

Enhancing Verification Processes: Leveraging DOORS add-on in the Sentinel-3 Ground Segment Re-Engineering Project

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Abstract

As part of the Copernicus program, operated by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) on behalf of the European Union, the Sentinel-3 mission has provided essential data for oceanography, land monitoring, and atmospheric applications since 2016. In preparation for the future expansion of the mission, EUMETSAT conducted the Sentinel-3 Ground Segment Re-Engineering (GSRE) project. It was a major initiative aimed at modernizing and enhancing the operational capabilities of the mission. The re-engineering effort focused on updating the ground segment infrastructure to support improved data processing, storage, and an upgraded mission control system. An extensive test campaign was conducted, with the verification and validation activities taking place in a combined manner.

To improve the efficiency and accuracy of the verification process, EUMETSAT aimed to leverage and enhance the capabilities of the commercial DOORS RMT (Requirement Management Tool) from IBM with a specialized add-on. The objectives were to link verification artifacts directly to requirements, automate various verification tasks, and enable real-time reporting. To address these needs, EUMETSAT developed an in-house extension for DOORS named Verification DOORS Integration (VERDI). Tailored to meet the strict requirements of space operations, VERDI integrates verification data with requirements and linking it to other systems. This add-on reduces manual effort, minimizes errors, and ensures that discrepancies are effectively managed throughout the project lifecycle. VERDI offers a powerful extension to DOORS that significantly streamlines and strengthens the verification process, resulting in more reliable and compliant outcomes.

During the GSRE project, VERDI enhanced verification processes by integrating with the existing requirements management system, improving traceability, and reducing manual effort through automation. Its real-time reporting and discrepancy management features streamlined issue resolution. On the other hand, the validation activities of the S3 GSRE project relied on traditional and manual methods. Validation activities were conducted through manual testing, spreadsheet tracking, and team-specific tools. Test cases were manually linked to operational requirements, and discrepancies were tracked using standalone systems.

This paper will demonstrate how developing add-ons that expand the capabilities of DOORS, like VERDI, can enhance the execution of large-scale projects such as the Sentinel-3 GSRE. Integrating VERDI into the verification process improved traceability, streamlined operations, and minimized manual errors, ultimately boosting the efficiency and reliability of the mission. The insights from this project highlight the significant benefits of using dedicated tools to optimize the management of complex projects.

Furthermore, this paper explores the potential benefits of utilizing DOORS VERDI in the validation phase of test campaigns for both future and ongoing missions. As an example, the validation phase of the S3 GSRE project is examined to show how the implementation of VERDI could have changed the validation processes and overall effectiveness of the project.

Keywords: Copernicus, Verification, Validation, VERDI, Re-Engineering, Operations

Acronyms/Abbreviations

DOORS	IBM Rational Dynamic Object Oriented Requirements System
EDEDaM	EUMETSAT DOORS Engineering Data Model
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FOS	Flight Operations Segment
GCP	Ground Control Procedures
GSRE	Ground Segment Re-Engineering
MME	Multi Mission Element
MPF	Mission Planning Facility
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
ORR	Operations Readiness Review
OVT	Operations Validation Test
PDGS	Payload Data Ground Segment
PDP	Payload Data Processing
RMT	Requirement Management Tool
TRB	Test Review Board
TRR	Test Readiness Review
VCB	Verification Control Board
VCD	Verification Control Document
VCM	Verification Control Matrix
VERDI	VERification DOORS Integration

1. Introduction

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) stands as an integral part of global weather monitoring and climate research. Established in 1986, EUMETSAT operates a sophisticated fleet of meteorological satellites that deliver crucial data for weather forecasting, climate monitoring, and environmental surveillance. Its mission is to provide accurate, timely, and reliable satellite data, enhancing the safety, security, and well-being of communities around the globe. Through collaboration with national meteorological services, international organizations, and space agencies, EUMETSAT plays a critical role in understanding and mitigating the impacts of climate change and extreme weather events.

EUMETSAT's collaboration with international partners, such as NASA, NOAA, and ESA, is a critical aspect of its operations. These partnerships facilitate the sharing of expertise, resources, and data, ensuring a coordinated approach to global weather and climate monitoring.

EUMETSAT's current satellite fleet includes the Meteosat series, which offers geostationary coverage over Europe, Africa, and the Indian Ocean, and the Metop series, which provides polar-orbiting observations for global coverage. A significant aspect of EUMETSAT's operational portfolio is its involvement in the Copernicus program, the European Union's Earth observation initiative. As part of this collaboration, EUMETSAT is responsible for the operation of the Sentinel-3 mission, dedicated to marine and land surface monitoring. Sentinel-3's instruments provide critical data for oceanography, vegetation monitoring, and climate studies. The mission supports a wide range of applications, from tracking sea-level rise and ocean health to assessing land use changes and agricultural productivity.

Looking ahead, EUMETSAT's mission portfolio will expand with the upcoming launch of the next satellite of Meteosat Third Generation, Metop Second Generation, Sentinel-3C, and Sentinel-6B, further enhancing its capability to deliver critical Earth observation data in the coming years. As the organisation continues to launch more missions, the existing ground infrastructure will need to be upscaled, with many systems requiring redesign to accommodate the new demands. The expansion of the ground segment involves upgrading communication networks, improving data processing capabilities, and enhancing the storage and distribution systems to handle the vast amounts of data efficiently, all of these whilst controlling and optimising the associated cost

Managing the complexity of these large-scale missions requires robust systems engineering practices. EUMETSAT must balance diverse requirements, integrate advanced technologies, and ensure the reliability of its systems.

Verification and validation processes are critical. These processes ensure that the ground systems meet their design requirements and operate effectively. By adhering to these principles, EUMETSAT minimizes risks and ensures the success of its missions.

One of the key challenges EUMETSAT faces is ensuring that its expanded ground segment can effectively manage the increasing complexity of satellite operations and data flows while avoiding excessive costs or operational inefficiencies. An example of such a project is the Sentinel-3 GSRE initiative [1], which aimed to modernize and optimize the infrastructure supporting the Sentinel-3 mission. This paper will explore how expanding of the capabilities of DOORS, a leading requirements' management tool, by developing verification support add-ons, such as VERDI, can improve the execution of large-scale projects like the Sentinel-3 GSRE, with a particular focus on streamlining verification activities. Furthermore, it examines the potential benefits of utilizing VERDI in the validation phase of test campaigns for both future and ongoing projects. By leveraging advanced tools and methodologies, EUMETSAT aims to ensure the reliability and efficiency of its ground segment, enabling it to meet the demands of current and future missions. It is important to note that VERDI is not part of the baseline but rather a supplementary add-on that EUMETSAT created as part of its commitment to finding more efficient and innovative ways to optimize operations and enhance mission success. Additionally, EUMETSAT continuously evaluates other tools and options to further improve performance and address evolving challenges in satellite operations.

2. Verification at EUMETSAT: Methodologies, Tools, and Best Practices

EUMETSAT's verification processes are designed to align with ECSS standards and best practice. EUMETSAT applies a rigorous and systematic approach to verification to ensure the quality and reliability of satellite systems, particularly for complex space missions like Sentinel-3. Verification at EUMETSAT is defined as a structured process that provides objective evidence that a system fulfils its specified requirements. The verification process is usually requirement-centric, meaning that the requirements serve as the verification reference, and the system in a defined configuration is the subject of verification. Once the system reaches the operational maturity, verification is driven by the need e.g. nominal upgrades, repairs, maintenance, and overhaul.

Two phases are distinguished in the context of verification. During development, verification is the primary means of reducing uncertainty and ensuring system acceptance. In the operational phase, verification is used to address anomalies, upgrades, or maintenance tasks, ensuring continued system reliability. Given that the Sentinel-3 mission is well established, this paper will specifically focus on the verification activities carried out during its operational phase, within the context of the GSRE Project.

2.1 Verification Process at EUMETSAT

The verification process at EUMETSAT follows a structured sequence of activities. These activities include:

- **Verification Planning:**
 - Identify appropriate verification activities for each requirement.
 - Define the scope of verification activities to ensure complete coverage of requirements.
 - Assign verification activities to requirements based on the selected method (e.g., testing, analysis).
- **Verification Execution & Reporting:**
 - Perform verification activities under the responsibility of the applicable engineer.
 - Report progress and results, ensuring alignment with the applicable requirements.
- **Verification Control & Close-out:**
 - Assess the sufficiency of verification results and determine system compliance.
 - Address any departures or insufficient verification activities by looping back to planning or execution.
 - Close out verification by establishing a final status for each requirement, approved by the Verification Control Board (VCB).

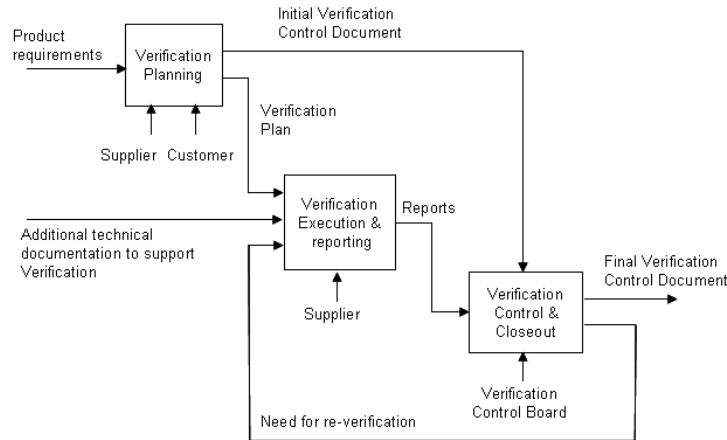


Fig. 1 Verification Process

2.2 Verification Methods

EUMETSAT leverages multiple verification methodologies to ensure system compliance with requirements, including testing, analysis, review and inspection, to provide comprehensive evidence that the system meets its specified requirements. Analysis is used to assess system behaviour under theoretical or simulated conditions, reviews ensure that design and implementation align with requirements, and inspections validate physical or functional characteristics. These methods complement testing, which focuses on empirical validation of system performance. By integrating these diverse verification methodologies, EUMETSAT ensures a thorough and multi-faceted approach to verification, addressing all aspects of system functionality and performance. This approach is overseen by the VCB, which ensures that verification activities are well-coordinated, documented, and aligned with project goals, ultimately delivering a system that is both reliable and compliant with its requirements.

2.3 VCB and Verification Control Document

The Verification Control Document (VCD) is a pivotal element within the verification process, meticulously designed to manage and document the verification activities associated with project requirements. Its structured hierarchy, typically comprising three levels - Requirement Verification Objects, Stage Objects, and Verification Activity Objects - facilitates a clear organization of requirements and their corresponding verification processes. Each VCD is enriched with a variety of attributes that capture essential information, such as the Verification Stage, which indicates the specific phase of verification, and the Verification Method, which defines the approach taken for verification, such as Analysis, Inspection, or Testing. The Verification Status attribute reflects the outcome of these activities providing stakeholders with a comprehensive view of compliance progress. Additionally, the Compliance Status and Close-Out Status attributes further enhance the VCD's utility by indicating whether requirements are compliant and whether all verification activities have been completed. A notable feature of the VCD is its integration with dynamic attributes that automatically extract and update information from linked modules, such as the Requirement Module and Test Specification Module, ensuring accuracy and efficiency in tracking verification statuses. The inclusion of a consolidation script automates the collection of verification activity statuses, streamlining the decision-making process during VCB meetings. Furthermore, the VCD can be customized and viewed in various formats, allowing for tailored reporting that meets the diverse needs of project stakeholders. Overall, the VCD serves as a comprehensive framework for managing verification activities, ensuring that all requirements are systematically verified and documented, thereby enhancing the overall quality and accountability of project deliverables.

2.4 Verification vs. Validation

As this paper will also address validation, it is important to clearly distinguish between verification and validation. While these processes are complementary, they serve distinct purposes. Verification ensures that the system complies with its specified requirements, providing objective evidence of functionality and performance. In contrast, validation ensures that the system is acceptable for its intended use, taking into account any remaining uncertainties. It is important to underline that verification cannot replace validation, as it only confirms compliance with requirements, not the system's operational suitability in real-world conditions.

3. Introduction to DOORS at EUMETSAT

In the context of modern systems engineering, particularly in the space sector, the complexity of managing requirements and verification processes has imposed the implementation of advanced tools and methodologies. One of the invaluable tools available on the market that offers robust capabilities for requirements management, traceability, and verification is DOORS.

DOORS is a leading Requirements Management Tool (RMT) designed to facilitate this process. DOORS provides a platform for capturing, organizing, and maintaining requirements, enabling teams to manage large volumes of information while ensuring traceability, consistency, and compliance with project objectives [2].

Capitalizing on these features, EUMETSAT has developed a tailored framework known as the EUMETSAT DOORS Engineering Data Model (EDEDaM), which optimizes the use of DOORS for requirements and verification engineering. EDEDaM was specifically developed to address the need for a tailored solution that optimizes the use of DOORS by offering a comprehensive, structured, and standardized framework for requirements and verification engineering. Unlike generic implementations, EDEDaM is tailored to EUMETSAT's specific operational needs. This customization is critical for managing the unique challenges of mission specific systems, as well as the multi-mission elements.

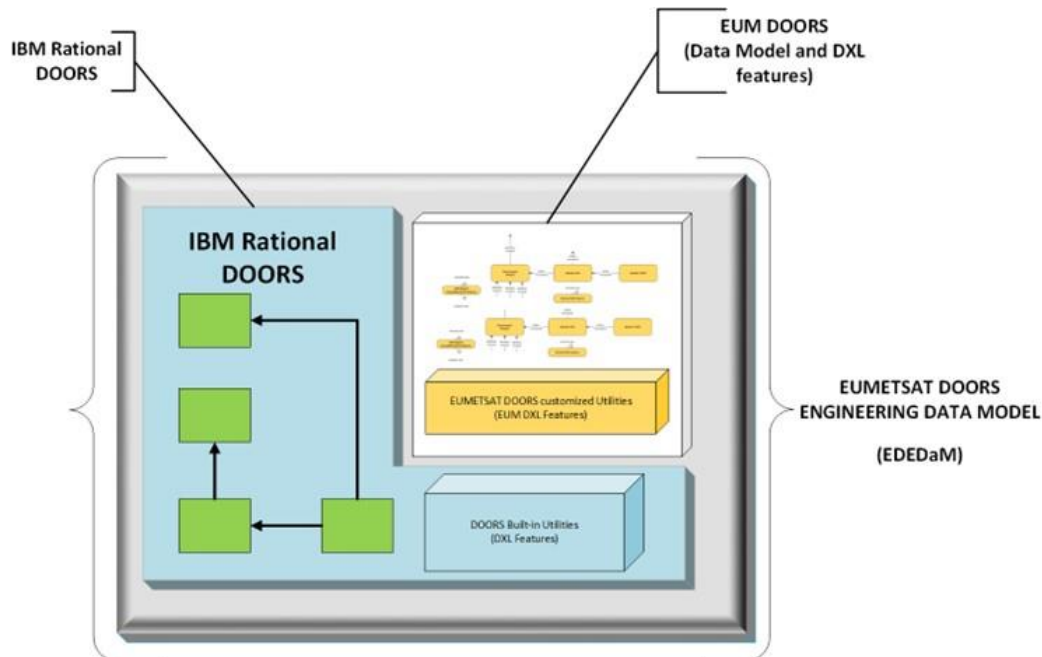


Fig. 2 Architecture of EDEDaM

3.1 Key Objectives of EDEDaM

EDEDaM serves as a comprehensive framework for EUMETSAT's Requirements and Verification Engineering (RVE) activities. Its primary objectives include:

- **Standardizing Requirements Management:** EDEDaM provides a unified approach to capturing, organizing, and tracking requirements across all levels of a system's hierarchy. This ensures that requirements are clearly defined, consistently managed, and easily traceable throughout the project lifecycle.
- **Enabling Verification Control:** The framework integrates verification activities into the requirements management process, ensuring that each requirement is systematically validated. This includes defining verification methods, documenting results, and maintaining traceability between requirements and verification artifacts. This objective is covered by VERDI add-on.

- **Supporting Multi-Mission and Service Development:** EDEDaM is designed to handle the complexities of multi-mission elements, where overlapping lifecycles and interdependencies must be managed. It also supports service development by enabling both top-down requirement definitions and bottom-up capability declarations.
- **Facilitating Reuse and Adaptation:** The framework includes mechanisms for managing generic requirements and instantiating them in specific projects. This promotes reuse, reduces redundancy, and ensures consistency across different missions and programs

3.2 Modules Structure

DOORS provides a consistent structure to manage the verification process through various modules:

- **Requirements Module:** This module contains individual requirements populated with System Requirements Document information.
- **Verification Control Data (VCD) Module:** Generated by DOORS, this module includes verifiable entities linked to the requirements.
- **Test Specification Module:** This module is populated with test cases, procedures, and steps, linking back to the requirements, and providing fields for recording test outcomes and anomalies.

3.3 VERDI Add-on

The VERDI framework is an add-on to the DOORS RMT, specifically designed to enhance verification engineering processes. VERDI aims to streamline the verification process by providing a structured approach to defining roles, stages, and responsibilities. It facilitates the management of verification activities throughout the lifecycle of a project. It provides a clear definition of key terms such as requirement object, verification object, verification stage, and verification activity. VERDI allows users to define and manage various verification activities associated with requirements. This includes specifying the methods of verification, the stages at which verification occurs, and the criteria for success (pass/fail criteria). The framework supports the storage of pass/fail criteria within DOORS, enabling automatic calculation of verification statuses for test activities. This is particularly useful in complex scenarios where many-to-many relationships exist between requirements, stages, and criteria.

In addition, VERDI extends its functionality by linking verification activities at lower levels, based on the predefined allocation set up in the relevant requirement document. That covers verification activities not only on the ground segment level but also on facility and sub-segment system level providing transparency and control over verification activities, while also streamlining the process for complex, multi-levelled projects.

VERDI is fully integrated with the DOORS RMT, allowing for seamless interaction between requirement management and verification processes. This integration ensures that all verification activities are linked to their corresponding requirements, providing traceability and accountability.

Beyond these capabilities, VERDI also extends its functionality to interact with other essential DOORS modules, including the Requirement Module and Test Specification. By facilitating direct communication between these modules, VERDI enhances the ability to track and manage requirements across multiple stages, ensuring that each requirement is not only verified but also tested in alignment with defined specifications.

The framework is designed to handle various use cases, from simple verification scenarios to more complex cases involving multiple stages and methods. It provides a flexible and scalable solution for managing verification activities across different projects.

3.4 VERDI and VCD

The relationship between the VERDI framework and the VCD is integral to the effective management of verification activities within the DOORS Tool. VERDI serves as an add-on that enhances the capabilities of the VCD by providing a structured approach to defining roles, stages, and responsibilities in the verification process. While the

VCD acts as a comprehensive repository for documenting verification activities, including attributes such as verification stages, methods, and compliance statuses, VERDI facilitates the organization and execution of these activities by establishing clear methodologies and pass/fail criteria. This synergy allows for seamless integration, where the VCD captures the outcomes of verification efforts defined by VERDI, ensuring that all verification activities are traceable to their corresponding requirements.

4. Sentinel-3 Ground Segment Re-Engineering

The Sentinel-3 Ground Segment Re-Engineering project was a comprehensive effort aimed at modernizing and migrating the Sentinel-3 mission's ground segment. Several key challenges and future requirements of the Sentinel-3 mission were identified and addressed. One of the primary drivers for the re-engineering effort was the need to resolve hardware obsolescence. The primary driver for this re-engineering effort was the need to address the aging infrastructure and its risk to the reliability and continuity of operations. As the technology evolved, it became clear that the hardware and software systems supporting the ground segment were requiring upgrades to ensure long-term functionality.

A central aspect of the re-engineering was the upgrade of the hardware and software of two sub-systems:

- **Payload Data Processing (PDP)** known as the Payload Data Ground Segment (PDGS) in the legacy system, is responsible for processing the satellite's data and transforming it into actionable information for scientific, operational, and commercial applications.
- **Flight Operations Segment (FOS)** is responsible for satellite monitoring and control by managing all platform activities and commanding payload schedules throughout the mission phases. This covers Mission Control System, Flight Dynamics Facility and, following the GSRE project, Mission Planning Facility (relocated from the old PDGS).

The integration of the Mission Planning Facility (MPF) into the FOS sub-segment was another element of the re-engineering process. Although the MPF was always logically considered part of the FOS, it was physically located in the PDGS servers. The decision to move it physically was primarily driven by the need to align with EUMETSAT's standard practice. By incorporating the MPF into the broader FOS structure, EUMETSAT created a more streamlined and efficient operational flow.

A major goal of the re-engineering project was also to fully integrate the Sentinel-3 Ground Segment with Multi-Mission Elements (MMEs) covering dissemination and archival of the scientific products and monitoring and reporting of the system, some of which were new or substantially revised since the original development of the Sentinel-3 ground segment. The Sentinel-3 ground system was aligned with the standardised shared computing and storage infrastructures to improve efficiency, reduce redundancy, and optimize resource utilization across multiple missions. Additionally, implementing EUMETSAT's standards for security, architecture, and virtualisation ensured that the ground segment would remain robust, scalable, and adaptable to future needs.

The re-engineering also sought to improve operations and maintenance concepts, with an emphasis on extending the capabilities of the ground segment to support future Sentinel-3 satellites, such as Sentinel-3C and -D. The latter was particularly important for ensuring that EUMETSAT would be able to continue supporting the Sentinel-3 mission as new satellites were launched, with verified growth capabilities for future needs. Finally, the re-engineering project included the transition of services for the Backup Control Centre to the new infrastructure, ensuring continuity and reliability for all operational activities.

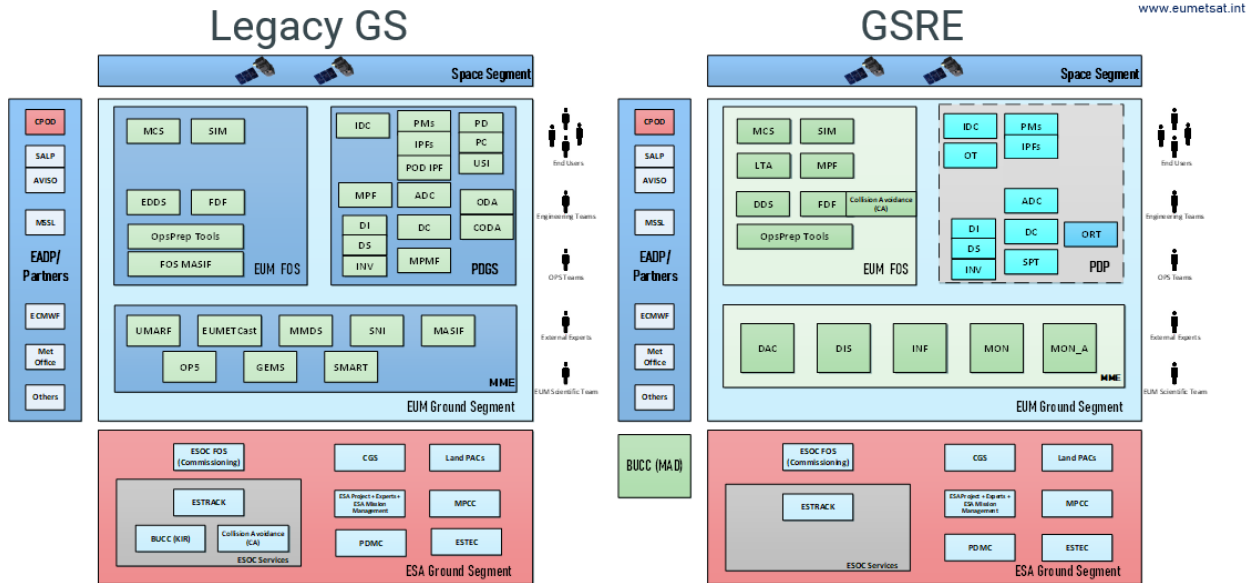


Fig. 3 Comparison of the Legacy and GSRE Ground Segment

4.2 Verification during Sentinel-3 GSRE

Central to the verification process was VERDI, which has been instrumental in streamlining verification activities. This section provides a detailed overview of the verification process during the GSRE project, focusing on the application of VERDI and its role in ensuring compliance and traceability.

4.2.1 Application of VERDI in the GSRE Project

VERDI was fully applied at the ground segment level and sub-segment system level within the GSRE project. Its primary purpose was to provide a structured and standardized approach to verification, ensuring that all requirements were systematically validated and traceable.

However, VERDI was not used for sub-segment internal verification due to conflicts with existing tools and approaches for the re-used parts, as well as the involvement of external suppliers in the development process. Additionally, VERDI was not used for the verification of MMEs, as their verification documentation setup was not based on the framework.

Despite these limitations, the use of DOORS for requirements management up to the sub-segment level remained mandatory, ensuring consistency and traceability across the project. This approach allowed the GSRE project to balance flexibility with standardization, accommodating diverse verification methodologies while maintaining overall control.

4.2.2 Verification Control Matrices and Documentation

A basis of the verification process in the GSRE project was the Verification Control Matrices (VCMs), which were created for each applicable requirements document. These matrices were maintained and updated using the VERDI tool, ensuring consistency and accuracy throughout the project lifecycle. The VCMs served as a central repository for verification activities, linking requirements to their corresponding verification methods, results, and statuses.

At the Ground Segment level, the Sentinel-3 Ground Segment VCD captured the verification status of the requirements. The VCD was regularly updated to reflect the progress of verification activities, consolidating results from all levels in a bottom-up approach. This ensured that the verification status at each level was accurately reflected in the overall project documentation.

4.2.3 Verification Methods and Activities

The verification process in the GSRE project included a variety of methods:

- **Testing:** Empirical validation of system performance under controlled conditions.
- **Analysis:** Theoretical evaluation of system behaviour using models and simulations.
- **Review of Design:** Formal assessment of design documentation to ensure compliance with requirements.
- **Inspection:** Physical or functional examination of system components.

These methods were systematically applied based on the verification plan, ensuring that all requirements were validated using the most appropriate approach. The results of these activities were documented in the VCMs and reviewed by the relevant stakeholders.

4.2.4 Verification Control Board

To oversee the verification process, a dedicated VCB was established. The VCB met regularly to assess the overall verification status, review verification results, and confirm the closure of requirements verification. The board included representatives from the Ground Segment, Subsegments, Operations, Configuration Management, Quality Assurance, and Project Management, ensuring a comprehensive and collaborative approach to verification. Since testing was one of the verification methods, the Test Review Board (TRB) was responsible for reviewing and assessing test results, while the VCB was tasked with evaluating the overall verification status.

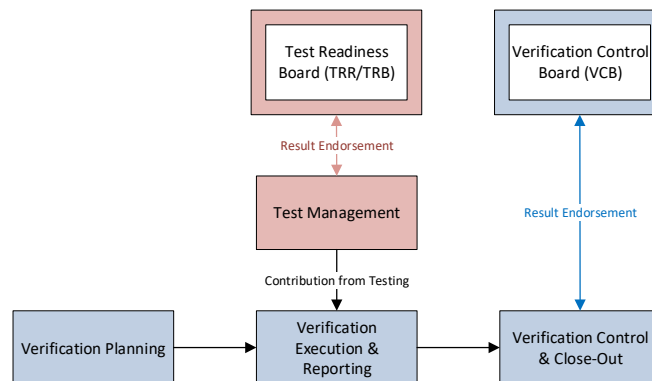


Fig. 4 Testing as Method of Verification

The VCB played a critical role in ensuring that verification activities were properly executed and documented. It also addressed any discrepancies or issues identified during verification, ensuring that all requirements were fully validated before system acceptance.

4.3 Validation during Sentinel-3 GSRE

The Sentinel-3 GSRE Project required a comprehensive validation process to ensure that the newly developed ground segment could effectively support operational services. Validation, distinct from verification, focuses on confirming that the system meets its intended operational objectives and user needs.

The primary objective of the operational validation process was to validate the system's operational activities, ensuring that the Operations Team could effectively manage the ground segment after its integration and verification. The validation process aimed to:

- Confirm the readiness of the ground segment for operational use.
- Ensure that all operational procedures, including nominal and contingency scenarios, were thoroughly tested.

- Prepare the ground segment for the Operational Readiness Review (ORR), including the migration of data and archives from the legacy system.

The validation process was structured into three phases, each focusing on different levels of operational readiness and complexity. These phases were designed to progressively build confidence in the system’s operational capabilities.

4.3.1 Ground Segment Validation Strategy

The operational validation of the ground segment followed a phase-based approach, ensuring a systematic and thorough evaluation of the system’s operational capabilities. The three phases were:

1. Phase 1: Stand-alone Procedures and Tasks Pre-Validation

This phase focused on validating low-level Ground Control Procedures (GCPs) in a stand-alone manner. The objectives were to:

- Assess the correctness of procedure content with respect to its objectives.
- Conduct informal dry-run testing on the early offline environment. Any testing not possible during this phase was completed via inspection, ensuring that all procedures were validated before progressing to the next phase.

2. Phase 2: Facility-Level Operations and Delta-Operations Requirements Validation

This phase involved the coordinated execution of procedures grouped. The objectives were to:

- Validate all processes and procedures in a comprehensive set of nominal and contingency scenarios.
- Ensure that the system could handle realistic operational cases, including unexpected events.
- Provide a building block for the final end-to-end validation.

3. Phase 3: End-to-End Ground Segment Operations Validation

The final phase focused on validating the entire ground segment, including its external interfaces. The objectives were to:

- Exercise all operational processes and procedures in a nominal timeline.
- Confirm the system’s readiness for operational use.
- Ensure that the new ground segment could seamlessly replace the legacy system without disrupting services.

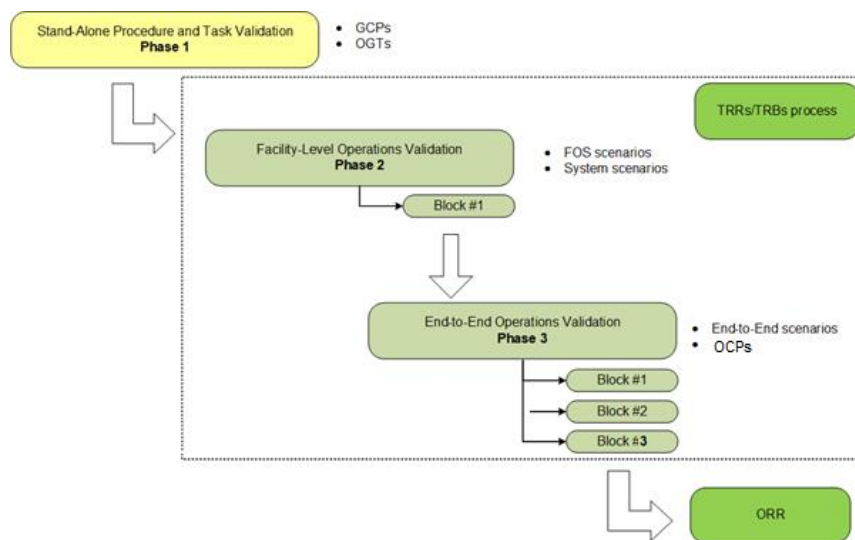


Fig. 5 Ground Segment Operations Validation Phases

The validation process was organized by Operational Validation Tests (OVTs), designed to validate the overall functionality and operational readiness of the ground segment. The OVTs focused on validating operational procedures, guides, and interface control documents, ensuring comprehensive coverage of end-to-end scenarios. The OVTs were conducted in alignment with formal Test Readiness Review (TRR) and Test Review Board (TRB) processes, which ensured systematic planning, execution, and review of test activities. The TRR confirmed test readiness by reviewing plans and resources, while the TRB monitored progress, assessed results, and approved test closures.

4.3.2 *Operational Scenarios for Validation in the Sentinel-3 GSRE Project*

The main driver for the validation was execution of operational scenarios, which served as the foundation for validating the ground segment's operational capabilities. These scenarios were designed to ensure comprehensive coverage of both ground and satellite operational processes.

Operational scenarios were a key component of the validation campaign, as they provided a structured approach to testing the ground segment's ability to support operational activities. Derived from the Reference Operations Plan, these scenarios ensured that all critical processes and tasks are exercised under realistic conditions.

Operational scenarios were designed to be flexible, allowing for adaptation based on the availability of system resources and project constraints. Based on each scenario a set of test cases were created, which was then executed either in full or in part, depending on the specific needs of each validation campaign. This flexibility ensures that validation activities could be tailored to the project's evolving requirements while maintaining a systematic approach. By focusing on these components, the scenarios ensured that all critical aspects of the ground segment are validated, from low-level procedures to end-to-end operational processes.

5. Discussion: Verification and Validation Processes in the Sentinel-3 GSRE Project

The Sentinel-3 GSRE Project required a robust and systematic approach to both verification and validation to ensure the reliability, functionality, and operational readiness of the ground segment. While verification focused on confirming that the system met its specified requirements, validation ensured that the system fulfilled its intended operational objectives. The framework played a big role in addressing the challenges of verification, but its applicability to validation was limited.

5.1 *Verification Process and the Role of VERDI*

The verification process in the GSRE project was designed to provide objective evidence that the ground segment met its specified requirements. This process, which is critical for ensuring that the system functions as expected, was requirement-centric, meaning that each requirement was systematically validated through a variety of methods, including testing, analysis, inspection, and review. In traditional verification control, these methods have been primarily managed manually or through isolated tools that often struggle with tracking complex dependencies and maintaining real-time consistency.

Traditionally, verification control relied heavily on spreadsheets, manual documentation, and document-based tracking systems. While these methods have been widely used, they often posed challenges in terms of traceability, efficiency, and the risk of human error. Verification processes based on manual tools required time-consuming updates and often lacked real-time visibility into the status of requirements and verification progress, making it difficult to ensure comprehensive compliance and alignment with project goals. Additionally, managing many-to-many relationships between requirements, test cases, criteria, and validation steps was cumbersome and prone to errors.

The GSRE project was particularly complex due to its scope and the coordination required across multiple teams and system elements. Verification activities needed to be closely aligned not only on the ground segment level but also on facility and sub-segment system level. Such extensive coordination across different layers of the project made tracking and ensuring the consistency of verification efforts even more challenging. This multi-faceted and dynamic environment demanded a solution that could effectively synchronize verification tasks across all levels of the project.

As the complexity of projects like the GSRE increased, there was a pressing need for a more robust and scalable solution. This is where VERDI proved invaluable.

VERDI DOORS significantly streamlined the verification process by providing a structured and automated framework for managing verification activities. Unlike traditional methods, VERDI integrated multiple aspects of the verification process, allowing for more accurate, real-time monitoring and management. Key contributions of VERDI included:

- **Integration with DOORS:** Traditional verification tools often operated in isolation, creating gaps between the management of requirements and verification activities. VERDI add-on solved this by integration with IBM DOORS. It ensured that all verification activities were aligned with project goals and requirements, providing a unified framework for managing both the requirements and verification processes. Any changes made to the requirements in DOORS, such as the addition or removal of requirements, were automatically reflected in the VCDs and other verification artifacts. This dynamic linking between requirements and verification documentation eliminated the need for manual updates, ensuring that all project components remained consistent and up to date.
- **Traceability:** VERDI ensured that all verification activities were carefully linked to their corresponding requirements, providing end-to-end traceability. This was critical for impact analysis and compliance assessment, as it allowed for quick identification of gaps or inconsistencies in the verification process. By tracking every requirement through all verification phases, VERDI enabled the verification team to maintain a clear audit trail, facilitating easier validation and review.
- **Automation:** A major limitation of traditional verification methods was the need for manual updates and status calculations. VERDI enhanced this by automating the calculation of verification statuses based on predefined pass/fail criteria. This automation not only reduced the time and manual effort needed but also minimized human errors that could compromise the integrity of the verification process. By having automated status updates, project managers and engineers could quickly assess verification progress and make informed decisions about next steps.
- **Real-Time Visibility:** VERDI provided real-time visibility into the verification and compliance status at different levels of the project, including the facility, sub-segment, and segment levels. This feature allowed project managers and verification teams to monitor the overall progress of the verification process and assess compliance with the project's requirements at any given time. This capability was essential for maintaining alignment across various teams and ensuring that verification milestones were met consistently throughout the project.
- **Centralized Management:** Another challenge with traditional verification methods was the decentralized nature of documentation. VERDI addressed this issue by providing a centralized repository for all verification artifacts, such as VCMs and VCDs. This centralization ensured consistency across all verification documents, promoted accountability, and made it easier for stakeholders to access up-to-date information. The centralized system also allowed for better coordination and communication among team members, ensuring that everyone was aligned on the verification status and outstanding tasks.
- **Coordination Across Segments and Facilities:** One of the greatest challenges in the GSRE project was the need for close coordination across all project levels. VERDI provided a framework that allowed for seamless coordination, ensuring that verification activities were synchronized across facility, sub-segment and segment levels. It enabled clear communication and alignment between teams working on different aspects of the project, ensuring that verification tasks were consistently executed, and progress was accurately tracked across all levels.
- **Anomaly Tracking Integration:** Another significant benefit of VERDI was its ability to integrate with EUMETSAT's Anomaly Processing Tool. Anomalies that occurred during the verification process were automatically tracked and linked to the relevant requirements and verification activities. This integration provided real-time visibility into issues that could impact verification progress or system performance, allowing teams to address potential risks or failures quickly and systematically. This streamlined the process of identifying, managing, and resolving anomalies while ensuring that they were fully documented and addressed before final system acceptance.

VERDI's ability to handle complex verification scenarios was particularly significant for the GSRE project. The project required managing many-to-many relationships between various requirements, test stages, and verification criteria, a task that traditional tools often struggled to handle efficiently. VERDI allowed for dynamic linking between these elements, making it easier to understand how changes in one area affected the overall verification process. This capability was crucial for accurately assessing verification progress, identifying issues early in the process, and making adjustments as necessary.

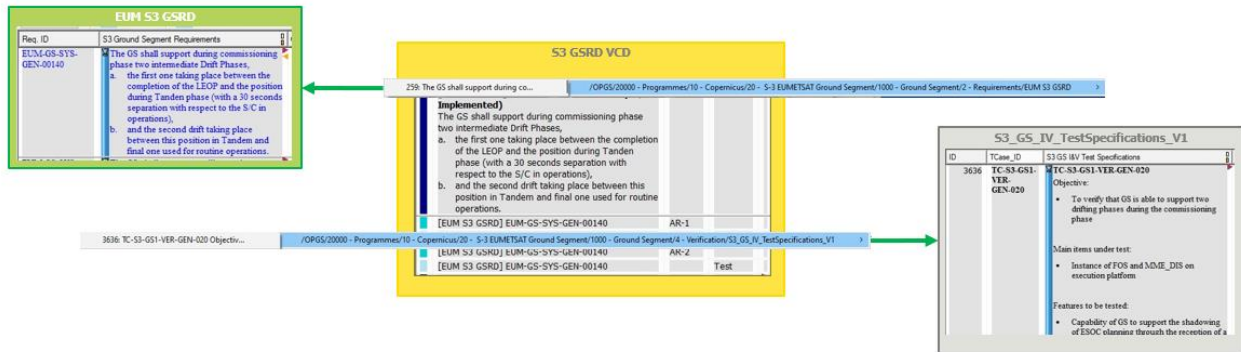


Fig. 6 Linking between modules in DOORS

Additionally, VERDI played a pivotal role in supporting the VCB by providing real-time insights into the verification status and ensuring that all requirements were fully validated before system acceptance. By streamlining the verification process, VERDI not only improved the efficiency of the project but also contributed to the overall quality and reliability of the ground segment.

Requirements	Object Lev	Ver. Results and Summary	Lower Level Requirement Close-Out Status Summary	DXL for Allocate to	Verificatio n Stage	Verificatio n Metho	Verification Level
[EUM S3 GSRD] EUM-GS-SYS-SEC-14360 (1, New) Inactive sessions (sessions without user activity) shall be locked after a configurable time period	5	Compliance Status Summary: 'TBD (LL Open)' ==== Stages ==== [AR-1] -> Compliance Status: "" Method: VLL, Status: (empty) -> 'TBD' [AR-2] -> Compliance Status: "" Method: VLL, Status: (empty) -> 'TBD' ----- LL Activity Status: TBD -----	Open [MODULE NAME] Req. ID: Compliance, Close-Out Stage: Compliance [EUM-S3-FOS-SRD] SEC.ACC.73770: 'C', 'CLOSED' AR2: "" [EUM-S3-PDP-SRD] EUM-PDP-CMN-SEC-11180: 'C', 'CLOSED' PDP V1 OSTR: "" [EUM-S3-SDef_DAC] SYS-0710: 'CS', 'OPEN'	FOS PDP V1 MME All			
[EUM S3 GSRD] EUM-GS-SYS-SEC-14360	5			FOS PDP V1 MME All	AR-1		
[EUM S3 GSRD] EUM-GS-SYS-SEC-14360	6			FOS PDP V1 MME All		VLL	Sub-segment
[EUM S3 GSRD] EUM-GS-SYS-SEC-14360	5			FOS PDP V1 MME All	AR-2		
[EUM S3 GSRD] EUM-GS-SYS-SEC-14360	6			FOS PDP V1 MME All		VLL	Sub-segment

Fig. 7 VCD with the Compliance Status and Lower-Level Status

In summary, while traditional verification methods provided a foundation for validating requirements, VERDI enhanced and modernized the process, enabling more efficient, accurate, and scalable management of verification activities. As the complexity of satellite operation systems continues to increase, tools like VERDI will be critical for ensuring that verification processes are both rigorous and adaptable to evolving needs.

5.2 Exploring The Potential of VERDI in The Validation Context

The validation process in the GSRE project focused on ensuring that the ground segment met its intended operational objectives. This process was organized using OVTs, which centered around validating operational procedures, guides, and interface control documents. The OVTs were conducted in line with

formal TRR and TRB processes, ensuring systematic planning, execution, and review of test activities. The traditional validation management methods were used as they were more suitable to address the operational needs.

While VERDI was not explicitly designed for validation, it could offer some benefits in the following areas:

- **Traceability:** VERDI's ability to link requirements to verification activities could be extended to validation, ensuring that operational objectives, expressed as scenarios, are traceable to their corresponding test cases.
- **Centralized Management:** The tool could provide a centralized repository for validation artifacts, such as operational scenarios and test cases, improving consistency and accessibility.
- **Automation:** VERDI's automation capabilities could streamline the tracking of validation statuses, reducing manual effort and improving efficiency.

Despite its potential benefits, VERDI is not ideally suited for validation due to several limitations:

- **Lack of Operational Context:** VERDI is primarily designed for requirement-centric verification, whereas validation focuses on operational objectives and user needs. This fundamental difference limits its applicability to validation activities. Validation requires a deep understanding of operational scenarios and real-world conditions, which are not fully captured by VERDI's requirement-driven approach.
- **Flexibility:** Validation often involves dynamic and evolving scenarios, particularly in operational testing. VERDI's structured and rigid framework may not provide the flexibility needed to adapt to these scenarios.
- **Expertise Intensive:** VERDI is a complex tool that requires significant expertise, training, and experience to use effectively. This steep learning curve can be a barrier to its adoption, particularly for teams focused on validation, which may not have the same level of familiarity with DOORS or VERDI as verification teams. The need for specialized knowledge can also lead to delays and inefficiencies, especially in large, multidisciplinary projects like GSRE.

While traditional validation methods were appropriate for the GSRE project and helped ensure its success, future projects may benefit from integrating tools like VERDI, keeping in mind the above limitations. As part of this research, Microsoft Access is currently being evaluated for its potential in supporting validation efforts. Such tools could enhance the validation process by improving traceability, centralization, and automation, potentially leading to greater efficiency and consistency in future missions.

6. Conclusion

The VERDI framework played a critical role in enhancing the verification process in the Sentinel-3 GSRE project, providing a structured, efficient, and scalable approach to managing verification activities. Its ability to ensure traceability, automate status calculations, and integrate with DOORS made it an invaluable tool for addressing the challenges of verification. By streamlining these processes, VERDI significantly contributed to maintaining consistency and accuracy throughout the project.

However, while VERDI could offer some benefits for validation, its requirement-centric design, lack of operational context, and steep learning curve limit its effectiveness in this area. Validation requires a more flexible, operationally focused, and user-friendly approach, which may not be fully supported by VERDI. Given these limitations, it is essential for future validation efforts to consider alternative or complementary tools and methodologies that can address the unique challenges of operational validation effectively.

In conclusion, while VERDI remains a powerful and indispensable tool for verification, its use in validation should be carefully considered. A balanced approach, leveraging VERDI's strengths while integrating other tools to address the needs of validation, will enable EUMETSAT to continue ensuring the success and reliability of its missions. By doing so, EUMETSAT can optimize its verification processes while refining its approach to validation in future projects.

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References

- [1] Fernando Pérez-López, Gianni Casonato, Jan P. Weber, Silvia Carosi, Eduardo Sanchez Suárez, Ricardo del Pino, Ignacio Oliva, Antonio Accardo, Andrew Holmes, Dennis Landmann, Hilary K. Wilson, Re-Engineering A Ground Segment – Preparing Sentinel-3 for the Future, 18th International Conference on Space Operations, Montreal, Canada, 26 - 30 May 2025.
- [2] Overview of DOORS, <https://www.ibm.com/docs/en/engineering-lifecycle-management-suite/doors>