



Introduction to an MBSE Case Study

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Digital Engineering Lead

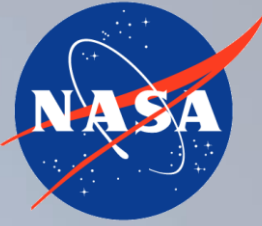
Moon2Mars Systems Engineering
and Integration (SE&I)

May 8, 2024

2024 SE WORKSHOP



MBSE Case Study Session Overview



Session Description

- During this interactive activity, we will review real-world challenges decision-makers have faced and work together in small groups to develop solutions to those challenges by applying the principles of model-based systems engineering (MBSE).

Learning Objective

- To use inductive reasoning to increase our understanding of how we can apply model-based systems engineering (MBSE) to the challenges we encounter as systems engineers.



The Challenge from M2M SE&I Leadership



The Ask

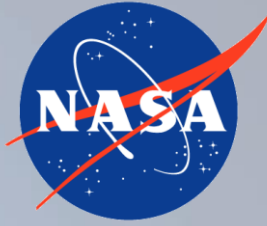
- M2M SE&I wants to reduce risk by ensuring there are adequately defined requirements that flow down.
- **Do we have all the requirements we need to support the technical baseline?**
- If we do not, what are the gaps in the requirements?
- Are there gaps in the architectural capabilities defined for Moon2Mars (M2M)?
- Is there clear traceability from the M2M Architecture Definition Document (ADD) to the Artemis Requirements Document?

The Task

- **Requirements Completeness Assessment**



Defining the Assessment Space: Sources of Truth



Level 0

**Moon2Mars Architecture
Definition Document (ADD)**

Objectives

Characteristics & Needs

Use Cases

Functions

Level 1

**Artemis Integrated Concept
of Operations**

Architectural Capabilities

Nominal Mission Model

**Design Reference Missions
(DRMs)**

**Artemis Requirements
Document (ARD)**

Requirements

Program Allocations

Verification Strategies

Level 2

Space Launch System (SLS)
Program System
Specification

Orion Multi-Purpose Crew
Vehicle (MPCV) Program
System Requirements
Document (SRD)

Gateway System
Requirements

Exploration Ground System
(EGS) Program System
Requirements

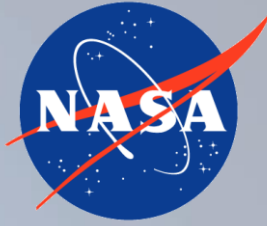
Human Landing System
(HLS) Program System
Requirements Document
(PSRD)

HLS Integrated Lander
Requirements Document -
Sustained Phase

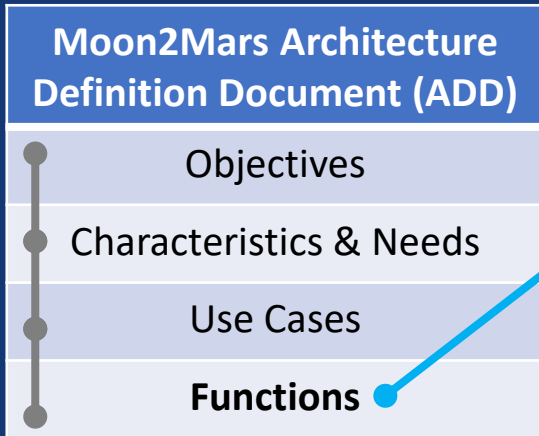
Extravehicular Activity and
Human Surface Mobility
Program (EHP) Systems
Requirements Document
(SRD)



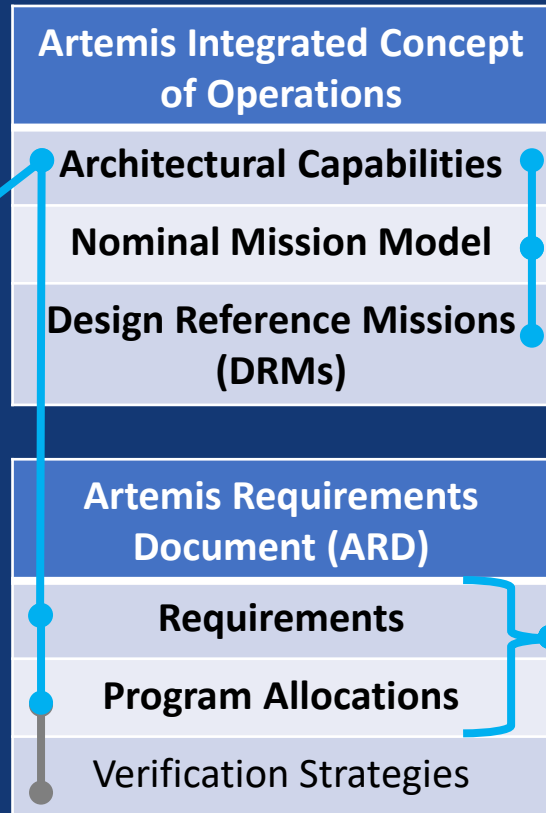
Advantages of Using MBSE for the Requirement Completeness Assessment



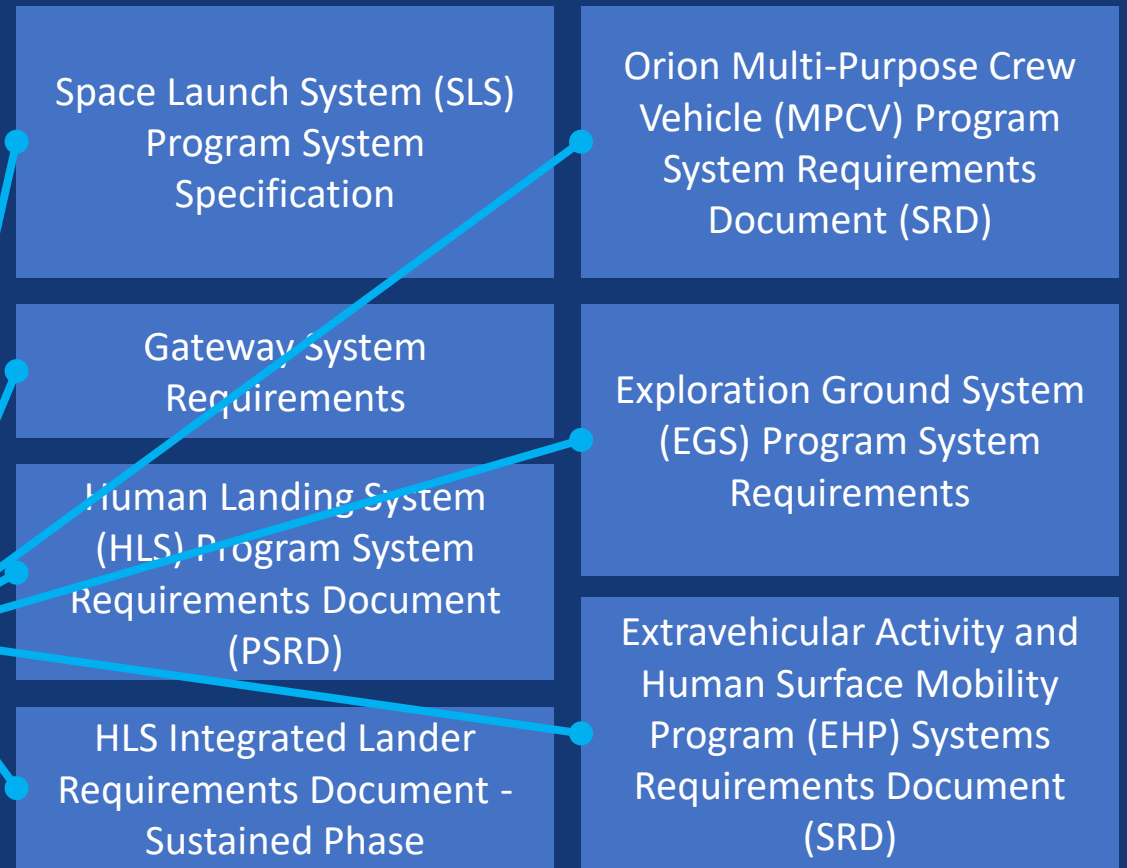
Level 0



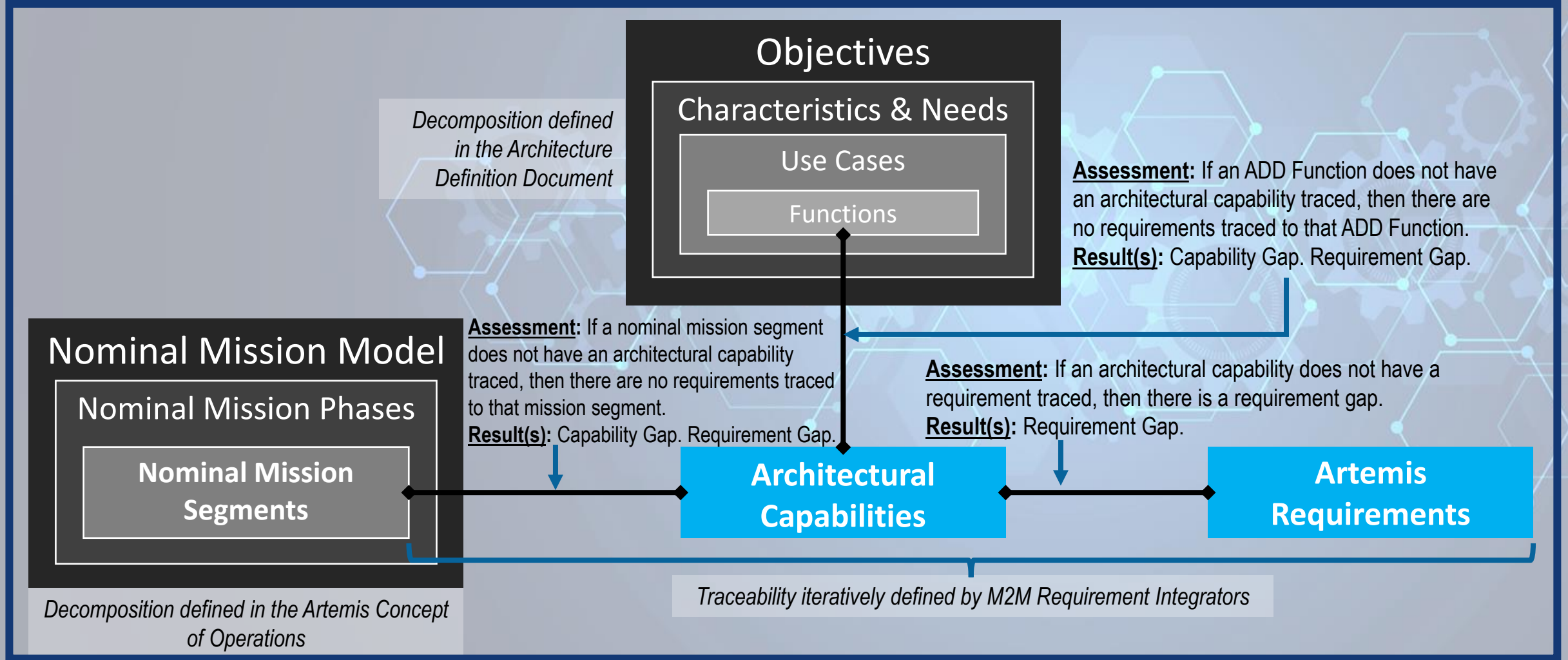
Level 1



Level 2

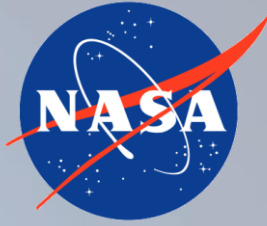


Assessment Cycle 1: Boundaries and Relationships





Assessing ADD Functional Gaps in the Architectural Capabilities



- **Assessment:** If an ADD Function does not have an architectural capability traced, then there are no requirements traced to that ADD Function.
- **Model:** Table view shows where there are no capabilities traced to functions, quickly identifying potential gaps.
- **Result(s):** Capability Gap. Requirement Gap.

SAO Model of M2M ADD

| # | M2M ADD Use Cases | M2M ADD Functions |
|----|---|--|
| 11 | <input type="radio"/> UC-068-L Position, navigation, and timing for crew and robotic assets in cislunar space <input type="radio"/> UC-002-L Stage crewed lunar surface missions from cislunar space | <input type="radio"/> FN-009-L Provide high availability position, navigation, and timing capability in cislunar space |
| 12 | <input type="radio"/> UC-068-L Position, navigation, and timing for crew and robotic assets in cislunar space <input type="radio"/> UC-002-L Stage crewed lunar surface missions from cislunar space | <input type="radio"/> FN-009-L Provide high availability position, navigation, and timing capability in cislunar space |
| 13 | <input type="radio"/> UC-147-L Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface <input type="radio"/> UC-148-L Habitation capabilities for extended-duration (year+) missions in cislunar space <input type="radio"/> UC-002-L Stage crewed lunar surface missions from cislunar space <input type="radio"/> UC-015-L Crew habitation for extended-duration (year+) mission(s) in cislunar space <input type="radio"/> UC-190-L Support crew extravehicular operations in cislunar space | <input type="radio"/> FN-010-L Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations |
| 14 | <input type="radio"/> UC-147-L Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface <input type="radio"/> UC-148-L Habitation capabilities for extended-duration (year+) missions in cislunar space <input type="radio"/> UC-002-L Stage crewed lunar surface missions from cislunar space | <input type="radio"/> FN-010-L Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations |

M2M Model of M2M Concept of Operations & Requirements

| ConOps Capabilities | Capability Description | M2M Requirement | Integrator |
|---|---|--|-------------------------------|
| <input type="radio"/> A.3.3 Provide Hardline Information Transfer | Provide Information (Commands, sampled data, discrete signals, human communication) transfer between the specified system type by Hardline data links | <input type="checkbox"/> ACD-R-53 Data Exchange Between Systems | Ash Holland |
| <input type="radio"/> A.3.13 Determine PNT | Acquire Position, Navigation, and Timing data for crewed and uncrewed systems. | <input type="checkbox"/> ACD-R-56 Mobile Lunar Surface Asset Location <input type="checkbox"/> ACD-R-57 Lunar Surface Crew Location | Ash Holland |
| <input type="radio"/> A.4.1 Provide Environmental Controls and Life Support | Provide capability to sustain crew, including breathing air, cabin pressure control, temperature and humidity control, waste management, environmental monitoring and detection (e.g. hazardous gas), and consumable water. | <input type="checkbox"/> ACD-R-14 In-Space Cabin Pressure <input type="checkbox"/> ACD-R-27 Surface Cabin Pressure <input type="checkbox"/> CESD-R-2 Crew Size <input type="checkbox"/> CESD-R-4 Orion Active Mission Duration <input type="checkbox"/> CESD-R-7 Post-Landing Crew Survival <input type="checkbox"/> ACD-R-63 Operating Crew Size <input type="checkbox"/> ACD-R-16 Lunar Surface Mission Duration | Darren Baird Conor O'Bryan |
| <input type="radio"/> A.4.5 Provide Habitability | Provide capability to support routine IVA activities including crew exercise system, living quarters, dining, and translation corridors. | <input type="checkbox"/> CESD-R-2 Crew Size <input type="checkbox"/> CESD-R-7 Post-Landing Crew Survival <input type="checkbox"/> ACD-R-16 Lunar Surface Mission Duration | Darren Baird Conor O'Bryan |

Functional Decomposition



Assessing Capability Gaps in the Nominal Mission Model



- **Assessment:** If a nominal mission segment does not have an architectural capability traced, then there are no requirements traced to that mission segment.
- **Model:** Dependency matrix shows where there are no architectural capabilities traced to nominal mission segments, quickly identifying potential gaps.
- **Result(s):** Capability Gap.
Requirement Gap.

Requirement Completeness Assessments

Search

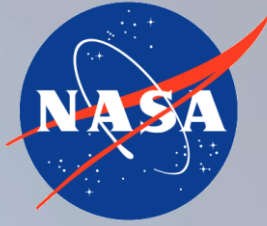
(D) Requirement Completeness Assessments

Nominal Mission Capabilities

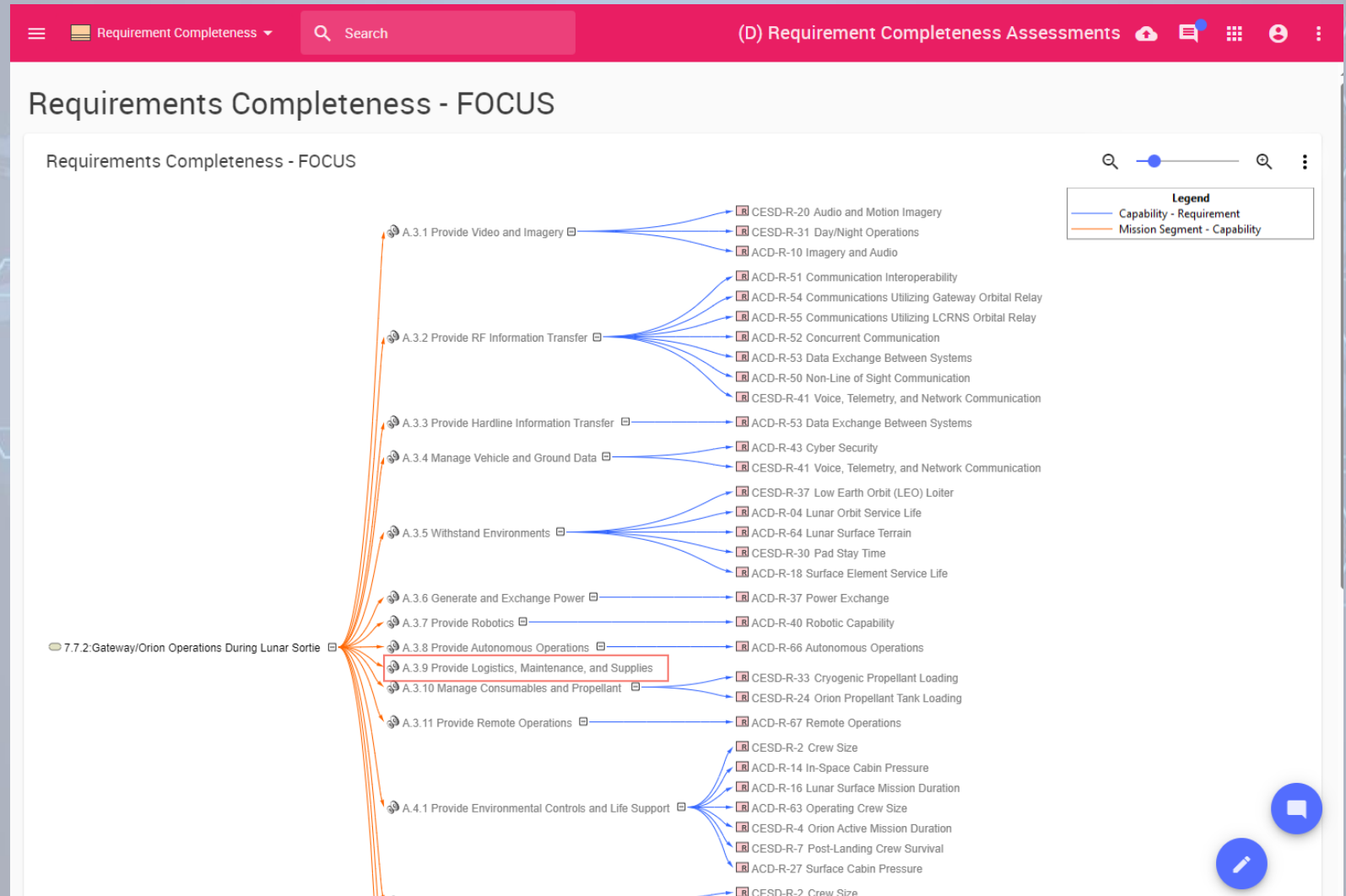
| Nominal Mission Capabilities | 7 | 7 | 4 | 7 | 4 | 2 | 11 | 9 | 15 | 14 | 13 | 11 | 12 | 12 | 12 | 15 | 12 | 23 | 14 | 12 | 13 | 11 | 13 | 10 | 10 | 8 | 1 |
|--|----|---|---|---|---|---|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|
| 7.1.1:SLS Offline Operations | 7 | ✓ | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.1.2:Orion Offline Operations | 7 | ✓ | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.1.3:Payload Offline Operations | 4 | ✓ | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.1.4:Integrated Vehicle Operations | 7 | ✓ | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.1.5:Orion Flight Crew Preparation for Launch | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.1.6:Pad and Launch Operations | 11 | ✓ | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.1.7:Launch Scrub | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.2.1:SLS/Orion Earth Ascent | 15 | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 7.3.1:Earth Orbit Operations and SLS Upper Stage | 14 | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 7.3.2:HLS Earth Orbit Operations | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.4.1:SLS/Orion Transit to NRHO | 14 | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 7.4.2:HLS Transit to NRHO | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.4.3:Gateway Elements Delivery to NRHO | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.5.1:RPODU Events | 13 | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 7.6.1:Crew Ingress | 11 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.6.2:Open Hatches Operations (HLS/Orion) | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.6.3:Open Hatches Operations(HLS/Orion/Gatew | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.6.4:Integrated Lander Departure Operations | 11 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.7.1:Orion Operations During Lunar Sortie | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.7.2:Gateway/Orion Operations During Lunar So | 15 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.8.1:Lunar Descent | 12 | | ✓ | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.9.1:Crewed Lunar Surface Missions | 23 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.9.2:Uncrewed Mission Operations | 14 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.10.1:Lunar Ascent | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.11.1:HLS/Orion Return RPOD | 13 | | ✓ | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.11.2:HLS Return RPOD with Gateway/Orion | 13 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.12.1:HLS/Orion NRHO Return Operations | 11 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.12.2:HLS Return RPOD with Gateway/Orion | 13 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.13.1:Lunar-Earth Transit | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.14.1:Entry, Descent, and Landing | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.15.1:Recovery | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7.16.1:In-Space Disposal | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |



Assessing Requirement Gaps in the Architectural Capabilities



- **Assessment:** If an architectural capability does not have a requirement traced, then there is a requirement gap.
- **Model:** Tree view shows where there are no requirements traced to architectural capabilities, quickly identifying potential gaps.
- **Result(s):** Requirement Gap.





MBSE Case Study Table Discussion

- **Challenge:** Your management tasks you with conducting a requirement completeness assessment for your area. How do you determine if you have a complete set of requirements? How will you ensure you've factored in all potential threads for identifying gaps?

Discussion Questions

- Where is the source of truth for your requirements?
- What other sources of truth do you need to factor into your assessment?
- What elements within those sources do you need to conduct your assessment?
- Are all those elements already linked together? What do you do if they are not linked together?
- Have you done this before? How did you approach it? Would a model-based/digital approach have helped?