LEVERAGING CAPELLA AND ARCADIA FOR SATELLITE SYSTEM DESIGN AND INTEGRATION

CAPELLA DAYS 24

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INTRODUCTION - PIXXEL

- Pixxel is a startup that is building a health monitor for the planet.
- This will be done through a constellation of Earth Observation Satellites that capture hyperspectral data.
- Three technical demonstration satellites have been launched and operated
- The commercial ‘Firefly’ satellites are being launched soon

George Savio
Systems Engineer

INTRODUCTION - BLUEKEI SOLUTIONS

- Pioneering in systems engineering / transformation through digital engineering in India and APAC
- Provides "Framework" for systematic and methodical approach to solution development and a Tool agnostic approach
- Focused approach in Systems Engineering to make an impact on business outcome

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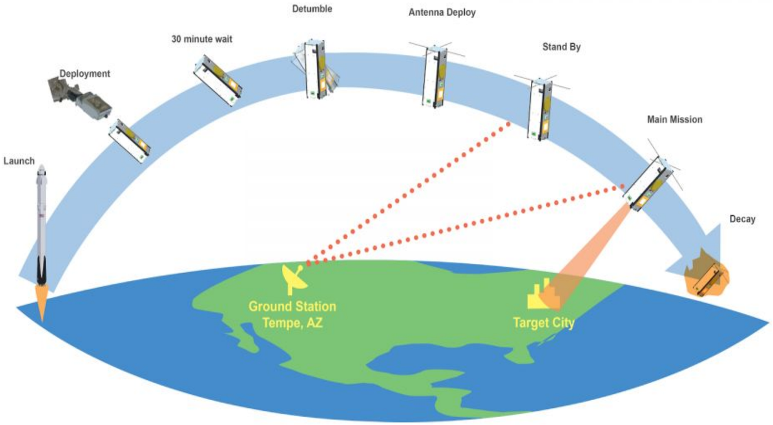
THE ELEMENTS OF SATELLITE CONSTELLATION

- **Satellite**
  - **Sensor**: Collects data from Earth's surface using electromagnetic radiation.
  - **Transmission**: Sends the collected data to ground stations.

- **Ground Station**: Receives, stores, and processes the data.

- **Data Use**: Processed data is used for applications like mapping and environmental monitoring.



THE INTERACTING TEAMS

- 🌠 Mission Design Engineers, Mission Operations Engineers
- 🛰️ Systems Engineering - System Architects
- 🛠️ Mechanical Engineering - Structural ,Thermal, Mechanism Propulsion Engineers
- 🔋 Electrical Engineering - Power Systems, Electronics, RF , Harness Engineers
- 🎮 Control Engineering - Attitude Control, GNC Engineers
- 💻 Software Engineering - Software, Firmware Engineers
- 🧪 Testing

PROBLEM

- **Fragmented Information Storage**: requirements, design decisions are scattered across multiple locations.
- **Lack of a Holistic View**: Due to the satellite's complexity, understanding the full scope of the system is difficult.
- **Siloed Multidisciplinary Teams**: Different teams, each focused on specific disciplines, often work in isolation.
- **Traceability**: A traceable link from high-level business decisions through to downstream engineering.

APPROACH

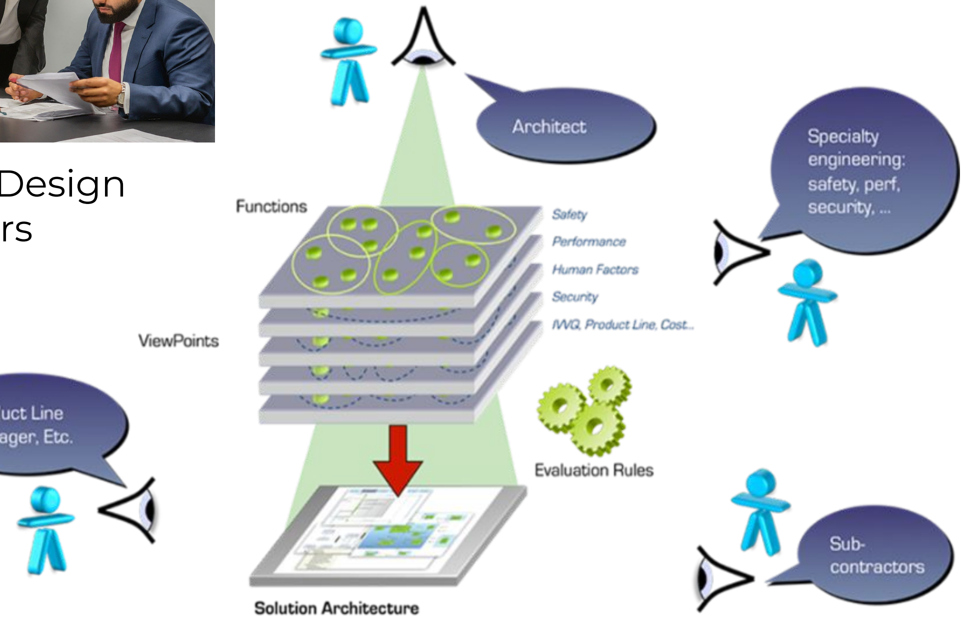
WHY MBSE ?

- Provides a centralized, model-driven environment where everything can be stored.
- Adopting MBSE while designing is a first step to get an entire project in a digital thread.
- "big picture" view helps in recognizing dependencies, interactions, and potential conflicts across the entire system.

WHY ARCADIA/CAPELLA ?

- Open source.
- The methodology and tool allow for the representation of systems quickly and is more friendly to be consumed by non SE engineers.

Mission Design Engineers

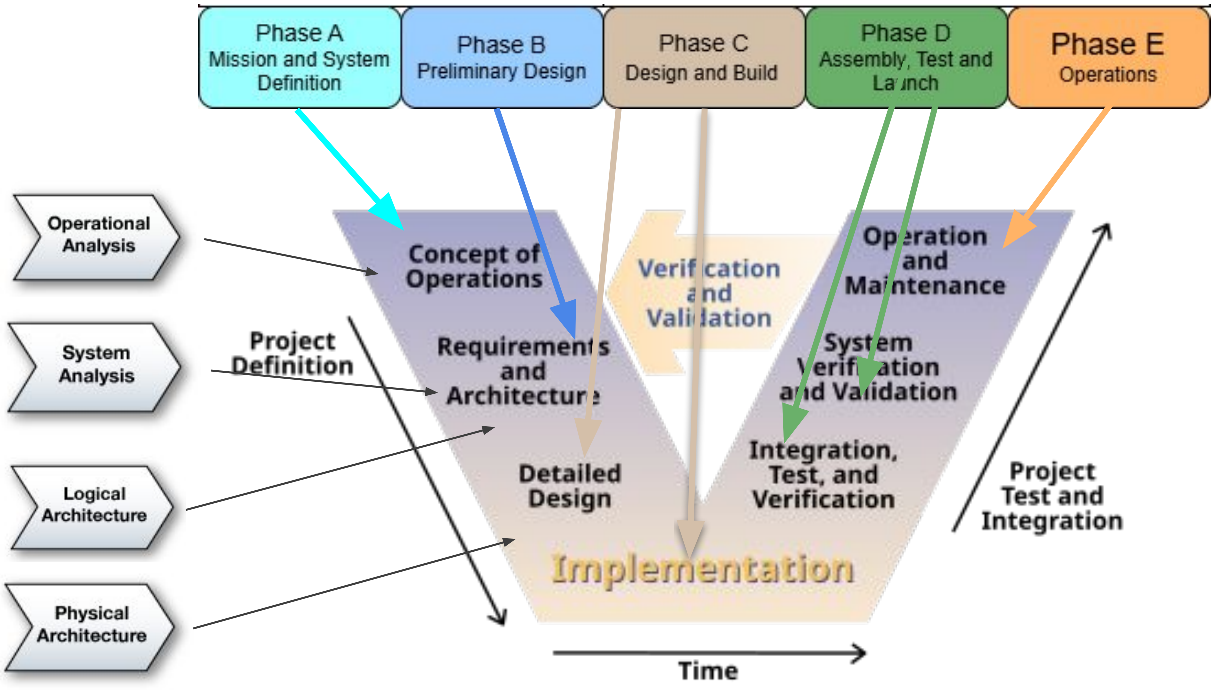


Testing

Systems Engineering - System Architects

Engineering - Software, Mechanical, Controls

PHASES OF A SATELLITE PROJECT



FORMULATION STAGE - PHASE A

Mission Analysis

- Mission Analysts perform a detailed assessment of the satellite's potential orbits.

- They determines how best to fulfil the mission objectives in terms of, achievable orbits, launch-vehicle capacity, available ground stations, operations

The output is a Reference Mission

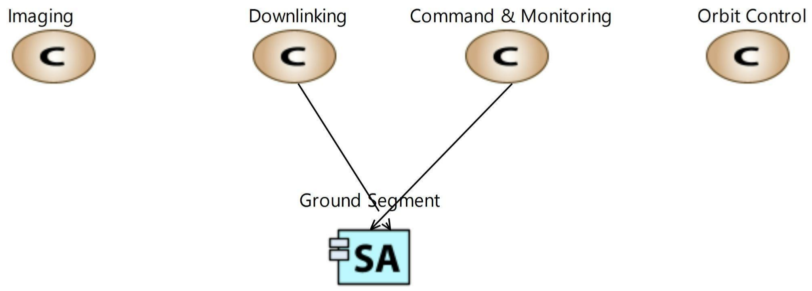
REFERENCE MISSION PROFILE - CONT.

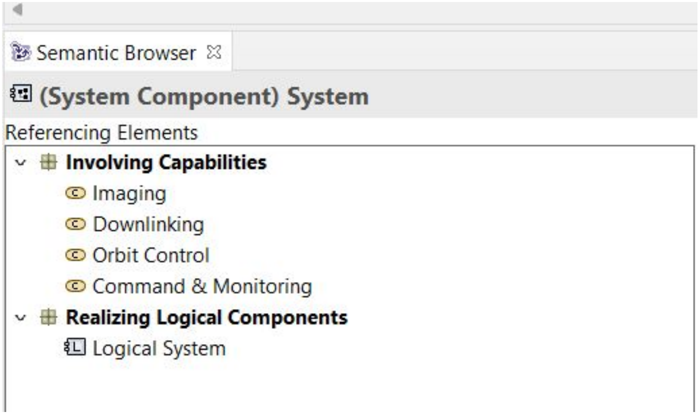
- The outputs of these analysis drive the requirements and design of the spacecraft.
- In order to derive requirements top down and in order to have the digital thread start as early as possible, these need to be inputted into the Capella Model
- The System of Interest is the Satellite
- <u>Hence we start our analysis at the System Analysis Level and input the Reference Mission Profile at this level</u>

INPUTTING THE REFERENCE MISSION PROFILE

The main Satellite operations are formalized as system capabilities

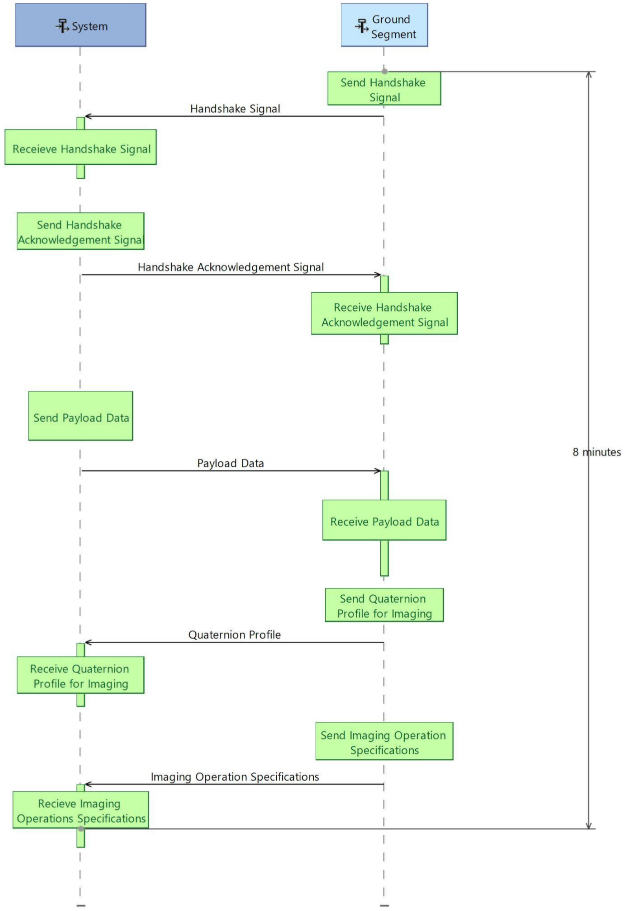
- Ground Pass
- Stationkeeping
- Downlink
- Imaging





INPUTTING THE REFERENCE MISSION PROFILE - CONT.

- Break the Reference Mission Profile into smaller segments based on the Satellite Operation
- Make a Sequence Diagram out of the small segments and link it to the Capability



FORMULATION STAGE - PHASE B

Given what the satellite as a system has to achieve - how does development move forward ?

Define What the System Must Do

- Break down requirements for each part of the satellite
- Define how different parts work together
- Specify how well each part must perform

Create the Basic Design

- Outline the overall satellite layout
- Document how parts connect and communicate
- Plan how the satellite will be operated

REQUIREMENTS IN EXCEL

- Followed INCOSE writing guidelines for requirement correctness & completeness
- Helps technical team to write structured requirements

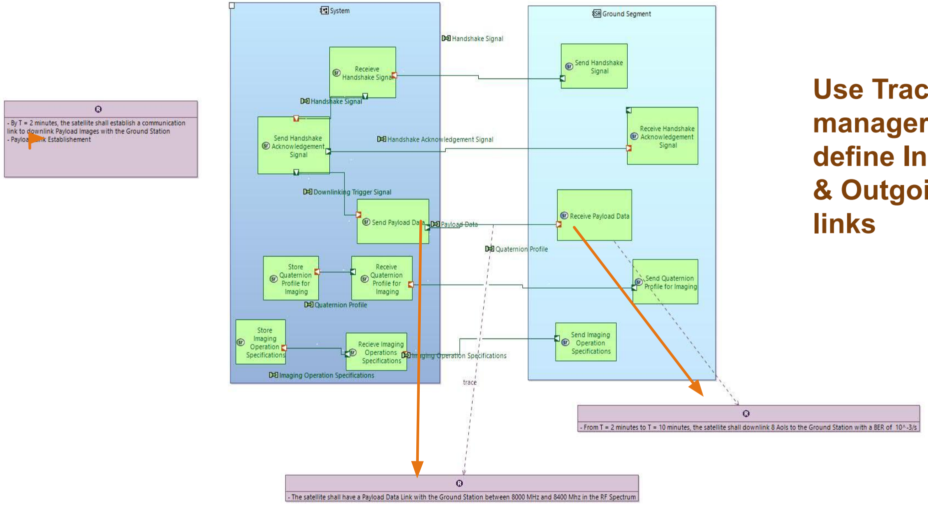
Systems Requirement writing template & data model

BLUEKEI SOLUTIONS — *System Requirements*

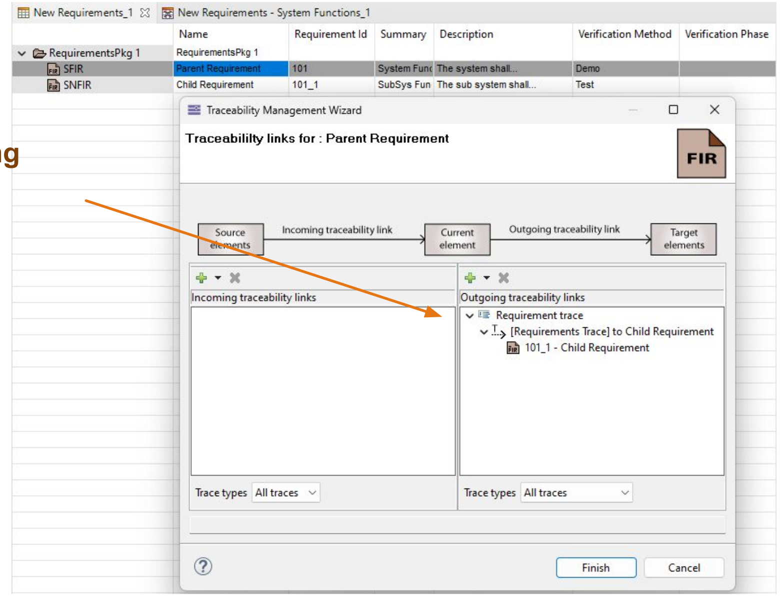
Stakeholder Requirement ID	System Requirement I	Name	Primary Text	Entity	shall/should	[to WHAT]	[HOW WELL]	[Under what Conditions]	[Duration]	dance TERFACE UT]	[accordance with INTERFACE INPUT]	[upon EVENT TRIGGER]	Rationale	System Requirement Category
				System	shall/should	FUNCTION	with PERFORMANCE	while in CONDITION						Functional
				System	shall/should	exhibit DESIGN CONSTRAINTS	with PERFORMANCE/Contraints	while in CONDITION			NA	NA		Design
				System	shall/should	exhibit CHARACTERSTIC		during/after exposure to ENVIRONMENT	[for EXPOSURE DURATION]		NA	NA		Environment
				System	shall/should	exhibit CHARACTERSTIC	with PERFORMANCE/Contraints	while in CONDITION	[for CONDITION DURATION]		NA	NA		ilities
			By T = 2 minutes, the sa shall establish a communication link to downlink Payload Images with the Ground Station	Satellite	shall	**establish communication** link to downlink payload images with GS	[TBD]					at/by 2 minutes		Functional
			From T = 2 minutes to T = 10 minutes, the satellite shall downlink 8 AoIs to the Ground Station with a BER of 10^-3/s	Satellite	shall	**downlink** 8 AoIs to the GC	with a BER of 10^-3/s	from T = 2minutes to T = 10 minutes						Functional
			The satellite shall have a Payload Data Link with the Ground Station between 8000 MHz and 8400 Mhz in the RF Spectrum	Satellite	shall	**have a Payload Data Link** with the Ground Station	between 8000 MHz and 8400 Mhz in the RF Spectrum							Design
			The satellite shall packetize the Payload Imagery as per the CFDS standard beofre downlinking	Satellite	shall	**packetize** the payload imagery	as per the CFDS standards	before downlinking						Functional

Structured requirements writing as per types of requirement.

REQUIREMENTS MODELLING IN CAPELLA



Use Trace manager to define Incoming & Outgoing links



Traces Requirements w/ Model elements

CONSISTENT SUBSYSTEM SPECIFIC VIEWS EXAMPLE

Given the System Functions - how shall the downstream domain engineers design their components?

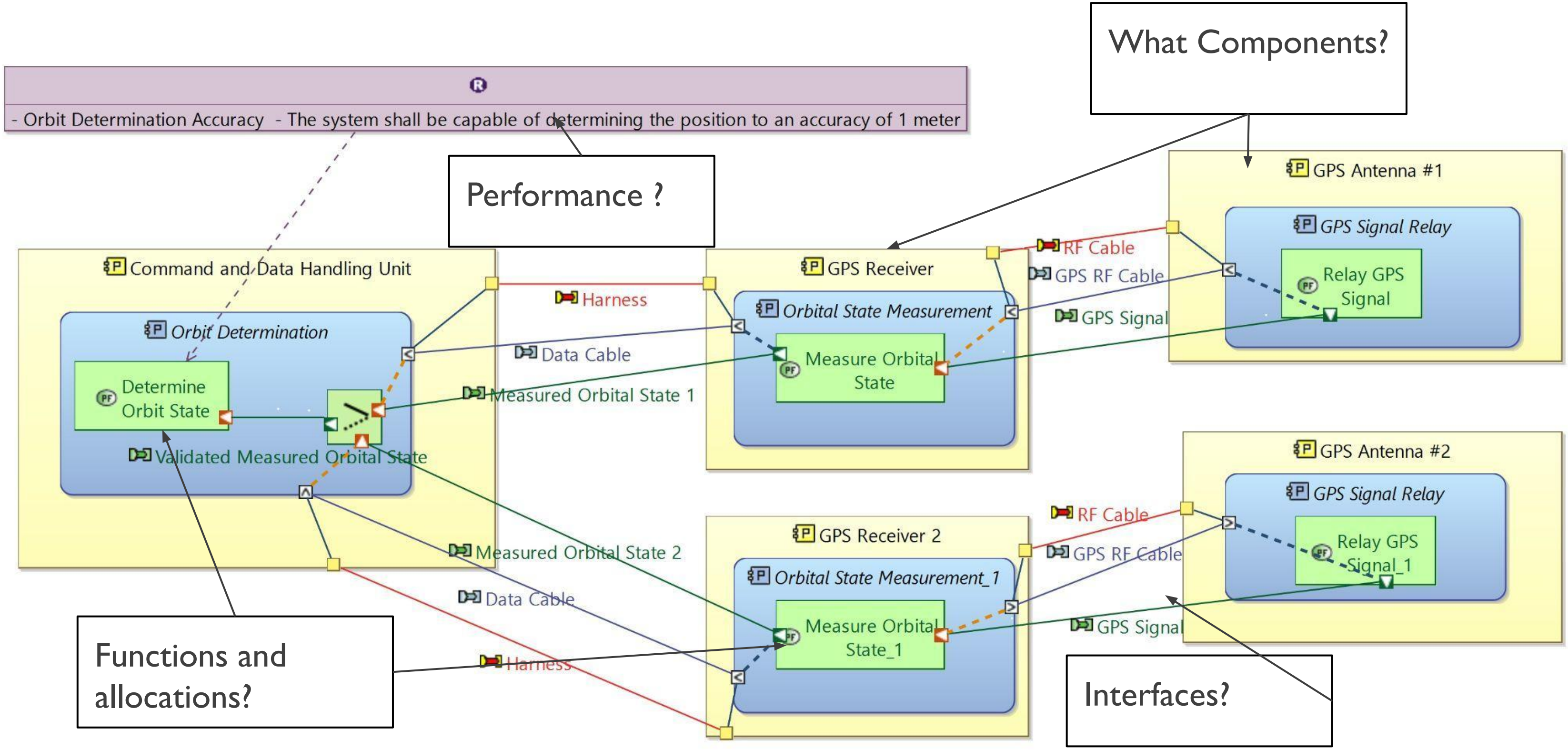
How do things get implemented at the lowest level ?

- What components are involved ?
- What functions must these components perform to achieve the capability
- What are the performance parameters for the functions?
- How are the components interfaced?

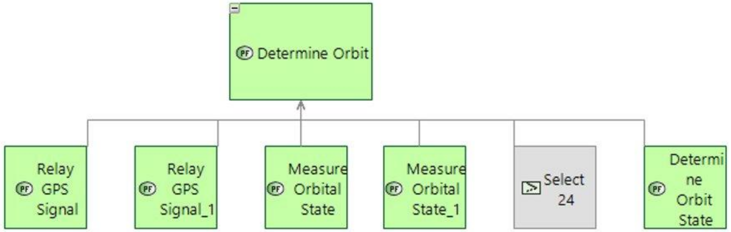
We highlight this with the example. One logical capability within Guidance, Navigation and Control is *'Determine the Orbit'*.

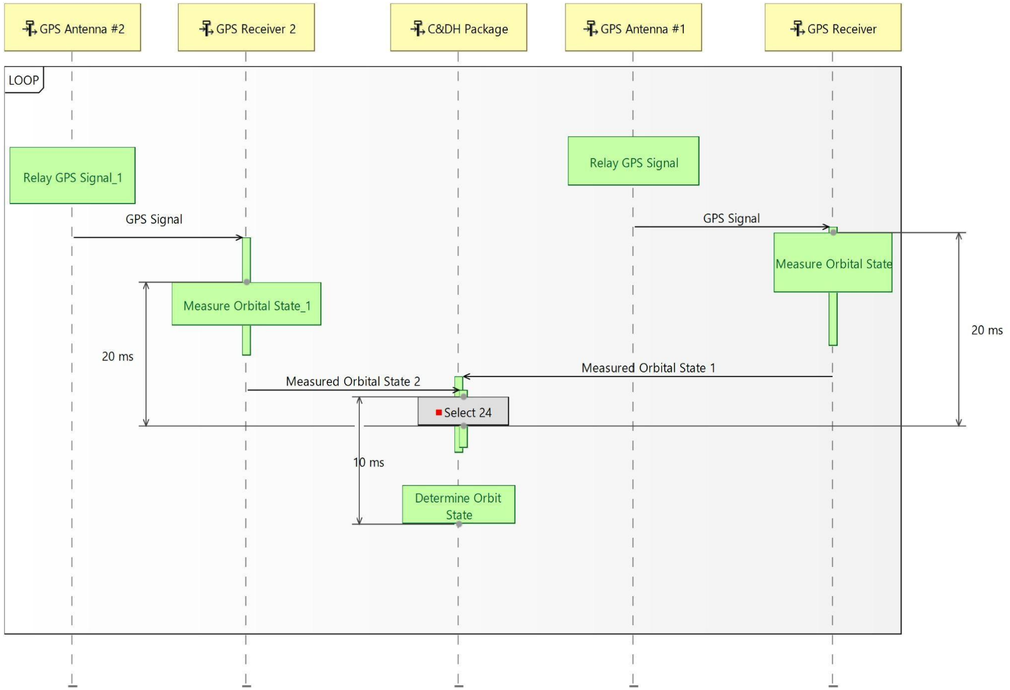
There will be GNC algorithms engineers, GNC hardware engineers, embedded engineers, software engineers, harness design engineers etc - WE NEED A CONSISTENT SET OF VIEWS THAT SHOW THE EMERGENCE OF THE SYSTEM FUNCTION

SUBSYSTEM SPECIFIC VIEWS EXAMPLE



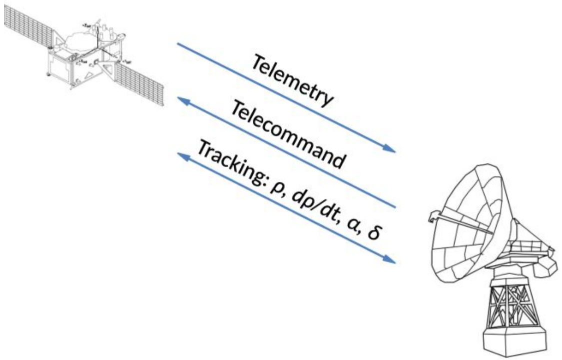
SUBSYSTEM SPECIFIC VIEWS EXAMPLE





Subsystem Specific Views - Monitoring and Commanding

Monitoring and Commanding is crucial for the operation of a satellite. They involve Telmetries and Telecommands



Telemetry

What is it? : Real-time data collected from satellite sensors and subsystems

Why is it needed? : Monitor satellite health, performance, and mission progress

Examples: Power levels, temperature, attitude, payload status

Telecommand

What is it? : Instructions sent to the satellite to control its operations

Why is it needed? : Adjust satellite parameters, initiate actions, manage payload

Examples: Adjust orbit, capture image, update software

FORMALIZING TELEMETRIES AND TELECOMMANDS

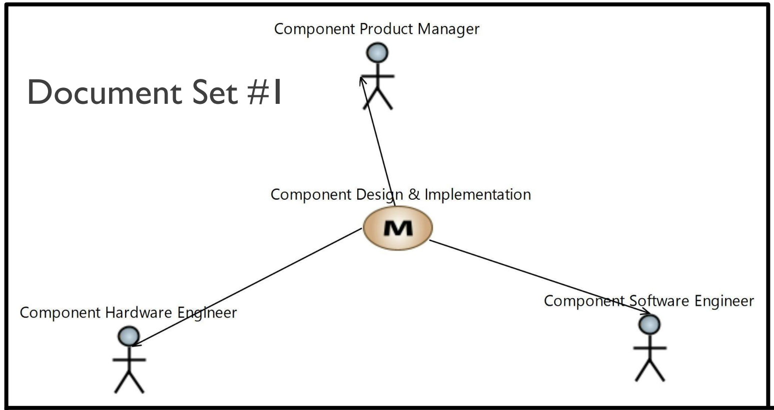
Why should the System Model formalize telemetry?

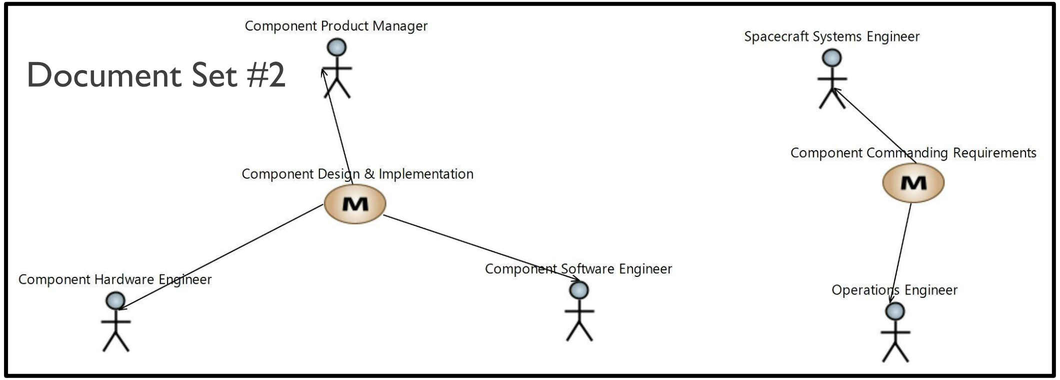
There are many engineers/stakeholders that will have to deal with telemetry such as

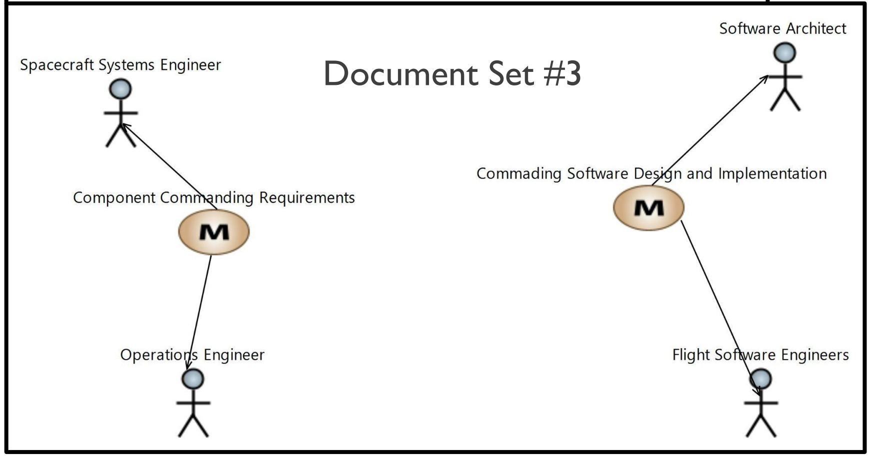
- Engineers responsible for component/process
- Engineers doing software interfacing of component
- Engineer working on ground systems for managing data
- Operators on ground

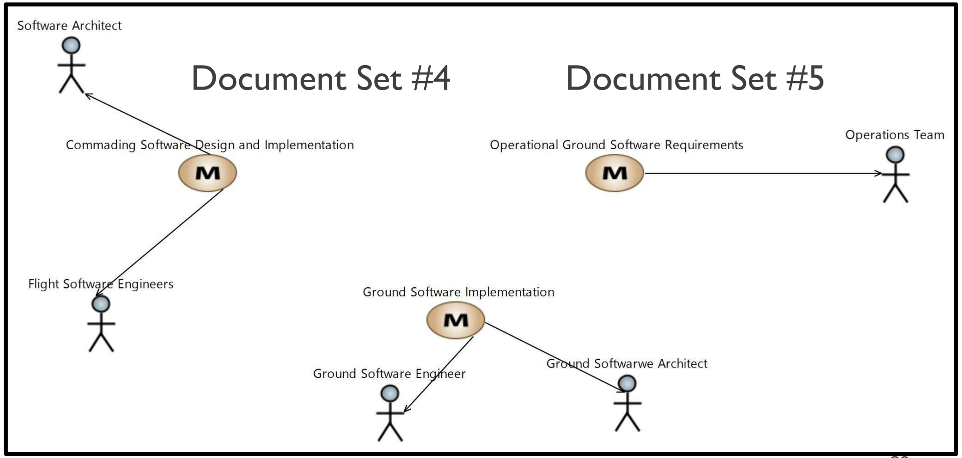
With so many documents, there has to be consistency ! Formalizing them in the model ensures consistency

ENGINEERING INTERACTIONS REQUIRED

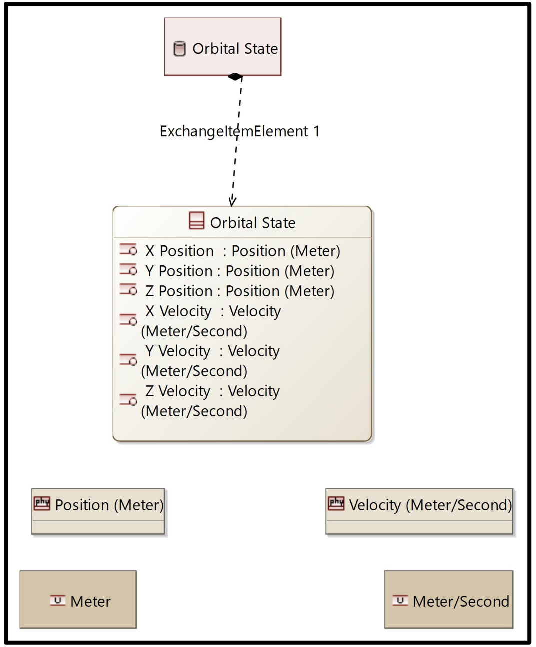




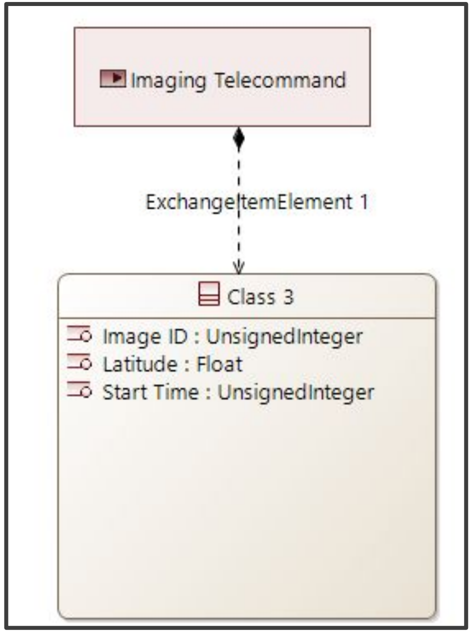




TELEMETRY AND TELECOMMAND DEFINITION

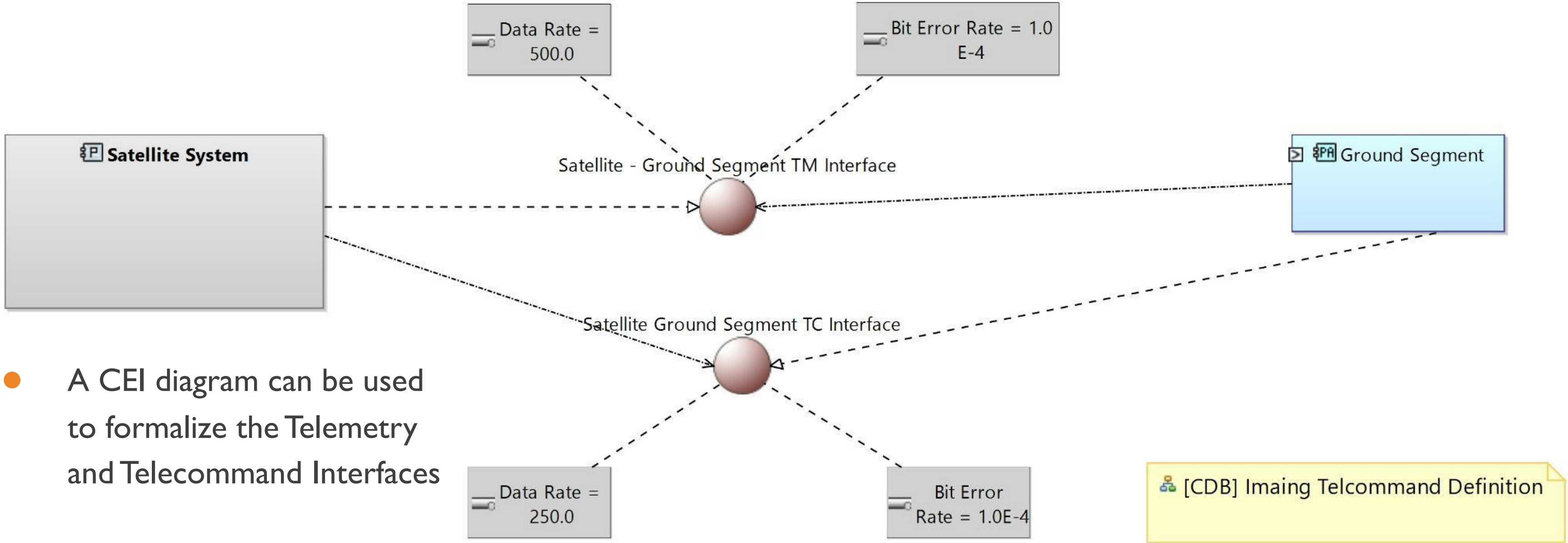


Every Telemetry is modelled as an Exchange Element



The arguments and attributes relevant for the execution of the telecommand are defined using the data modelling feature of

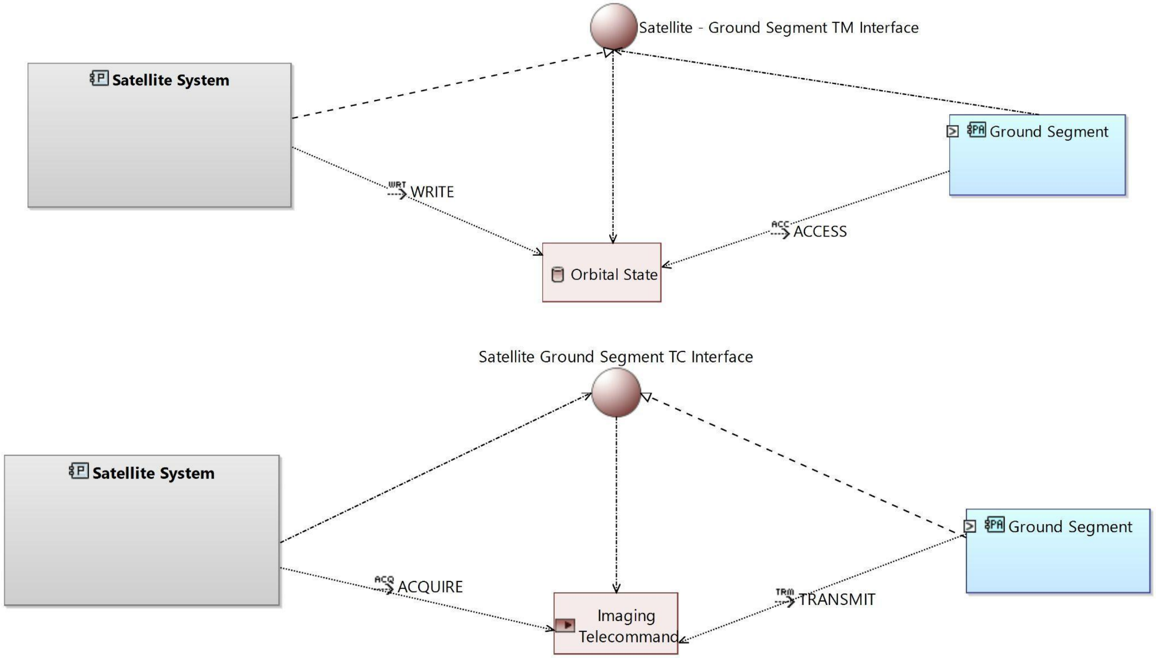
TELEMETRY AND TELECOMMAND INTERFACE DEFINITION



- A CEI diagram can be used to formalize the Telemetry and Telecommand Interfaces

EXCHANGE ELEMENT ALLOCATION

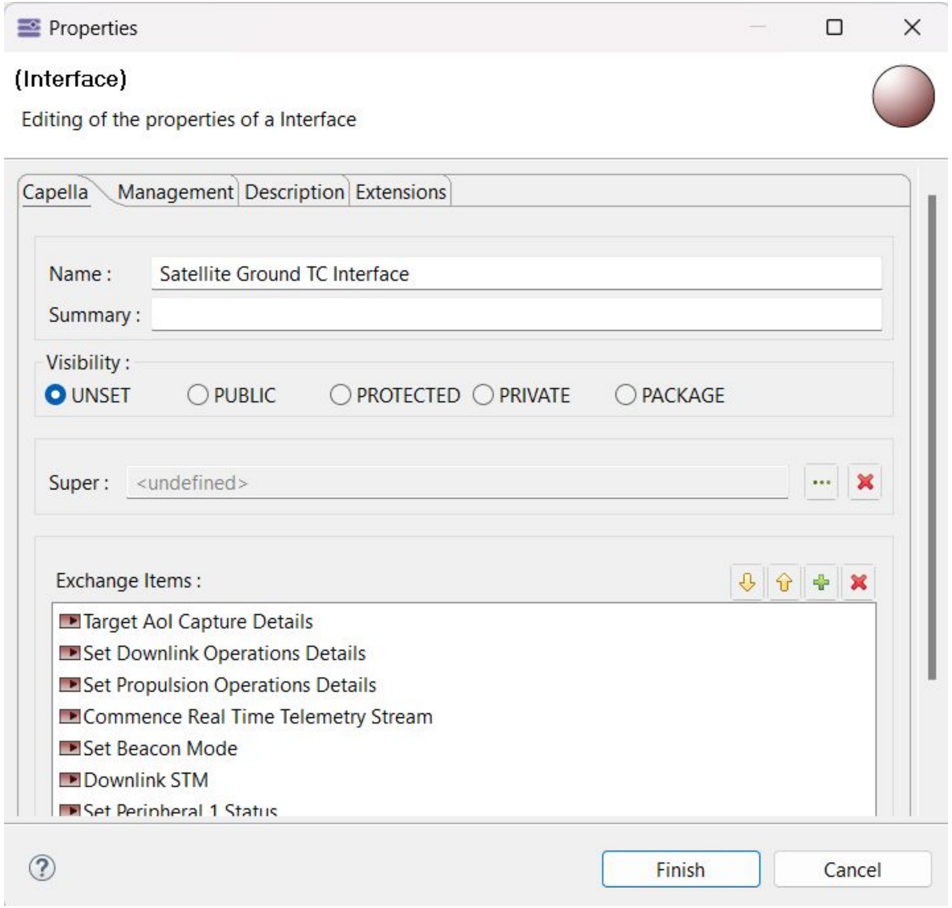
The Exchange Element is then allocated to the Satellite-Ground Segment TM Interface and TC Interfaces



COMPLETE LIST OF TCS

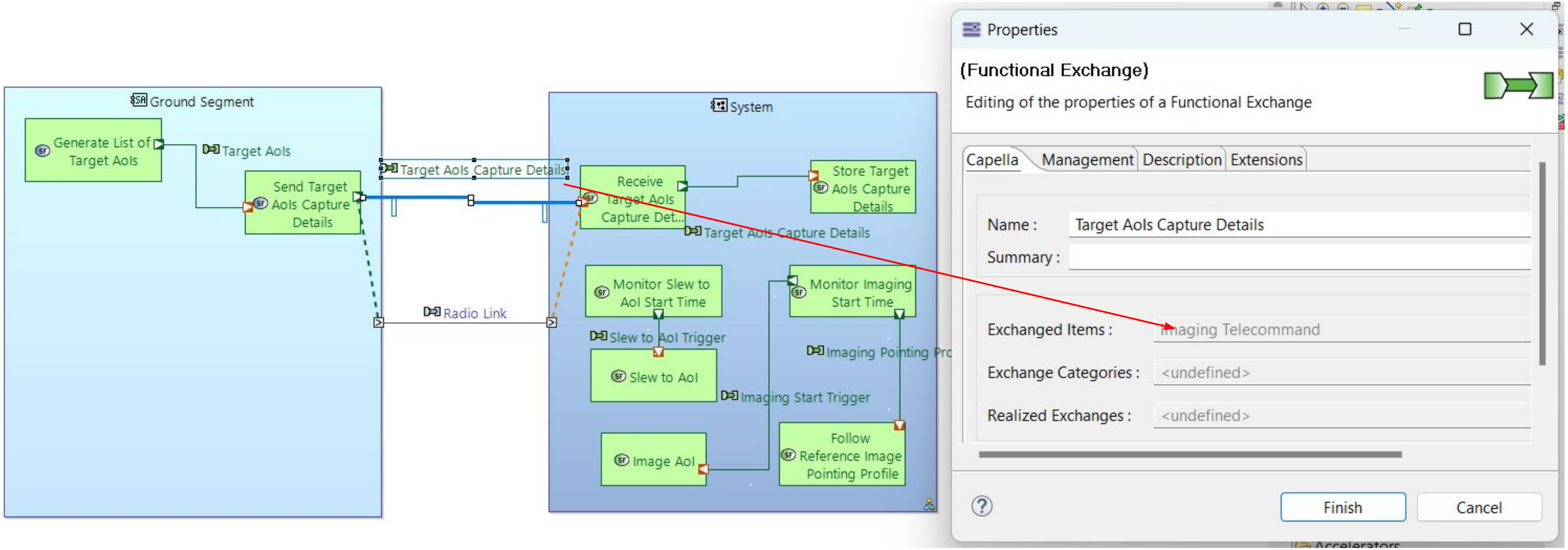
Since all TCs will be defined in this manner, we will have a consistent list of TCs as well as their implementations.

All of these can be found by double clicking the TC interface element



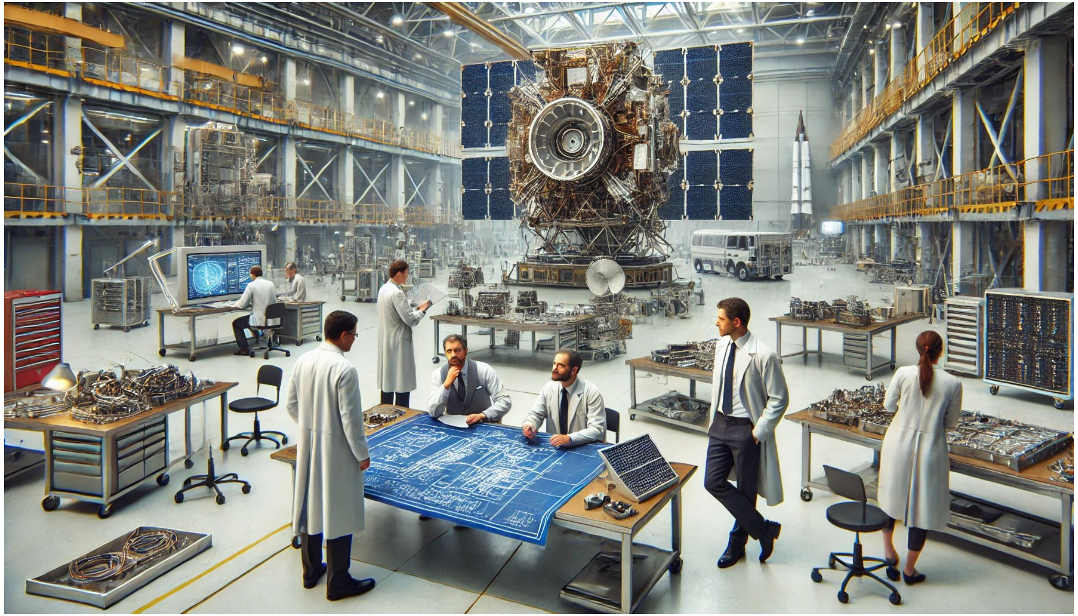
Telecommand Usage by Components

- In this example we can see how the ‘Imaging Telecommand’ is used in between Ground and Space.
- Double Clicking F.E. allows us to find the involved Exchange Items to get formal definition



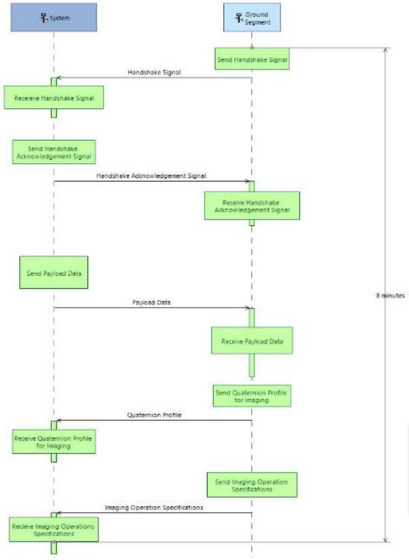
PHASE C

The model now contains information on the different system components and what functions they must perform. This is the basis for detailed design and then manufacturing by the different groups



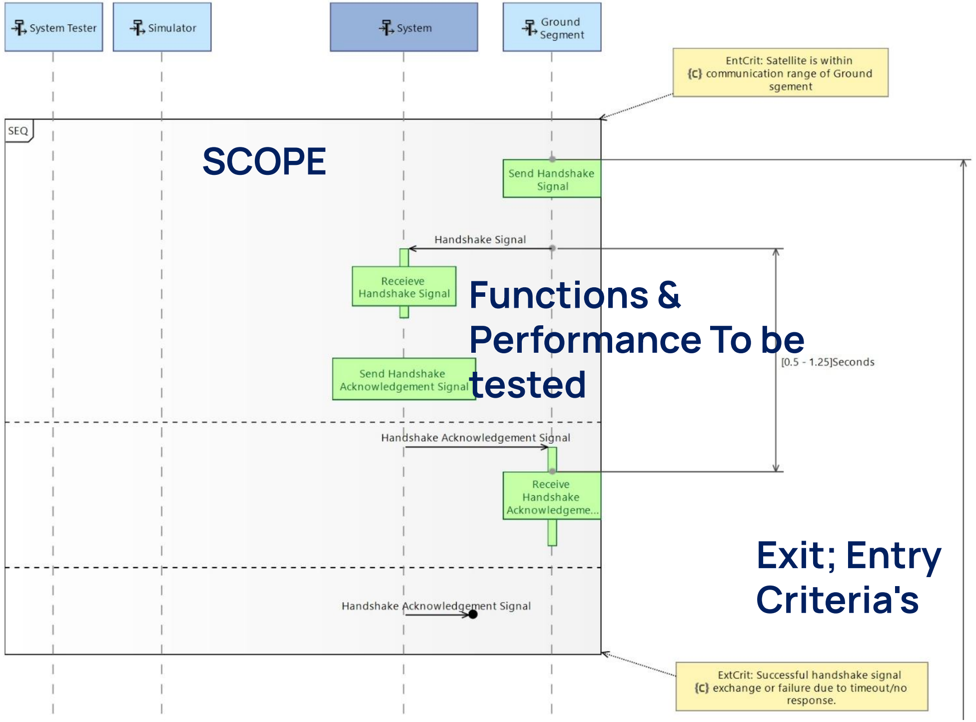
PHASE D – VALIDATION AND TESTING

Model used as reference for, Test cases planning, Fault analysis, trade study etc.



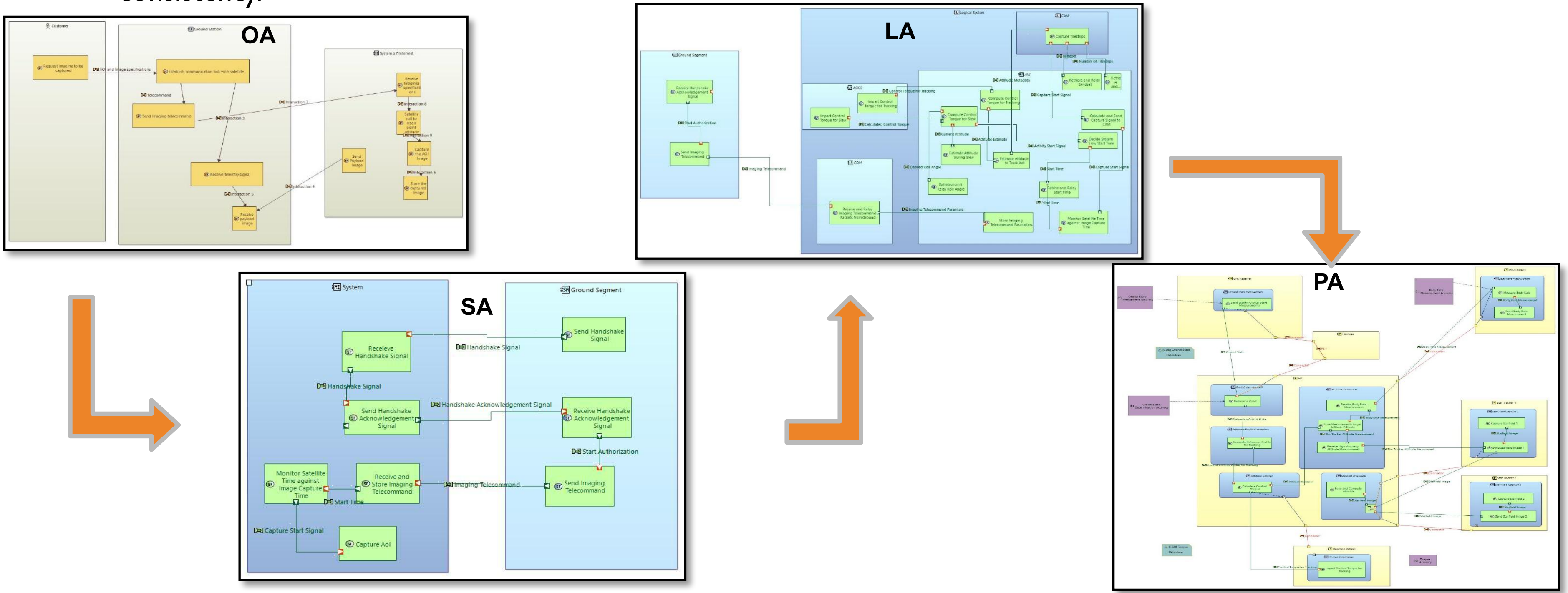
Name Clone of [ES] GroundStationPass	Last change date 2024-06-13 17:16:46	
Test case 101 Functional testing of 'Hanshake signal'	Test Details (DOE) Brief of scenario - test the successful exchange of Handshake signal to establish comunication link	
Test Setup Ground station communication equipment. Satellite communication module (simulated or actual hardware). Simulator to mimic space conditions	Test environment Simulated space environment, ground station control system.	

Same artifact used to plan test cases & test case attributes



CONCLUSION

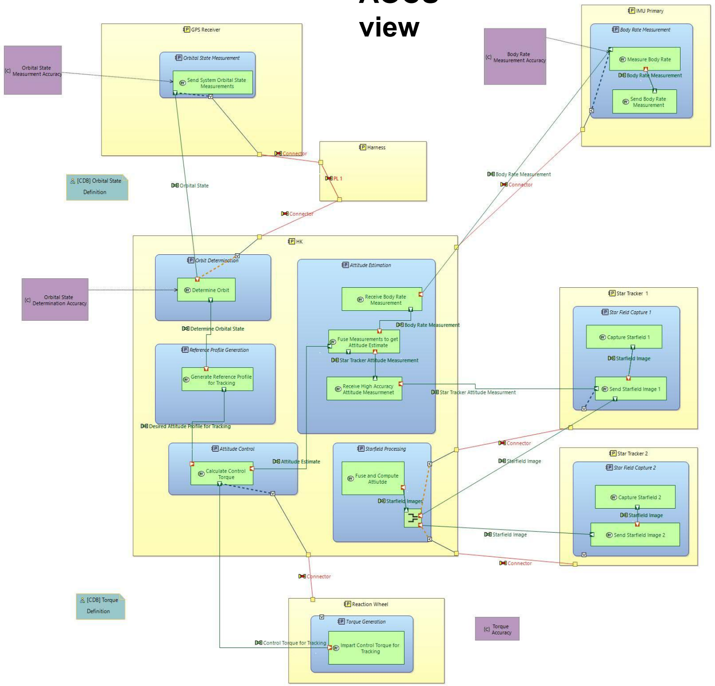
- Capella model acting as Single Source of Truth (SSOT) to build, change & maintain Satellite's data
- Model semantics helping to define standard definition & relationships between satellite's data forcing a degree of consistency.



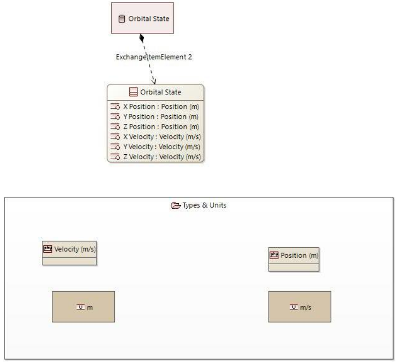
CONCLUSION

- Multiple views created & managed in single model for multiple team to consume.
- Modelling interfaces with relevant details complements ICDs & have handshake agreement between technical teams.

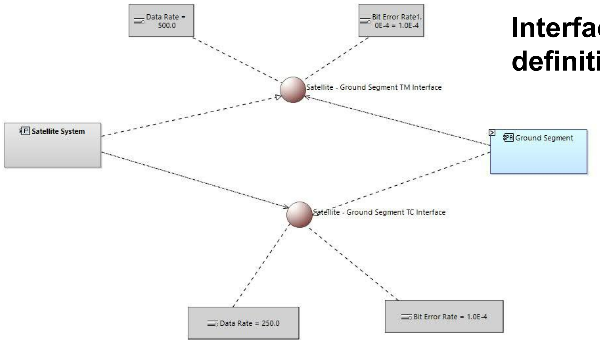
AOCS view



Exchange element definition



Interface definition



Benefits realized

- The complex system has been modelled systematically that helped to break the complexity.
- Supplementary visual diagrams through Capella enabled teams to have a better understanding visually.
- MBRE : Modeling requirements helped in writing precise and concise requirements.
- The establishment of SE processes ensures that the impact of changes and decisions are understood by the teams involved.
- Reusability artefacts reduces the lead time in product development.

FUTURE SCOPE

- Enables multiple architectures decisions for future programs
- For designing bigger satellites, same artefacts can be used and they become the baseline to start the work with.
- Trade space analysis For future, trade space analysis for different architecture of satellites (parametrized capella model).
- Functional architecture availability leads to System of systems capability definition.
- Enhancing the right side of V model :
  - Supporting with Integration ,Verification and Verification

THANK YOU

Questions?