International Council on Systems Engineering
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Performing Verification and Validation in a Model-Based Environment

Rebecca Mulholland
Cameron Bentley
Jeffery L. Williams, Ph.D.

INCOSE International Symposium 2025 | Ottawa, Canada

Opening Comments

- The presentation is scheduled for 25 minutes
- We have too many slides
- The focus will be on the high points of the material
  - Some slides will be reviewed quickly
  - Because of the importance of some we will take minute or two to explain
- All slides will be available

Agenda

- Background and Acknowledgements
- Development of the Validation Suite for Needs & Requirements
- Development of the Design & System V&V Process Modes
  - Modeling the V&V Planning Process
  - Capture of V&V Compliance Results

Background & Acknowledgements

Acknowledgements

This paper is the result of work performed by Rebecca Mulholland & Cameron Bentley as part of their capstone project for an MSE in Systems Engineering.

Their work also contributed to the development of the model in use for the development of the Guide to Model Based Needs & Requirements.

Both have graduated and are now employed with Leidos.

Background: Summary of Abstract (1 of 2)

- Verification and Validation (V&V) are critical processes that ensure alignment between stakeholder needs and system realization.
- There is limited guidance for implementing V&V in a model-based environment.
- This paper presents an adaptable methodology leveraging Cameo Systems Modeler and a SysML-derived Meta-Model to perform V&V.
  - The methodology is aligned with the INCOSE Needs and Requirements Manual (NRM).
- The proposed approach is split into two major processes:
  - Needs and requirements V&V
  - Design and system V&V

Background: Summary of Abstract (2 of 2)

- Needs and requirements V&V integrates automated and manual methods for ensuring need and requirement sets are written in compliance with the INCOSE NRM guidelines
- Design and system V&V uses a custom profile to define system V&V attributes and activities used for V&V planning

This model-based framework enhances the efficiency and accuracy of both needs and requirements V&V and system and design V&V

Validation Suite for Needs & Requirements

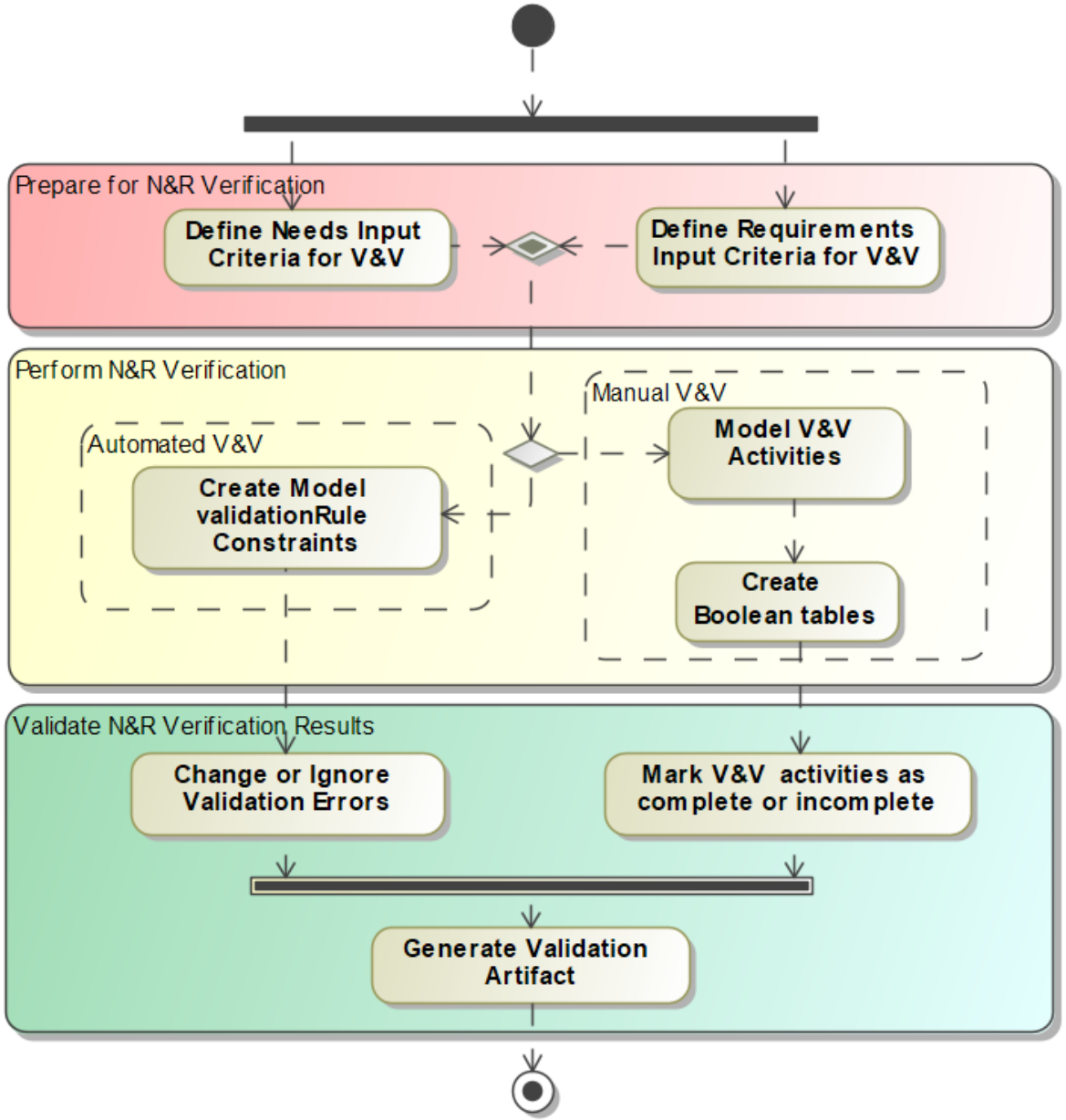
Needs and Requirements V&V

- Need Verification
  - Confirmation that the need statements & set of needs comply with the ***rules and characteristics*** defined by the NRM (NRM, §2.3.3.1)
- Requirement Verification
  - Confirmation requirement statements and sets of requirements comply with the ***rules and characteristics*** defined by the NRM (NRM, §2.3.3.1)
- Need and Requirement Verification is implemented in using a set of validation rules

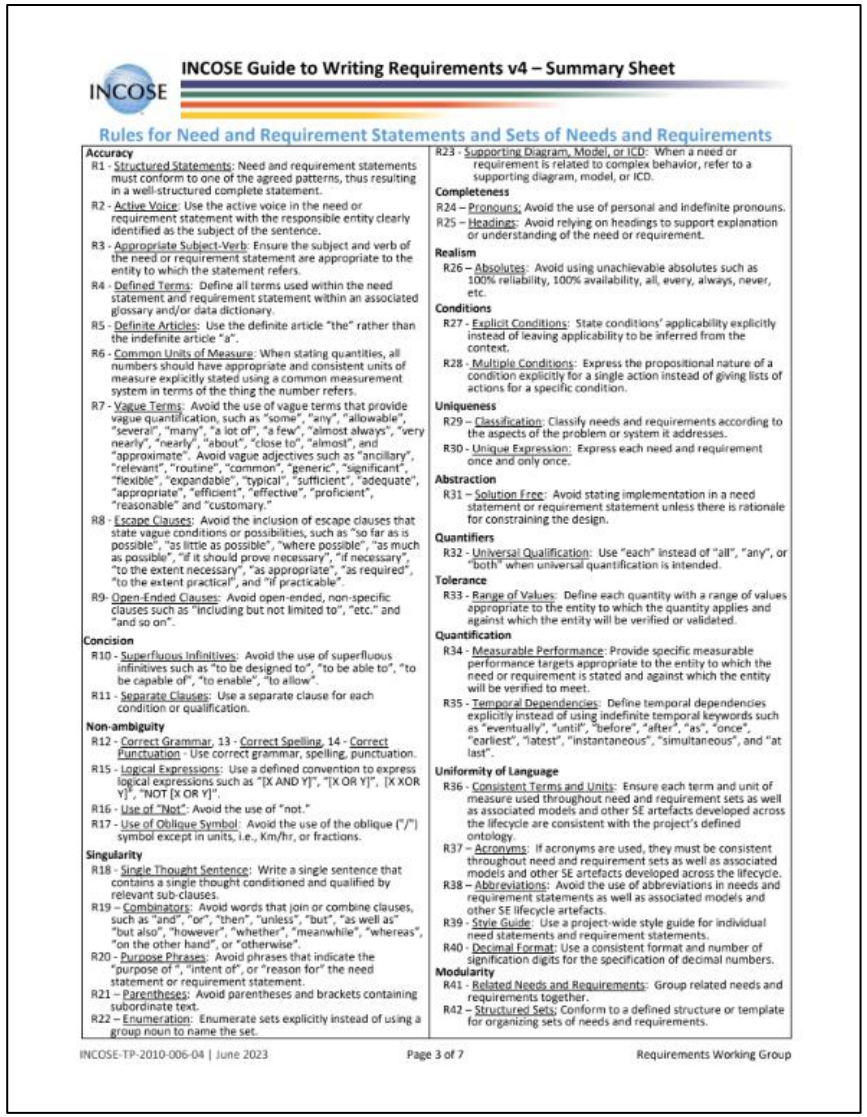
Needs and Requirements V&V

- Need Validation
  - Confirmation that the needs clearly communicate the intent of the agreed-to lifecycle concepts, constraints, and stakeholder real-world expectations from which they were transformed (NRM, §2.3.3.1)
- Requirement Validation
  - Confirmation that the requirements clearly communicate the intent of the needs, parent requirements, and other sources from which they were transformed (NRM, §2.3.3.1)
- Need and Requirement Validation is implemented by attaching artifacts documenting concurrence between stakeholders (NRM, §2.3.3.1)

Need and Requirements V&V Process



Guide to Writing Requirements in a Validation Suite



INCOSE Guide to Writing Requirements v4 – Summary Sheet

Rules for Need and Requirement Statements and Sets of Needs and Requirements

Accuracy

R1 - Structured Statements: Need and requirement statements must conform to one of the agreed patterns, thus resulting in a well-structured complete statement.

R2 - Active Voice: Use the active voice in the need or requirement statement with the responsible entity clearly identified as the subject of the sentence.

R3 - Appropriate Subject-Verb: Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers.

R4 - Defined Terms: Define all terms used within the need statement and requirement statement within an associated glossary and/or data dictionary.

R5 - Definite Articles: Use the definite article "the" rather than the indefinite article "a".

R6 - Common Units of Measure: When stating quantities, all numbers should have appropriate and consistent units of measure explicitly stated using a common measurement system in terms of the thing the number refers.

R7 - Vague Terms: Avoid the use of vague terms that provide vague quantification, such as "some", "any", "allowable", "several", "many", "a lot of", "a few", "almost always", "very nearly", "nearly", "about", "close to", "almost", and "approximate". Avoid vague adjectives such as "ancillary", "relevant", "routine", "common", "generic", "significant", "flexible", "expandable", "typical", "sufficient", "adequate", "appropriate", "efficient", "effective", "proficient", "reasonable" and "customary."

R8 - Escape Clauses: Avoid the inclusion of escape clauses that state vague conditions or possibilities, such as "so far as is possible", "as little as possible", "where possible", "as much as possible", "if it should prove necessary", "if necessary", "to the extent necessary", "as appropriate", "as required", "to the extent practical", and "if practicable".

R9- Open-Ended Clauses: Avoid open-ended, non-specific clauses such as "including but not limited to", "etc." and "and so on".

Concision

R10 - Superfluous Infinitives: Avoid the use of superfluous infinitives such as "to be designed to", "to be able to", "to be capable of", "to enable", "to allow".

R11 - Separate Clauses: Use a separate clause for each condition or qualification.

Non-ambiguity

R12 - Correct Grammar, 13 - Correct Spelling, 14 - Correct Punctuation - Use correct grammar, spelling, punctuation.

R15 - Logical Expressions: Use a defined convention to express logical expressions such as "[X AND Y]", "[X OR Y]", [X XOR Y]", "NOT [X OR Y]".

R16 - Use of "Not": Avoid the use of "not."

R17 - Use of Oblique Symbol: Avoid the use of the oblique ("/") symbol except in units, i.e., Km/hr, or fractions.

Singularity

R18 - Single Thought Sentence: Write a single sentence that contains a single thought conditioned and qualified by relevant sub-clauses.

R19 – Combinators: Avoid words that join or combine clauses, such as "and", "or", "then", "unless", "but", "as well as" "but also", "however", "whether", "meanwhile", "whereas", "on the other hand", or "otherwise".

R20 - Purpose Phrases: Avoid phrases that indicate the "purpose of ", "intent of", or "reason for" the need statement or requirement statement.

R21 – Parentheses: Avoid parentheses and brackets containing subordinate text.

R22 – Enumeration: Enumerate sets explicitly instead of using a group noun to name the set.

R23 - Supporting Diagram, Model, or ICD: When a need or requirement is related to complex behavior, refer to a supporting diagram, model, or ICD.

Completeness

R24 – Pronouns: Avoid the use of personal and indefinite pronouns.

R25 – Headings: Avoid relying on headings to support explanation or understanding of the need or requirement.

Realism

R26 – Absolutes: Avoid using unachievable absolutes such as 100% reliability, 100% availability, all, every, always, never, etc.

Conditions

R27 - Explicit Conditions: State conditions' applicability explicitly instead of leaving applicability to be inferred from the context.

R28 - Multiple Conditions: Express the propositional nature of a condition explicitly for a single action instead of giving lists of actions for a specific condition.

Uniqueness

R29 – Classification: Classify needs and requirements according to the aspects of the problem or system it addresses.

R30 - Unique Expression: Express each need and requirement once and only once.

Abstraction

R31 – Solution Free: Avoid stating implementation in a need statement or requirement statement unless there is rationale for constraining the design.

Quantifiers

R32 - Universal Qualification: Use "each" instead of "all", "any", or "both" when universal quantification is intended.

Tolerance

R33 - Range of Values: Define each quantity with a range of values appropriate to the entity to which the quantity applies and against which the entity will be verified or validated.

Quantification

R34 - Measurable Performance: Provide specific measurable performance targets appropriate to the entity to which the need or requirement is stated and against which the entity will be verified to meet.

R35 - Temporal Dependencies: Define temporal dependencies explicitly instead of using indefinite temporal keywords such as "eventually", "until", "before", "after", "as", "once", "earliest", "latest", "instantaneous", "simultaneous", and "at last".

Uniformity of Language

R36 - Consistent Terms and Units: Ensure each term and unit of measure used throughout need and requirement sets as well as associated models and other SE artefacts developed across the lifecycle are consistent with the project's defined ontology.

R37 – Acronyms: If acronyms are used, they must be consistent throughout need and requirement sets as well as associated models and other SE artefacts developed across the lifecycle.

R38 – Abbreviations: Avoid the use of abbreviations in needs and requirement statements as well as associated models and other SE lifecycle artefacts.

R39 - Style Guide: Use a project-wide style guide for individual need statements and requirement statements.

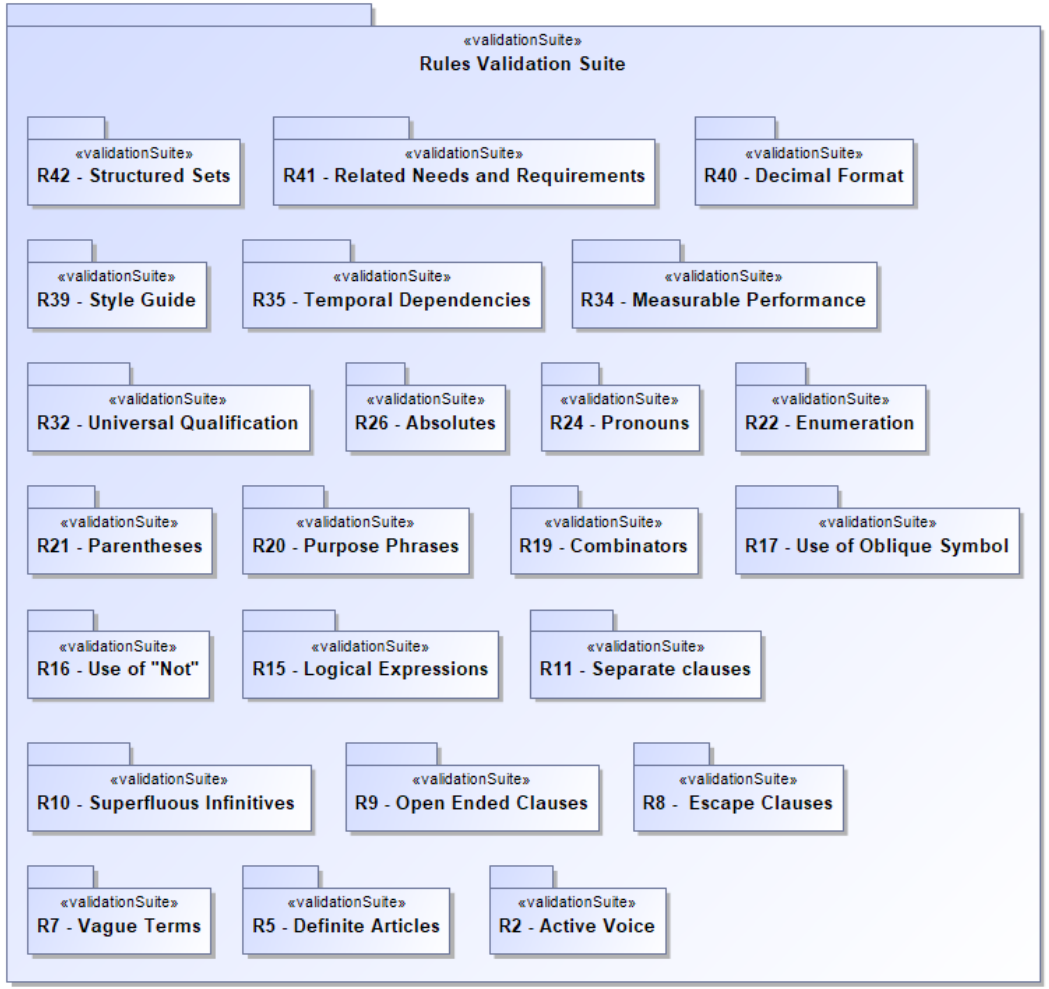
R40 - Decimal Format: Use a consistent format and number of signification digits for the specification of decimal numbers.

Modularity

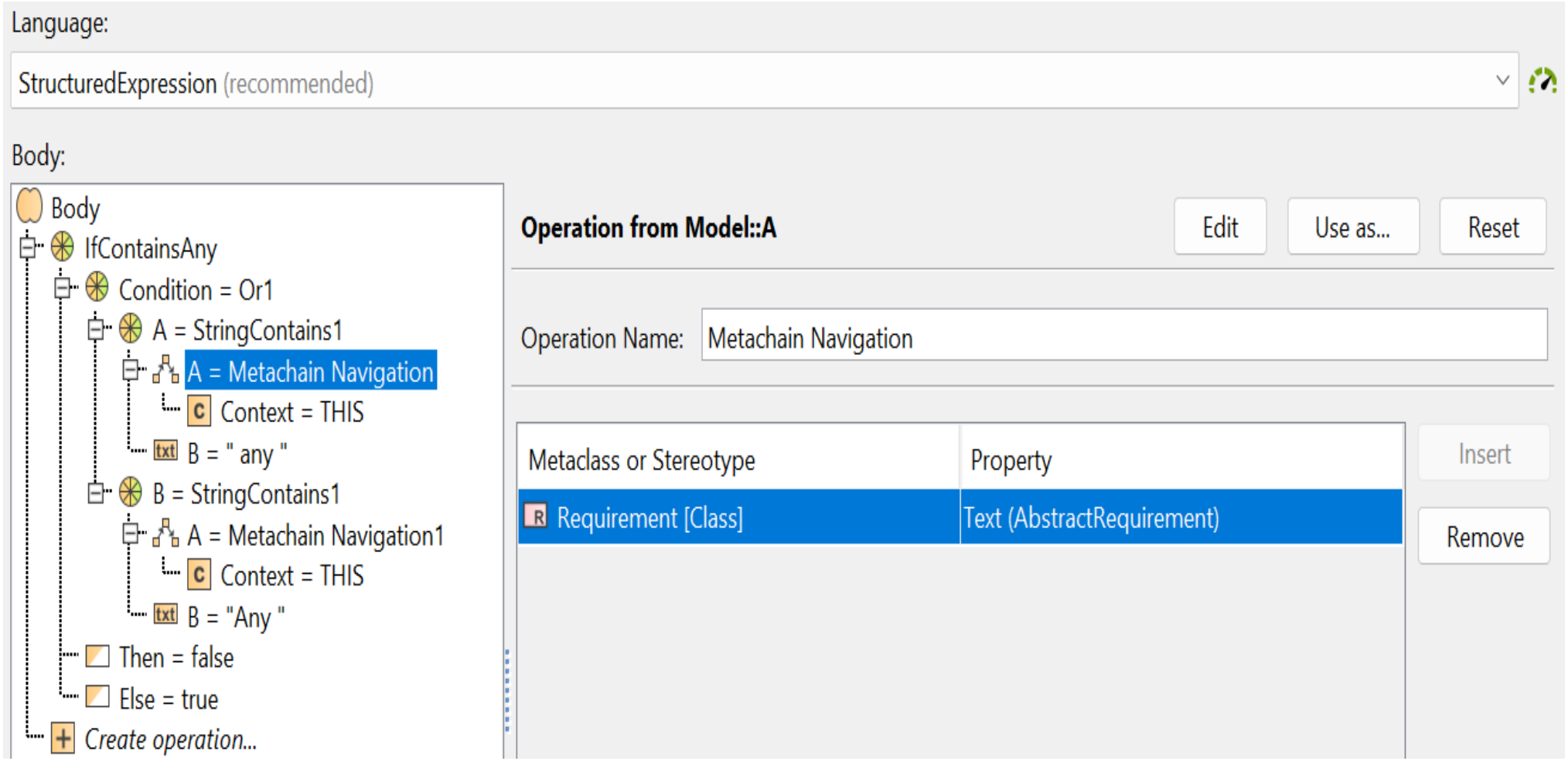
R41 - Related Needs and Requirements: Group related needs and requirements together.

R42 – Structured Sets: Conform to a defined structure or template for organizing sets of needs and requirements.

INCOSE-TP-2010-006-04 | June 2023 Page 3 of 7 Requirements Working Group



Example Structured Expression



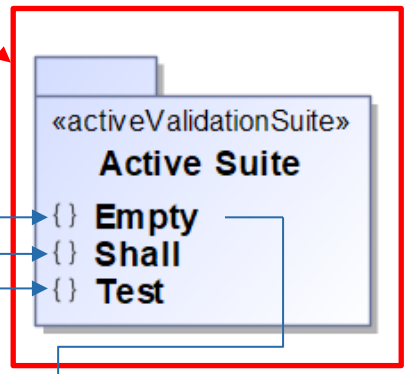
Example Structured Expression

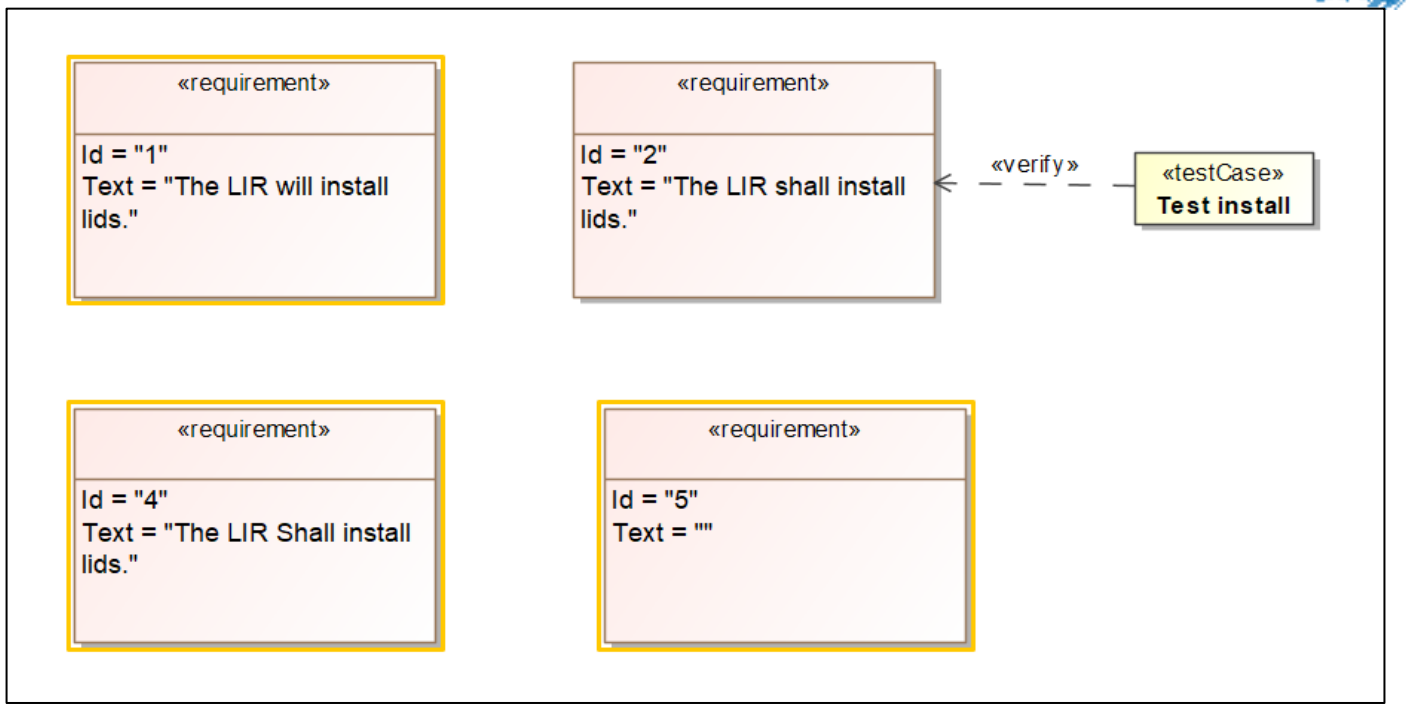
1. ifThenElse: This statement tests if the text field of the need or requirement has the string any within it and returns a Boolean true or false. If true is returned, the model displays an error.
2. or: This statement splits the validation suite into 2 statements to account for the case-sensitive nature of the expression. If either statement returns true, the then statement above executes.
3. stringContains: The string contains an expression that compares a system element or expression against a defined string. In this case Any and any are tested for.
4. Meta-chain Navigation: This is an expression that queries the system element, in this case, the requirement and need attribute text.

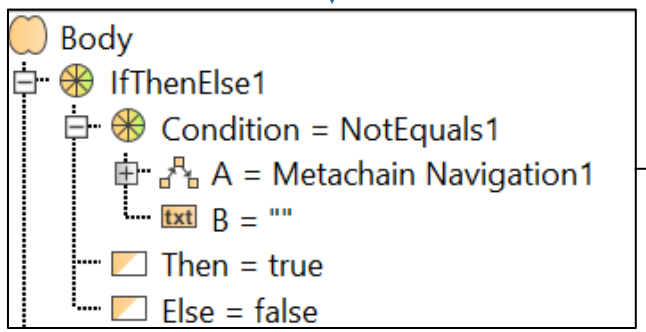
Validation Suite Example

Validation Suite

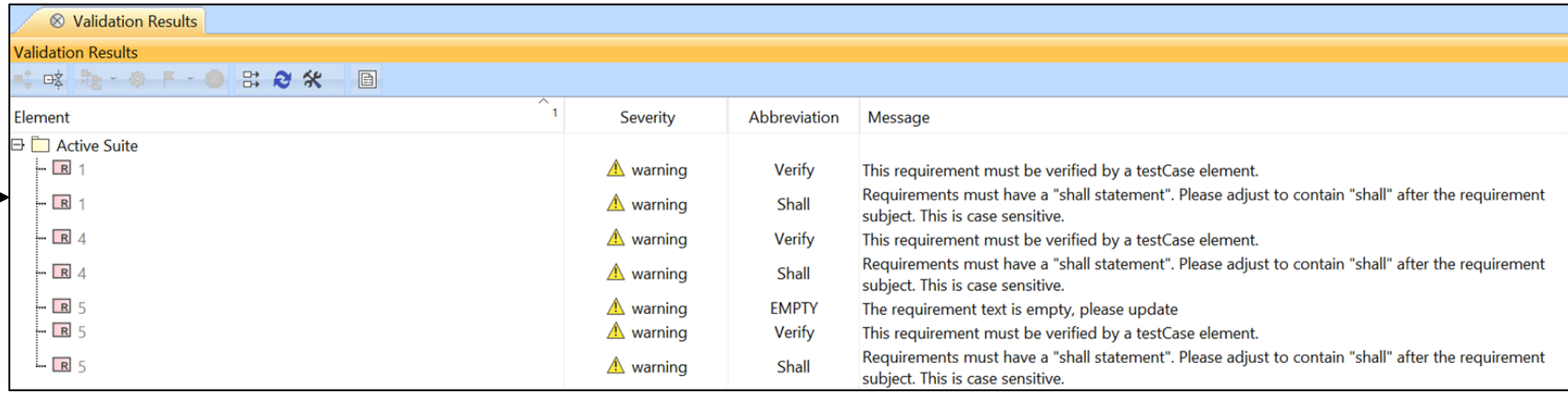
Validation Rules







Structured Expression



Desing & System System Verification Process

NRM Design and System V&V Definition

- **Design Verification** - Confirmation that: 1) the design reflects the set of design input requirements, 2) the set of design output specifications clearly implements the intent of the design as communicated by the set of design input requirements, and 3) the design meets the rules and characteristics defined for the organization's processes, guidelines, and requirements for design (NRM, §2.3.3.1)
- **System Verification** - Confirmation that the designed and built or coded System of Interest (SOI): 1) has been produced by an acceptable transformation of design inputs into design outputs; 2) meets its set of design input requirements and set of design output specifications; 3) no error/defect/fault has been introduced at the time of any transformation; and 4) meets the requirements, rules, and characteristics defined by the organization's best practices and guidelines (NRM, §2.3.3.1)

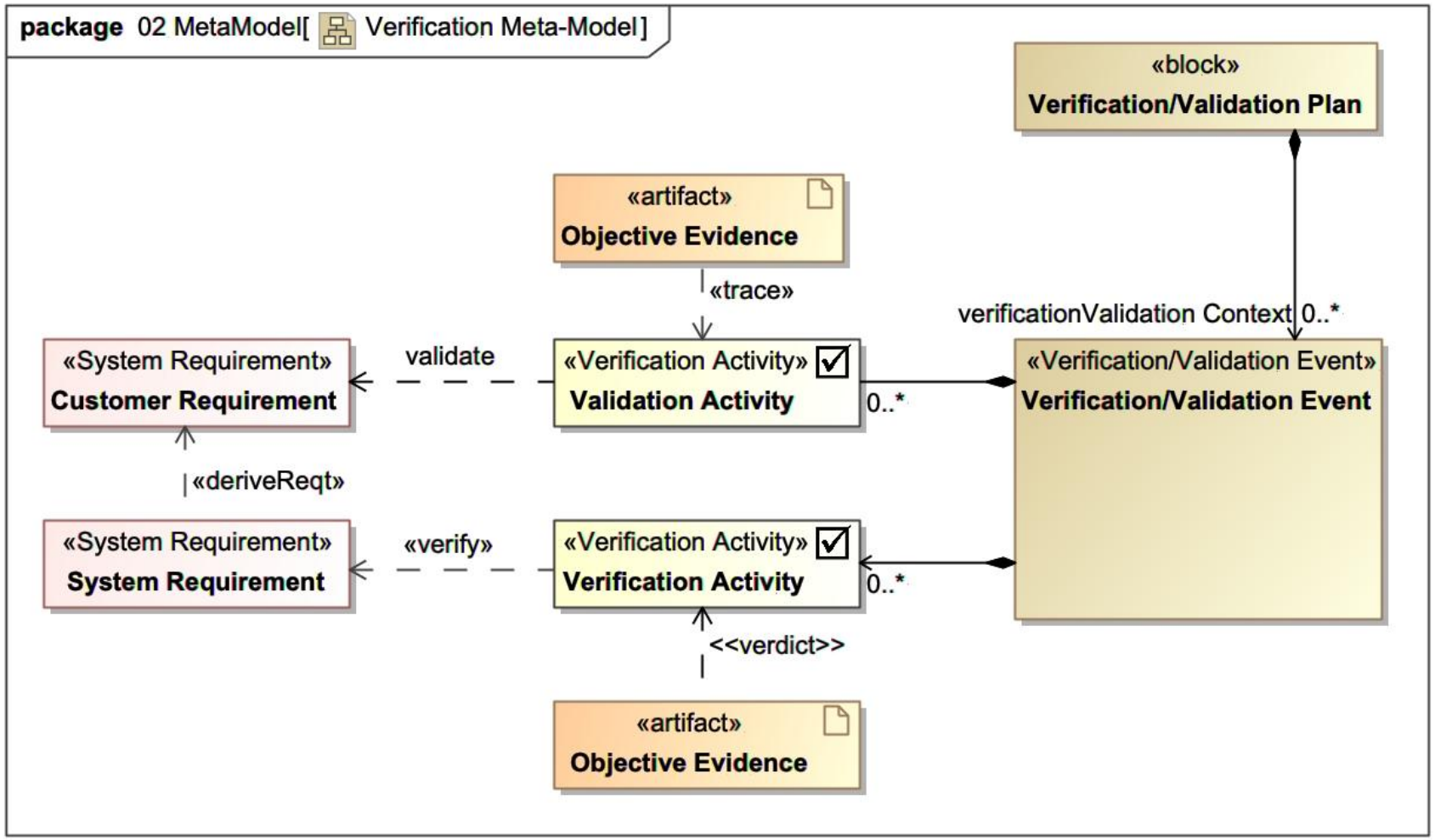
NRM Design and System V&V Definition

- **Design Validation** - Confirmation that the design, as communicated in the set of design output specifications, will result in a system that meets its intended purpose in its operational environment when operated by the intended users as defined by the set of needs and does not enable unintended users to impact the intended use of the system negatively (NRM, §2.3.3.1)
- **System Validation** - Confirmation that the designed, built, and verified SOI will result or has resulted in an SOI that meets its intended purpose in its operational environment when operated by its intended users and does not enable unintended users to negatively impact the intended use of the system as defined by its set of needs (NRM, §2.3.3.1)

Meta Model Specializations for V&V

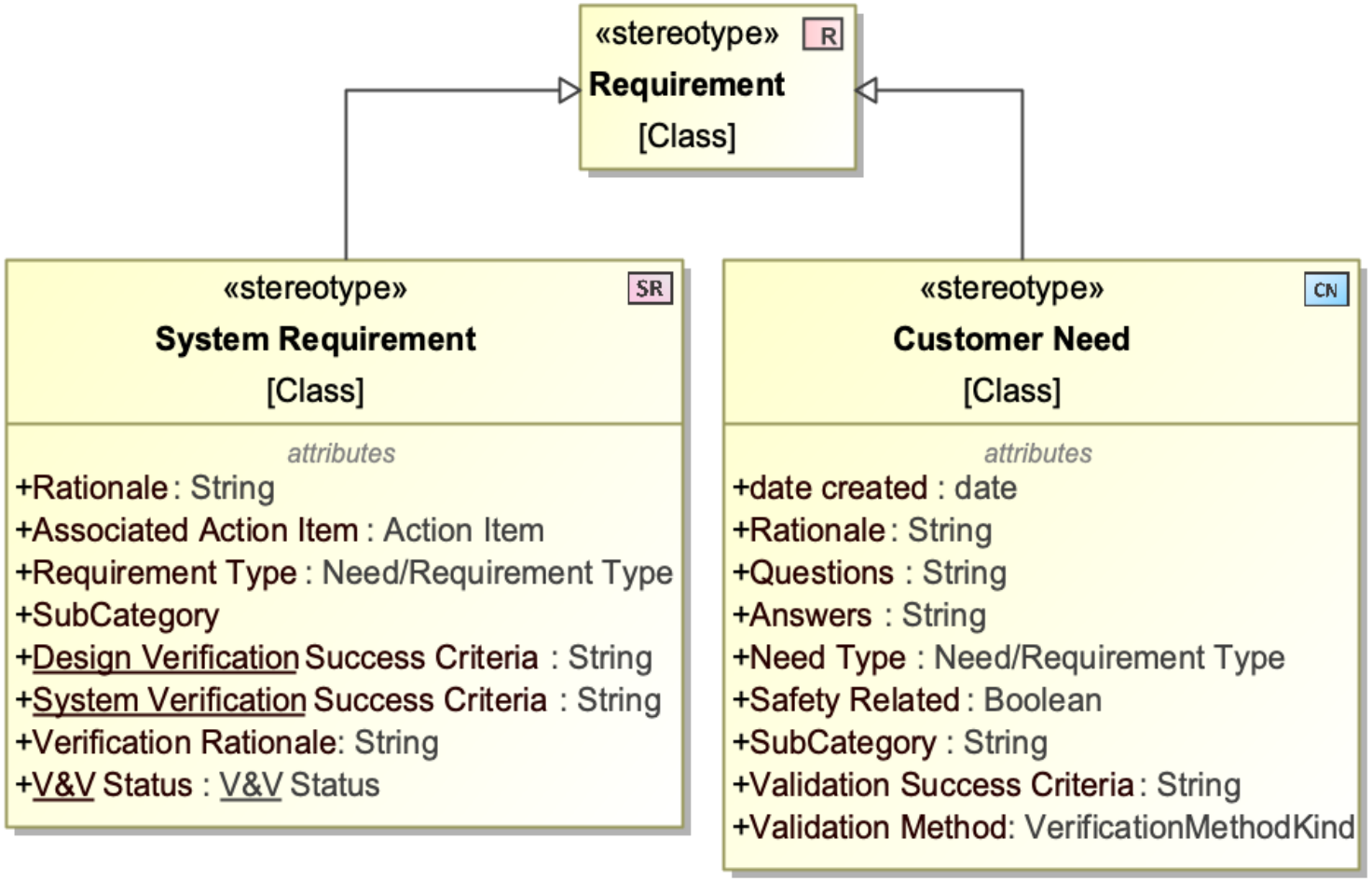
System Verification and Validation Meta-Model

- The V&V Meta-Model
- Created to focus on the required relationships
  - V&V elements,
  - requirements,
  - system architecture.



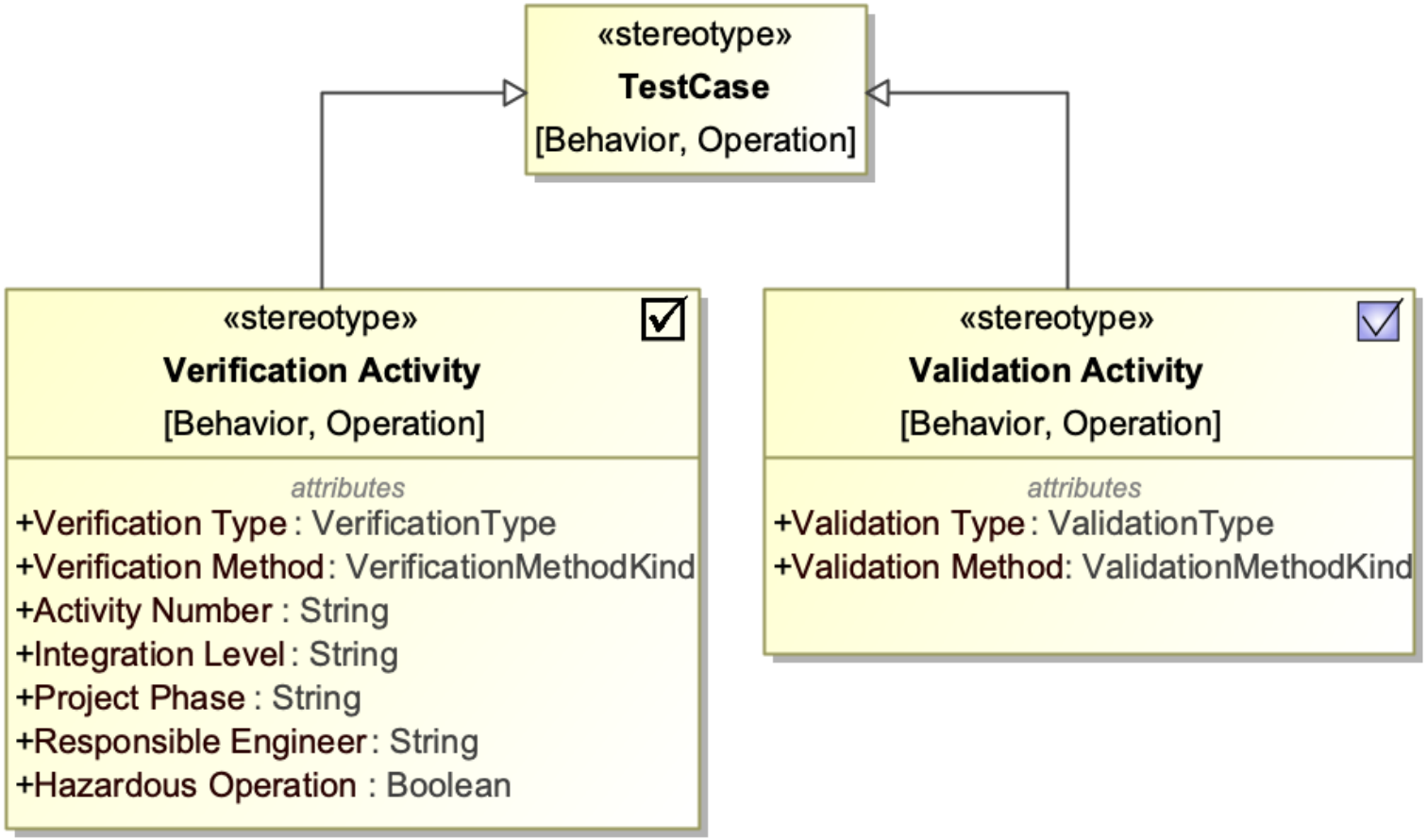
Verification and Validation Attributes

- Adding the attributes
- Reduces the necessity to relate an instance with each need and requirement
- Simplifies compliance with the NRM.



Verification and Validation Activities

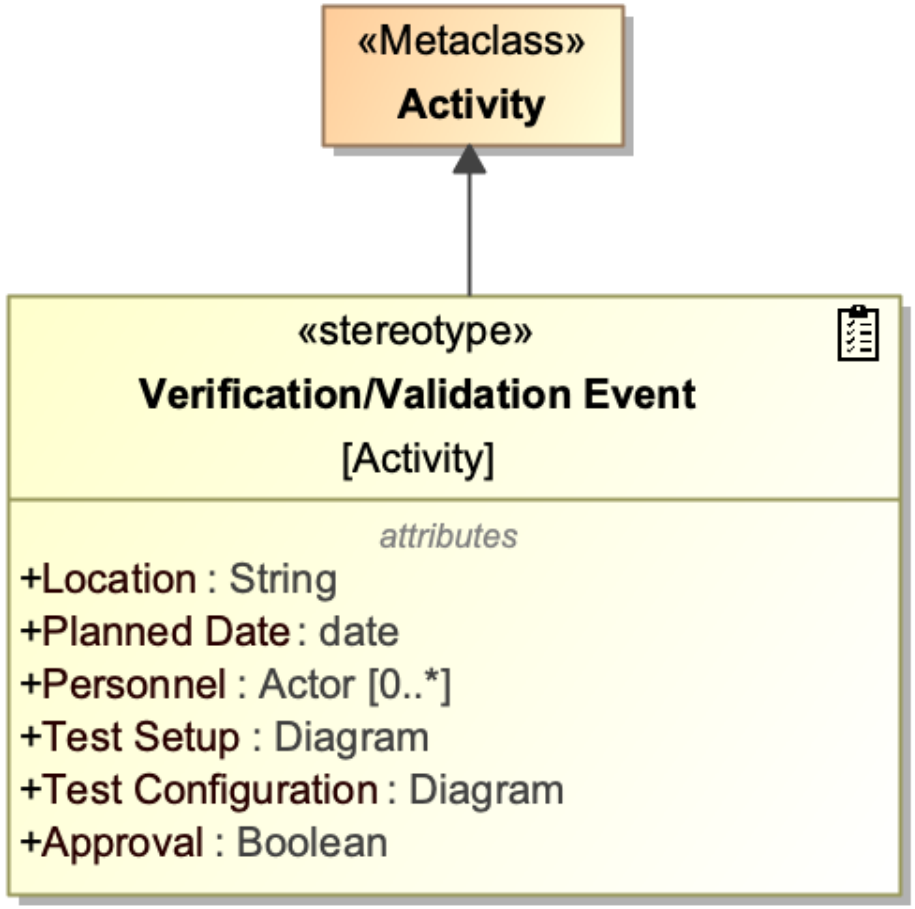
- V&V activities derived from the TestCase stereotype
- Verification types
  - Needs
  - Requirements
  - Design
  - System



Create a verification activity for each type of verification.

Verification and Validation Event

- Verification and validation events group verification and/or validation activities into an event where they can be executed according to a plan.
- Note that some attributes are typed by Diagrams.
  - This is not a SysML relationship and is not defined in the V&V Meta-Model.
  - This allows for an informal link to diagrams created in the model that further define test setups and test configurations.



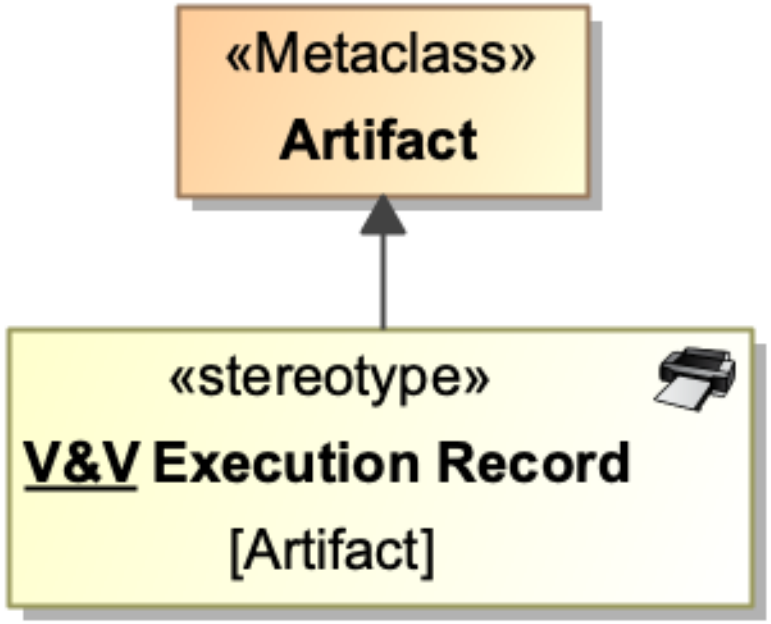
Example of an Informal Diagram Link

Name	Approval	Planned Date	Location	Test Configuration	Test Setup
LIR Logistics Demo	false	12/1/2024	Log Facility	Development LIR Test Unit Configuration	LIR Log Demo Set Up

- Test setups and configurations are defined in Block Definition Diagrams (BDD).

V&V Execution Record

- In order to collect objective evidence of verification an artifact called a V&V Execution Record is created
- The SE team captures the results and uploads to the model for traceability



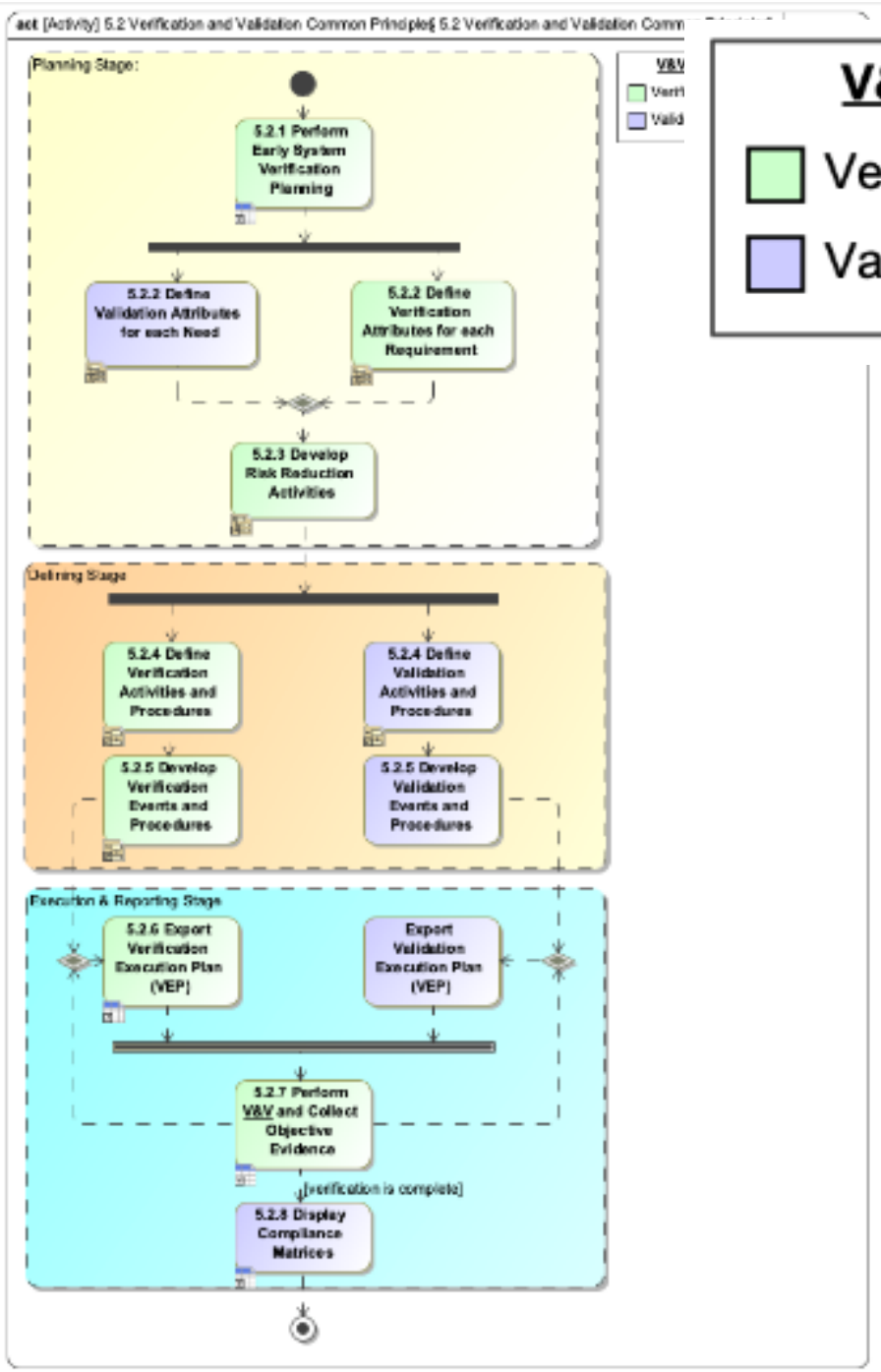
Take Away

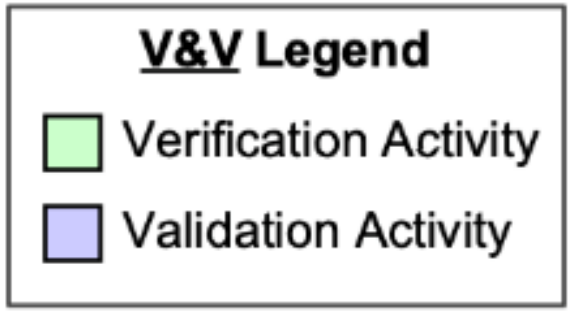
- The Verification and Validation Meta-Model defines the relationships between needs, requirements, verification/validation activities, objective evidence, and events.
- Each customer need must be validated by a validation activity.
- Each system requirement must be verified by a verification activity.
- Both of which are linked to artifacts that document objective evidence.
- These activities are grouped into verification or validation events, forming a cohesive verification and validation plan.

- This approach ensures consistent traceability
- Supports integration of V&V activities across the system lifecycle,
- Aligns with the INCOSE NRM.

The V&V Process

- The 3 stages of the process are
  - Planning
  - Defining
  - Execution & Reporting
- The following slides breakdown the process

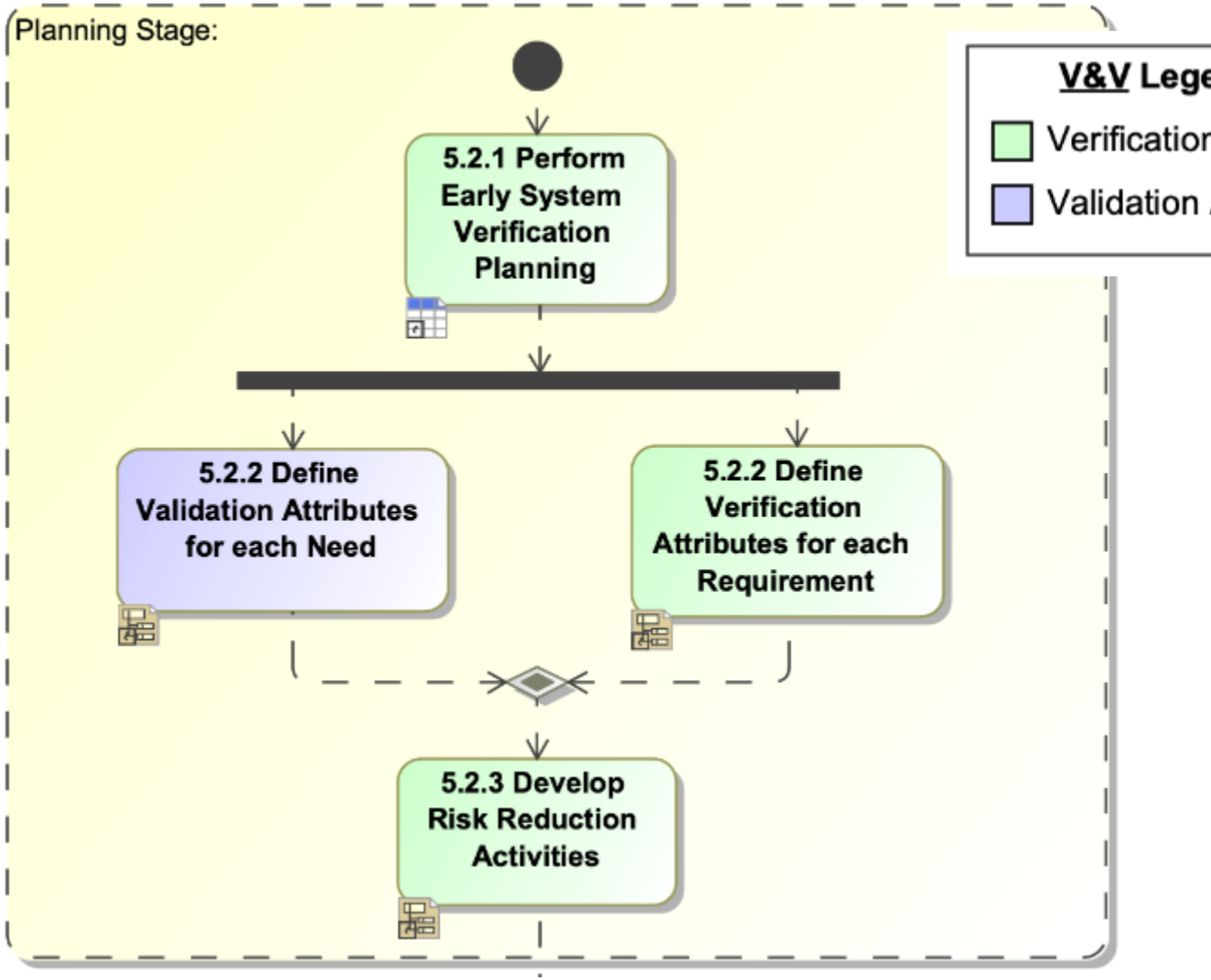




Planning Stage

Planning Stage

- Step 1: Early System Verification Planning



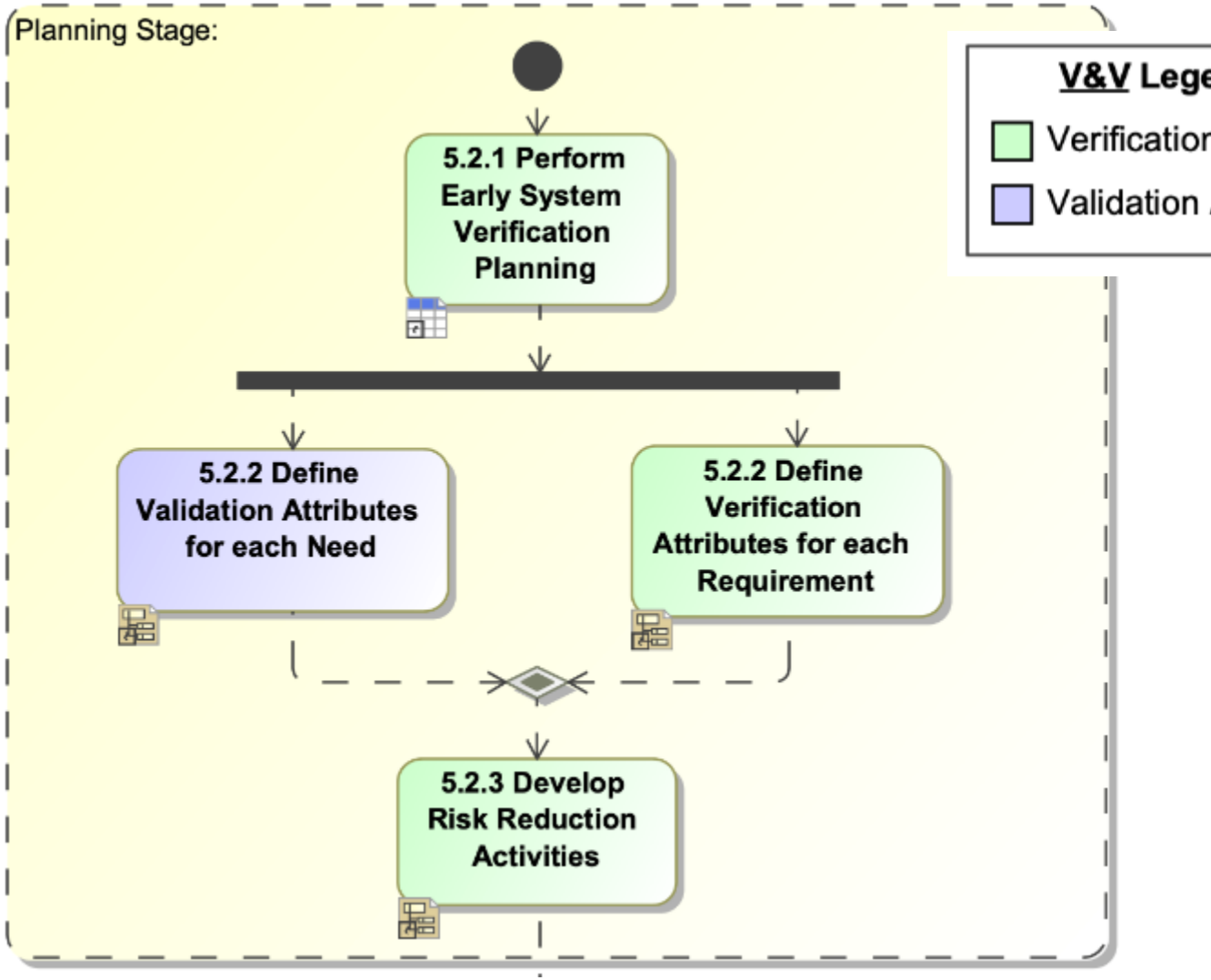
Initial Verification Events

#	△ Name	Documentation
1	LIR Environmental Test	An environmental test event is planned to verify the LIR's compliance to MIL-STD-461E for radiated emissions, its ability to survive a drop test and perform nominally in required environmental conditions.
2	LIR Lid Installation Demonstration	A lid installation demonstration will be performed for all types of required lids and jars and will demonstrate the required performance of the LIR during a day shift.
3	LIR Motion Detection Demonstration	A motion detection demonstration will be performed to verify that the LIR reacts as required to motion.
4	Nominal Operation Test	An initialization test event will be performed to collect data and verify that the LIR turns on properly.

- Documentation of common or already known verification events

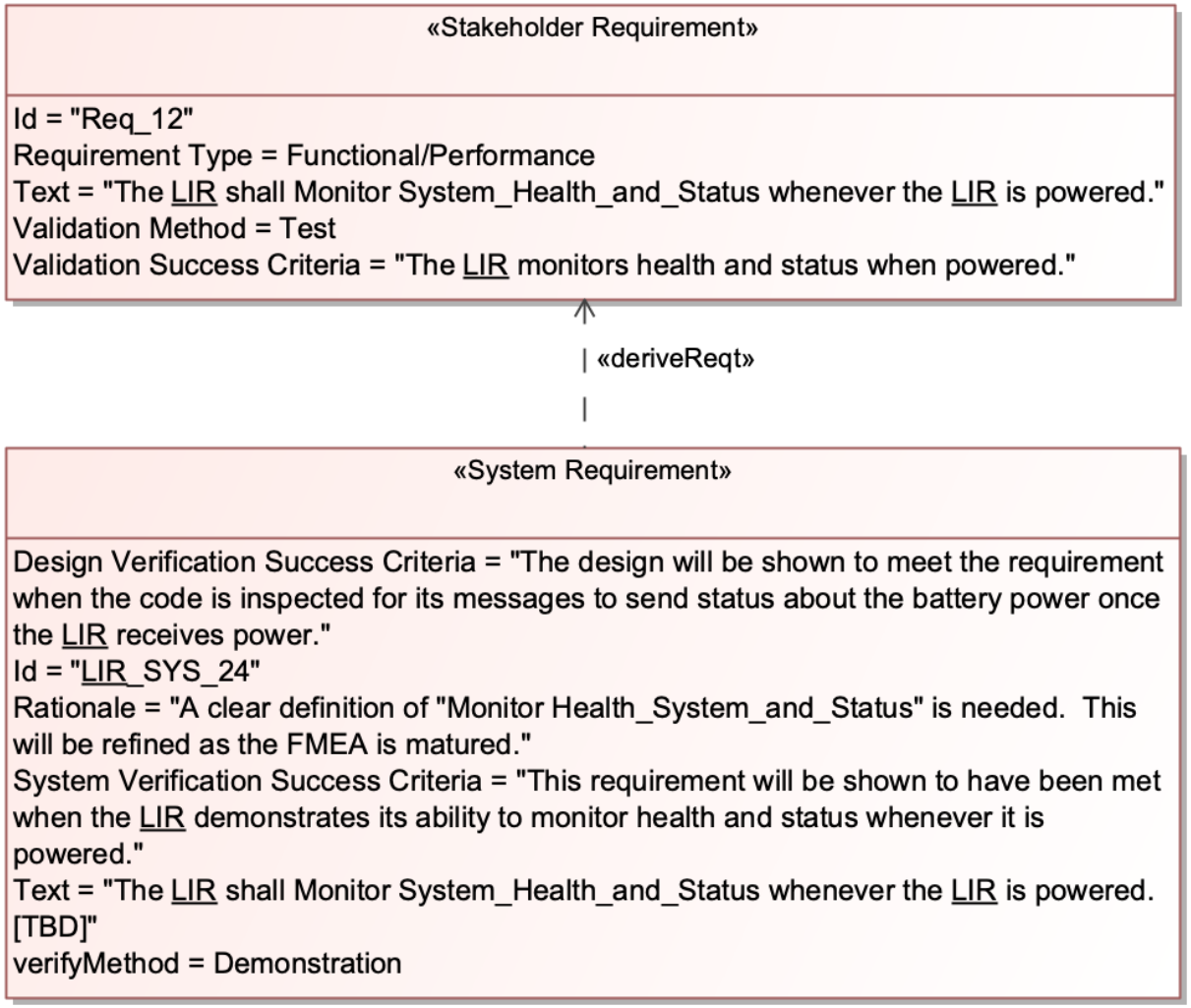
Planning Stage

- Step 2 define attributes for V&V



Need & Requirements V&V Attributes Example (1 of 2)

- As system and subsystem requirements are defined, V&V attributes should be defined as early as possible
- Note: this process deviates in implementation from the NRM but satisfies the intent and simplified the V&V process



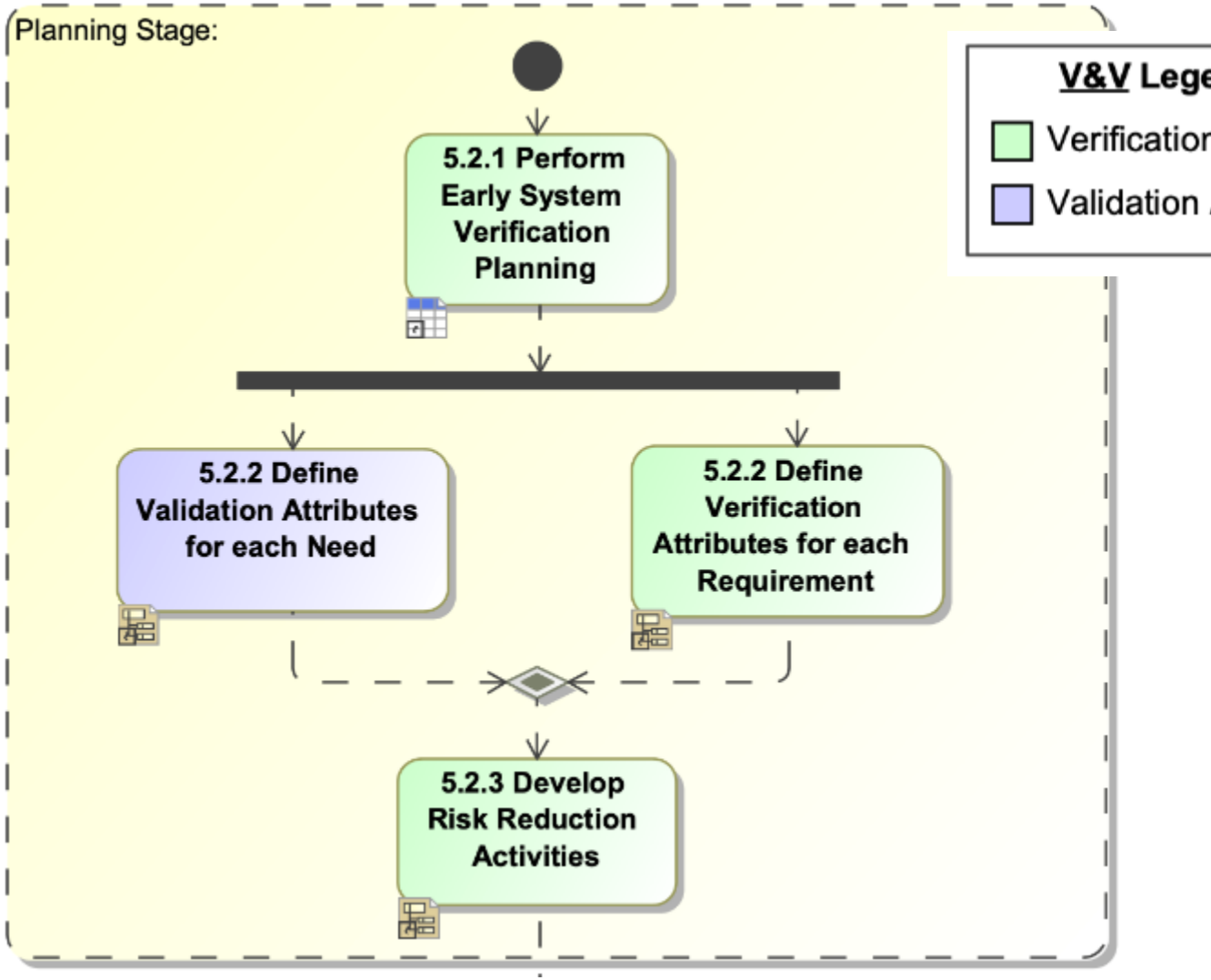
Need & Requirements V&V Attributes Example (2 of 2)

#	Id	△ Name	Text	Verified By	Verify Method	Design Verification Success Criteria	System Verification Success Criteria
5	LIR_SYS_6	SR LIR_SYS_6	The LIR shall install lids on Jars positioned on the JPS conveyer belt as defined in the JPS ICD.	☑ Install Lid ☑ CAD Inspection	Demonstration	The design will be shown to meet the requirement when the LIR CAD is measured and inspected to ensure that the LIR design can grasp jars positioned on the conveyer belt defined in the JPS ICD.	This requirement will be shown to have been met when the LIR installs lids that are positioned as defined by the JPS ICD throughout an entire shift.
6	LIR_SYS_7	SR LIR_SYS_7	The LIR shall maintain the Jar position within +/- .1 inches on the conveyer belt during lid installation.	☑ Install Lid ☑ CAD Inspection ☑ BOM Inspection	Inspection	The design will be shown to meet the requirement when the finalized LIR BOM and CAD components are inspected for tolerances within +/ - 0.1 inches.	This requirement will be shown to have been met when the LIR installs lids that are positioned as defined by the JPS ICD throughout an entire shift with a measured deviation in jar position of less than 0.1inches.
7	LIR_SYS_8	SR LIR_SYS_8	The LIR shall install lids on plastic jars with an opening of 2±.01 inches with a torque (τ) of 26≤τ≤30 inch pounds.	☑ Lid Installation Torque Analysis ☑ Torque Test ☑ Install Lid	Test	The design will be shown to meet the requirement when the mechanical analysis confirms that the finalized LIR design can install lids with an opening of 2 +/- 0.1 inches at a torque between 26 to 30 inch pounds.	This requirement will be shown to have been met when the LIR JHS Torque test confirms that the JHS installs lids with an opening of 2 +/- 0.1 inches at a torque between 26 to 30 inch pounds. AND when the LIR successfully installs 95% all of required lids from the Lid Spec during a simulated day shift at the required torque.

Example System Verification Matrix

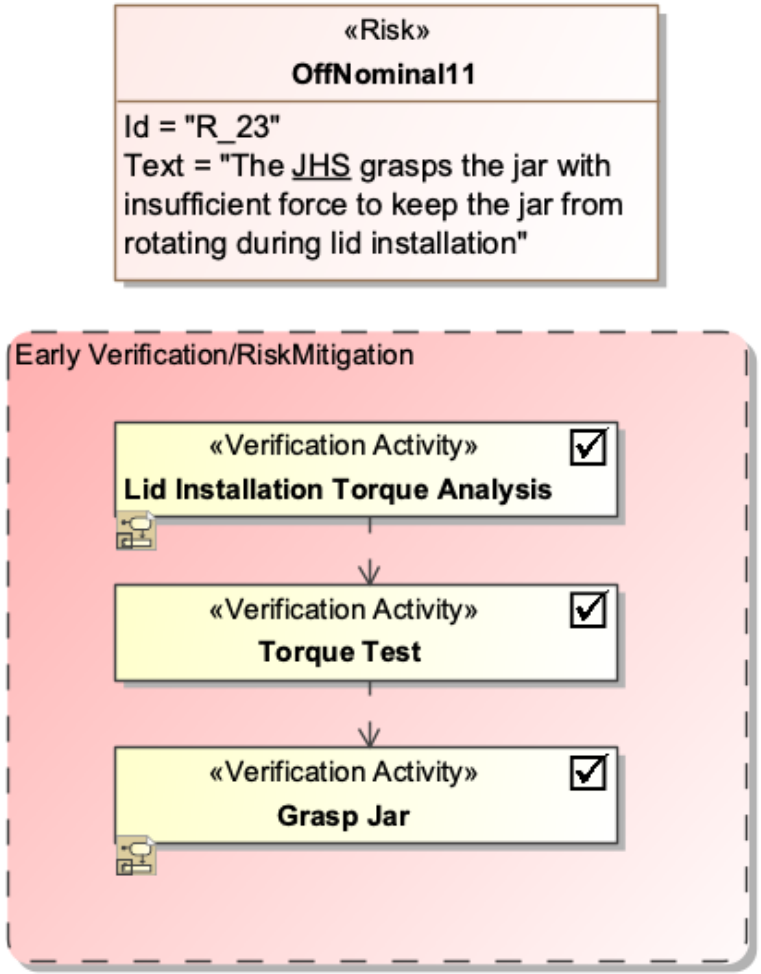
Planning Stage

- Step 3 Define Risk Redetection Steps



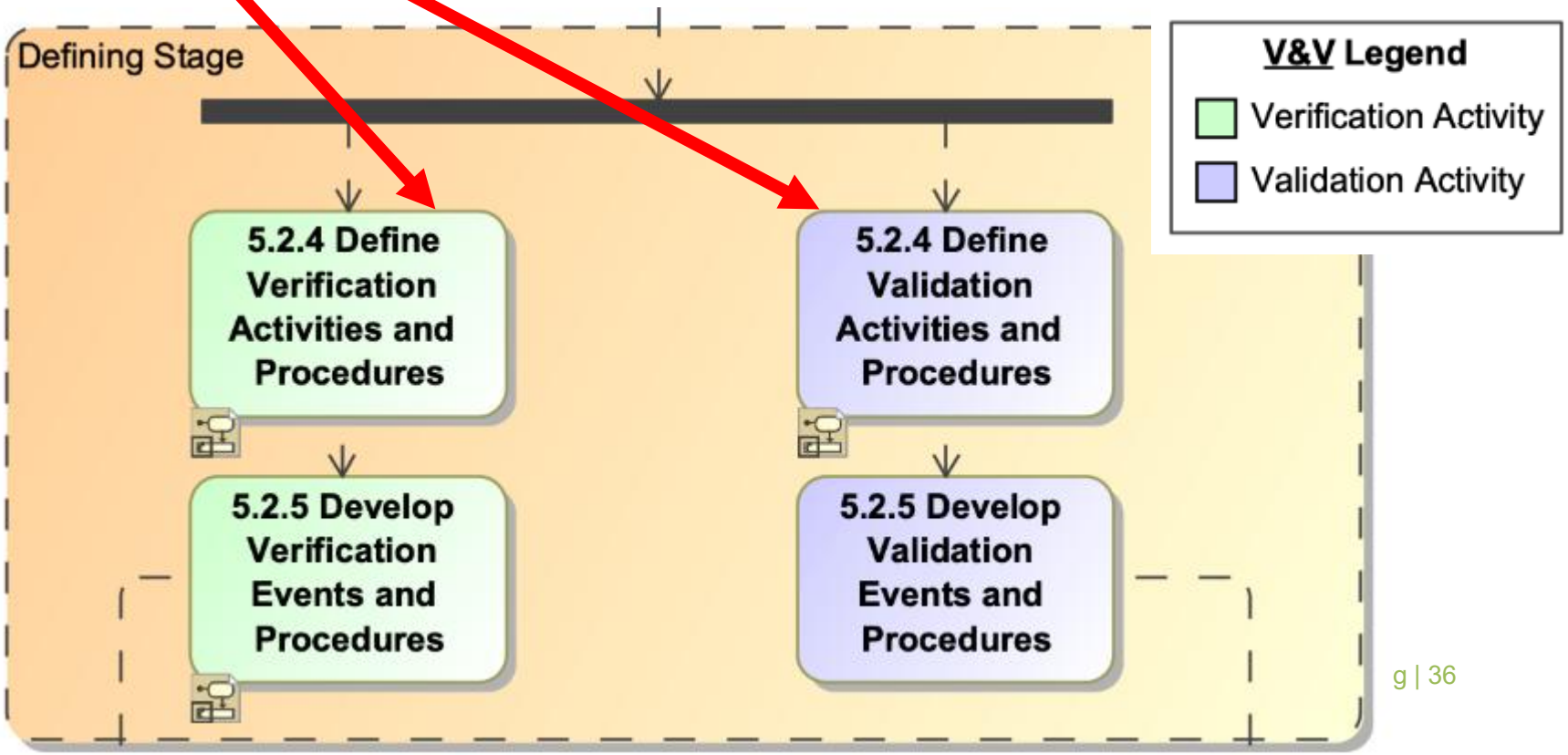
Defining Risk Mitigation Steps

- Risk mitigation strategies often include a series of development testing or analysis to buy down risk.
- The risk mitigation activities are modeled as verification activities and linked to associated requirements using the *verify* relationship.



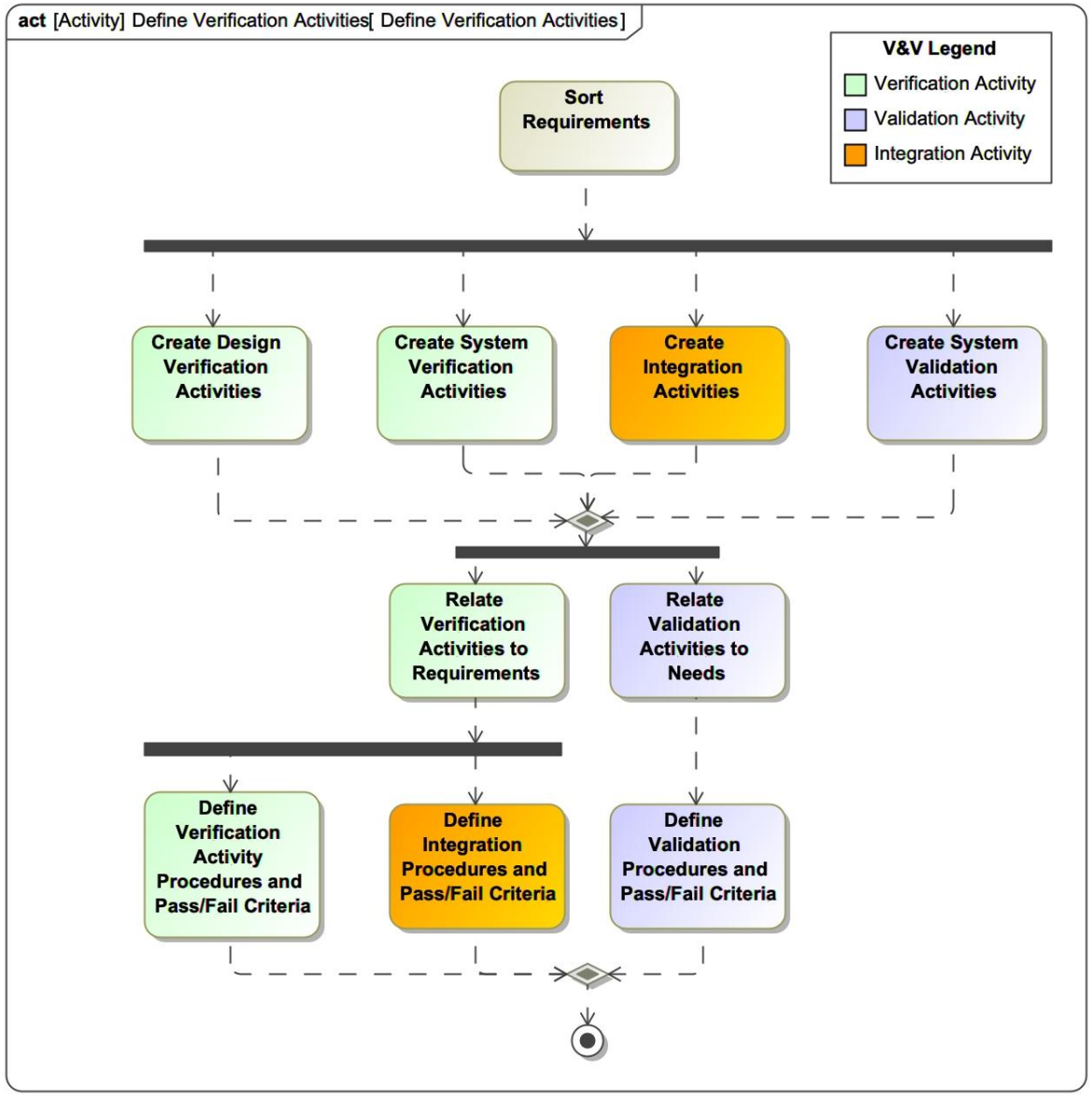
The Defining Stage

- Step 1 Define V&V Activities



Derivation of V&V Activities

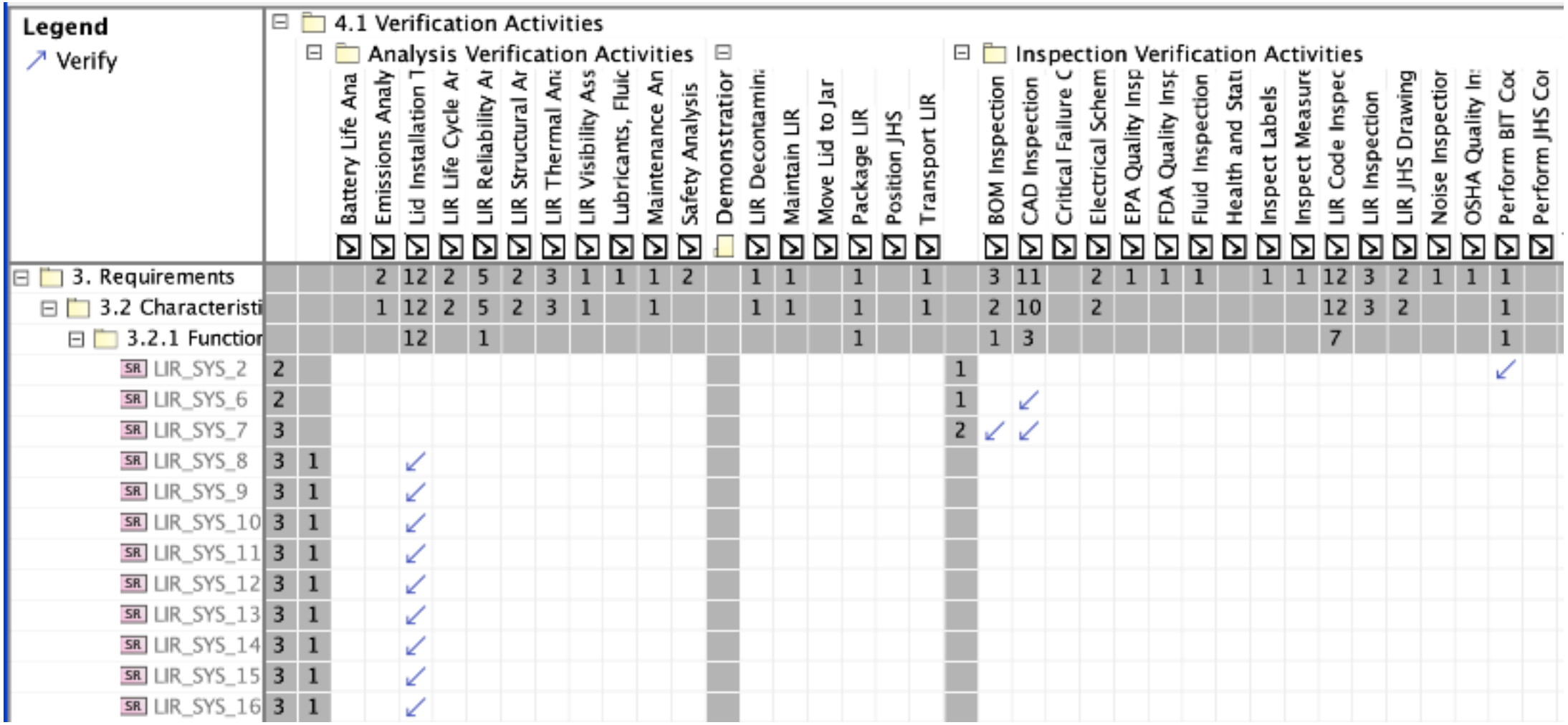
- Defining verification and validation activities is a detailed and tedious process
- Requirements need to be sorted based on VMs
- V&V activities are created for both design and system V&V and can be reused
- Attributes for the activities are defined and related to requirements via the verify relationship
- Procedures are mapped out with pass/fail criteria



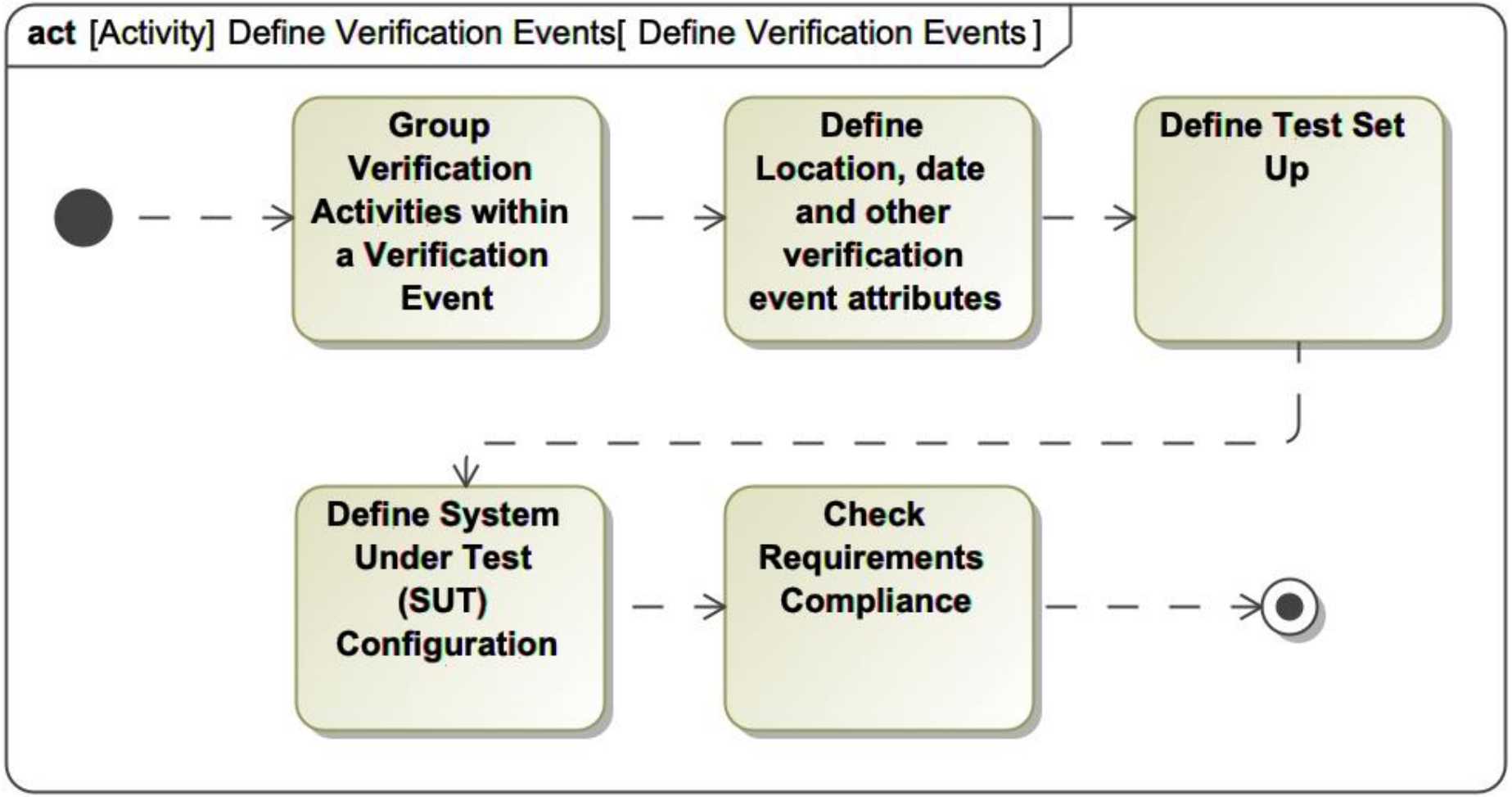
Create V&V Activities

#	△ Activi... Num...	Name	Verification Type	Verification Method	Integration Level	Project Phase
1	A-1	☑ Battery Life Analysis	Design Verification	Analysis	Subsystem	Detailed Design
2	A-2	☑ Grasp Jar	System Verification	Test	System	Test
3	A-3	☑ Install Lid	System Verification	Test	System	Test
4	A-4	☑ Lid Installation Torque Analysis	Design Verification	Analysis	System	Detailed Design
5	A-5	☑ LIR JHS Drawing Inspection	Design Verification	Inspection	Subsystem	Detailed Design
6	A-6	☑ LIR Life Cycle Analysis	Design Verification	Analysis	System	Detailed Design
7	A-7	☑ LIR Reliability Analysis	Design Verification	Analysis	System	Detailed Design
8	A-8	☑ Move Lid to Jar	System Verification	Demonstration	System	Test
9	A-9	☑ Obtain Lid	System Verification	Test	System	Test
10	A-10	☑ Perform BIT Code Inspection	Design Verification	Inspection	Software	Detailed Design
11	A-11	☑ Perform JHS Compliance Assessment with JPS ICD	Design Verification	Inspection	Software	Detailed Design

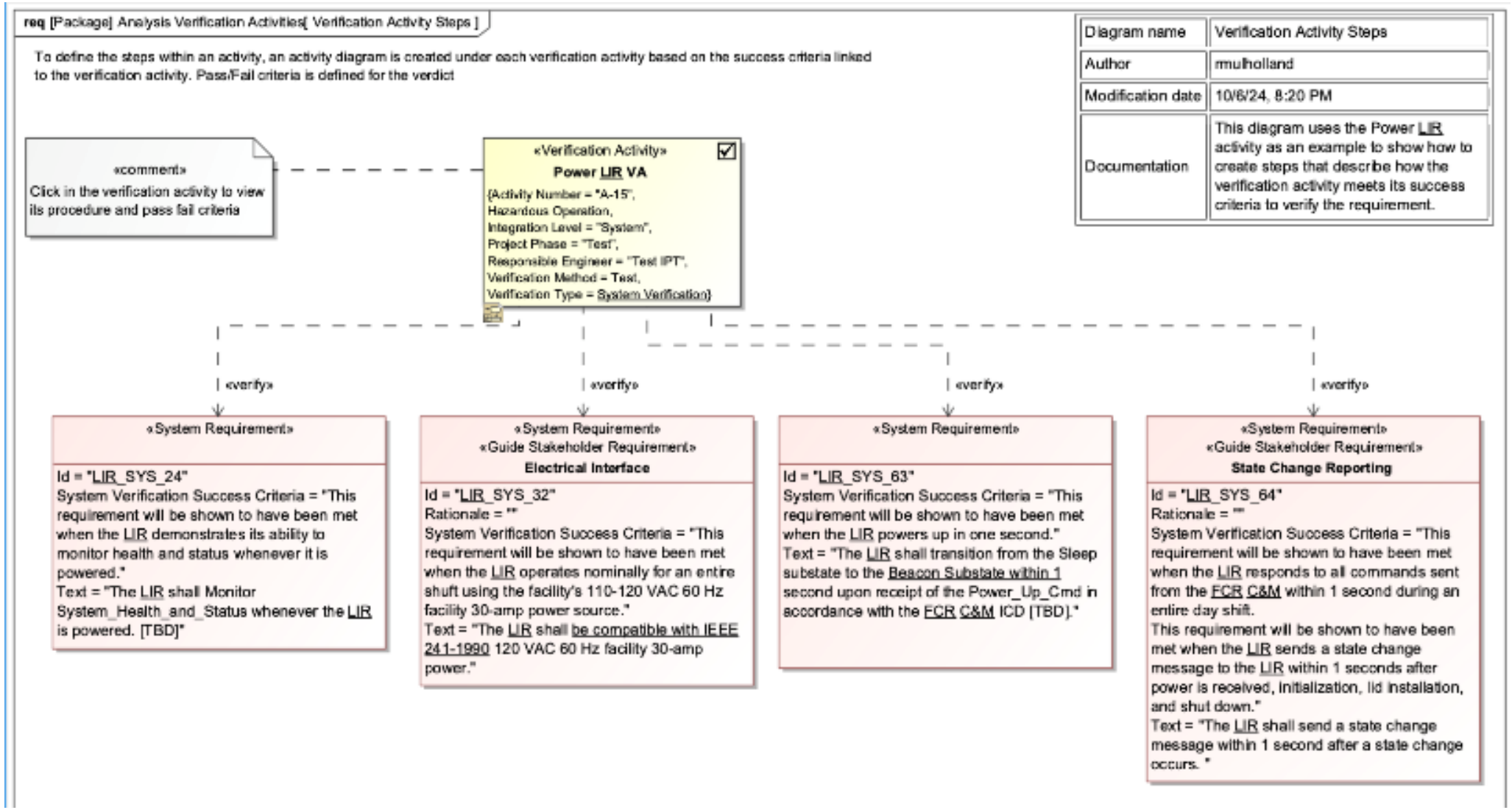
Relate V&V Activities to Requirements



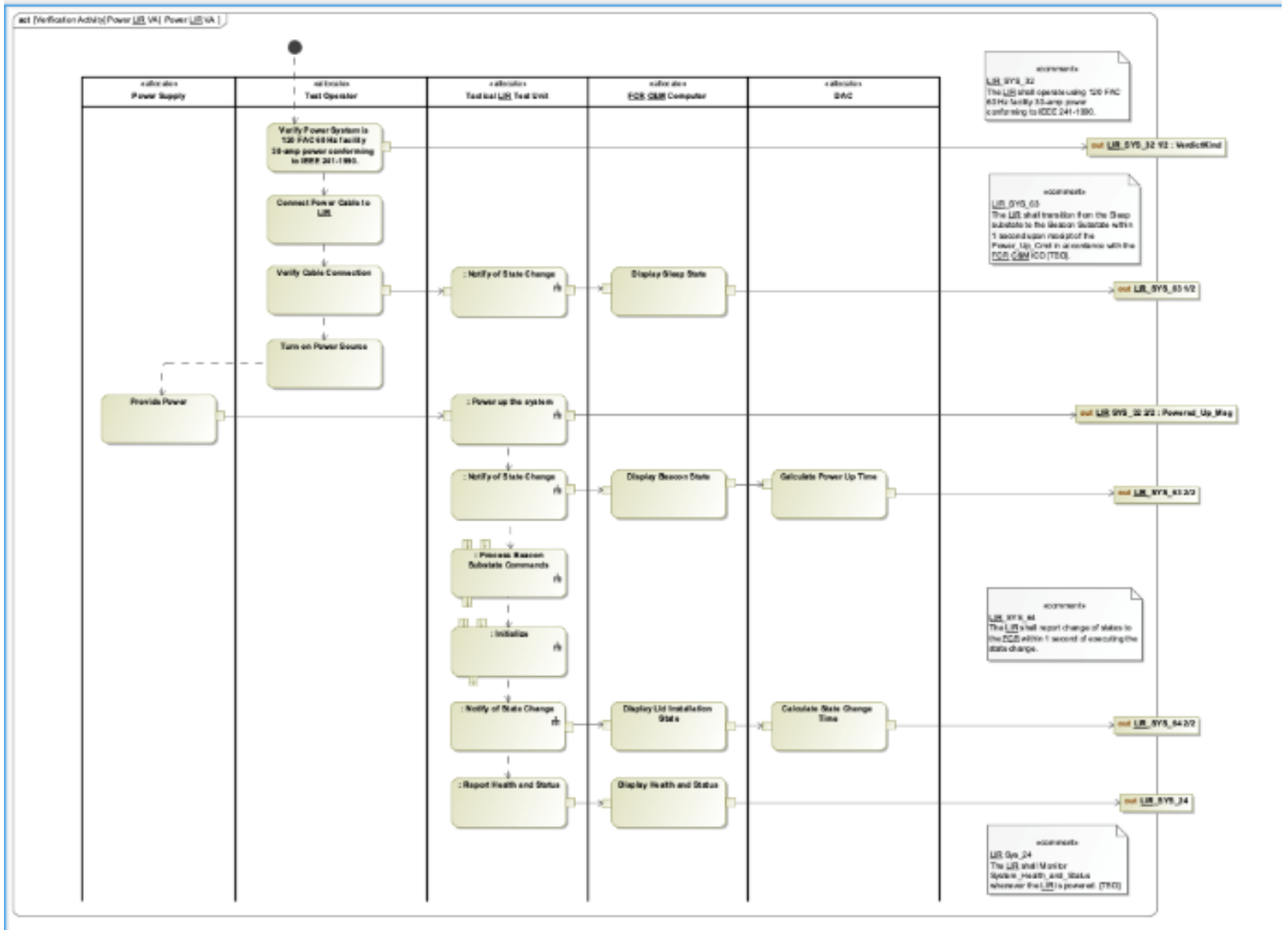
Process for Developing Verification Events



Define V&V Activitiey, Procesures and Pass/Fall Criteria

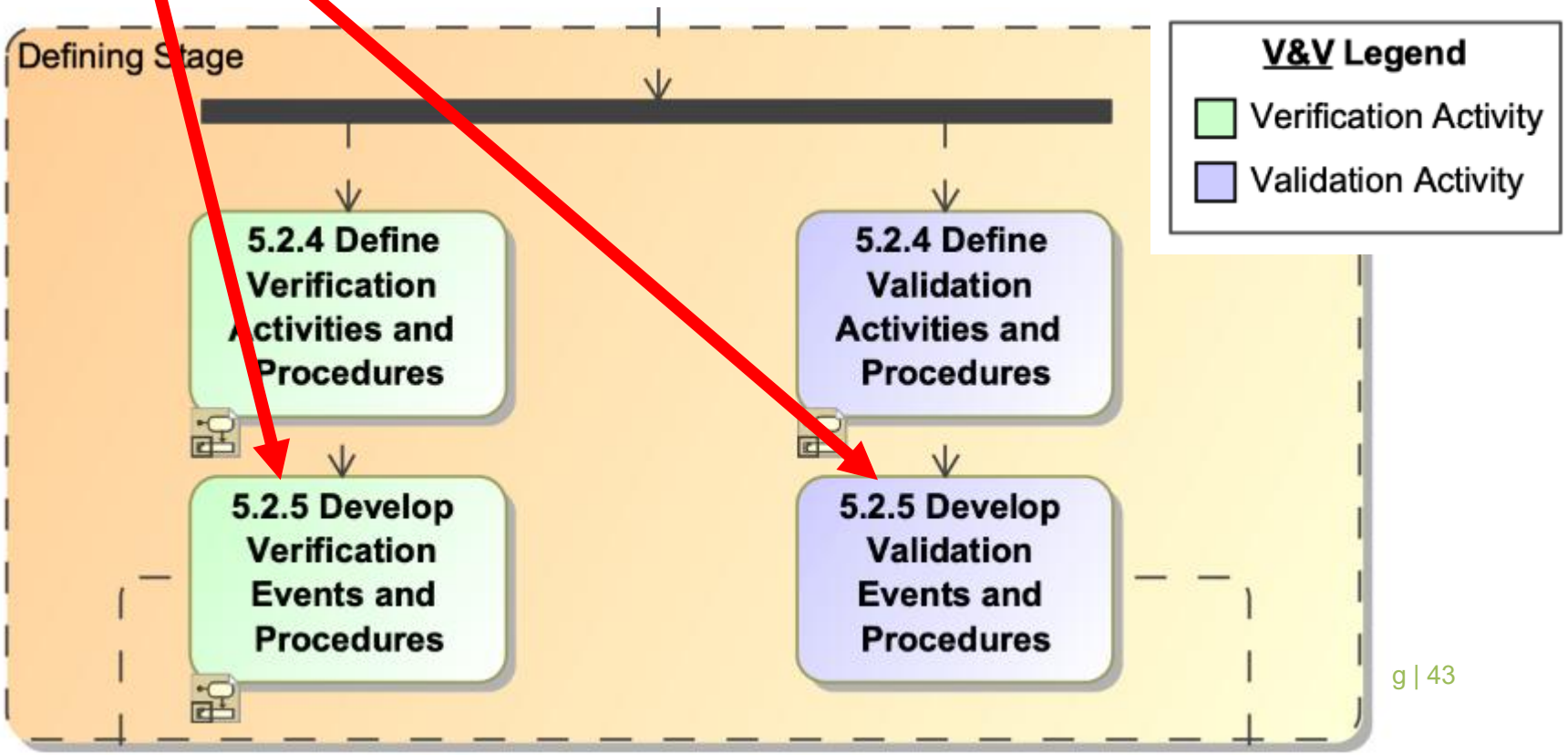


Define V&V Activitiey, Procesures and Pass/Fall Criteria

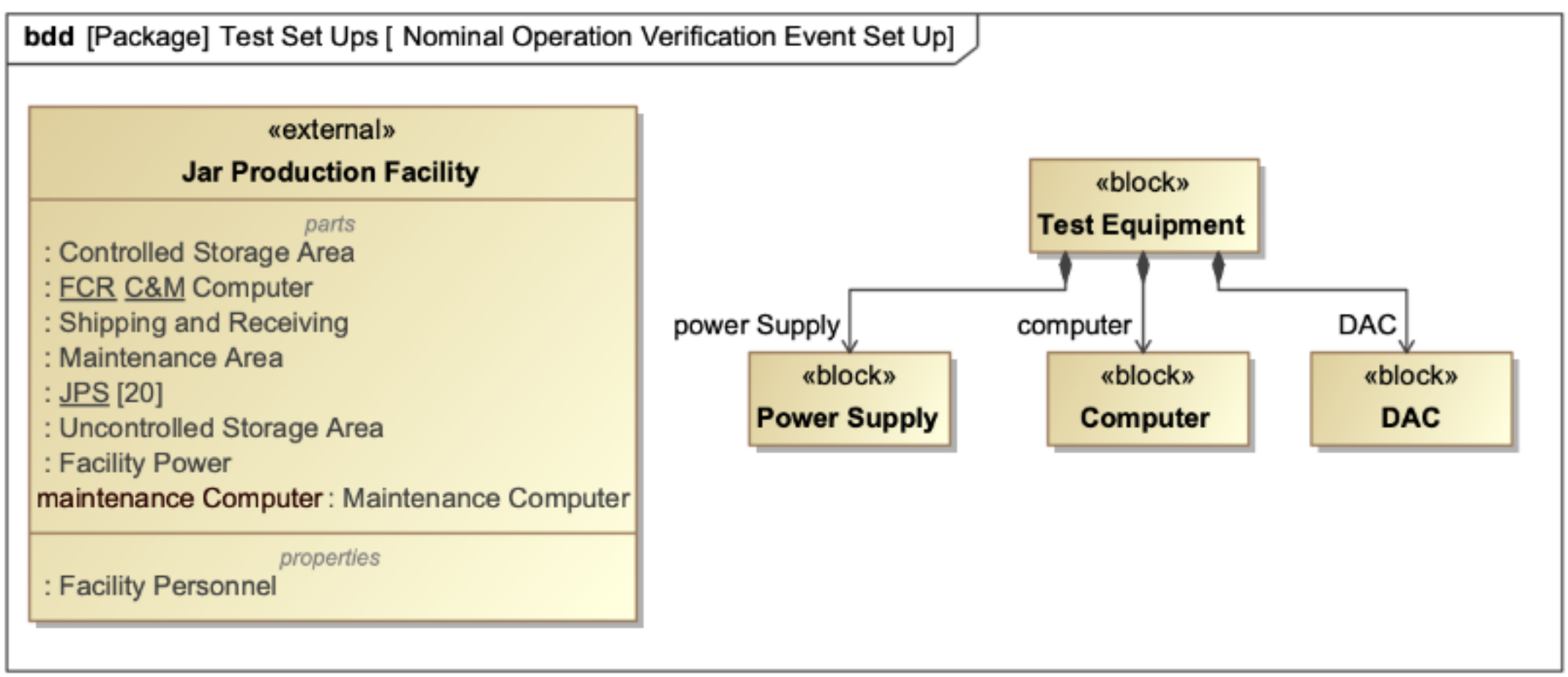


The Defining Stage

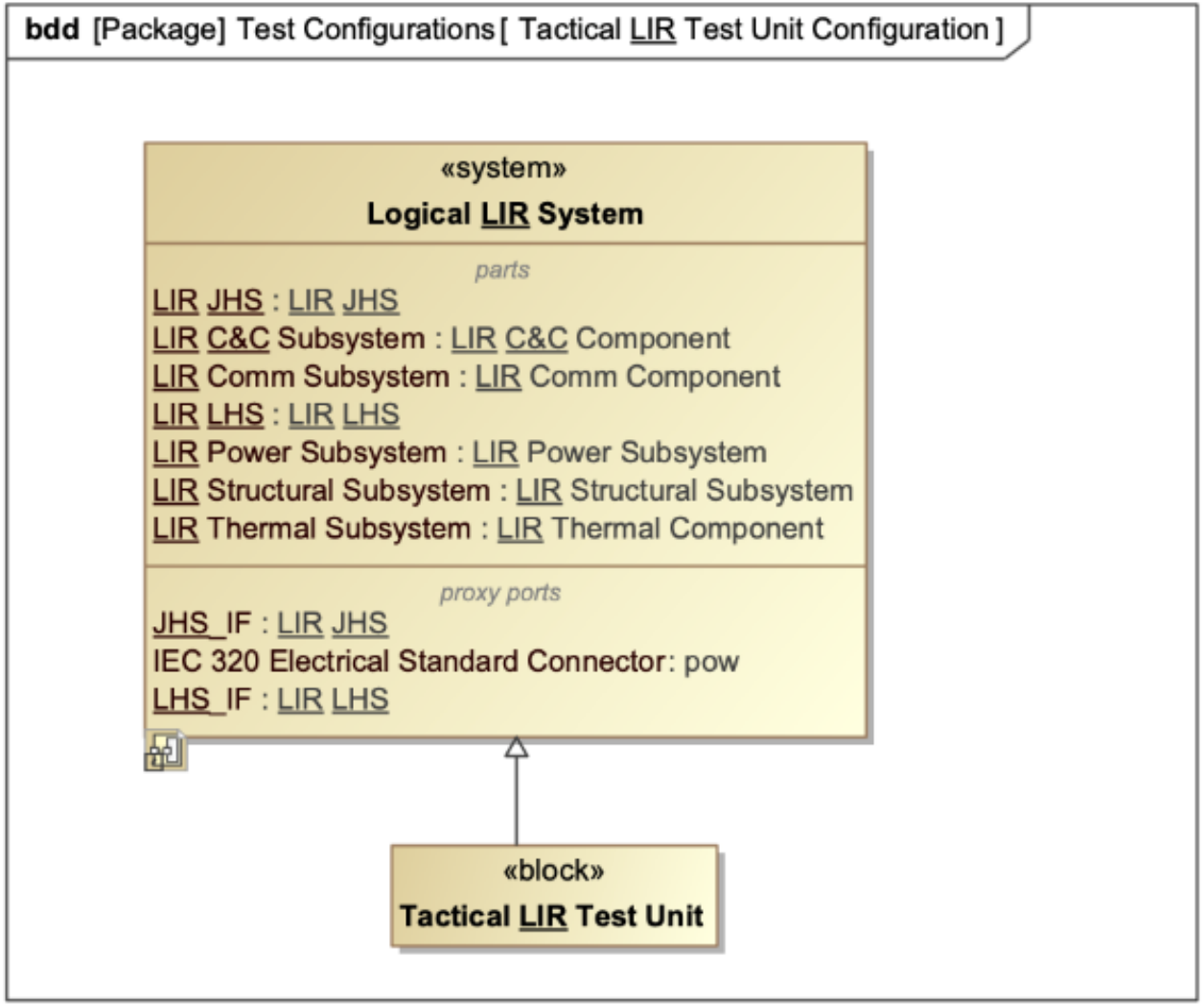
- Step 2 Develop V&V Events and Procedures



Modeling the Test Set Up



Identification of System Under Test

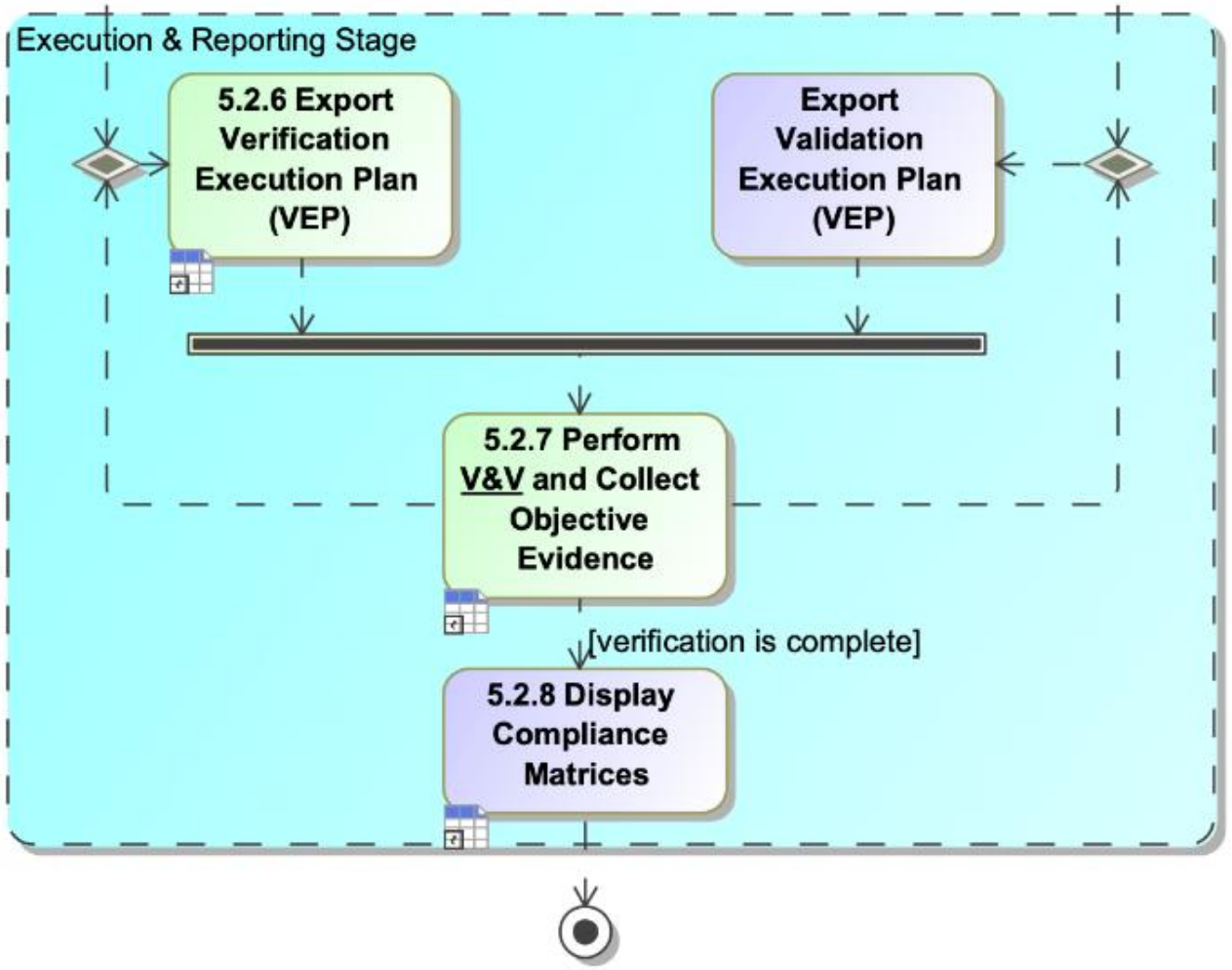


Verification Execution Plan Example

Name	Approval	Planned Date	Location	Test Configuration	Test Setup	Personnel	△ Verification Activities	Verified Requirements
LIR Environmental Test	☐ false			Tactical LIR Test Unit Configuration	Nominal Operation Verification Event Set Up	Test Operator		
LIR Lid Installation Demonstration	☐ false							
LIR Motion Detection Demonstration	☐ false							
Nominal Operation Test	☐ false	7/31/24	Jar Production Facility	Tactical LIR Test Unit Configuration	Nominal Operation Test	Test Lead Test Operator	☑ Position JHS ☑ Move Lid to Jar ☑ Grasp Jar ☑ Install Lid ☑ Obtain Lid ☑ Perform LIR Initialization ☑ Power LIR ☑ Shut down LIR	SR 228 R003 SR 229 R004 SR 230 R005 SR 231 R006 SR 232 R007 SR 233 R008 SR 234 R009 SR 235 R010 SR 242 R017 SR 268 R033 SR 226 R001 SR 237 R012 SR 255 R020 SR 244 R019

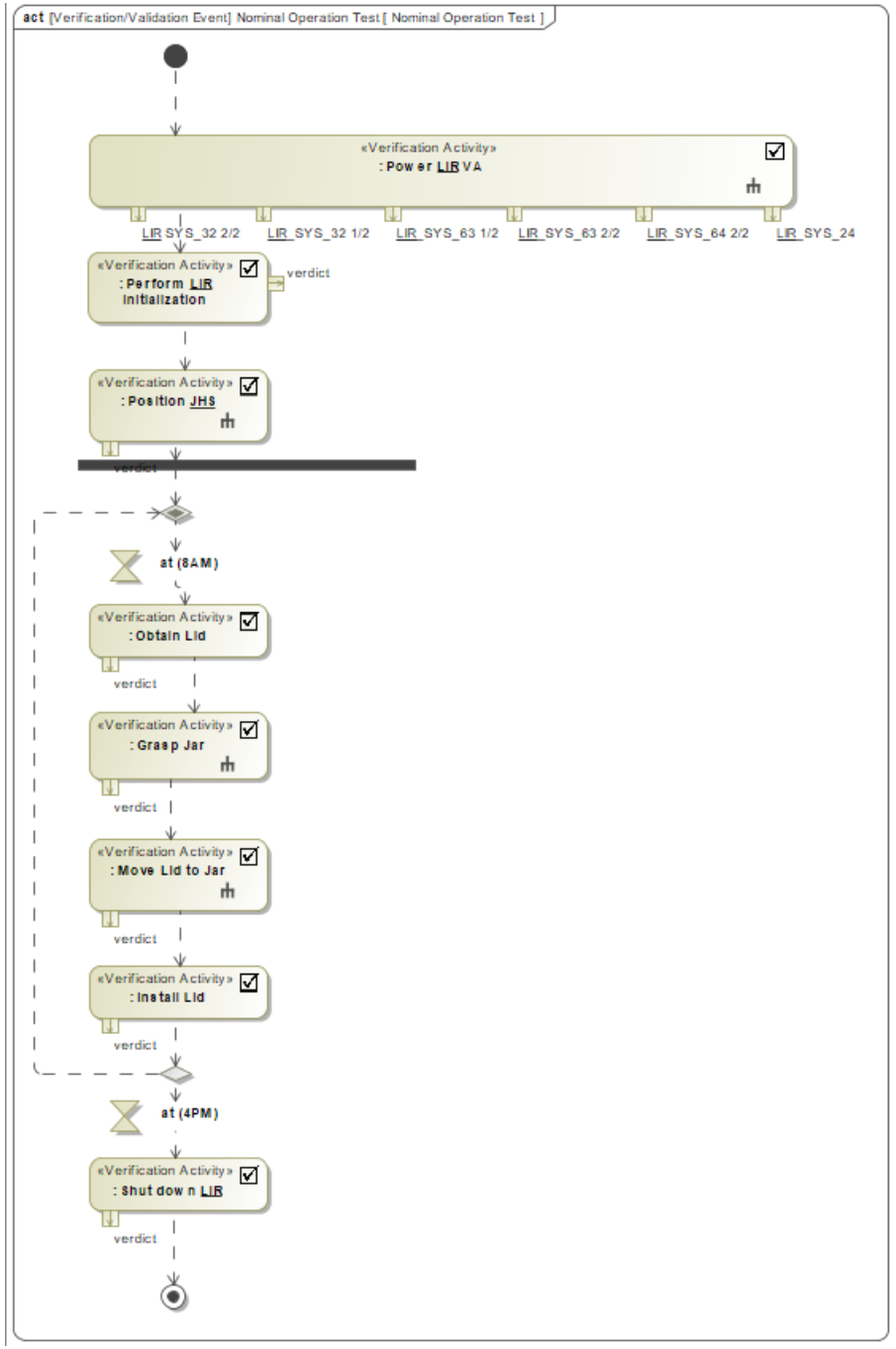
Execution & Reporting

- There are 3 stages that are critical are critical to Execution & Reporting
  - Exporting the VEP created during Planning
  - Collection of the V&V results
  - Display or communication of the Compliance Assessments



Execution & Collection of VEP

- As the Nominal Operation Test is executed each a verification activity is initiated for each step.
  - Each step returns a verification assessment that is captured.



Conclusions

Conclusions

- The paper presents a methodology compliant with the INCOSE NRM for performing
  - Needs and requirements V&V and
  - Design and system V&V

Conclusions

- Design & System V&V
  - The process is described using
    - Activity diagrams,
  - Presenting a customized V&V profile, and
  - Providing examples for each step

Conclusions

- Needs and requirements V&V
  - Performed early in the system lifecycle and
  - Uses Cameo's *validation suites* to develop automated constraints on the need and requirement text-based attributes.
  - A manual process is also presented to check more abstract best practices for needs and requirements sets along with validation.

Conclusions

- Performing model based design and system V&V increases
  - traceability of V&V attributes to needs and requirements,
  - test coverage across the design,
  - and the ability to reuse verification activities throughout the lifecycle
- The process also enables V&V planning, management, and creation of a master verification execution plan.

References

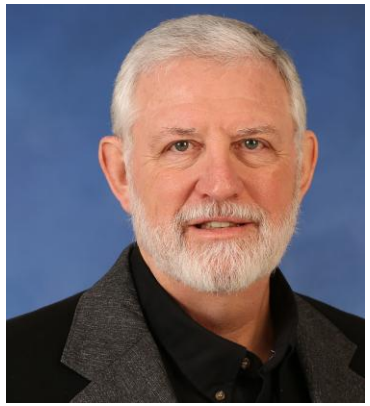
- *INCOSE Needs and Requirements Manual, Needs, Requirements, Verification, Validation across the Lifecycle.* (2024). Hoboken, New Jersey: John Wiley & Sons, Inc
- *Guide to Writing Requirements*, INCOSE-TP-2010-006-04, ver/rev:4, 1 July 2023. International Council on Systems Engineering, San Diego, California, USA

Author Bio's

Rebecca Mulholland. Rebecca works as a Systems Engineer at Leidos where she has experience with requirements management, system architecture and verification and validation across numerous complex defense and space programs within the company. She specializes primarily in Model- Based Systems Engineering (MBSE) which enabled her to contribute to research in this area while obtaining her Master's Degree at UAH. She graduated with a Bachelor's degree in Mechanical Engineering from Auburn University in 2020 and received her Master's degree in Systems Engineering from UAH in 2024.

Cameron Bentley is a Systems Engineer at Leidos and a recent Master of Science graduate in Industrial and Systems Engineering from the University of Alabama in Huntsville. He has experience in Model-Based Systems Engineering (MBSE) and Agile Systems Engineering within the Aerospace and Defense industry. Cameron has been an INCOSE member since 2022, holds the ASEP certification, and actively contributes to the Requirements Working Group, particularly in the development of the Guide to Model-Based Needs and Requirements.

Author Bio's



Jeffery L. Williams, Ph.D. Dr. Williams is a lecturer at the University of Alabama in Huntsville where he teaches model-based systems engineering courses as well as systems engineering fundamentals and other core engineering courses. Dr. Williams retired from industry after almost 49 years with experience that spans Aerospace & Defense, Rail, and Commercial Aircraft Systems Development. Dr. Williams has BA and MA degrees in Mathematics from the University of West Florida and Ph.D. in Applied Science from Lyle School of Engineering at Southern Methodist University.