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System Verification Approach, Methods and Tools for Galileo

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ABSTRACT

The objective of this paper is to present an overview of the approach applied for Galileo system verification. To this end it includes an overview on Galileo and verification and validation background followed by a description of the methods to be applied and the tools required for the verification on system level.

The high level Galileo mission requirements [1], which capture user requirements, have been translated by ESA into Galileo system requirements [2]. These system requirements have formed the basis for specifying the Galileo system, segments, and elements. Thus, for the verification and the validation of the Galileo system it is necessary to verify the Galileo system against these requirements.

This paper addresses the approach for system verification and elaborates on methods and tools to be applied throughout the various system development phases up to full deployment and operational readiness of the Galileo system.

The Galileo system requirements document [2] lists requirements for the final operational capability of the Galileo system. The requirements consist of:
Service Requirements, Functional Requirements, Implementation Requirements, Operational Requirements, Security Requirements, Safety Requirements, Verification Requirements, Signal-in-Space Requirements, External Interfaces Requirements

Suitable system verification methods are applied – as far as applicable and possible – for the following three milestones:
System Critical Design Review (S-CDR)
In-Orbit Validation (IOV) Review
Final Validation Review (FVR) with Final Operational Capability (FOC)

The set of identified system verification methods for each milestone has been used as the main input in order to specify the requirements for the verification tools and to map the tools requirements to existing tools, i.e. checking if the requirements are adequately covered by these tools.
Then the analysis of system verification tools has allowed the definition and selection of the most suitable tools to be used for the verification process, taking into account also the validation status and the quality standard followed by the tools (in view of the future certification of the Galileo system).

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1 Introduction

For a better understanding the Galileo system is described in terms of the context of its development and the key design drivers. This is followed by a brief description of its architecture and the current status.

Before stepping to Galileo verification itself some background information on verification is given. This includes the definition of related terms, standards and norms, and the system lifecycle.

Based on the explanations given before the verification approach for Galileo is sketched taking into account the requirements on system and segment level, the verification methods, and the phases and milestones for Galileo deployment.

After having described the verification approach, the completeness of verification for each phase is given and the main verification activities are summarized for each phase.

In the next step the approach and the selection of verification tools is derived. This implies that requirements for verification tools are described. After this the tools needed are identified and missing tools, missing tools interfaces, and missing tool features are described.

Finally, the paper concludes with a summary of the work performed and an outlook is given.

2 Overview on Galileo

2.1 Galileo in Context with GPS and GLONASS

Galileo is a European satellite navigation system under civil control, whereas GPS (USA) and GLONASS (Russia) are controlled by military. Galileo is an independent system, but interoperable with GPS and compatible with GLONASS.

In comparison to GPS and GLONASS [14], which each provide 2 services with higher and lower precision (C/A code and P-code for GPS and SP, HP for GLONASS respectively), Galileo provides several services in terms of accuracy, service guarantee, integrity, and other parameters. These services are:

- The Galileo Open Service (OS) is defined for mass-market applications. It will provide signals for timing and positioning, free of charge without service guarantee or liability.

- The certified Safety-of-Life Service (SoL) will be used for all applications which require a certain level of reliability and integrity of positioning. Typically these are transport applications, where lives are at stake if the performance of the navigation system is degraded. To minimize the risk for losses of life, the SoL provides a timely integrity warning to the users in case the positioning performance is degraded to a critical level due to partial or full system failure.
- The Commercial Service (CS) aims at market applications requiring additional data disseminated via the Signal in Space (SIS) in addition to the positioning and timing performance offered by the Open Service. The additional data can result in an increase of the positioning performance, e.g. by means of wide-area differential corrections. The CS will provide the added value data on payment of a fee.
- The Public Regulated Service (PRS) provides an access-restricted signal with increased robustness for times, in which the other Galileo services are not available. The access to the PRS signals is restricted to governmental approval and yields at key applications of public service and infrastructure, e.g. rescue forces or police.
- The Search and Rescue Service (SAR) is an important improvement of existing search and rescue systems. It provides the capability of combining SAR functionality with precise real-time positioning, reception of distress messages anytime nearly anywhere on Earth, and the provision of a confirmation of reception to the user in distress.

2.2 Key Drivers for System Architectural Design

The Galileo system has been designed to provide worldwide high precision positioning and timing services by global transmission of signals [15] optimized for three main user categories identified by comprehensive market research and consultation of key user groups [11]. The architecture is therefore driven by consideration of key performance parameters, technology available and regulatory constraints set by the ITU-R Radio Regulations and the present usage of the frequency spectrum allocated. The key performance parameters are 3d-positioning accuracy, availability of accuracy, continuity of service and integrity.

The first and largest target group identified is the market for an open access service with commercial, professional, and private applications in the positioning and timing domain. The second group concerns the market that relies on provision of a service applicable for safety-of-life critical applications, initially driven by the demands of the aeronautical community but equally interesting for maritime, railway and future road transport applications. The third main target group is represented by Governmental users dedicated to organizations and services which heavily rely on a high level of security of the information provided through Galileo.

A signal and frequency plan was derived to satisfy needs of the identified target communities. Main driving parameters for the quality of service are: performance (primarily in terms of positioning and timing **accuracy**), user perceived quality of service through **coverage** area of services (global, regional or local), **availability** of services, and margins for the provision of services in the context of service **continuity**.

Especially the implementation of a sophisticated **integrity** warning function –the level of confidence the user can have in using Galileo services for his operations – into the system has driven the design of the Galileo architecture. A large impact on the Galileo architectural concept has the requirement that the Galileo operating entity offers some services, which are subject to a "guarantee of services". This has a substantial influence on the quality of services and consequently on the system design.

Important are also aspects of Galileo system security with respect to the system design. In addition interoperability and compatibility of Galileo with GPS on different levels is an important requirement. Interoperability between Galileo and GPS is understood in this context such that the combined reception of signals from both systems on two given frequencies will significantly improve the availability of accuracy as well as the reliability based on a combined receiver design.

Galileo has been designed to provide and, in most cases, exceed the given perceived navigation performance set by the civil GPS-C/A code signal and its augmentation systems (WAAS, EGNOS, and MSAS). The main performance drivers are in the areas of high precision time references, the geodetic reference frame, and the state-of-the-art design of wide band signal structures.

Galileo will define its own Galileo System Time and also implement a Galileo Geodetic Reference Frame (ITRF0x), independent from the GPS used WGS84-frame but with a maximum deviation of less than 5cm from it.

The Galileo architecture has been designed in a way that the operations of Galileo in different phases (In-Orbit Validation, Constellation Deployment, Nominal Operations, Replenishment, etc.) can be conducted and maintained with an appropriately expanding ground station infrastructure. Therefore the necessary support structure (Training and Simulations, Mission Planning, Archiving, Flight Dynamics Fault Detection and Isolation etc.) will gradually be implemented following

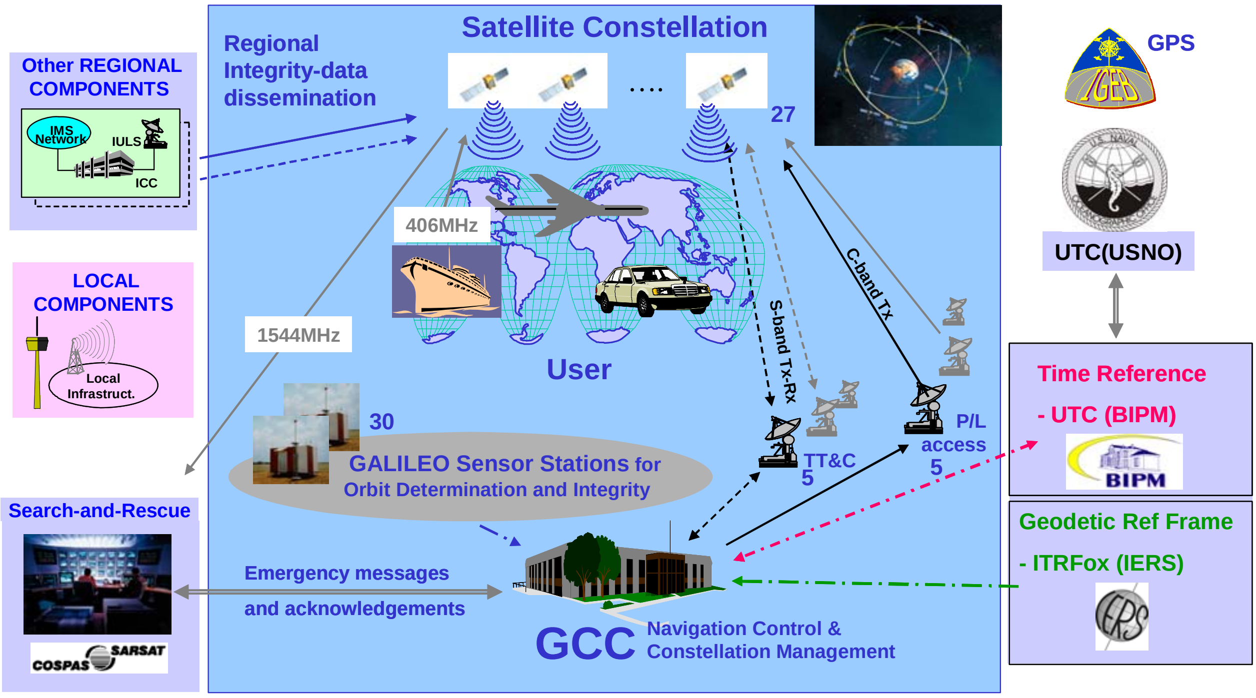

Figure 1: Galileo Overall Architecture

the progress of the system implementation, also taking into account the need for flexibility in terms of improvements, innovations, and modernizations.

2.3 System Description

Figure 1 illustrates the Galileo overall architecture.

The Galileo Space Segment will be comprised of a constellation of 30 satellites (27 operational and 3 active in-orbit spares) in medium-Earth orbit (MEO) for global coverage. Each satellite will broadcast precise time signals, together with clock synchronization, orbit ephemeris and other data. A user equipped with a suitable receiver (i.e. Galileo User Segment) will be able to determine his position to within a few meters when receiving signals from just four Galileo satellites.

The Galileo Ground Segment will control the whole Galileo constellation, monitoring satellite health and up-loading of data for subsequent broadcast to users. The key elements of this data, clock synchronization and orbit ephemeris, will be calculated from measurements made by a world-wide network of stations.

Galileo will provide an interface to Service Providers. These Service Providers will give users a point-of-contact to the Galileo system, will provide a variety of value-added services and will play a role in collecting fees. This interface may also include provision of special data, such as clock and ephemeris history and predictions to scientific users.

External components, such as GPS, GLONASS, LORAN-C, may be interfaced to Galileo receivers to provide combined navigation services.
Galileo will thus provide a range of guaranteed services to users equipped with receivers meeting Galileo specifications [16].

2.4 Status

Currently the Galileo system design is consolidated in the Galileo phase B2 study which will be completed in 2003. In parallel, the project Galilei initiated by the European Commission is focusing on service definition, non-technical aspects of service provision, interoperability aspects between different systems for navigation purposes and local elements. Main objective of all these activities is to prepare for the C/D-phase of the program that will commence with the actual development and validation of the Galileo architecture before the end of 2003 to keep the target of full operational capability for Galileo in 2008 [15].

3 Background on Verification

Before describing the approach for the verification and validation of the described Galileo system a background on verification is given.

The aim of verification and validation is to prove that a system (e.g. Galileo) works in a proper way (in accordance with the requirements imposed upon the system) and that the intended services are provided properly (in accordance with user needs/expectations). Furthermore the risk of mission failure shall be minimized through a proper implementation of the verification and validation process.

3.1 Definition of related Terms

The purpose of this section is to identify and explain the terminology that is used in the context of verification.

“How to assure whether an item (such as component, equipment or system) is satisfactory or not?“ Before defining any terms, it is worth considering the concepts underlying this question. What is satisfactory can be defined in many different ways:

- The producer assures that the item is satisfactory
- It is proved that the item fulfils the intended use
- A legal party assures that the item is satisfactory

These viewpoints require different kinds and levels of assurance.

From the experience it is known that just because the supplier asserts that an item is correct, it does not mean that the item is satisfactory. It may be expected that a legal party may assure that the item complies with the agreed requirements. Different levels expressing assurance whether an item is satisfactory are:

- Verification
- Qualification
- Validation
- Certification

Verification asks the question "is the system built correctly?" The mission requirements are transformed into specifications. Verification is checking that the system is built according to its specifications and also fulfils the requirements of the certifying user group.

Verification means to show that the system is built in the correct way.

Qualification is the process of determining that the product, as designed, is capable of meeting all its specified performance requirements in its operational environment with specified margins appropriate for the technologies used and the intended application.

The process consists of testing the performance of the unit (product) under extreme specified operating conditions, which are not necessarily the conditions for which the unit was designed. These tests may also include abbreviated lifetime tests under higher stress conditions (e.g. radiation dose).

Before starting the qualification of a unit it is essential to analyze its technical specifications and to derive the test requirements from them. The aim of this task is to assure that the unit operates within the specified extreme environmental conditions for which it was designed.

Validation answers the question "is it the right system?" "Is the knowledge base correct?" or "Is the program doing the job it was intended to do?" Thus, validation is the demonstration that a system performs the functions fulfilling the mission requirements and it is usable for the intended purposes.

Certification is the procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements.

Certification implies the formal approval (or legal recognition) that a product, service, organization or person complies with published norms, usually having a legal status.

Certification is done for special applications only; its purpose is to avoid hazards and risks and to enable widespread use without the need for repeated evaluation. Certification and safety standards shall be reflected in the mission requirements.

Other terms often mentioned in this context are accreditation and demonstration.

Accreditation is related to security. It is a formal statement by the accreditor or the Departmental Security Officer (DSO) confirming that the use of a system to process, store, or forward protectively marked information under conditions specified in the System Security Policy meets the security requirement and does not present an unacceptable risk [12].

Demonstration is a process whereby evidence is produced to provide confidence that the specified requirements are fulfilled. Note: A demonstration usually requires all or part of a deliverable product to be operated in a manner typical of its intended use. This operation may occur in an environment less stressful than the specified operational environment [5].

Figure 2 shows the temporal sequence of the processes. It starts with the verification process and is followed by the qualification, the validation, and the certification process. The certification process is the last process, but has an impact on the verification and qualification process. Specified standards and rules of the certification process have to be considered in the requirements for the verification and qualification process.

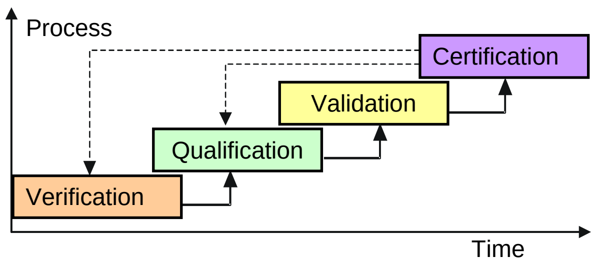

Figure 2: Temporal Sequence of Verification, Qualification, Validation, and Certification Processes [7].

3.2 Standards and Norms

Possible standards and norms applicable for the verification, qualification, and validation activities are e.g.:

- ISO (International Standardization Organization)
- MIL-STD, AQAP (Allied Quality Assurance Publication [NATO]) (Military Standards)
- ECSS (European Co-operation for Space Standardization)

For certification activities the standards and norms of agencies responsible for a particular application of the Galileo service may also be considered.

As requested by ESA the ECSS standard ECSS-E-10-02A [4] has been applied for the verification approach of Galileo.

3.3 System Lifecycle

Within the design, development, and manufacturing of a system, the verification and validation process is necessary to achieve a good final product and to assess that its performances satisfy the requirements for which the system has been planned.

The process of proving that Galileo is in compliance with the mission and system requirements must be carried out through sets of checks and tests of the overall system and subsystems. The major scope of validating the service is to assess whether the actual mission requirements are satisfied. In fact before starting the assessment of the service, the system (in terms of infrastructure that provides the service) must be checked if it is built correctly to the design specifications (verification). In this way the validation may be described as an end-to-end verification, and verification activities shall be performed and completed before starting validation activities.

For a better understanding of the validation process the whole process of a system life cycle is shown in figure 3 with its top-down and bottom-up approach. It consists of two levels: mission level and system level. At mission level validation is carried out, whilst at system level a technical verification of the system is done.

The process starts with the mission requirements, which are transformed into system requirements. Once the system requirements are available the system can be designed. The process of system design consists of breaking down the system into subsystems and units. As soon as the lowest level of system break down is obtained the development can start.

Firstly, the units at the lowest level are developed. At this stage the unit is verified and qualified if necessary. This process continues up to the integration of the subsystems. The subsystem has to be verified and qualified, if necessary, case by case. In the next step the system is integrated and verified. Unless there are special requirements, qualification tests at this stage are not foreseen. As soon as the system is partially integrated, the verification activities of main system elements/segments should be performed. Once the verification has been performed, the overall mission performance requirements can be validated (validation).

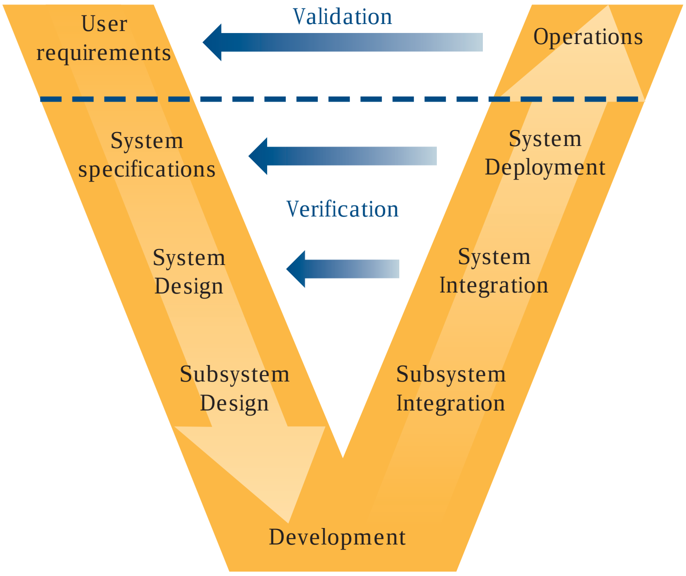

Figure 3: Link of V&V activities to overall design, development, and deployment of system

Not shown in the figure 3 is the certification process. Comprehension and expected level of certification has to be included into the mission requirements, as the required certification and safety standards should already be reflected there. As soon as the whole system is validated the certification of the system can begin. However, early consideration of the later certification would enable us to incorporate parts of this process already into the verification and qualification process saving eventually time and money because tests and declarations may not have to be repeated [7].

4 Verification Approach for Galileo

This section describes the verification and validation approach and activities for the Galileo system.

4.1 Requirements – System and Segment Differentiation

The Galileo system requirements document [2] lists requirements for the final operational capability of the Galileo system. The requirements consist of:

- Service Requirements
- Functional Requirements
- Implementation Requirements
- Operational Requirements
- Security Requirements
- Safety Requirements
- Verification Requirements
- Signal-in-Space Requirements
- External Interfaces Requirements

These requirements can be divided into 2 categories:

- Category 1: Requirements to be verified on system level, since more than one segment is involved.
- Category 2: Requirements that can and will be verified on segment level, since the functionality specified is related to a single segment. In this case the system verification reference is made to segment tests or verifications.

According to this differentiation, the verification of requirements may be performed either on system level or on segment level. Only requirements of category 1 have been considered here, i.e. requirements of system relevance.

4.2 Verification Methods

Verification shall be accomplished by one or a combination of the following verification methods [10]:

- Test
- Analysis
- Simulation
- Review-of-design
- Inspection

Test: When requirements have to be verified by measuring product performance and function under various simulated environments, the methods shall refer to as “Test”.

Analysis: When verification is achieved by performing theoretical evaluation by accepted techniques, the method shall be referred to as “Analysis“.

Simulation: When verification is achieved using simulation results based on simulators modeling the system.

Review-of-Design: When verification is achieved by review of records or by evidence origination from design documents or when approved design reports, technical descriptions, engineering drawings unambiguously show the requirement is met, the method shall be referred as “Review-of-design“.

Inspection: When verification is achieved by visual determination of physical characteristics, the method shall be referred to as “Inspection“.

4.3 Phases and Milestones for Galileo Deployment

The major consecutive phases for the Galileo deployment are [10]:

- Design and Development Phase
- In-Orbit Validation Phase (IOV)
- Full Deployment Phase

The verification methods described before are applied – as far as applicable and possible – in preparation of the following subsequent three milestones that are defined in the development process:

- System Critical Design Review (S-CDR) at the end of the Design and Development Phase
- In-Orbit Validation Review (IOVR) at the end of the In-Orbit Validation Phase
- Final Validation Review (FVR) at the end of the Full Deployment Phase

System Critical Design Review (S-CDR)

During the S-CDR the verification methods proposed at the beginning of the design phase shall be reviewed and accepted in order to be used for the IOV phase. Subsequently the test procedures and all the necessary verification tools for the IOV phase have to be written or established.

At the System CDR some of these principle methods are already addressed, especially with respect to:

- Analysis: where applicable first analysis for verification of system requirements shall be made available.
- Review of Design: at CDR the design of the System shall be reviewed and accepted. First verification of requirements by review shall be possible at this time.
- Simulation: some simulations are needed to demonstrate the adequacy of the design to met the system requirements.

In Orbit Validation Review (IOVR)
The IOV (In Orbit Validation) phase is characterized by the fact, that in this phase the system configuration to be accepted is not complete in the sense of the GSRD. The selected IOV configuration is providing a technical platform for early verification of system parameters. Despite of the limited IOV configuration compared to the FOC (Final Operational Capability) configuration:

- 4 satellites instead of 27+3 satellites
- limited ground segment (with reduced number of GSS, ULS, TT&C Station, Control Stations and no redundancies)

the GSRD remains the baseline for the system requirements. It is the objective of the IOV phase to verify and demonstrate at an early time, that the system finally implemented at FOC will meet the GSRD requirements. A major prerequisite of system verification for IOV is the adaptation of those GSRD requirements to IOV requirements which are specifically applicable for IOV.

The major verification method for space infrastructure systems, “Test/Measurement” [4], is not directly applicable for the incomplete IOV configuration. To overcome this problem other verification methods have to complement the ones mentioned above:

- Analysis
- Simulation
- Test/Measurement plus Simulation, including extrapolation from measured results

Final Validation Review (FVR)
The Full Deployment Phase is characterized by the fact that the system to be accepted at FVR is now complete and has reached the FOC, in the sense of the GSRD. The FOC configuration consists of:

- 27+3 satellites
- full ground segment (with complete network of GSS, ULS, TT&C Stations, Control Stations, and redundancies)

The GSRD is fully applicable and FOC performance and design has to meet the GSRD.

The major verification method for space infrastructure systems, “Test/Measurement”, shall be applied as far as possible. Simulations shall be used as a comparative tool and for parameters, which are difficult to measure (e.g. integrity risk). Another aspect is to use simulations for extrapolation of measurements (e.g. in case measurements are performed at a limited number of points, but the compliance with a requirement requesting world-wide coverage should be shown).

The verification policy applied is to prove as soon as possible, that the system already established or planned will work properly to minimize the risk. This implies that the verification process runs in parallel to the development process in each of the development stages/phases, which will be finalized not before FOC (i.e. when full system deployment is achieved).

5 Completeness of Verification and Methods

439 requirements on system level (i.e. category 1) of the GSRD have been investigated. For each of these requirements the verification method has been given for the milestones S-CDR, IOVR, and FVR.

The verification of a requirement is considered to be complete at a milestone (i.e. S-CDR, IOVR, FVR), when no more verification activities with respect to this requirement are needed after this milestone. If the verification of a requirement is not complete at a certain milestone a justification has been provided [8].

The completeness of verification reached at S-CDR is 3%, at IOVR 11%, and at FVR close to 100% [16] (see table 1). The table gives the group / type of requirement, the relevant number of requirements for this group, and the percentage of completion for each phase [8].

There are a few requirements which do not allow a full completeness of verification at FVR. These requirements request continuously on-going activities over the full-specified service duration (e.g. “The Full Operations shall provide the Galileo services at the required level of availability and reliability, continuously for the full-specified service duration.”).

A preliminary verification at FVR can be obtained by using analysis and simulations following the approach described above. It has to be stressed that a demonstration for the verification of requirements can be obtained in earlier phases in the sense of a preliminary verification, whilst the full verification of requirements is often only possible with the FOC.

Note that various verification methods may have an impact on the design and development of the Galileo segments in terms of specific requirements on segment functionality and interface capabilities, which will be further elaborated in the C/D phase of the Galileo program.

Table 1: Completion of Verification for the Design-and Development, IOV, and Full Deployment Phase

Type of Req.	No. of Req.	Design & Development	IOV	Full Deployment
Service	162	0,0%	10,0%	100,0%
Functional	42	0,0%	0,0%	100,0%
Implement.	95	8,0%	21,0%	100,0%
Operational	66	3,0%	14,0%	99,8%
Security	18	6,0%	0,0%	100,0%
Safety	13	15,0%	0,0%	100,0%
Verification	15	0,0%	7,0%	100,0%
External I/F	28	0,0%	0,0%	100,0%
Total	**439**	**2,9%**	**10,6%**	**100,0%**

1) Main reason for incompleteness is the necessary fully deployed constellation for the verification of services

2) Additionally, 1 requirement has to be verified on segment level here.

3) Additionally, 60 requirements have to be verified on segment level, which is not covered here.

4) All requirements except 1 are completely verified at FOC. The reason is that this requirement is verified after the full service duration.

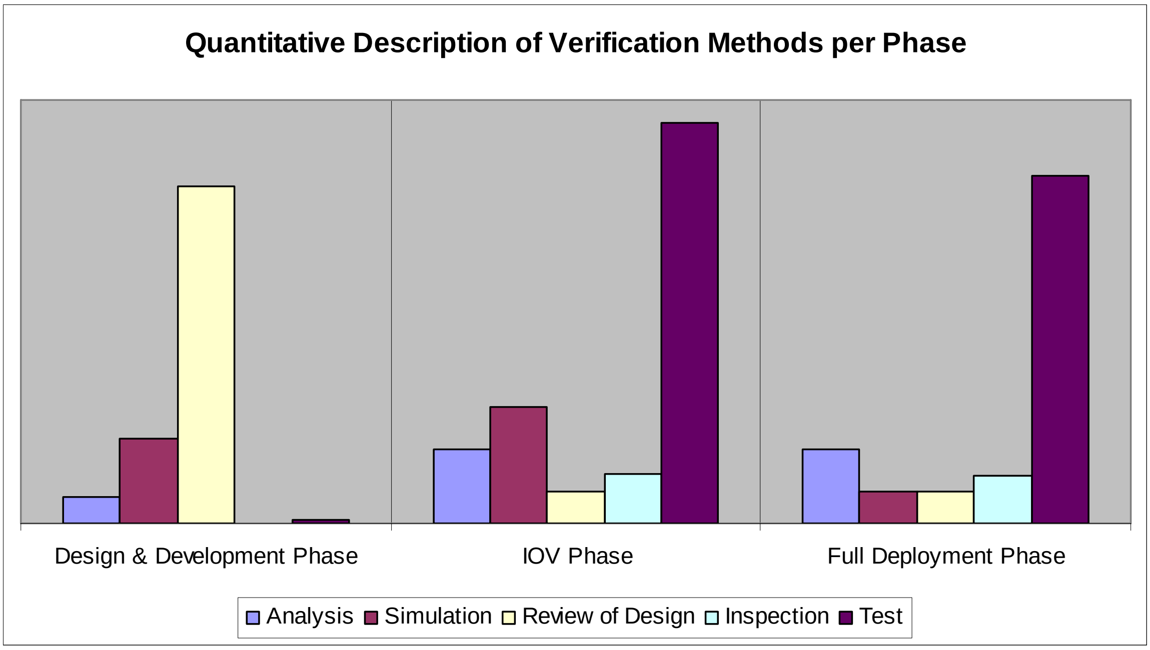

Figure 4: Verification Methods per Phase

Figure 4 gives an overview on verification methods for the different phases. It can be seen that in the Design- and Development phase mainly the method "Review of Design" is used as no infrastructure is available at that time. "Simulation" increases from Design- and Development phase to IOV phase as simulation and emulation needs grow with the deploying system and decreases in the Full Deployment phase when simulations are more needed for extrapolation. Later on in the IOV and Full Deployment phase "Test" becomes the main verification method, because infrastructure becomes available and allows to gain data from real measurements.

6 Verification Tools

6.1 Approach

The system verification methods for each phase have been used as the starting point for the specification of the requirements for the verification tools, and to map these tools requirements to the existing tools, i.e. checking if the requirements are adequately covered by tools as available/planned today.

The analysis of system verification tools has allowed the selection of the most suitable tools to be used for the verification process, taking into account also the validation status and the quality standards followed by the tools (in view of the future certification of the Galileo system).

The analysis of system verification tools also suggests possible updates to existing tools, in case some of the requirements were not adequately covered by existing tools, or recommended the procurement of new tools with detailed specifications.

The main goals of applying the system verification tools change with the system development phases and their corresponding verification objectives [9]:

- Up to S-CDR the tools will be used to simulate the system performances and to give proof that such performances are compliant to the specifications. Also, until CDR the GSTB (Galileo System Test Bed) [13] will be used to make early tests and experimentation on the system.
- Up to IOVR, the tools will be mostly used to combine simulations with measurements performed with the limited IOV system configuration. Whereas the system performance at this stage is much degraded with respect to FOC, extrapolations to the performances of the full system can be computed by interfacing the deployed elements to the simulators. At this stage, thanks to the real measurements, this allows for simulators algorithms to be refined and calibrated in order to better model the system.
- At FVR, the importance of simulation tools is minor because at this stage the verification can be performed essentially by test based on the FOC system configuration.

6.2 Considerations on the Selection of Tools

It is important, in view of the system certification, that the selection of the tools to be used for verification considers the following issues [9]:

- Independence of the tools used for the design from the ones used for the verification
- Concerning the quality standards for the software, the ECSS-E-40A [6] will be tailored and applied for the Galileo system
- Validation status of tools
- The criticality of the requirements to be verified. For requirements with a higher level of criticality it will be necessary to have high confidence in their verification. In this case it is reasonable to verify those requirements by means of more than one tool.
- The tool stability: some of the tools listed above have been developed using office tools, which may be intrinsically unstable or unable to reliably handle large amounts of data. For this reason their use for verification purposes has to be carefully evaluated considering that it may slow down very much the process and it could be more convenient to use other tools.
- Minimization of the number of used tools: in order to reduce the need of interfaces and to simplify the whole verification process.

6.3 Selection of Tools

A number of existing tools have been identified and described including essentially the tools that have been used for the definition and preliminary design phase. The tools considered are listed in [9]. Anyway, whereas this list is long, the primary tools that have been taken into account for the verification activities (see [13]) are the

- Galileo System Simulation Facility (GSSF)
- Galileo Signal Verification Facility (GSVF)
- Galileo System Test Bed (GSTB)

The justification for this choice remains in the fact that the three tools together give a good coverage of the verification needs and are a good starting point in case the verification needs require updates to the tools.

Moreover the other tools have been used for the design, so it is advisable to use different tools for the verification (if suitable, industry tools may be used as support, to give more confidence in the results, but it is important to have independent tools for verification).

The choice of focusing on GSSF, GSVF, GSTB has also been driven by the fact that the number of tools to be used for verification should be minimized and that the GSSF, GSVF, and GSTB will be used anyway as minimum set of tools.

<u>GSSF</u>

The GSSF is the Galileo System Simulation Facility providing the following capabilities [9]:

- (End-to-End) System Simulations: The analysis of the end-to-end navigation and integrity performance of the complete Galileo System. Consequently, GSSF needs to provide the capability of simulating, in detail, and analyzing all aspects of the Galileo System: the Space Segment, Ground Segment, User Segment, and the Environment.
- Service Volume Analyses: The analysis of service volume aspects of the Galileo System, i.e. global and/or regional coverage analyses, navigation performance estimation, and availability/continuity analyses. These analysis types require GSSF to provide a higher level analytical capability that does not need the complete system to be simulated in detail.
- RAMS Analyses: The analysis of the Reliability, Availability, Maintainability and Safety (RAMS) aspects of the Galileo system. Thus GSSF must provide a toolbox that allows the RAMS engineers to perform this type of analyses.
- Hardware-In-The-Loop (HITL) analyses: It is envisaged that, on longer term, GSSF will be used to support HITL analyses, e.g. connect an actual user receiver into a simulation of the space segment, environment and ground segment. Thus, GSSF must provide the capability of interfacing a System Simulation to actual hardware.

GSVF

The Galileo Signal Verification Facility (GSVF) is a test-bed laboratory facility. The test-bed will be capable of fully verifying in a laboratory environment the positioning performance under realistic system conditions for various signal configurations, optimizing a number of GNSS-2 system parameters and comparing expected system performance with actual measurements before deploying the satellite constellation.

The test-bed consists of three major sub-systems [9]:

- The simulator, which generates the signals that a receiver would receive from the satellite constellation, and hence allows the simulation of the motion of the receiver and the satellites and various propagation effects;
- The receiver, which acquires the satellite signals, demodulates and decodes the data received from the satellites, and measures carrier phase and pseudo-range;
- The Navigation Processing Unit (NPU), which controls and monitors the receiver, and processes the raw measurements from the receiver;

GSTB

The Galileo System Test Bed (GSTB) is subdivided in two main development steps, Version 1 (V1) and Version 2 (V2), with the following scope [9]:

- GSTB V1: As part of V1, measurements from the GPS system are collected to verify Galileo concepts for Orbit Determination & Time Synchronization (OD& TS) and Integrity algorithms.
- GSTB V2: will consist of at least one experimental Galileo satellite and an extension of GSTB V1 Ground Segment including Galileo receivers and processing algorithms. It will allow on-board hardware early verification, clock technology verification, and SIS transmission chain verification.

In those cases where the verification needs are not covered by the abovementioned set of tools, it has been evaluated whether it is better to extend their functionality, to use other existing tools, or to develop new tools.

Among the tools that have been identified as currently missing is the Galileo Test Receiver Support Facility (TRSF), required as a tool capable of receiving the Galileo Signal-In-Space and analyzing associated performance characteristics.

6.4 Requirements for Verification Tools / Facilities

The System Verification Tools Requirements (SVTR) have been produced according to the verification methods. The SVTR have been issued either as use cases or as explicit requirements (that may also be derived from previous use cases). The tool requirements can be traced to the relevant verification method, are linked to the development phase in which they are applicable, and give a mapping to the applicable type of tool.

In the next step these requirements have been mapped to the existing tools where possible, leaving a subset of tools requirements that need to be implemented either as a complement to the existing tools, or as new tools.

Hence the tools have been selected for each phase and missing tools have been identified according to the tool selection as mentioned before.

The missing features / tools have been described for each tool requirement per phase.

Additional features have been identified for both GSSF and GSVF for all phases (Design and Development Phase, IOV Phase, and Full Deployment Phase).

A complementary tool set has been specified, based on the tools requirements not expected to be covered by future versions of the baseline tools set. This complementary tool set includes the following:

- A tool capable to receive the actual Galileo Signal In Space, either from the GSTB, the IOV satellites or the fully deployed Galileo constellation, including an analysis environment in support of system verification. The tool includes a Galileo User Test Receiver and is named Test Receiver Support Facility (TRSF).
- A tool in support of verification of requirements related to the susceptibility to interference, including jamming and spoofing: the Interference Generator Tool (IGT) as well as a related tool in support of the analysis of the signal spectrum as received by monitoring stations and users: the Spectrum Analyzer Tool (SAT).
- A tool dedicated to the analysis and assessment of timing and frequency services as provided by Galileo: the Time and Frequency Accuracy Measurement Facility (TFAMF).
- A tool capable to assess nominal and non-nominal operational conditions: the Galileo Operations Simulator (GOS).
- A tool capable to assess and analyze requirements related to Search-And-Rescue functionality supported by Galileo: the SAR Beacon and Support Facility (SBSF).
- A tool dedicated to security aspects in relation to signal encryption: the Encryption Test Facility (ETF).
- An environment providing the necessary interfaces between the various tools.

7 Conclusions

Starting from the Galileo system requirements all the requirements relevant to be verified at system level have been identified. For each of these requirements the verification method at each Galileo development stage has been described including the completion status. From the verification methods the requirements for the verification tools have been derived. These requirements have been mapped to tools for each stage. The tools needed have been identified and missing tools, missing tools interfaces, and missing tool features have been described.

The next step will be a consolidation of the verification activities and related tools with respect to the updated GSRD [3] as main input.

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Biography

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