DESIGN OF THE INTEGRATION AND TECHNICAL VERIFICATION AND VALIDATION PHASE OF THE GROUND SEGMENT OF THE HYPERSPECTRAL SATELLITE MISSION ENMAP

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ABSTRACT:

EnMAP (Environmental Mapping and Analysis Program) is a German hyperspectral satellite mission, with a ground segment operated by the Earth Observation Center (EOC) and the German Space Operation Center (GSOC) of the German Aerospace Center (DLR). The Ground Segment comprises all the facilities and systems required on Earth to control and operate the mission. It specifically facilitates access for the user segment to the space segment, including the commanding of the satellite, ordering and receiving data, and finally the processing, archiving and distribution of data.

This paper gives an overview of the design of the Integration and Technical Verification and Validation (ITVV) phase of the Ground Segment. It starts with the design of the Ground Segment resulting in the development model, which consists of the requirements imposed on the Ground Segment, the spanning of the product tree with its contributing subsystems and their further differentiation, and the interfaces connecting them providing the needed functionality. This view of the Ground Segment is complemented with a model based on use cases allowing to characterize the Ground Segment by its dynamic behaviour fulfilling the above tasks.

Based on the above knowledge the different stages of the ITVV Phase are presented and the dependencies between the phases are pointed out, to finally guarantee a fully validated mission.

1. INTRODUCTION

EnMAP (Environmental Mapping and Analysis Program) is the first German spaceborne hyperspectral mission. The Earth Observation Center (EOC) at the German Aerospace Center (DLR) has had extensive experience with airborne and spaceborne acquisition, processing, and analysis of hyperspectral images. Jointly with the German Space Operations Center (GSOC), which controls and commands several satellite missions, EOC is responsible for establishing and operating the Ground Segment of the upcoming hyperspectral satellite mission EnMAP.

The mission has been outlined by Stuffler et al. (2007), Rossner et al. (2009) and Kaufmann et al. (2009), with parameters of the mission from the viewpoint of the Space Segment presented by Stuffler et al. (2009). The design of the Ground Segment was described by Müller et al. (2009) Storch et al. (2010), and Habermeyer et al. (2010). The setup of the processing chain was introduced by de Miguel et al. (2010), Müller et al. (2010), Storch et al. (2009), and operational quality control aspects have been covered by Bachmann et al. (2010).

This paper focuses on the design and the organization of the Integration and Technical Verification and Validation (ITVV) Phase of the ground segment. During this phase the ground segment demonstrates its capability to facilitate access for the user segment to the space segment, including the commanding of the satellite, ordering and receiving data, and finally the processing, archiving and distribution of data. This comprises all the facilities and systems required on Earth to control and operate the mission.

The paper is structured as follows: 1) the parameters of the mission; 2) the ground segment's design based on the development model is sketched. This includes the requirements imposed on the ground segment, the projection onto the subsystems, the development of interfaces; 3) this is complemented by supplementary perception based on the major scenarios to take the dynamic behaviour of the ground segment into account; and 4) the concept for the technical verification and validation of the ground segment is presented, with the dependencies of the different stages discussed.

2. THE ENMAP MISSION

The major objectives of the EnMAP mission are to measure, derive, and analyze diagnostic parameters, which describe vital processes on land and water. Geochemical, biochemical, and biophysical parameters are assimilated into physically based ecosystem models, which ultimately provide information reflecting the status and evolution of various terrestrial ecosystems. Based on these quantitative measurements remote sensing standard products can be substantially improved and new user-driven information products will be generated, which could until now only be produced in the framework of scientific airborne hyperspectral campaigns. During the five year mission operation lifespan beginning in 2015, EnMAP will provide information about the status of different ecosystems and their response to natural or anthropogenic changes of the environment (Rossner et al., 2009). This will be evaluated by an international user community comprising research institutions and industry coordinated by the mission principal investigator (Kaufmann et al., 2009) GeoForschungsZentrum Potsdam (GFZ).

The EnMAP satellite will be operated on a sun-synchronous orbit at an altitude of 645 km and a local time descending node set to 11:00 h ± 18 minutes. This will allow the system to observe any location on the globe under defined illumination conditions featuring a global revisit capability of 21 days under a quasi-nadir observation, with an across-track tilt of at most ± 5°. The local time descending node also allows for a maximum reflected solar input radiance at sensor with an acceptable risk for cloud coverage. The satellite has an across-track tilt capability of ± 30° enabling a revisit time of four days (Stuffler et al., 2009). The hyperspectral instrument will be a pushbroom imaging systems with two spectrometers covering a spectral range from 420 nm to 2450 nm. The VNIR (visible and near infrared) portion will comprise approximately 96 bands, resulting in 6.5 nm spectral resolution and a Signal-to-Noise-Ratio of 500, whereas the SWIR (shortwave infrared) will comprise approximately 136 spectral channels, resulting in 10 nm spectral resolution and a Signal-to-Noise-Ratio of 150. Each sensor will have an analogue-to-digital converter resolution of 14 bits (Stuffler et al., 2007).

Orbit	Sun-synchronous
Local Time	11:00±18 minutes
Altitude	645 km
Inclination Angle	97.96°
Global Revisit Capability	21 days
Orbit Period	97 minutes
Pointing Angle	± 30°
Target Revisit Time	4 days
Ground Pixel Size	30m x 30m
Swath Width	30 km
Number of bands	232
Wavelength Range	VNIR: 420 – 1000 nm SWIR: 900 – 2450 nm
Signal-to-Noise-Ratio	VNIR (495 nm): 500 SWIR (2200 nm): 150
Dynamic Range	14 Bit

Table 1: Parameters of the EnMAP Mission

The ground pixel size will remain constant over the whole mission lifespan at a given latitude (e.g. 30 m × 30 m at nadir at 48° northern latitude). With this configuration a pointing accuracy of better than 500 m is expected, which will be improved to a pointing knowledge of better than 100 m by ground processing. The key parameters of the mission are listed in Table 1.

The data can be ordered and will be made available through a state-of-the-art web interface described by Heiden et al. (2010).

3. THE DESIGN OF THE ENMAP GROUND SEGMENT

The Ground Segment is responsible for ordering, commanding, receiving, processing, archiving and distributing the mission's data. To facilitate these duties the established development model includes: Requirements, Product Tree, Interfaces, Assemblies and Test

Plans, and Assemblies and Test Reports (Fig. 2), the numbers below the constituents with a leading "#" indicating the number of elements of the specific constituent type. Müller et al. (2009), Storch et al. (2010) and Habermeyer et al (2010) have discussed the design of the ground segment already. The main issues of the above works are stated here, as an understanding of the following section, where it comes to the verification and validation of the whole Ground Segment will not be complete without them.

To further differentiate the above tasks, requirements were formulated and a product tree was established to fulfil the requirements assigned to the Ground Segment. Among the constituents of the Ground Segment interfaces and interface items were defined. During the ITVV phase the interfaces and interface items are tested. The actual planning of the tests during the Verification and Validation Phase is the matter of discussion in section 4. Requirements, Product Tree and Interfaces are addressed in the following subsections.

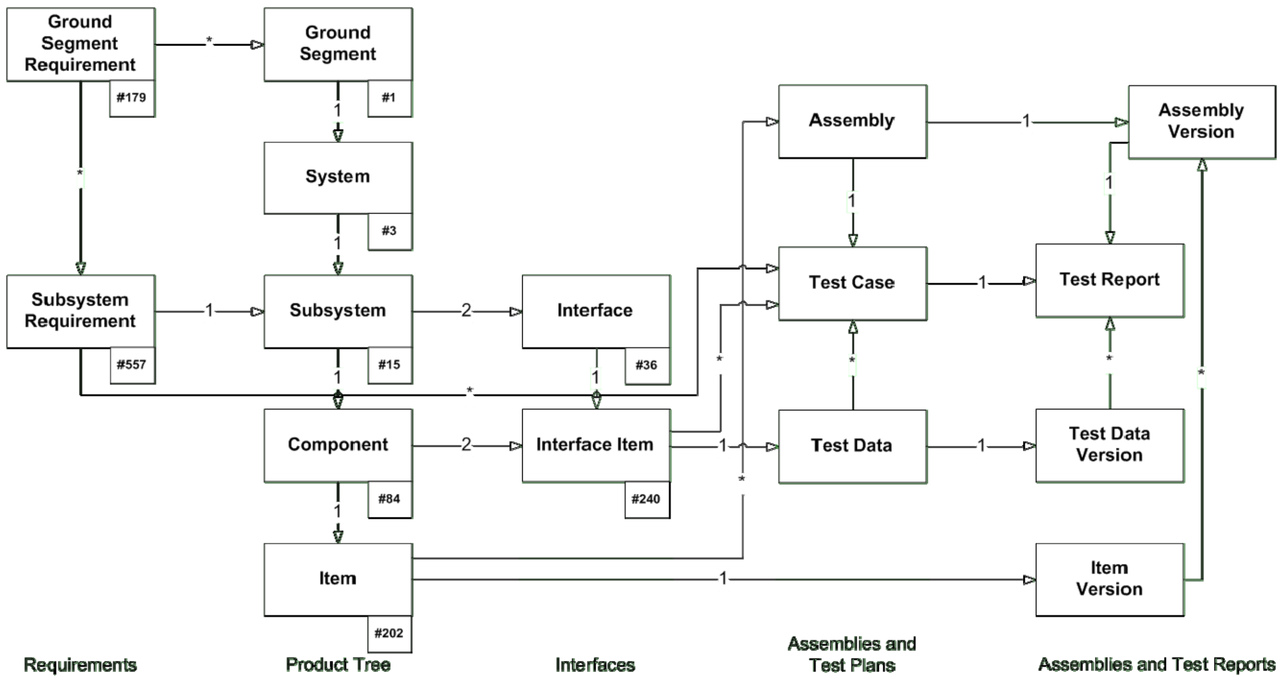

Figure 1. Development Model of the Ground Segment

3.1 Requirements

The development of the Ground Segment is driven by the ground segment requirements provided by the Space Agency. The ground segment requirements cover all major aspects of the Ground Segment, in particular the operational phases. The 179 ground segment requirements are decomposed into 557 subsystem requirements, each traced to exactly one particular subsystem. This includes a statement on the subsystem compliance and is performed such that the functionality of the Ground Segment as a whole is guaranteed by the set of subsystems, and such that the ground segment requirements are fulfilled.

3.2 Product Tree with Subsystems

The previously mentioned subsystems forming the Ground Segment are grouped into three systems, namely the Mission Operations System (MOS), the Payload Ground System (PGS), and the Processor, Calibration, and Validation System (PCV). This separation is necessary just for management purposes since the subsystems are assigned to different organizations with different management responsibilities. Each subsystem is further decomposed into components. The subsystems are the first level seen from the Ground Segment as root of the product tree where this separation takes place. A component can typically provide a specific functionality on its own. Therefore each component is further decomposed into items which form the leaves of the product tree.

The Ground Segment which fulfills all agreed ground segment requirements is decomposed into the following 15 subsystems (Figure 3 provides an overview of the subsystems as well as the interfaces spanned between them):

- **Instrument Planning** provides a state-of-the-art web-portal to the user segment to manage their proposals and observation requests. It also supports technical scientific review.
- **Mission Planning** arranges observation requests, data downlinks, and other planned activities in a conflict-free timeline that does not violate any resource constraints.
- **Ground Data Systems** consists of the world-wide ground station network for telemetry and telecommanding. The main S-Band ground station with its antenna and on-site equipment is located in Weilheim, Germany. It is a multi-mission facility.
- **Neustrelitz Ground Station** represents the main X-Band ground station with its antenna and on-site equipment located in Neustrelitz, Germany. It is a multi-mission facility and responsible for reception of mass-data.

- The **Processing System** generates archive products as well as spectral, radiometric, geometric, or atmospheric corrected hyperspectral images on an operational basis.
- **Data and Information Management System** is a multi-mission facility which combines distributed archiving and dissemination of data products also to the user segment through an online interface.
- **Production Management** handles all request work-flows related to user orders and provides help desk functionalities.
- **Instrument Monitoring** analyses the long-term behavior and malfunctions of the instrument estimated based on housekeeping telemetry, calibration data, and Earth measurements.
- **Auxiliary Data Ingestion** collects all supplemental information for hyperspectral image generation such as spectral, radiometric, and geometric calibration and reference tables as well as orbit and attitude products.
- **Spectral and Radiometric Calibration** generates calibration and reference tables based on dark current measurements, measurements of internal sources such as lamps and Light-Emitting Diodes, and Sun measurements for spectral and radiometric characterization and calibration.
- **Validation and Ground Calibration** generates geometric calibration and reference tables based on different on-ground measurements. Additionally, the accuracy of all processing levels of hyperspectral data is assessed to detect calibration or processing errors.
- **Flight Dynamics** comprises orbit and attitude determination as well as orbit prediction based on relevant on-board data, such as data from the Global Positioning System and on-ground measurements such as ranging and angle tracking.
- **Flight Operations** monitors and controls the satellite and support operations. It is used to generate and send telecommands to the spacecraft and to receive its telemetry. Within the control room environment the data streams are stored and analyzed as well as simulations are performed.
- The **Development Processor** is used as a platform under version control for the development of the processing chain to be integrated in the Processing System (see above). This comprises processor elements to generate quality information, quicklooks, water-land masks, cloud masks, tiling, correction of known effects like odd-even and non-uniformity, conversion to physical at-sensor radiance values, direct geo-referencing with image-to-image adjustment and atmospheric corrections separated for land and water surface applications.
- The **Communication Subnet** (EOC part) and **Infrastructure** (GSOC part) connects all subsystems located in Germany, namely Berlin, Munich, Neustrelitz, Oberpfaffenhofen and Weilheim.

3.3 Interfaces

There are 36 interfaces between different subsystems of the Ground Segment as well as additional subsystem internal interfaces and 8 interfaces for Ground Segment external entities. These interfaces comprise 240 interface items connecting different subsystems of the Ground Segment.

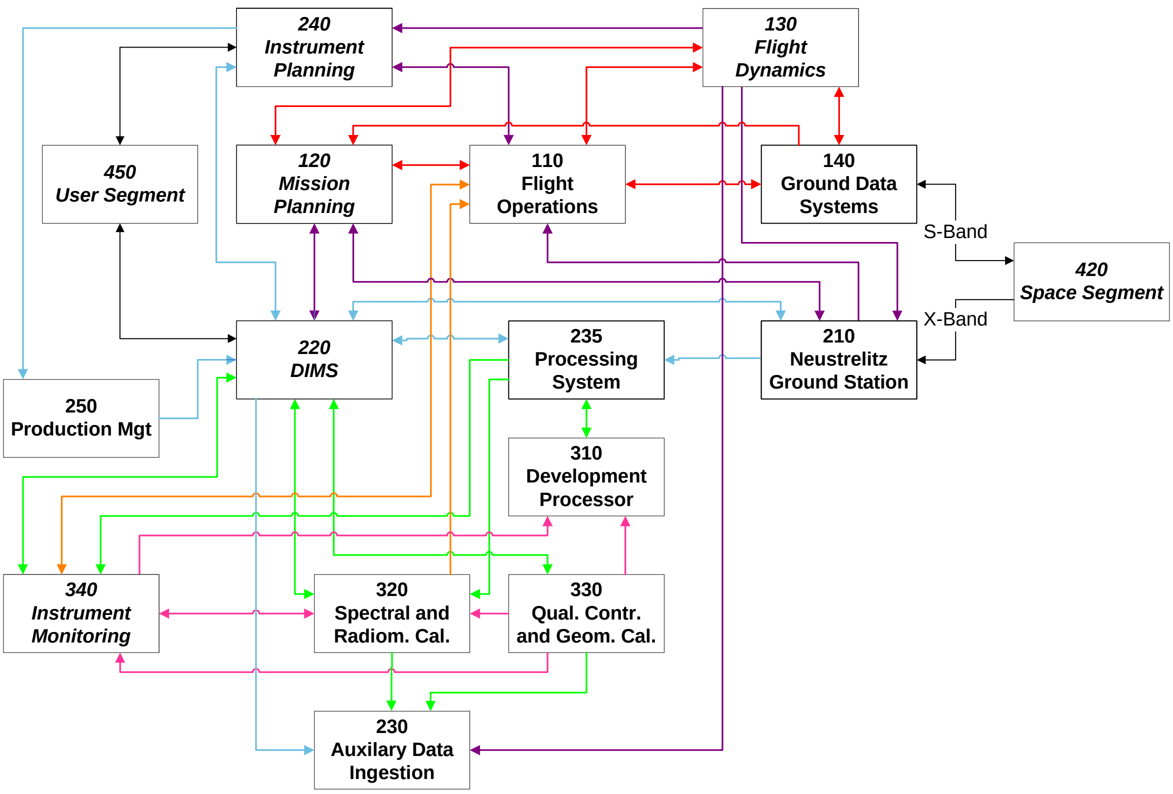

Figure 2. The Subsystems of the Ground Segment and the interfaces defined between them

3.4 Scenarios

The static architecture of the Ground Segment with its product tree and interfaces is complemented by major scenarios to identify the dynamic behavior of the Ground Segment. This view allows a bigger picture of the ground segment in the context of the tasks to be fulfilled. Scenarios are formulated in the context of user administration, proposal handling, ordering process, processing of Earth observation requests with a profound quality control as well as the handling of calibration observation requests and the resulting generation of calibration table products. Besides those user-oriented scenarios, additional scenarios covering monitoring, commanding and maintenance of the satellite, such as monitoring of the instrument, monitoring of the satellite, commanding of satellite, anomaly handling, orbit maintenance, collision avoidance, onboard software maintenance and on-board calibration cyclogram maintenance are formulated to show the ground segment with its functional responsibilities. These scenarios form the basis for the technical verification and the operational validation as presented in the following section.

4. VERIFICATION AND VALIDATION

4.1 Terminology

Oriented on the ECSS standard, the Verification and Validation in the Ground Segment can be separated in two distinct tasks, the Technical Verification and Validation (TVV) on the one hand, consisting of a verification test to demonstrate conformance of the system with design specification and interfaces to other ground segment systems, and a "validation test to demonstrate that the element fulfills its requirements specification and to provide a preliminary confirmation that it is fit for use". On the other hand, the Operational Validation (OV) which covers activities, whose objective "shall be to exercise the complete ground segment, the operations and support teams plus the full set of mission operations data, in simulations of realistic operational scenarios. It shall constitute the operational qualification of the whole ground segment."

4.2 Environment

In order to understand the proposed approach for the Integration, Technical Verification and Validation, and Operational Validation, the term "environment" has to be specified. An environment is a particular configuration of items. For the execution of the tests three environments are differentiated, where only the latter two are used for tests that are actually documented in the project:

- **Development Environment (DE):**

The environment that consists of a set of processes and programming tools to cover the responsibilities of the subsystems.

- **Integration Environment (IE):**

In this environment the integration of the subsystems is accomplished. The subsystems are either already integrated into the ground segment or are ready to be integrated. Tests at this level are significant as connections to other subsystems can be actively built up or can be generated by realistic simulations.

- **Operational Environment (OE):**

Comprises the applications and systems, and supporting systems infrastructure, that are actually used in the EnMAP Ground Segment for the production from the commanding of the data to the delivery to the end user.

The Integration Environment needn't be physically different from the Operational Environment, it also can be modelled logically.

4.3 Stages

Figure 3 illustrates the schedule of the EnMAP Ground Segment for technical verification and operational validation with respect to the major milestones. We distinguish eleven stages of integration of the Ground Segment:

- Subsystem TVV: This comprises all tests which are performed internally within the subsystem and typically during the production activities beginning after Critical Design Review (CDR). These tests will at most consist of unit tests. No restrictions apply, as these tests are to be conducted in the Development Environment or the Integration Environment.
- Subsystem TVV in Integration Environment: This comprises all functional tests to prove that the subsystem is able to fulfill all its requirements. They demonstrate at the Technical Verification and Validation Readiness Review (TVVRR) for each subsystem, that it is ready for technical verification at Ground Segment-level, namely ready for integration in the (more critical) operational environment.
- Ground Segment Interfaces TVV in Integration Environment: This comprises all interface tests between two subsystems. They demonstrate, for each pair of subsystems sharing an interface, that they are ready for further verification and integration.
- Subsystem TVV in Operational Environment: This comprises all functional tests to prove that the subsystem fulfills all its requirements. They demonstrate for each subsystem, that it is ready for mission verification activities.
- Ground Segment TVV in Operational Environment: This comprises major interface tests for specific workflows in a technical scenario based on the above scenarios on Ground Segment level. They demonstrate at TVVR the technical readiness of the Ground Segment.

- Mission (Simulator) TVV: This comprises tests between a subsystem of the Ground Segment (or even parts of a subsystem of the Ground Segment) and a simulator for a Ground Segment-external part of the mission.
- Mission (Flight Model) TVV: This comprises tests between a subsystem of the Ground Segment (or even parts of a subsystem of the Ground Segment) and a flight model for a Ground Segment-external part of the mission.
- Subsystem OV: This comprises all internal training and subsystem simulations. These training and simulations are carried out within the operational environment of the corresponding subsystem and are documented to the Ground Segment. They demonstrate at Operational Validation Readiness Review (OVRR) for each subsystem, such that they it is ready for operational validation at Ground Segment-level.
- Ground Segment OV: This comprises trainings and simulations for specific workflows in an operational scenario based on the above scenarios on Ground Segment level. They demonstrate the operational readiness of the Ground Segment.
- Mission OV: This comprises training and simulations for specific workflows in an operational scenario on mission-level. They demonstrate at Operational Readiness Review (ORR) the operational readiness of the mission.

The gray lines indicate the situation when only a part of a subsystem of the Ground Segment is involved in a mission (flight model) verification activity such as for S- or X-Band Suitcase Tests.

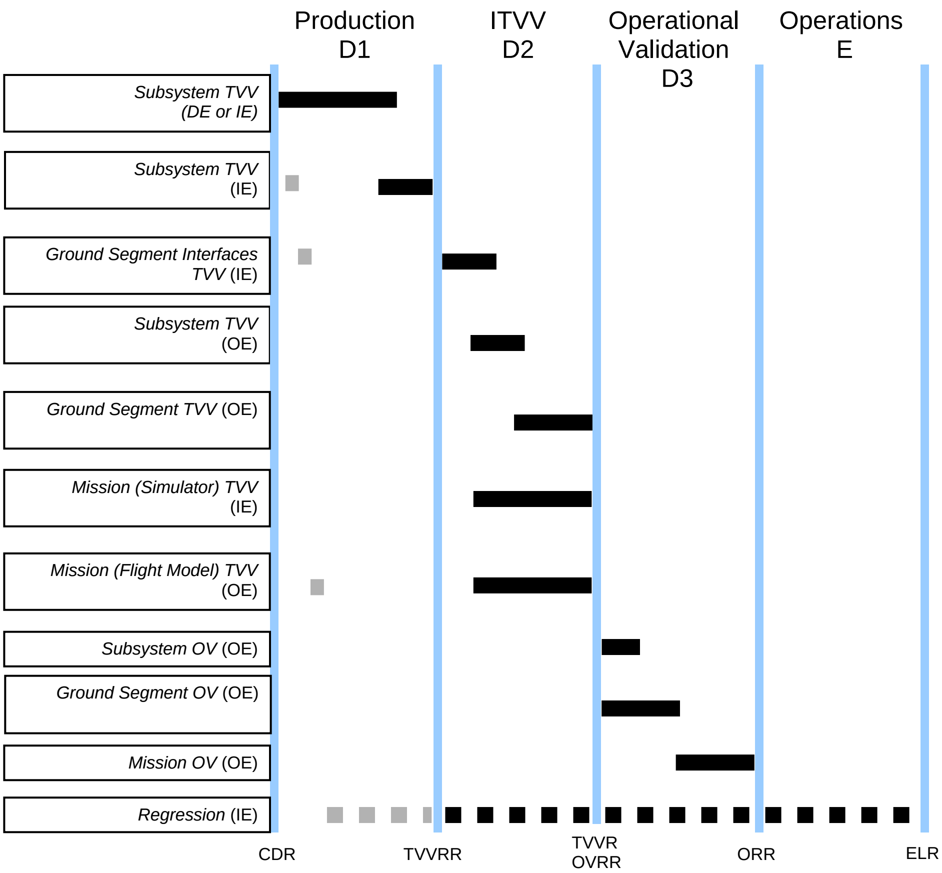

Figure 3. Verification and Validation Schedule

4.4 Dependencies

Figure 4 illustrates the dependencies of the eleven stages of integration of the Ground Segment, where solid lines are mandatory dependencies and dotted lines are optional dependencies.

If an appropriate simulator is available, all verification and validation activities carried out with a flight model are carried out with the given simulator beforehand. For mission validation a flight model will be applied preferably without a simulator, where appropriate. However, the remaining tests must be conducted with a simulator.

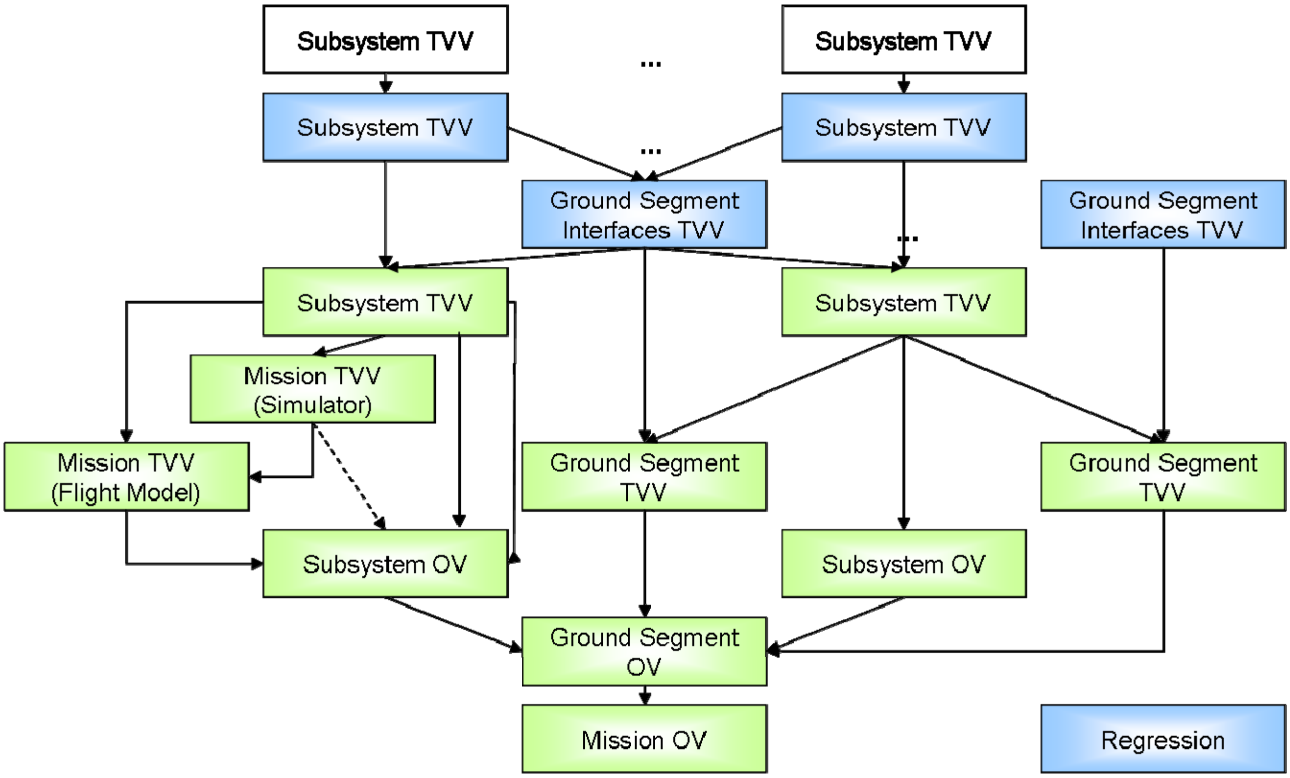

Figure 4. Verification and Validation Dependencies

5. CONCLUSIONS

The design of the Integration and Technical Verification and Validation Phase of the EnMAP Ground Segment has been shown. Starting with the Mission parameters the derived requirements formulated for the Ground Segment have been sketched, the Product Tree with its constituent subsystems and their interfaces spanned among them described. With the scenarios a complementary description for the dynamic behaviour of the Ground Segment was given. Based on that knowledge the schedule for the implementation of the various stages of the test activities as well as their dependencies was demonstrated.

With the execution of the above procedure the ground segment will demonstrate its readiness for a successful EnMAP mission.

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