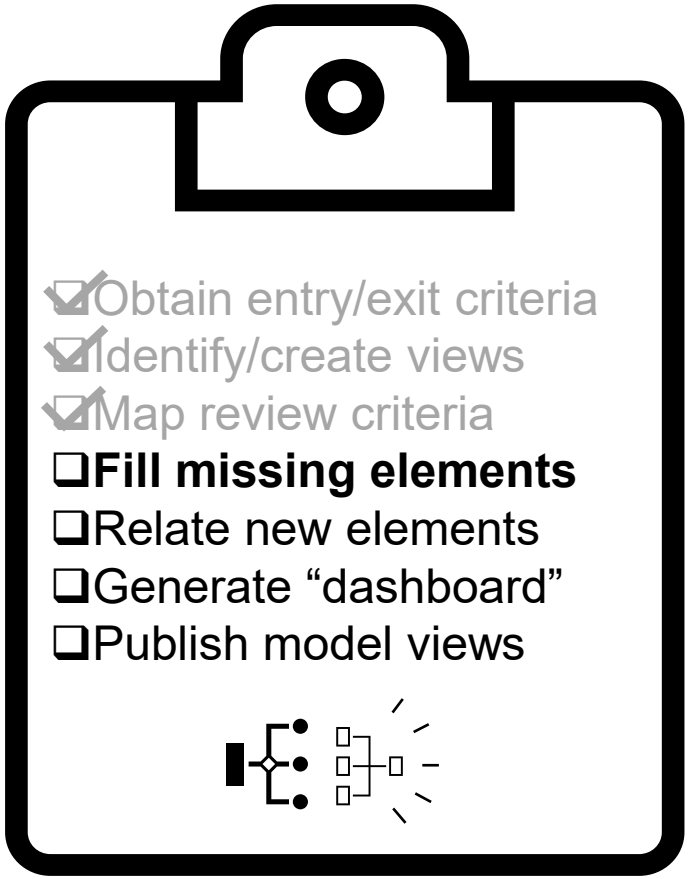


Level 1 Requirements

Level 2

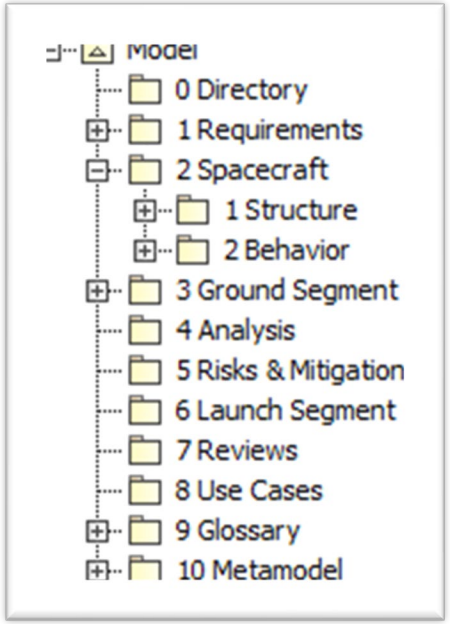


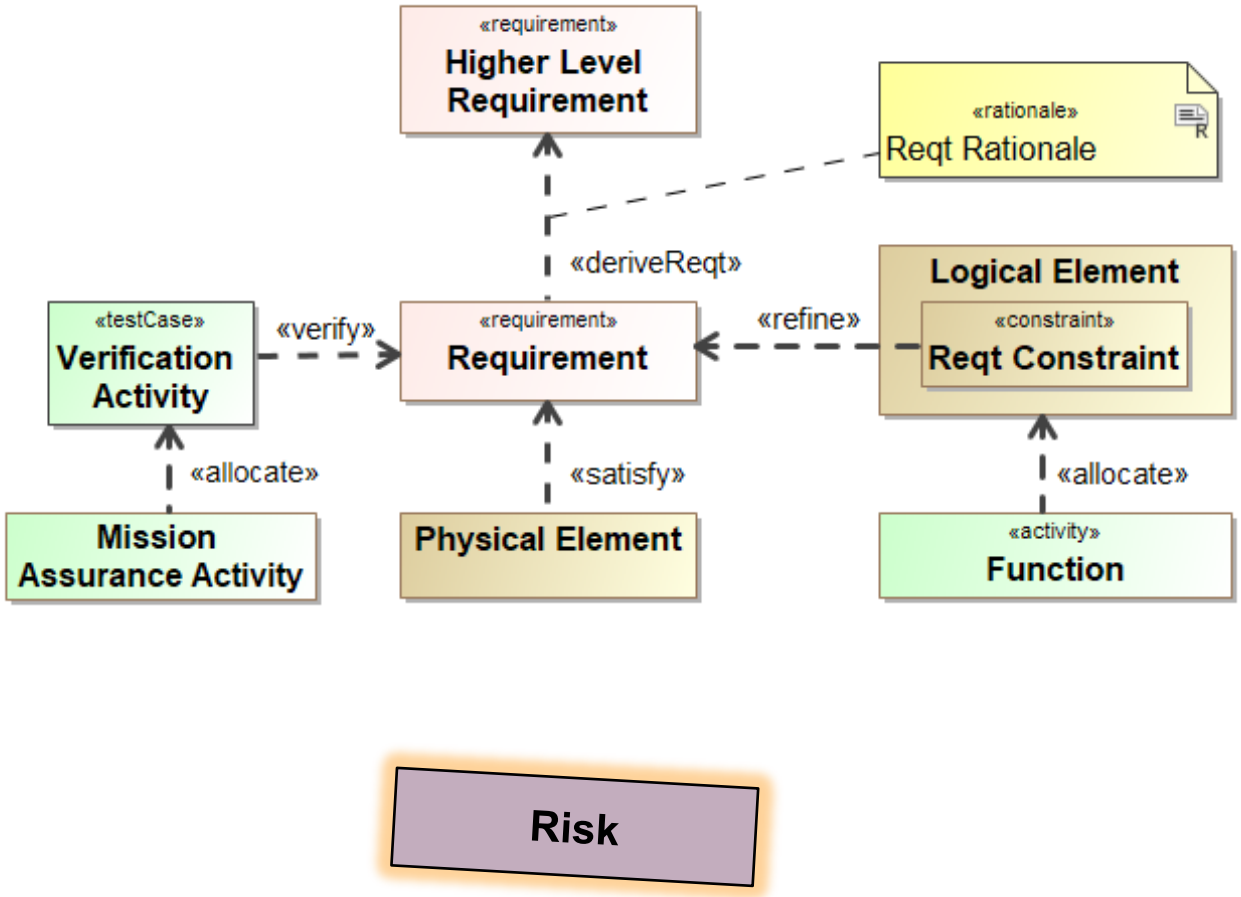
Create or Import Missing Elements



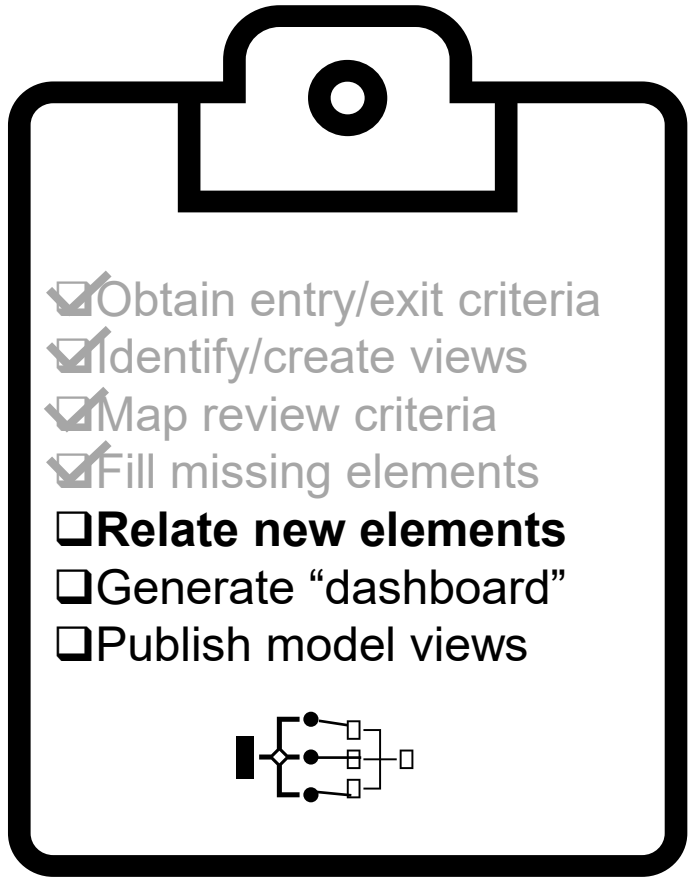
Create or Import Missing Elements

- Identify new elements that you want to include
- **Example**: Suppose the review you are conducting contains criteria that address risk, but there are no elements or views that address this directly
  - *Create new element type (Risk) and place it in a package where you organize all the review model elements*
  - *Reviewers and modelers create or import risks using this stereotype*
  - *Give attributes to Risk, like "Likelihood" and "Consequence"*



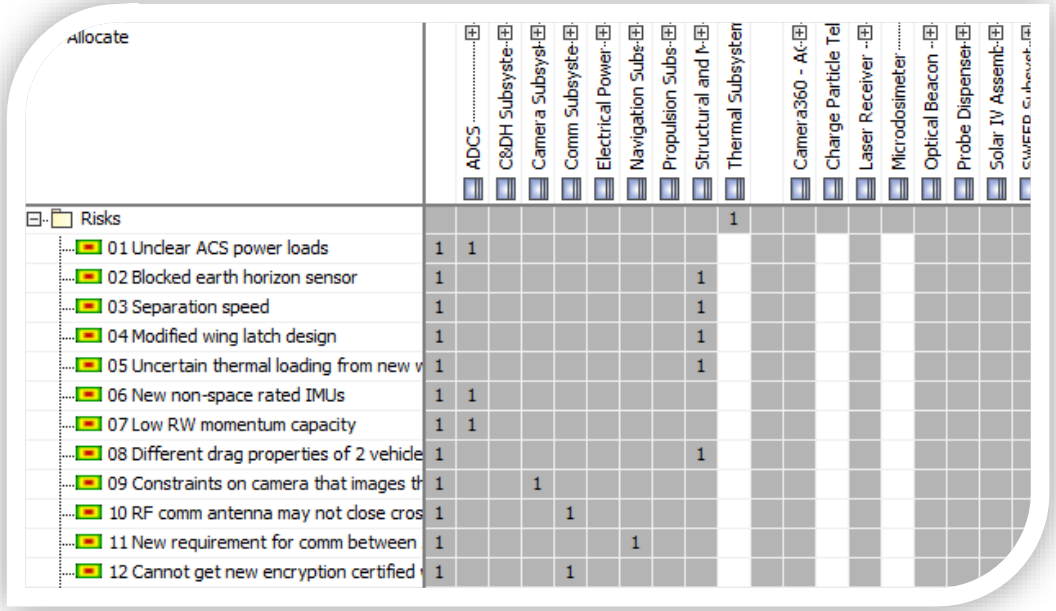


Relate New Elements With Rest of the Model

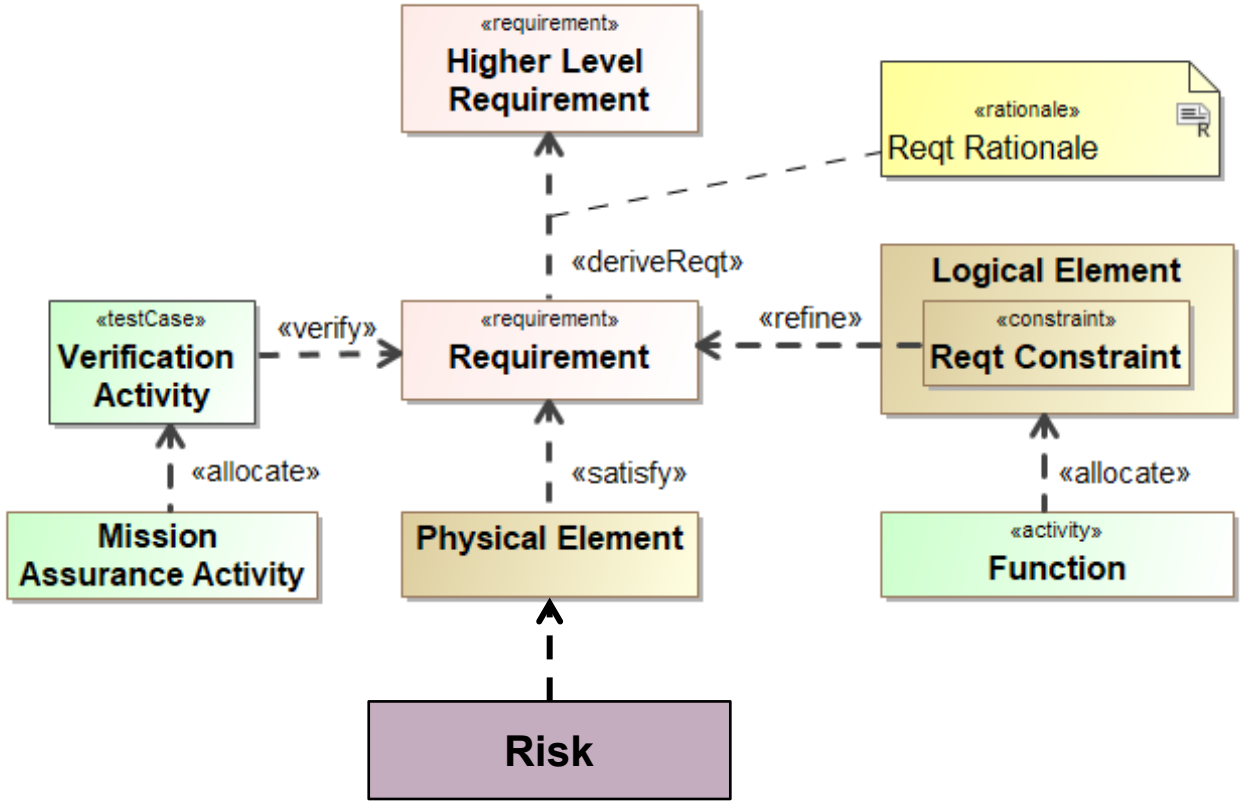


Relate New Elements With Rest of the Model

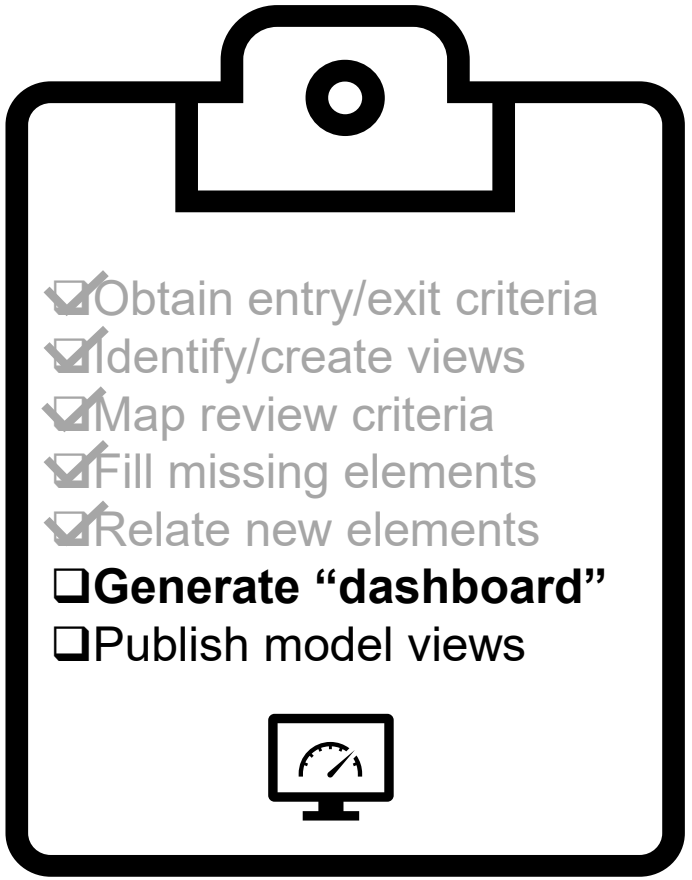
- New elements added to the model need to be connected to the rest of the model elements
- **Example**: We added a new element “Risk”, and now we need to relate it to the rest of the model elements with an appropriate relationship (like “allocate”)
- Create views that help reviewers assess risk-related criteria



Risk Traceability Matrix

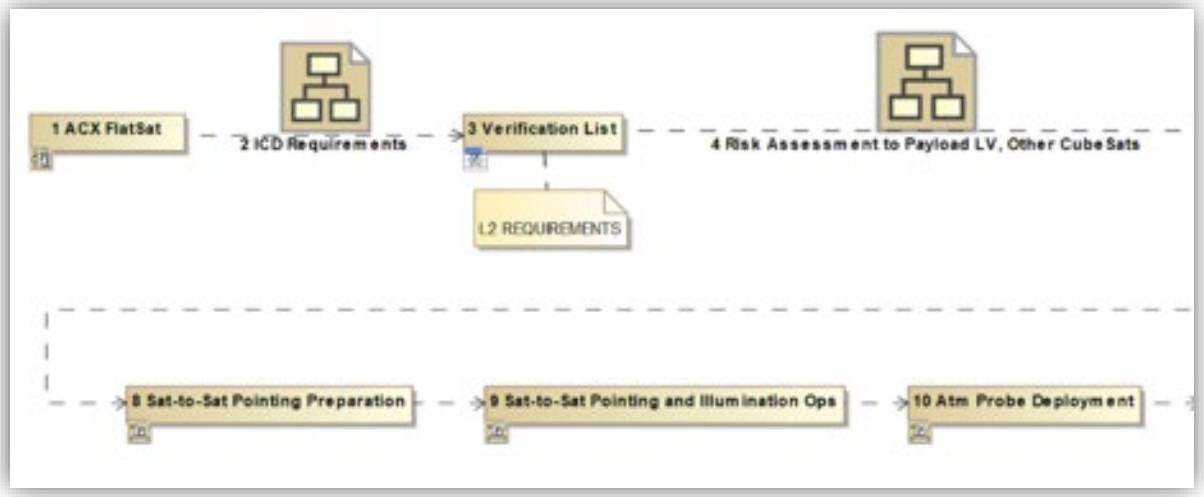


Generate Review "Dashboard"

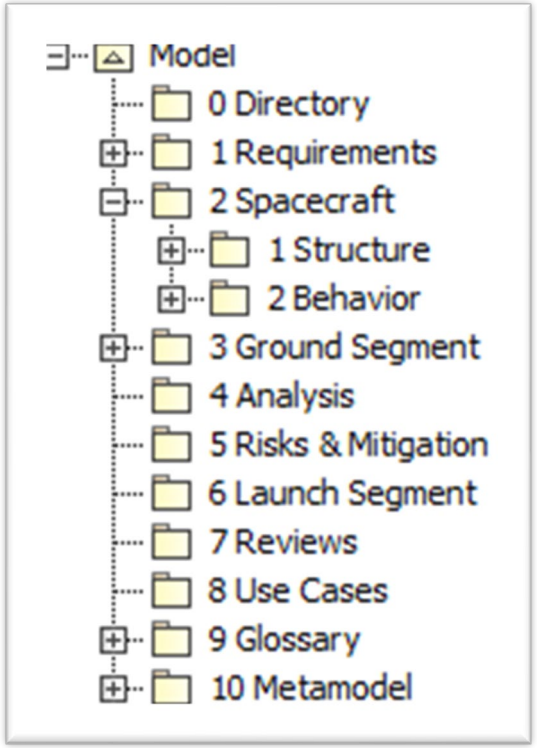


Generate Review "Dashboard"

- Make life easy for others who may not be familiar with the model
- If you do reviews directly from the model vs. PowerPoint presentations, then organize a "dashboard" that flows through review events in order with hyperlinks for easy access
- Include a package in the Containment Tree organizing all review material

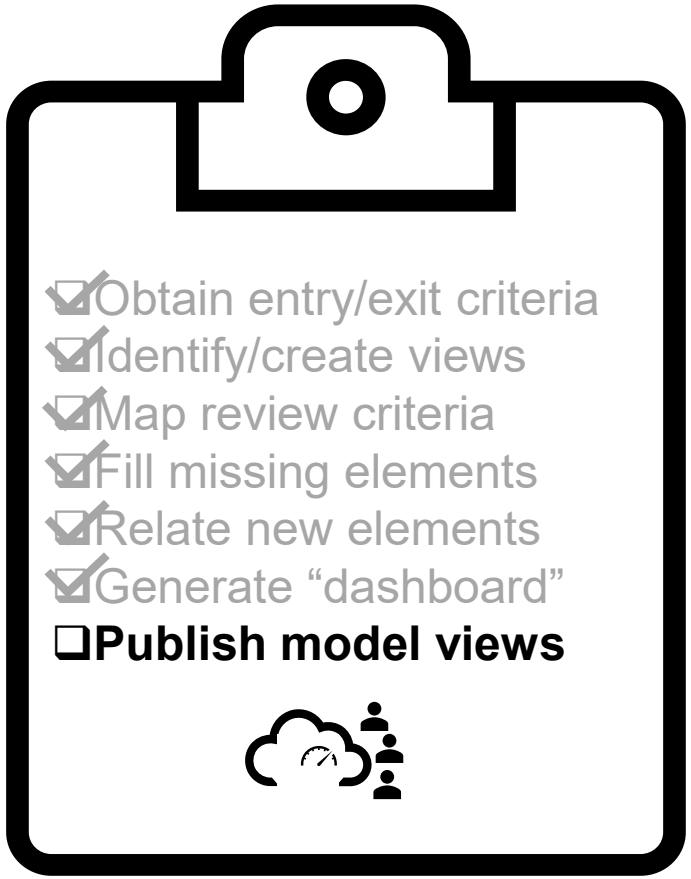


Example Review Dashboard



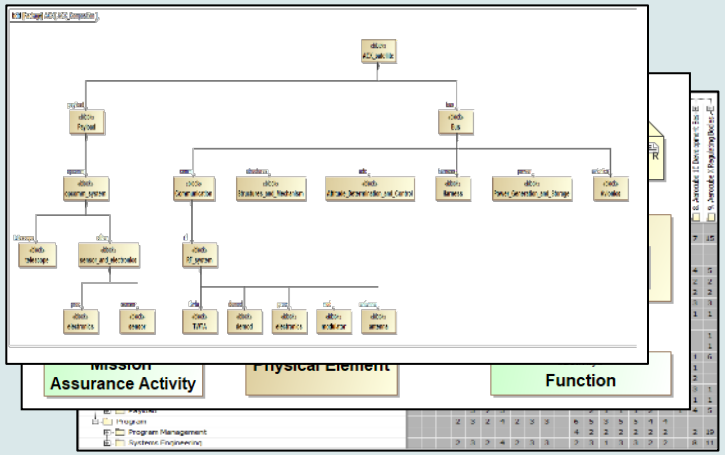
Containment Tree with "Reviews" Package

Publish Model Views

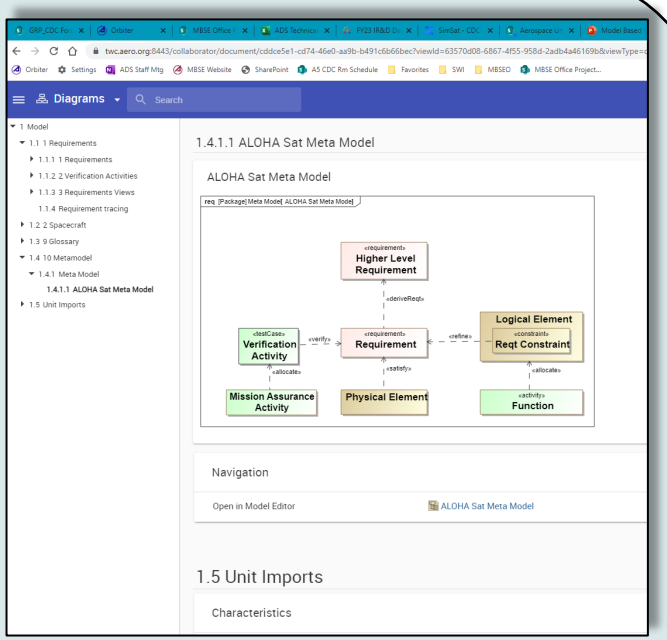


Publish Model Views

- Make model available to stakeholders and other reviewers who do not use the modeling tools



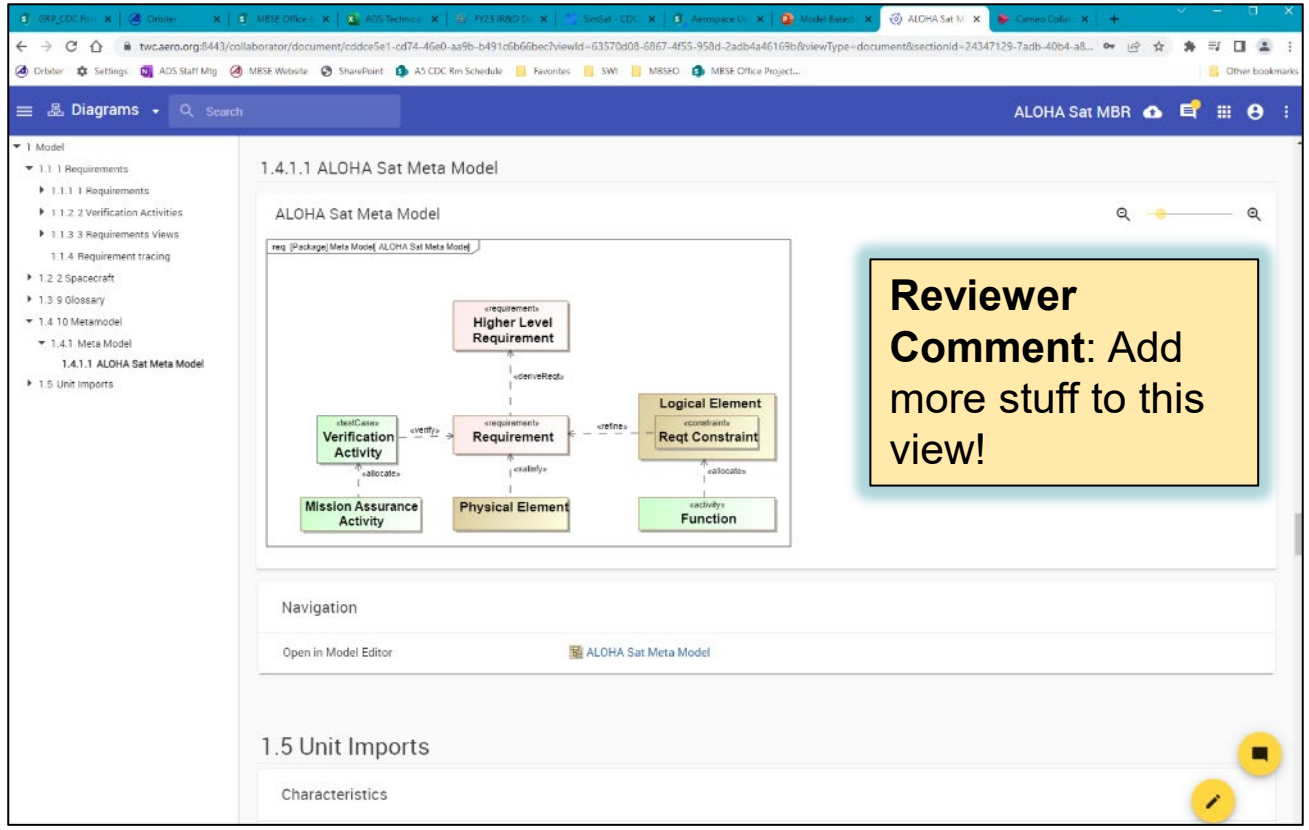
Interconnected **Review Model.** Modelers collaborate with Reviewers to make this using modeling tools.



Published views linked directly to the model. Other reviewers and stakeholders can access these via a web browser and make comments. No modeling tools necessary.

Publish Model Views

- **Modelers** publish views to a space on the cloud that all stakeholders can access
  - *Consider a space that contractors, Government, FFRDCs, and others can access*
- **Reviewers** will then access the model and make comments for others to see, discuss via discussion threads, and disposition
  - *No special tools necessary, just need a web browser*
  - *Next section will address this in more detail*

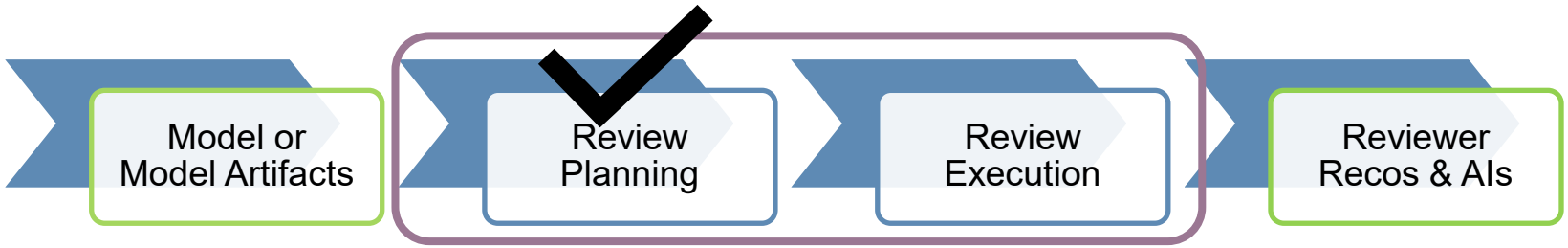


Published Review Model that is accessible via web

Model-Based Review Planning

Summary

- Discussed advantages of model-based reviews and different review approaches
- Presented an approach to planning for an upcoming review
- Next up … Review Execution



Model-Based Review Execution

Kevin Sanchez
Digital Systems Engineering Department

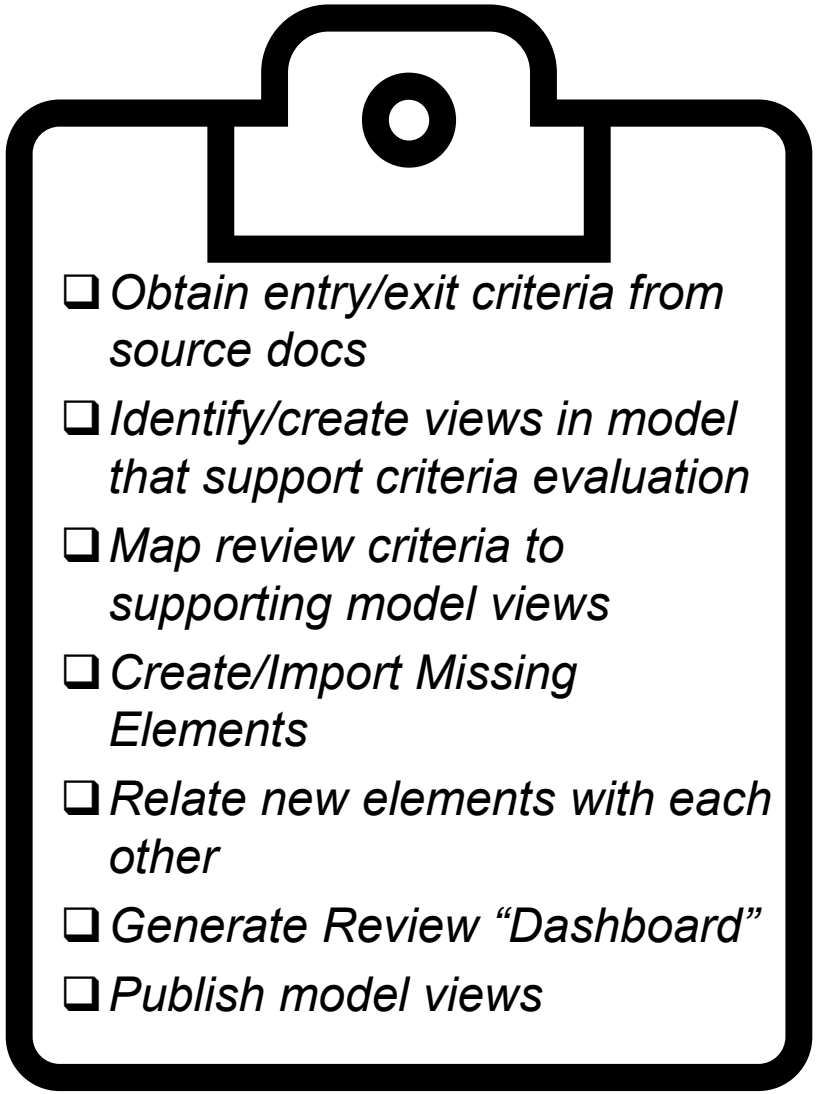
25 February 2025

Contents

- *Review Process*
- *Review of Requirements Satisfaction and Verification*
- *Executing a Review*
- *Providing Review Feedback in Model*
- *IEEE PDR Acceptance Criteria in Model Form*
- *Quantitative Requirements (mass)*
- *Validation Rules*

For purposes of this class

- Most relation terms take on their SysML definition
  - *Verify, satisfy, allocate, trace, derive*
- Model Builder vs Model Reviewer
  - *Class is focused on reviews, but as a reviewer could be useful to build some views*
- This tutorial covers a fictional Satellite modelled in SysML
  - *We are at the system level*
- The model will support PDR
- Contains requirements, planned tests, architecture, some initial parameters



Review planning and preparation demonstration

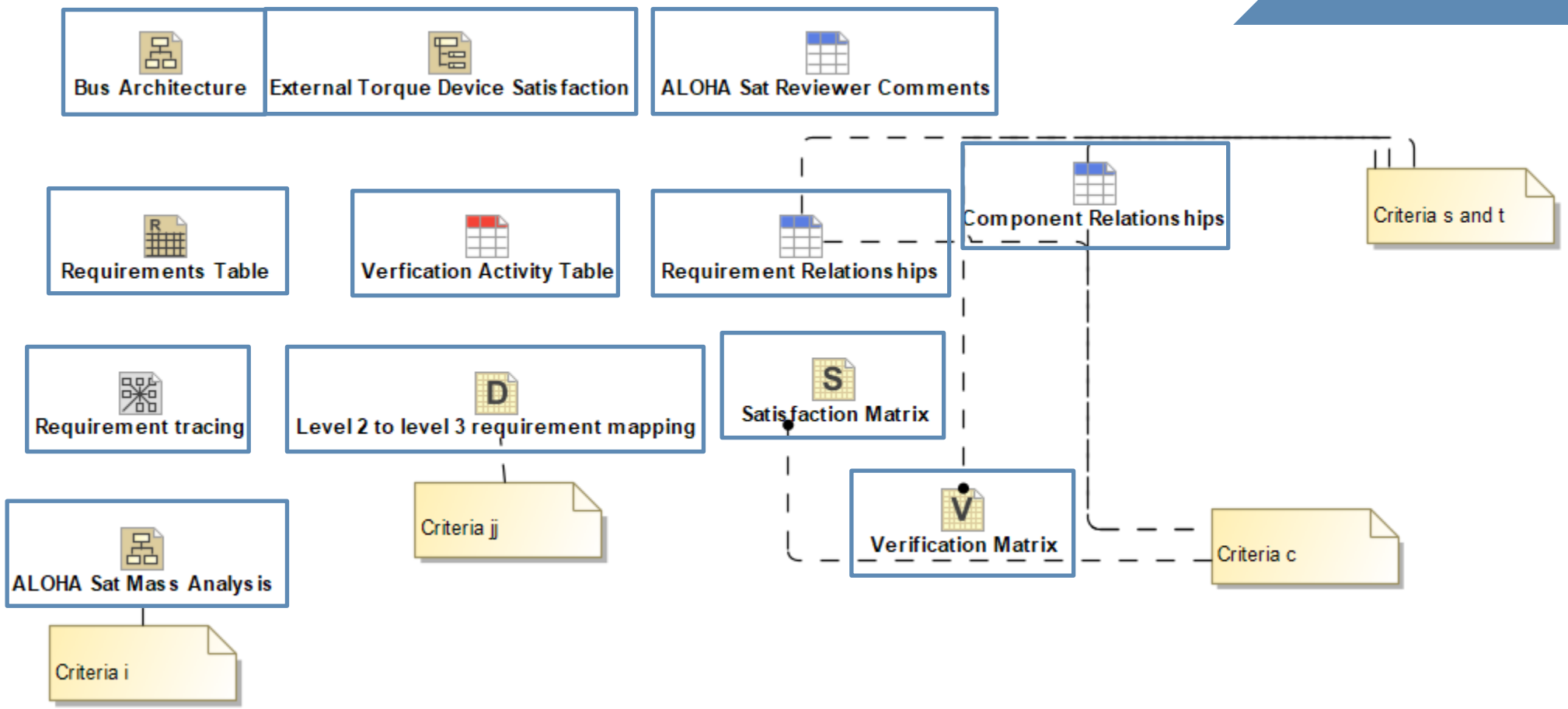
Review execution exercise

Use of Requirements in Model Based Reviews

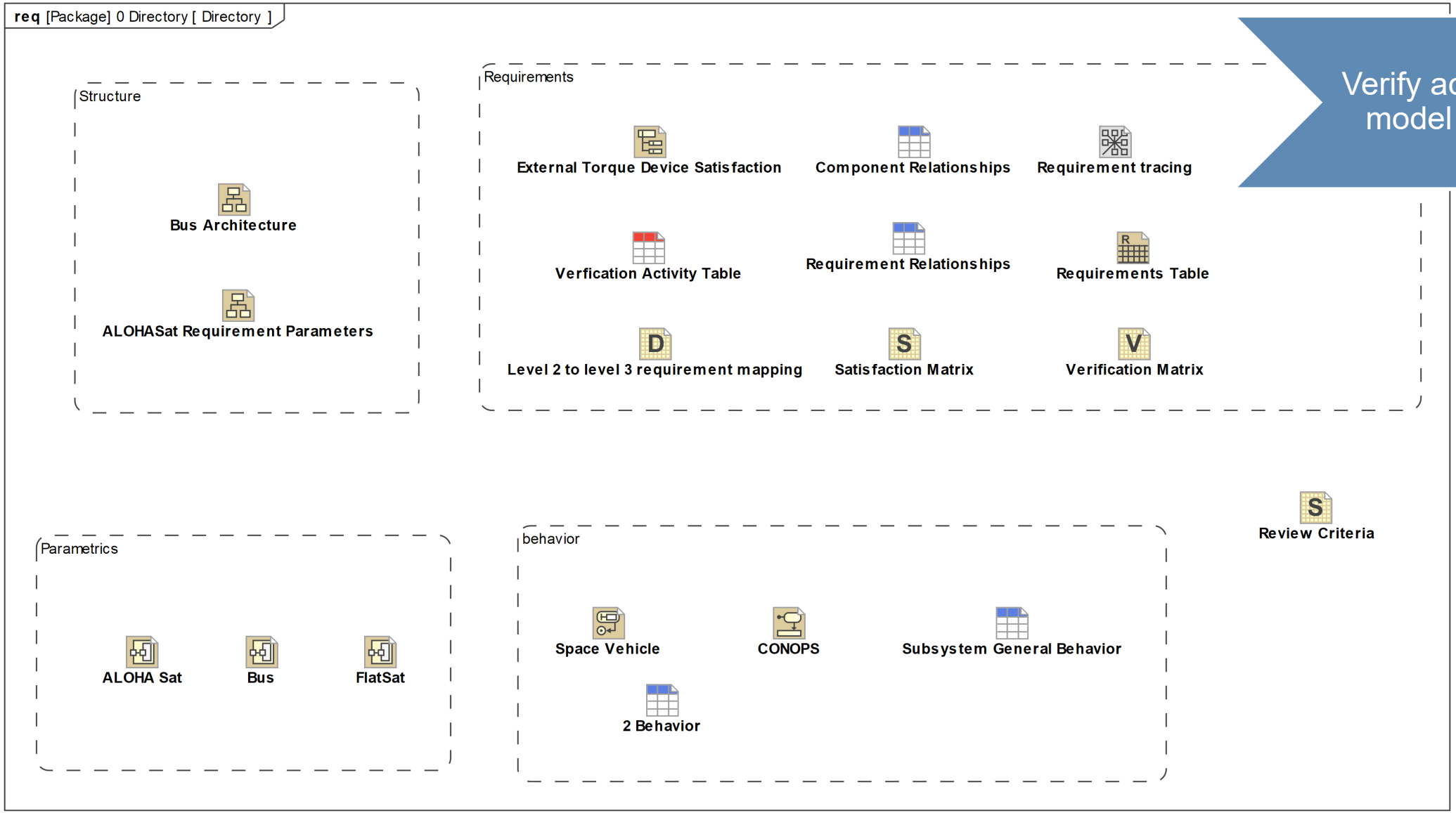
- Requirements are a type of element
- You can use relationships to relate requirements to other elements
  - *Satisfy and Verify are two types of relationships*
  - *You can also derive or trace requirements from other requirements*
- Modelers may build elements and relationships in different types of ways(BDD, requirement diagram, direct in containment tree, etc.)
- In order to review, you must be able to find and visualize the modeled relationships
- You can do this most effectively through tables or matrices
  - *Tables work great for legacy reporting requirements (excel, charts)*
  - *Matrices work great for showing overlaps and lacking relationships*
- You can create a “metachain” to elements that are related through multiple relationship-element layers

Model Dashboard

Verify access to model views



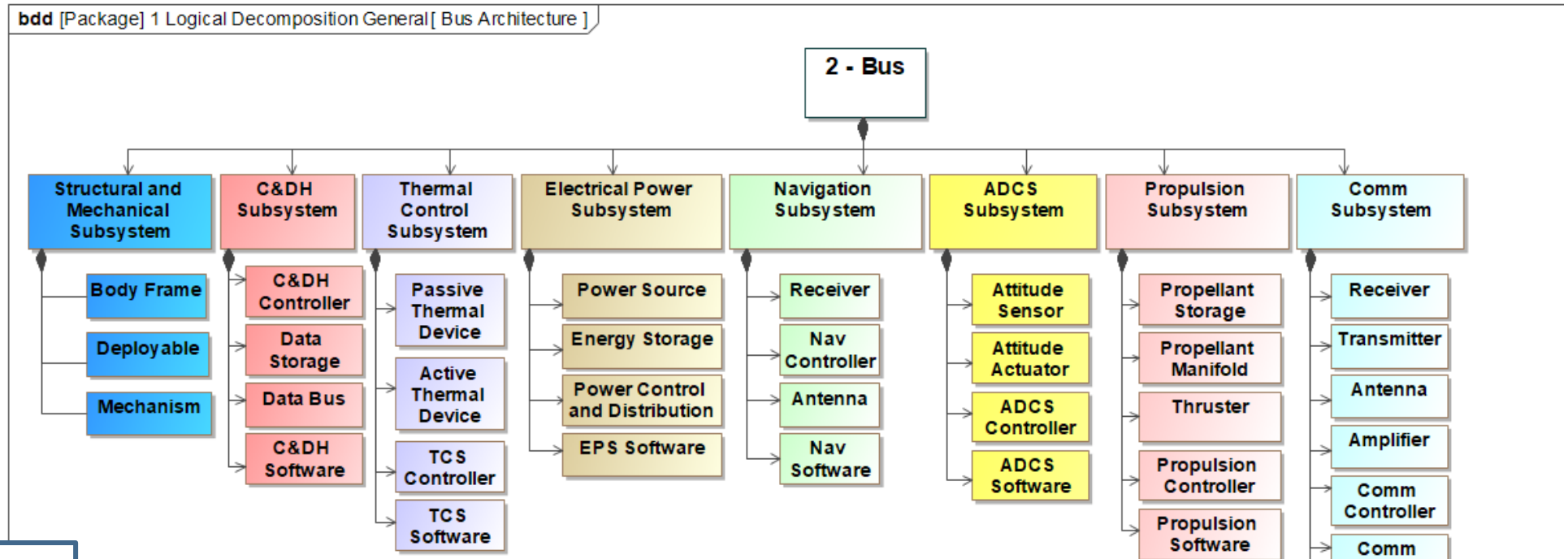
Alternative Model Dashboard



Verify access to model views

Satellite System of Interest

Structure Elements



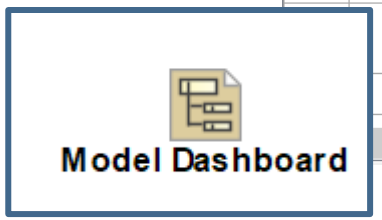
Model Dashboard

Block Definition Diagrams show what elements are composed of other elements

Requirements in SysML modeling tool

Requirement Elements

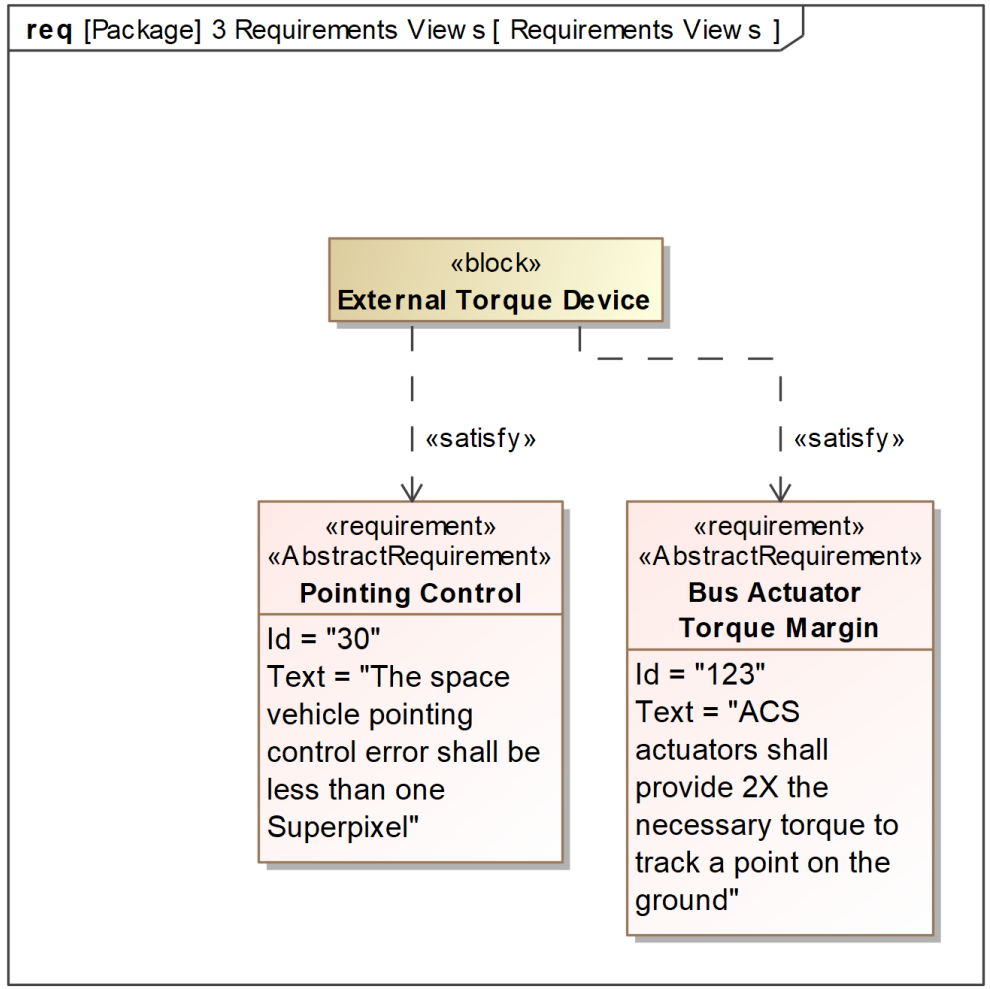
#	Name	Text
1	Level 1	
2	27 Form Factor	ALOHASAT shall conform to a 3U (3Ux1U) CubeSat form factor
3	84 Seasonal Data Collection	ALOHASAT shall collect data during all seasons
4	97 Compliance with Regulations	ALOHASAT shall comply with all Regulating Bodies and Governing Documents
5	116 Science Goal	ALOHASAT shall take optical images of Hawaii on every pass over.
6	Level 2	
7	Level 2 Bus	
8	18 C&DH Telemetry Storage	The space vehicle shall store selected telemetry parameters as part of its SOH packet
9	30 Pointing Control	The space vehicle pointing control error shall be less than one Superpixel
10	49 Space Vehicle Commanding Reliability	The Spacecraft Bus shall have redundant TT&C radios
11	55 Autonomy	The spacecraft shall provide the capability to perform autonomous out of view operations
12	58 Bus Data Storage Margin	The Bus shall provide 2X the necessary predicted flash storage for payload data
13	59 SV Safe Mode Power Usage	The CubeSat shall have a positive power balance when in Safe mode
14	66 Space Vehicle Thermal Control	The Spacecraft Bus shall maintain spacecraft components within operational temperatures for on-orbit operat within survival/non-operational temperatures in safe/contingency modes.
15	70 Bus power safe mode	The Space Vehicle shall be power positive while in Safe Mode.
	95 Space Vehicle Structural and Mechanical	The Spacecraft Bus shall provide structural and mechanical accommodations for the payload and spacecraft c transport, launch, and on-orbit operations.
	103 Space Vehicle Electrical Power	The Spacecraft Bus shall provide sufficient power to support payload and bus operations for all mission phas

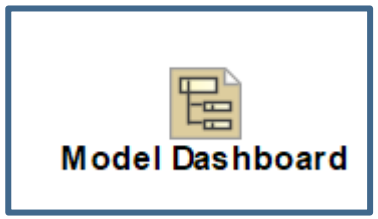


Tables are familiar and let you see all the properties of a particular element that you may want, only can see so many elements at a time

SysML Requirements Diagram

Satisfy Relationships



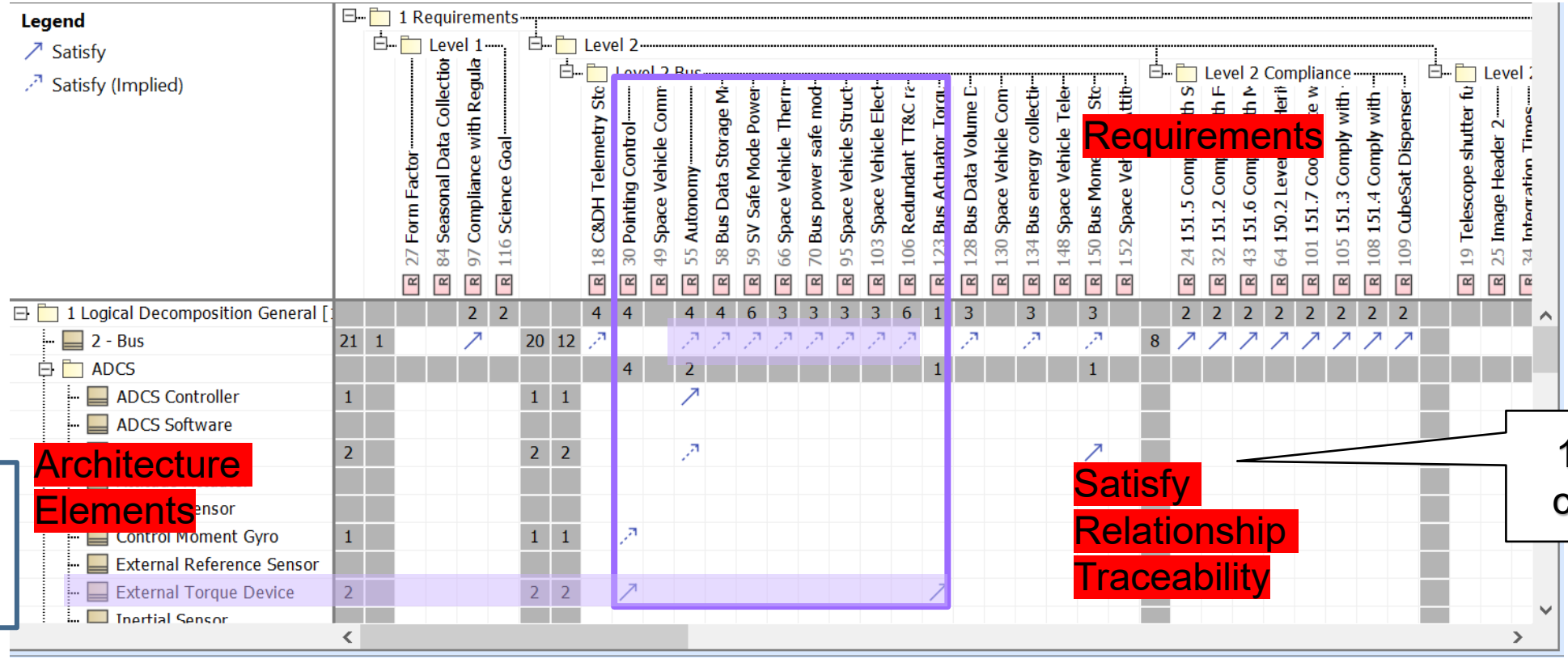


Requirement diagram can give a nice graphical representation of some requirements and a few relationships, but can get really big, really fast

Dependency Matrix showing Satisfaction of Requirements by Components

- Can see how many relationships between elements
- **What do empty rows or columns mean?**

Navigate dashboard to look for criteria – find some views supporting



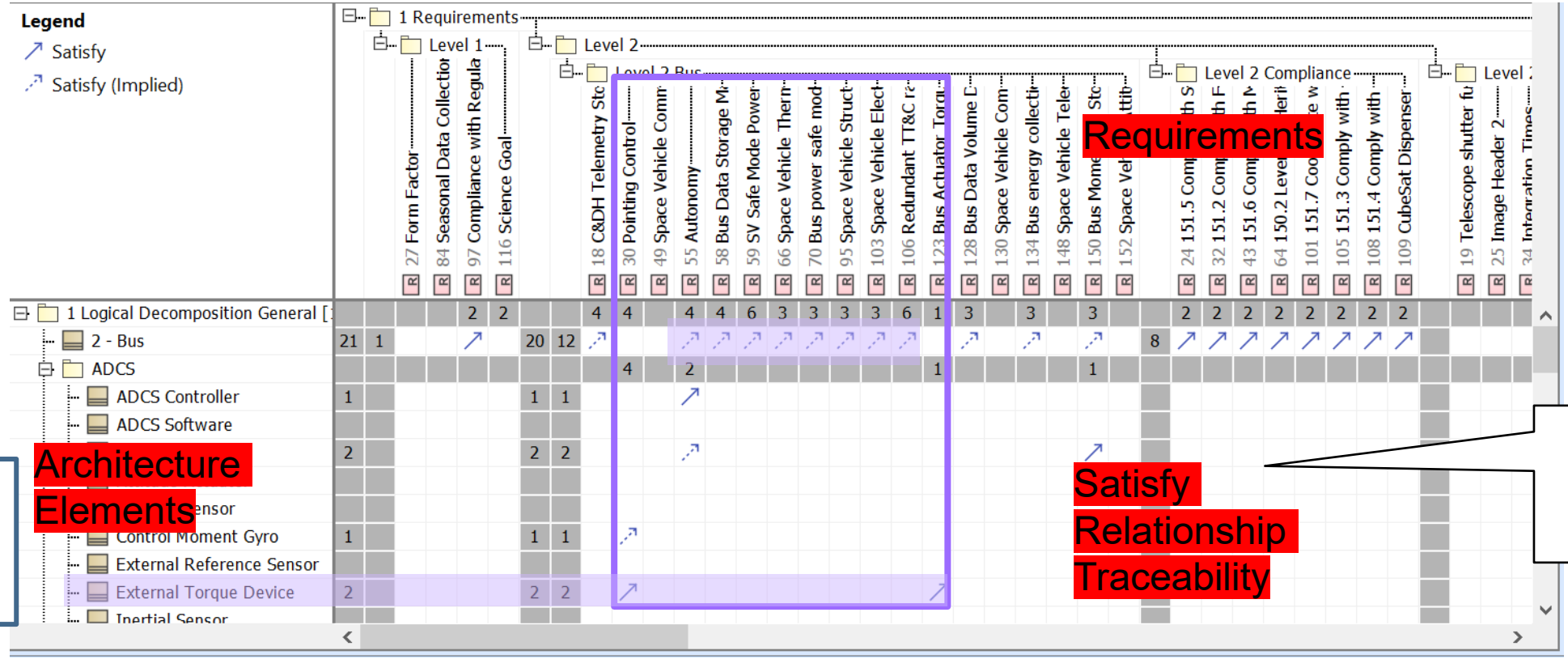
Model Dashboard

Matrices can show a lot of information about relationships between two groups of elements, lacks in showing any more details or relationships between more than two groups of elements

Dependency Matrix showing Satisfaction of Requirements by Components

- Empty columns - requirements that are not satisfied
- Empty rows - blocks that don't have a satisfy relationship, may not be necessary

Navigate dashboard to look for criteria – find some views supporting



Model Dashboard

Matrices can show a lot of information about relationships between two groups of elements, lacks in showing any more details or relationships between more than two groups of elements

Formulation of Verification Objectives

assifier: ALOHASAT Verification Activity ... Scope (optional): ASAT Verification Activities Master {}xy ... Filter:

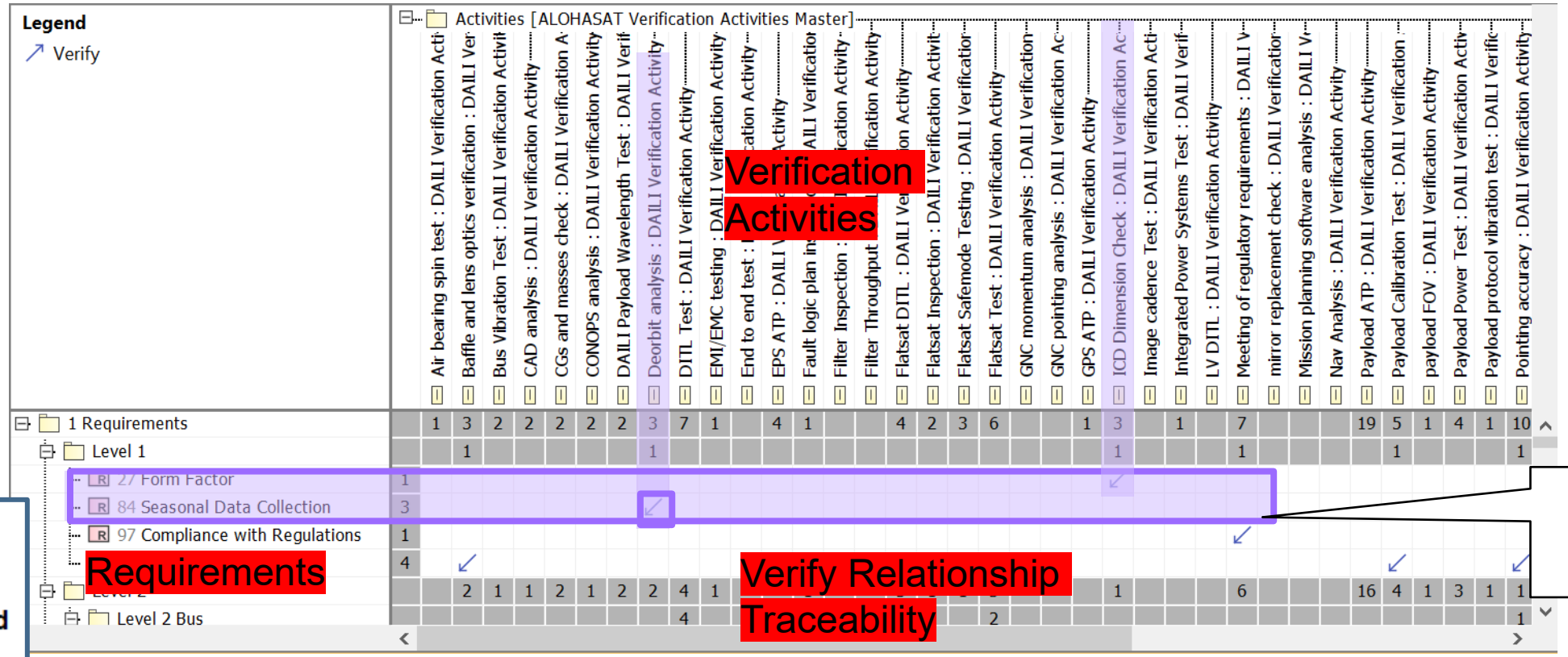
Name	Method : String	Documentation : String	Status : String
EMI/EMC testing	Test	Test system for possible electromagnetic emissions/interference and compatibility	Not ready
End to end test	Test		
EPS ATP	Test	Shows protections for over and under voltage of batteries as well as operation solely from solar power (no batteries). Test activation switches (wing latch, payload, etc.)	Ready to start
Fault logic plan inspection	Inspection	Inspect fault logic plan, including safe modes and flow diagram	Complete
Filter Inspection	Inspection	Verify the band limits, check paperwork for filters	Complete
Filter Throughput	Test	Acceptance test for imager filter performance.	Complete
Flatsat DITL	Demonstration	Operate payload on lab bench in flight-like configuration and power cycle the payload during both full frame and data collection modes.	Not ready
	Inspection	Verify hardware is interconnected properly.	Not ready

Model Dashboard

Verification Activities are great for defining tests or other activities used in verification of requirements

Dependency Matrix showing Verification of Requirements by Verification Activities

Navigate dashboard to look for criteria – find some views supporting



Matrices can show a lot of information about relationships between two groups of elements, lacks in showing any more details or relationships between more than two groups of elements

Table showing Requirements and Verification Objectives for Each Component

- This kind of information can also be used to generate a test plan from the model

#	Name	Satisfies	Related Verifications
1	Thermal Control Subsystem	66 Space Vehicle Thermal Control	Thermal Department Analyses : ALOHASAT Verification Activity TVAC Test : ALOHASAT Verification Activity
2	C&DH Controller	59 SV Safe Mode Power Usage	Systems Engineer Analyses : ALOHASAT Verification Activity
3	Power Control and Distribution	59 SV Safe Mode Power Usage	Systems Engineer Analyses : ALOHASAT Verification Activity
4	External Torque Device	30 Pointing Control 123 Bus Actuator Torque Margin	Pointing Budget analysis : ALOHASAT Verification Activity Pointing accuracy : ALOHASAT Verification Activity
5	Momentum Exchange Device	30 Pointing Control	Pointing Budget analysis : ALOHASAT Verification Activity Pointing accuracy : ALOHASAT Verification Activity
6	2 - Bus	97 Compliance with Regulations 24 151.5 Comply with Safety Regulations 32 151.2 Comply with FCC 43 151.6 Comply with Mission Assurance Strategy 64 150.2 Leverage Heritage Systems and Software 105 151.3 Comply with Space Debris Regulation (< 25 yrs) 101 151.7 Coordinate with JSpOC 108 151.4 Comply with ITAR 109 CubeSat Dispenser	Meeting of regulatory requirements : ALOHASAT Verification Activity Fault logic plan inspection : ALOHASAT Verification Activity EMI/EMC testing : ALOHASAT Verification Activity Deorbit analysis : ALOHASAT Verification Activity ICD Dimension Check : ALOHASAT Verification Activity CGs and masses check : ALOHASAT Verification Activity
	Electrical Power Subsystem	70 Bus power safe mode 103 Space Vehicle Electrical Power 134 Bus energy collection	DITL Test : ALOHASAT Verification Activity Thermal Cycle Functional Test : ALOHASAT Verification Activity Systems Engineer Analyses : ALOHASAT Verification Activity

Model Dashboard

Beyond showing properties of an element, tables can show elements that are related to an element, and elements related to that element, and so on

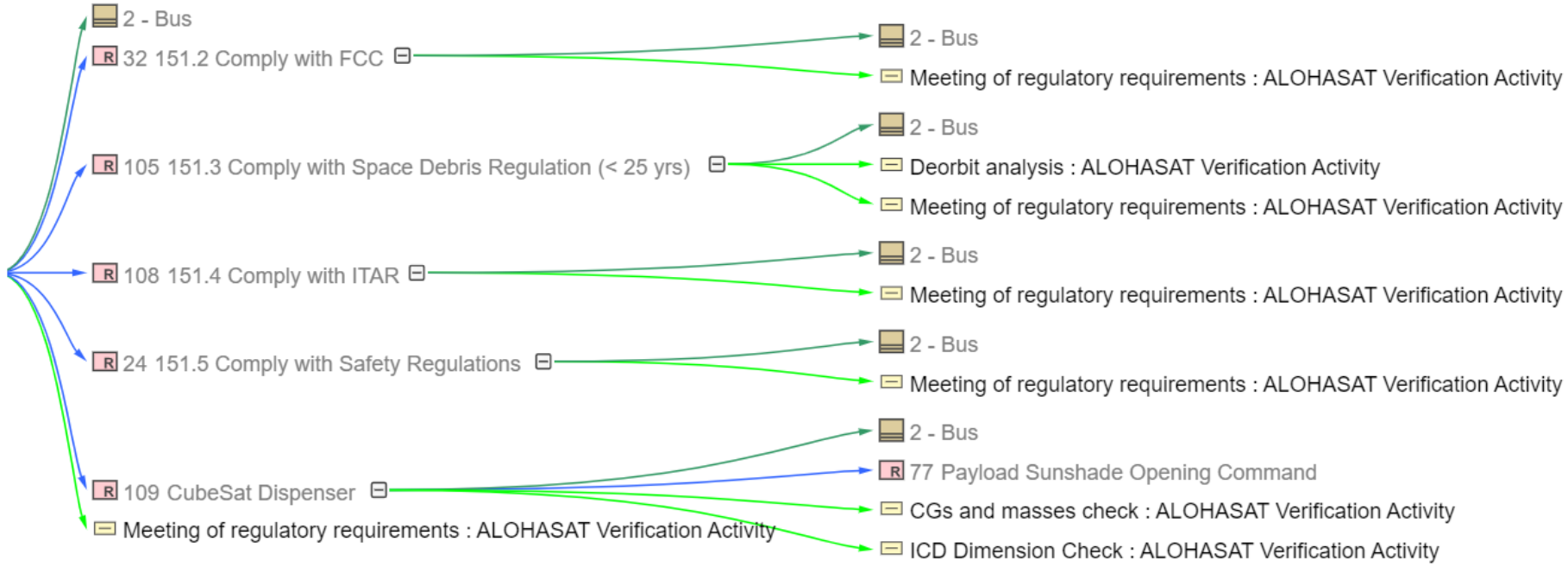
Components and Verification Objectives for Each Requirement

#	Name	Satisfied By	Verified By
1	Redundant TT&C radios	Transmitter Receiver	
2	Space Vehicle Thermal Control	Thermal Control Subsystem	Thermal Department Analyses : ALOHASAT Verificat TVAC Test : ALOHASAT Verification Activity
3	Space Vehicle Structural and Mechanical	Structural and Mechanical Subsystem	
4	SV Safe Mode Power Usage	Power Control and Distribution C&DH Controller	Systems Engineer Analyses : ALOHASAT Verification
5	Science Goal	Imager	Baffle and lens optics verification : ALOHASAT Verifi Pointing accuracy : ALOHASAT Verification Activity Payload Calibration Test : ALOHASAT Verification Ac Verify SNR : ALOHASAT Verification Activity
6	Pointing Control	External Torque Device Momentum Exchange Device	Pointing Budget analysis : ALOHASAT Verification A Pointing accuracy : ALOHASAT Verification Activity
7	Bus Actuator Torque Margin	External Torque Device	
8	Bus power safe mode	Electrical Power Subsystem	DITL Test : ALOHASAT Verification Activity Thermal Cycle Functional Test : ALOHASAT Verificati
9	Space Vehicle Electrical Power	Electrical Power Subsystem	Systems Engineer Analyses : ALOHASAT Verification
10	Bus energy collection	Electrical Power Subsystem	
11	C&DH Telemetry Storage	Data Storage	DITL Test : ALOHASAT Verification Activity
12	Bus Data Storage Margin	Data Storage	DITL Test : ALOHASAT Verification Activity

Model Dashboard

Different focuses allow viewing the same information in different ways

Relation Map



Model Dashboard

Legend

- Derived
- Packaged Element
- Satisfied By
- Verified By

Relation Map intuitively shows different relationships between elements

IEEE 15288.2 Criteria in Model Format

Identifier	Acceptability Criterion Text	Inferred Mode Acceptance Criterion	Use of Model in Design Review
c	Interoperability functional performance requirements are allocated to all system, segment and subsystem preliminary designs.	Interoperability, functional, and performance requirements are listed and have "satisfy" relationships to structural or behavioral elements in the design. Views (tables) list performance requirements and model elements to which they have been allocated.	Assess completeness and correctness of performance requirements and links to structural and behavioral elements using SysML requirement
s	DT&E elements are correlated with the preliminary design.	Model elements for Developmental Testing and Evaluation (DT&E) are defined, identified with appropriate stereotypes, and allocated by means of verify relationships to requirements	Assess completen requirements identified as DT&E using requirements tables and filtering for that attribute. Assess completeness and correcteness of rationale allocations to the design elements (should be included as a column in those tables)
t	OT&E allocated requirements are incorporated into the preliminary design.	Model elements for Operational Testing and Evaluation (OT&E) are defined, identified with appropriate stereotypes, and allocated by means of verify relationships to requirements	Assess completeness and correctness of requirements identified as OT&E using requirements tables and filtering for that attribute. Assess completeness and correcteness of rationale allocations to the design elements (should be included as a column in those tables)

Review documented criteria that you are looking for

Requirements Inferred from IEEE 15288.2 PDR Acceptability Criteria

Acceptability Criterion Text	Inferred Mode Acceptance Criterion	Use of Model in Design Review
Requirements allocation and derivation from system to segment, subsystem and component levels are complete, traceable to the preliminary design and all “to be determined” (TBD items are being tracked to resolution).	All requirements in the model have • (i) SysML"satisfied by" relationships to architectural elements or • (ii) SysML "derived" or "refined" relationships. All requirements have SysML "verified by" relationships to verification methods. Model views (tables) are present in the model to show • (i) relationships from higher to lower level requirements (using the "derived" or "refined" relationships) and • (ii) the relationship between all requirements and the system architectural elements to which they have been allocated using the "satisfied by" relationship. For requirements that are not directly allocated to system design elements, views are present to show the trace from such requirements to requirements to which system elements have been allocated (using the "satisfied by" relationship). Requirements with TBD items are identified with the appropriate stereotypes or properties and can be retrieved through a model view.	Assess the views traces of requirements from system to segments, subsystems, and component levels and to assess completeness and correctness of traces from requirements to model elements. Use views to assess completeness of TBD items.

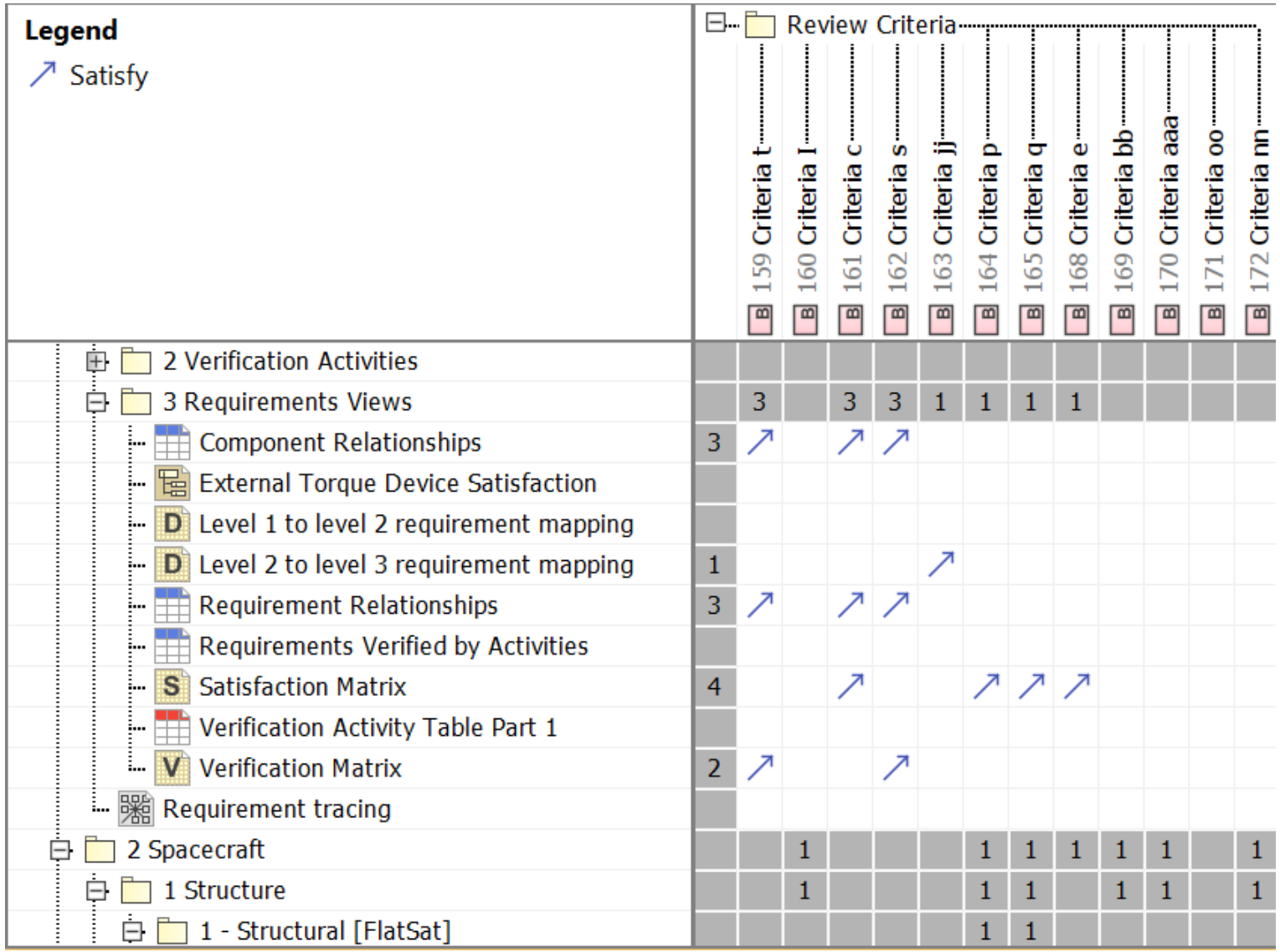
15288.2 criteria jj

Review Criteria in Model

Review documented criteria that you are looking for

#	Name	Text
1	Criteria t	OT&E allocated requirements are incorporated into the
2	Criteria l	Mass properties margins (average or complex) are e correlated with the preliminary design, including allowable growth allocations and metrics.
3	Criteria c	Interoperability functional performance requirements are allocated to all system, segment and subsystem preliminary designs.
4	Criteria s	DT&E elements are correlated with the preliminary design.
5	Criteria jj	Requirements allocation and derivation from system to segment, subsystem and component levels are complete, traceable to the preliminary design and all "to be determined" (TBD items are being tracked to resolution).
6	Criteria p	The preliminary data storage physical architecture fully addresses elements, including communications and processing capacity.
7	Criteria q	The data storage logical architecture defines a complete list of data receivers to include both computer and human agents.
8	Criteria e	System operational functions and environments for the preliminary design are traceable to the supplier's CONOPS and the allocated baseline.
9	Criteria bb	Functional failure modes, effects, and criticality analysis (FMECA) is completed.
10	Criteria aaa	System end-to-end data flow is complete and documented in the preliminary design.
11	Criteria oo	Key allocated performance requirement parameters developed and assessed at SFR are implemented in each major subsystem and component preliminary design.
12	Criteria nn	Key allocated performance requirements are traceable to the system's preliminary design at the segment, subsystem, and component levels as applicable.

Criteria Satisfaction within the Model



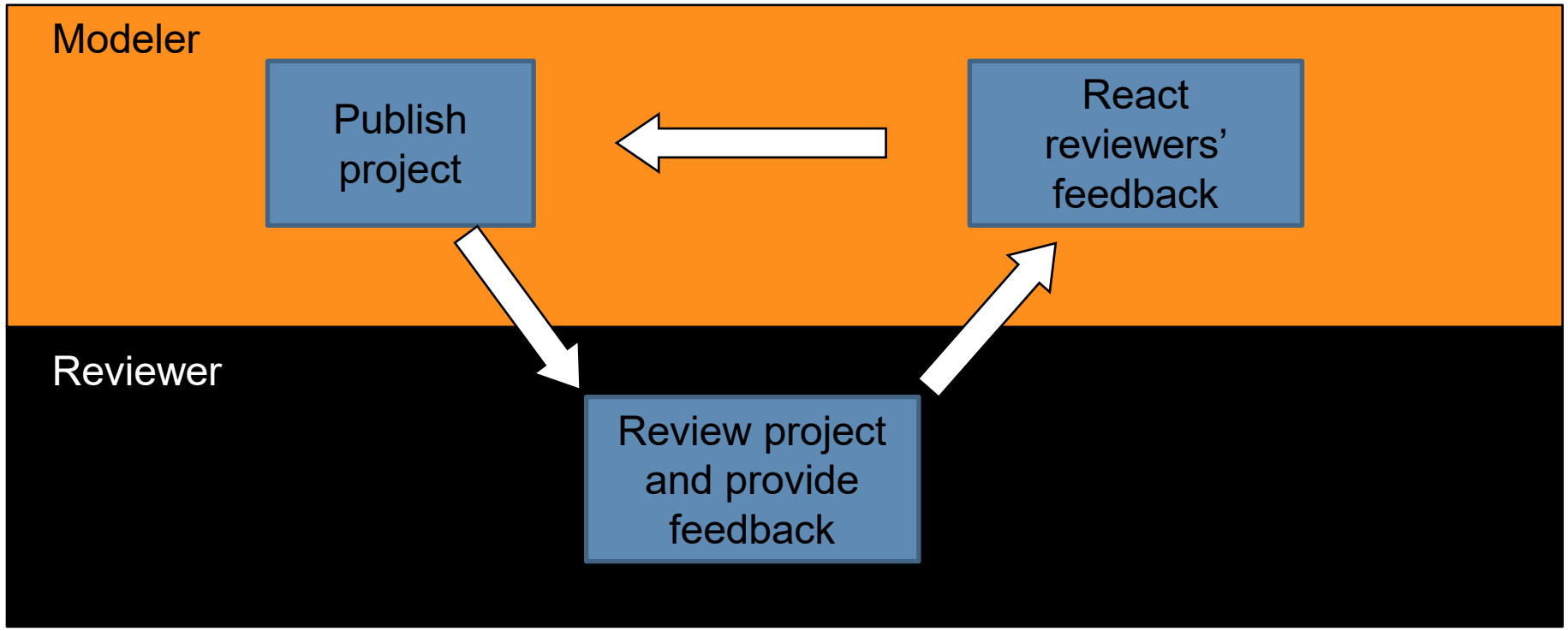
Review documented criteria that you are looking for

Our Special application of a matrix

Providing Review Feedback in the Model

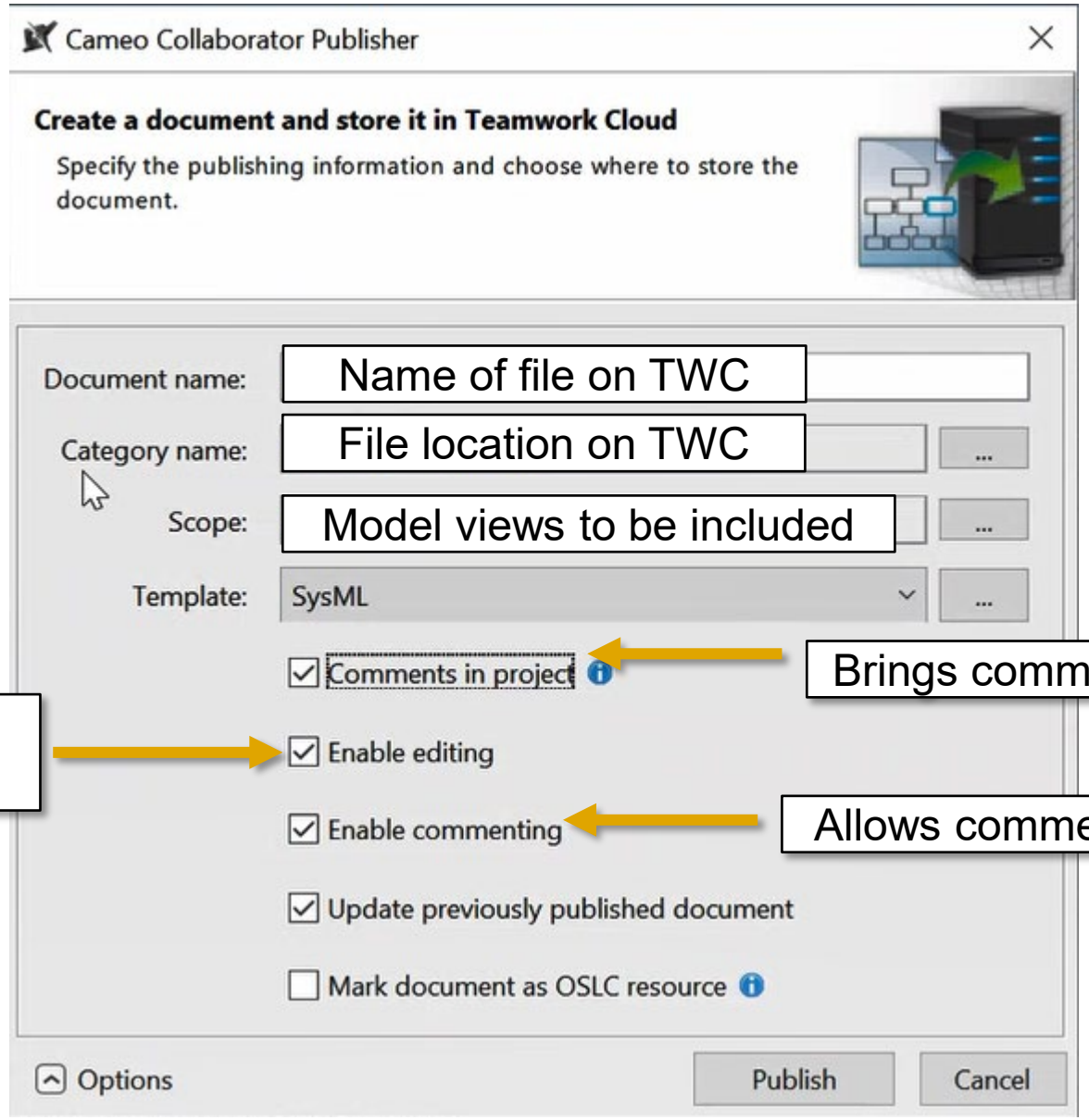
Cameo Collaborator Overview

- A tool to publish views from the model to web interface for others to see
  - *Modelers can publish the views from the model*
  - *Reviewers can comment*
  - *Comments can be viewed by everyone on the web, or brought back into the model*



Other tools such as MBEE exist to facilitate reviews in and out of Cameo.

Collaborator View in Cameo

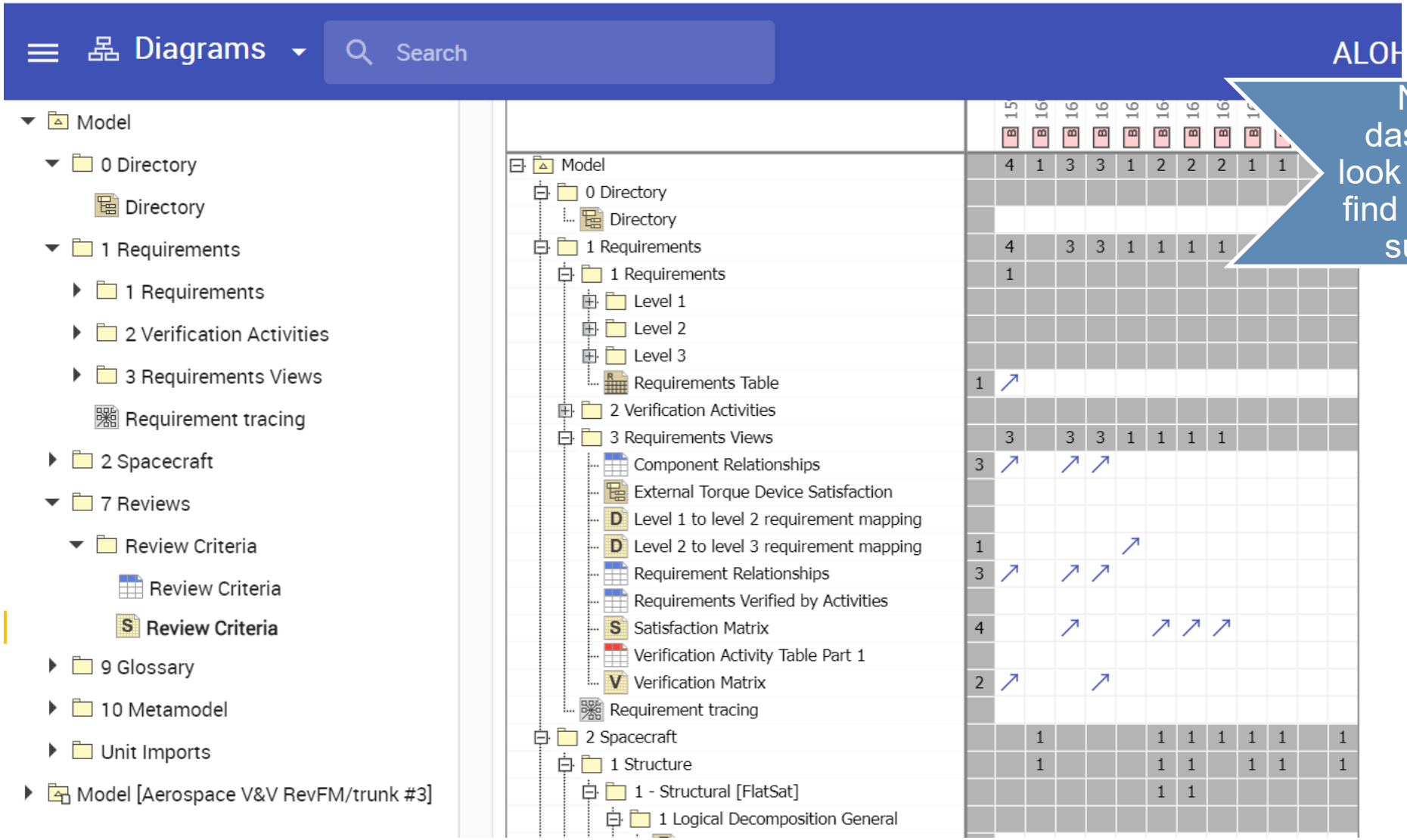


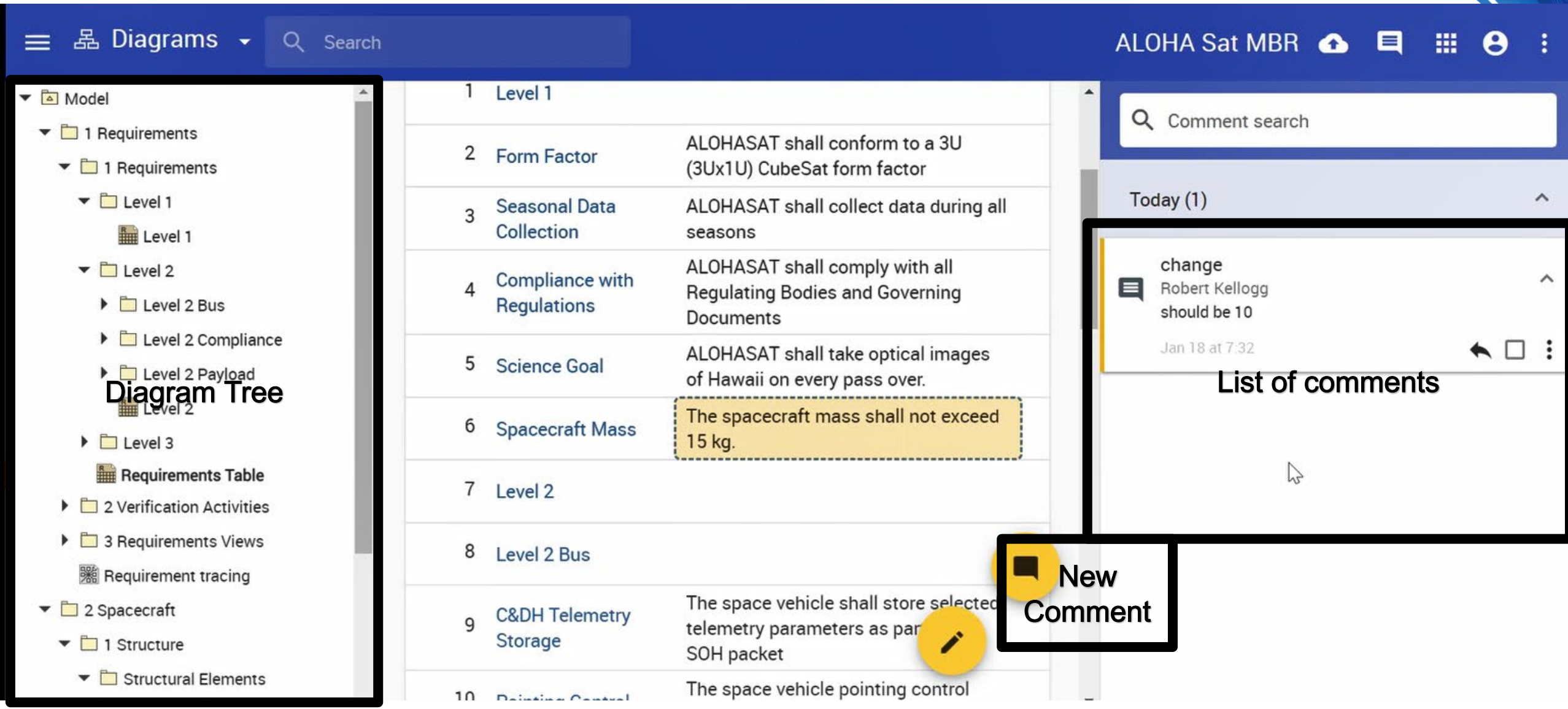
Brings comments into model

Allows editing of text based fields

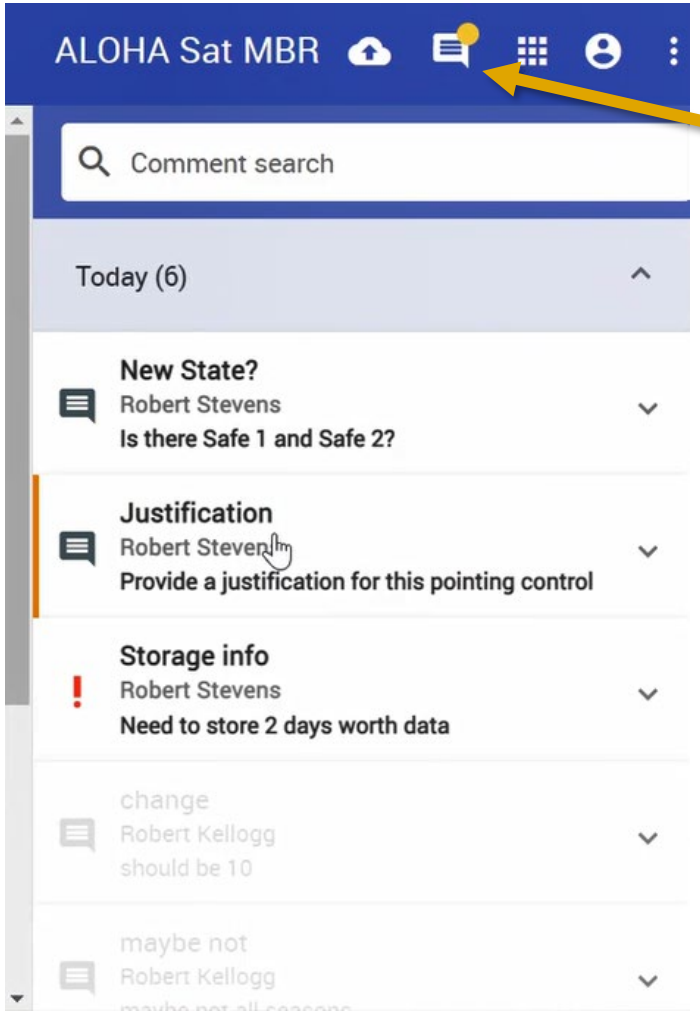
Allows commenting

Criteria Satisfaction within the Model

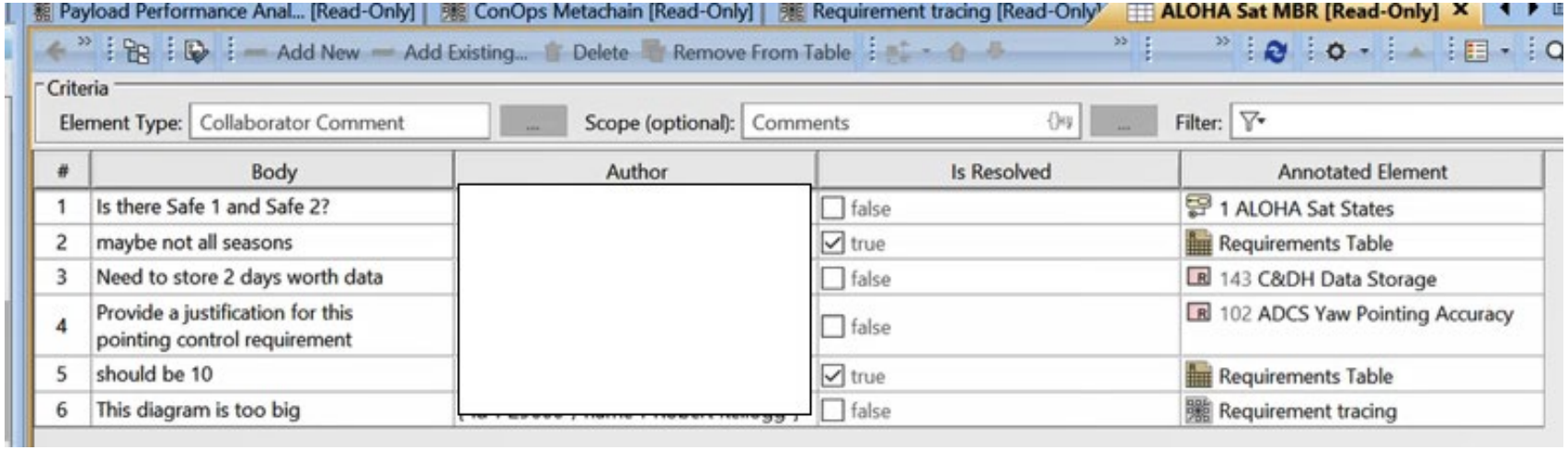


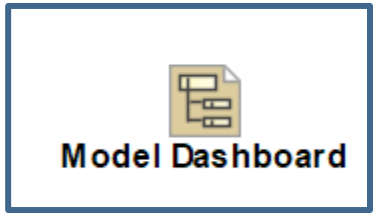

Diagrams
Search
ALOHA Sat MBR
Model
1 Requirements
1 Requirements
Level 1
Level 1
Level 2
Level 2 Bus
Level 2 Compliance
Level 2 Payload
Level 2
Level 3
Requirements Table
2 Verification Activities
3 Requirements Views
Requirement tracing
2 Spacecraft
1 Structure
Structural Elements
Diagram Tree
1 Level 1
2 Form Factor
ALOHASAT shall conform to a 3U (3Ux1U) CubeSat form factor
3 Seasonal Data Collection
ALOHASAT shall collect data during all seasons
4 Compliance with Regulations
ALOHASAT shall comply with all Regulating Bodies and Governing Documents
5 Science Goal
ALOHASAT shall take optical images of Hawaii on every pass over.
6 Spacecraft Mass
The spacecraft mass shall not exceed 15 kg.
7 Level 2
8 Level 2 Bus
9 C&DH Telemetry Storage
The space vehicle shall store selected
telemetry parameters as par
SOH packet
10
The space vehicle pointing control
Comment search
Today (1)
change
Robert Kellogg
should be 10
Jan 18 at 7:32
List of comments
New Comment

Comments transferred to model



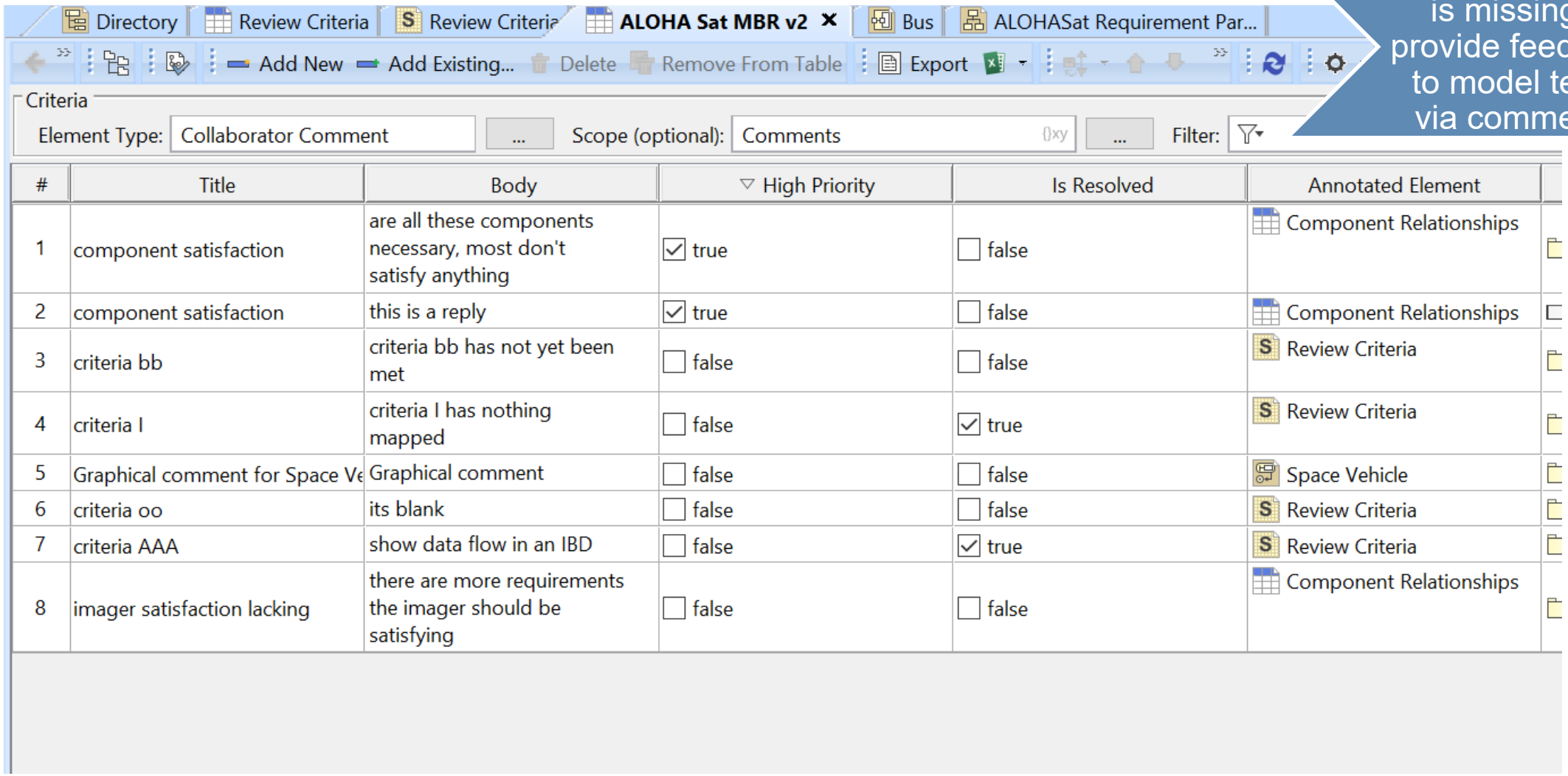
- Can see list of comments in collaborator view
- Resolved comments are faded or marked resolved
- Both link to the related element





Comments in the model

Discover a view is missing – provide feedback to model team via comments



#	Title	Body	High Priority	Is Resolved	Annotated Element
1	component satisfaction	are all these components necessary, most don't satisfy anything	☑ true	☐ false	Component Relationships
2	component satisfaction	this is a reply	☑ true	☐ false	Component Relationships
3	criteria bb	criteria bb has not yet been met	☐ false	☐ false	Review Criteria
4	criteria l	criteria l has nothing mapped	☐ false	☑ true	Review Criteria
5	Graphical comment for Space Ve	Graphical comment	☐ false	☐ false	Space Vehicle
6	criteria oo	its blank	☐ false	☐ false	Review Criteria
7	criteria AAA	show data flow in an IBD	☐ false	☑ true	Review Criteria
8	imager satisfaction lacking	there are more requirements the imager should be satisfying	☐ false	☐ false	Component Relationships

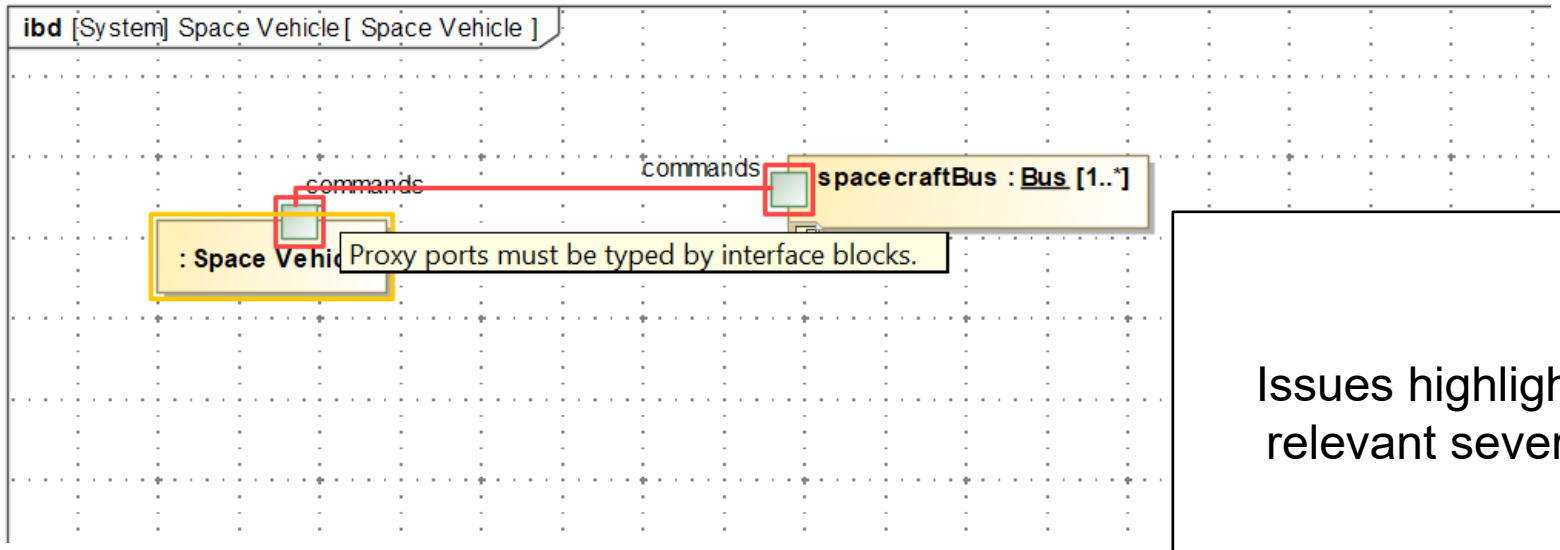
Verification and Validation Rules

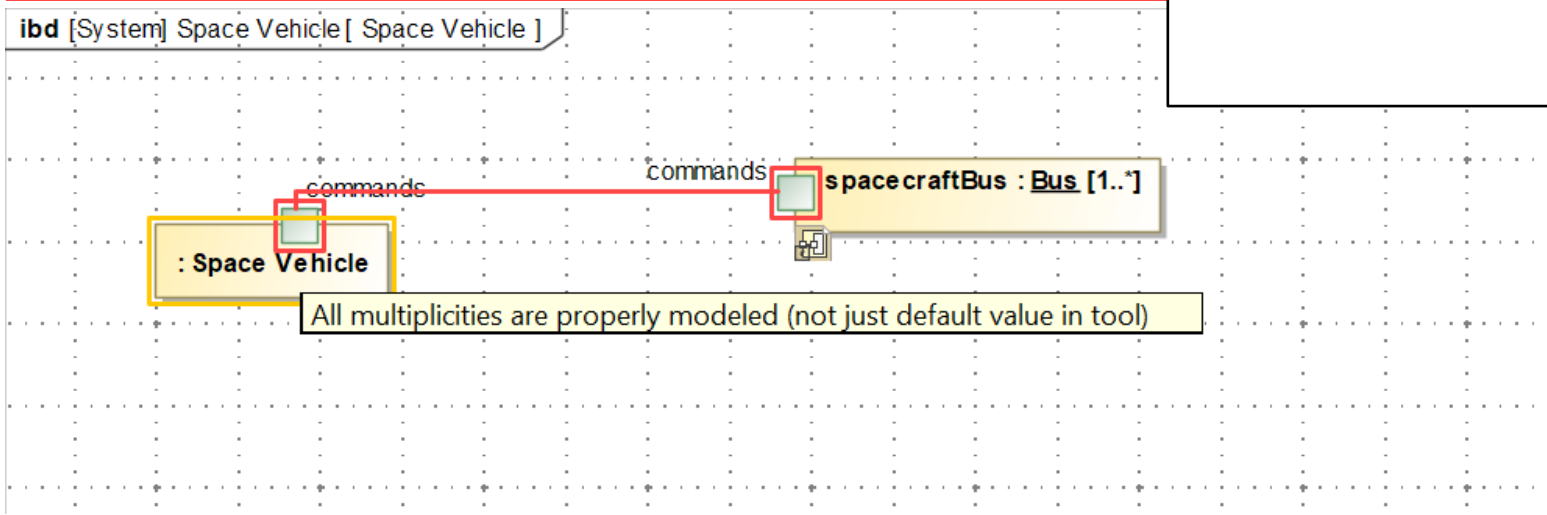
With IEEE 15882.2 acceptance criteria

Verification and Validation Rules

- Create rules within MBSE tool about how to model
  - *Can create rules specific to the program or review you are supporting to check entire model*
- Binary statements related to model contents
- Warned when rules are not met
- Aerospace has developed suite of rules to make sure best modeling practices are followed

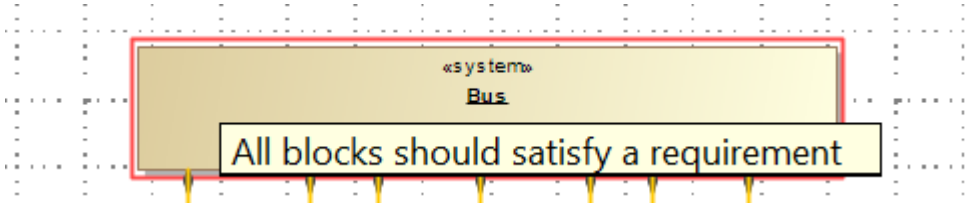
Validation Rule Examples and Severity





Issues highlighted with relevant severity level

Review Criteria as Validation Rules



- Here we are requiring that all blocks satisfy a requirement
  - Absence of satisfaction may indicate that the block is not necessary
- Can identify whether certain criteria that may be necessary for review are present
- Translate design review entry/exit criteria into model validation rules
  - Criteria can be made into both the automated validation rules and manually validated by model reviewers

Automated Requirement Verification

Weight Calculation Verification

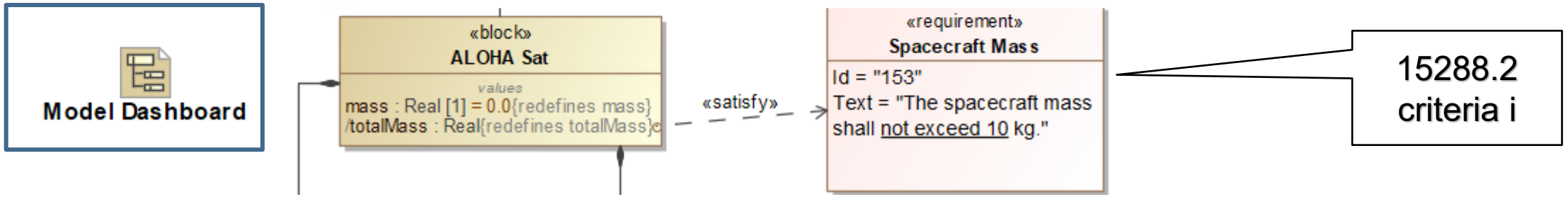
- Requirement Verification can be done within the model
- This requires relating parameters to their relevant requirements
- Parameters (Value properties) can be added to architecture elements (blocks)
- Just like how requirements could relate to other elements, we can relate the value properties directly to requirements
- This automatically ties them together and allows for analysis and simulation within the tool

IEEE 15288.2 Criteria in Model Format

Identifier	Acceptability Criterion Text	Inferred Mode Acceptance Criterion	Use of Model in Design Review
i	Mass properties margins (average or complex) are established for PDR and correlated with the preliminary design, including allowable growth allocations and metrics.	Requirements with quantitative attributes (power, weight, related items) are parameterized, these parameters can be identified, the parameters are allocated to lower design levels using parametric diagrams or sequence diagrams (for timing), and these values are identifiable in the requirements for the lower level design items.	Assess completeness and correctness of requirements in model for quantitative attributes and parametric diagrams showing lower level allocations using requirements tables and filtering for that attribute

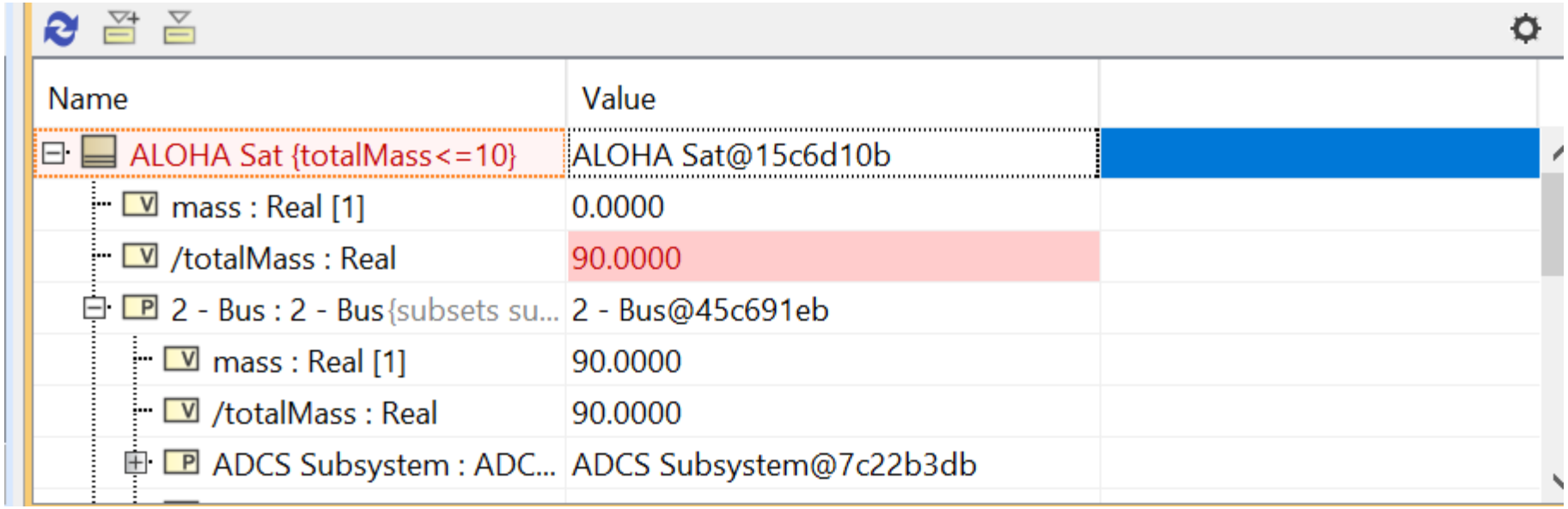
Tie values to requirements

Value properties are values that sit on an element and contain parameter values that can be evaluated



- Have the new total mass value property satisfy the total mass requirement.
- Any value properties can be used to satisfy requirements(lifetime, power, size, etc.)

Requirement Satisfaction of Parameters



- When modeled correctly, the model can be simulated to see what the total mass is

- Parameter dashboard shows that the 90kg mass of the sat exceeds the requirement

Satisfaction in Table

Criteria

Scope (optional): Level 1 ... Filter: Context (optional): aloha sat : ALOHA Sat ...

Requirement Verification: Pass Fail ...

#	Name	Text	Value	Property	Bounds	Margin
1	27 Form Factor	ALOHASAT shall conform to a 3U (3Ux1U) CubeSat form factor				
2	84 Seasonal Data Colle	ALOHASAT shall collect data during all seasons				
3	97 Compliance with Re	ALOHASAT shall comply with all Regulating Bodies and Governing Documents				
4	116 Science Goal	ALOHASAT shall take optical images of Hawaii on every pass over.				
5	153 Spacecraft Mass	The spacecraft mass shall not exceed 10 kg.	90	totalMass : Real	<=10	-80

- Underlined words are processed as inequality and used in calculation
- The lack of satisfaction can also be viewed within a requirement table

Summary

We covered three aspects of model-based reviews for systems

- *Reviews in a Lifecycle-Managed Digital Engineering Environment (Lerner)*
- *Model-Based Review Planning (Stevens)*
- *Model-Based Review Execution (Kellogg)*

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Concept Design Center, El Segundo, CA