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Virtualisation of the test environment for signalling

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Abstract

ERTMS is a well-known, well-performing technology applied all over the world but it still lacks flexibility when it comes to authorisation and certification procedures. The key of its success in the future lies as much in cost reduction as in simplification of placing in service procedures. This holds true for the implementation of a new subsystem and even more so for new software releases related to subsystems already in service.

Currently the placing in service process of ETCS components and subsystems requires a large amount of tests due to the complexity of the signalling systems and the different engineering rules applied. The S2R Multi-Annual Action Plan states that the effort and time consumption of these onsite tests are at least 30% for any particular project. VITE research project (VIrtualisation of the Test Environment) aims at reducing these onsite tests to a minimum while ensuring that laboratory tests can serve as evidence for valid system behaviour and are accepted by all stakeholders involved in the placing in service process. This paper presents the first VITE results.

Keywords: virtual testing; lab testing; standard architecture; test process framework; ERTMS; shift2rail, testing tools

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Nomenclature

CCS	Control, Command and Signalling
EMC	Electromagnetic Compatibility
ERTMS/ETCS	European Rail Traffic Management System / European Train Control System
ETCS	European Train Control SystemI/F interfaces
IC	Interoperability Constituent
IM	Infrastructure Managers
IOP	Interoperability testing according to UNISIG subset 110
IOT	Interoperability testing according to ISO/IEC/IEEE 24765, 2010
NSA	National Safety Authority
NoBos	Notified Bodies
OBU	On Board Unit
PC	Project Coordinator
RBC	Radio Block Center
RPC	Remote procedure call
RUs	Railway Undertakings
S2RJU	Shift2Rail Joint Undertaking
SS	SubSet
TCL	Test Control and Logging
TCP/IP	Transfer Control Protocol/Internet Protocol
VITE	Virtualisation of the Test Environment
XML	eXtensible Markup Language
XML-RPC	Remote procedure call based on XML format

1. Introduction

VITE project is funded under Shift2rail call S2R-OC-IP2-02-2015 and addresses the execution of virtual tests in the laboratory with the aim of replacing most of the ERTMS/ETCS tests that are currently run on-site (Fig.1).

In the ERTMS/ETCS system, several on-board and track side components interact in a complex manner and are governed by safety-critical software, thus constituting an enhanced signalling system allowing trains to run safely and with high performances all across Europe. The tests required by the TSI CCS [R4] address the conformity and suitability for use of ETCS Interoperability Constituents ICs (e.g. the on-board European Vital Computer, or the trackside Eurobalise), and the adequacy of the entire Control-Command Subsystem (on-board + trackside) to be placed in service. A critical aspect regards integration tests - with e.g. ICs needing integration into the subsystem, and with on-board and trackside components having to work together. It is during these tests that the greatest difficulties are encountered, leading to lengthy and costly campaigns with significant effort for on-site activities. Within this domain, VITE's main objectives include:

- Defining a test process framework based on user’s (NoBos, IMs, RUs, NSAs) criteria and best practices in order to minimize the tests to be performed on-site
- Optimizing the testing protocols
- Defining, developing and demonstrating a laboratory architecture that allows for local and remote tests
- Demonstrating the feasibility of executing ETCS test at lab, by performing an analysis of the uncertainties in both on-site and lab tests and therefore a comparison between the executions of test on-site vs the execution in the lab.
- Assessing the methodology proposed, ensuring it fits in the European process for placing in service of CCS components and subsystems

The results of the present research are expected to be an important step towards a laboratory test environment capable of coping with the reproduction of real scenarios -highly requested by Infrastructure Managers, National Safety Authorities and Railway Undertakings- in order to demonstrate the suitability of an on-board subsystem for a specific railway line and its related trackside subsystem.
We are confident that the results of VITE project:

- will increase the confidence in the lab testing results

- will enhance the capability of labs (new functions, modules, I/F)
- will contribute to simplifying the certification and authorisation process without decreasing the level of safety
- will allow for more widely accepted testing process by the rail stakeholders

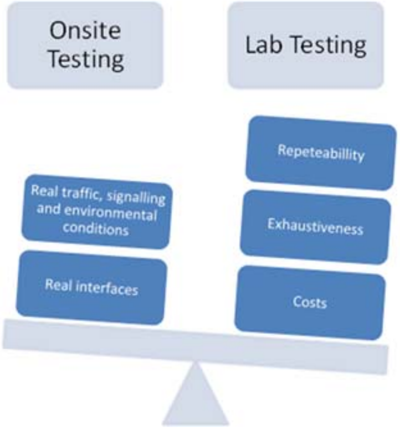


Fig. 1 Onsite testing vs lab testing

After the first year of research VITE project team has analysed the state of the art of the testing process for CCS subsystems and the lab architectures used in different testing campaigns and has produced the first results on the test process framework and the lab architecture to be used for the demonstration that are presented in this paper, while the final results of the project will be available at the end of 2018.

2. Test process framework

When comparing lab testing vs onsite testing, the majority of experts will highlight the advantages of testing in the lab that are summarized in Figure 1.

The only advantage of site testing is the “reality” of the environment where the tests are to be performed. The lab is a priori a better environment for exhaustiveness (allowing an almost unlimited number of tests), repeatability (signalling and testing conditions are recorded in the lab thus tests can be replayed easily) and costs as no train, driver, testing responsible person or even formal safety approval are needed for the execution of the tests.

How it is possible then that effort and time consumption of the onsite tests are at least 30% of a particular project?

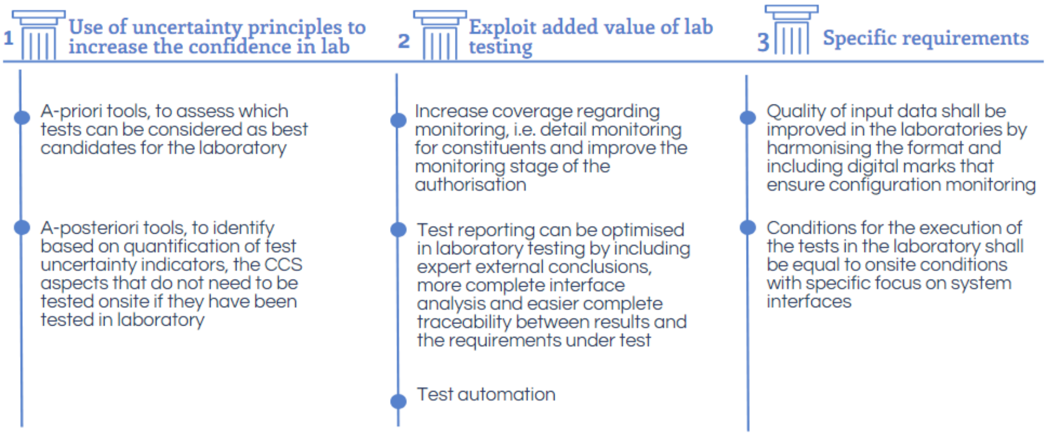
After the state of the art analysis it can be concluded that 1) several tests are currently being performed in laboratories and 2) it is possible for others to be executed in laboratories if these are compliant with specific requirements. Nevertheless, it is clear that 3) some kind of tests cannot be performed in the lab because they are affected by real conditions that are very complex and nowadays still expensive to simulate. The relative amounts of resources for the three test categories identified are difficult to derive because the effort for testing campaigns is far from being standard. X2RAIL-1 project in its benchmarking report [R1] has concluded that the greatest effort in resources is needed for acceptance, compatibility, data, ETCS subset 076, IOP subset 110, IOT, system and validation tests. Of these subset 076 are the ones that are performed completely in the lab. The rest of the testing campaigns identified are related to trackside or onboard subsystems and interaction (integration) of both of them.

VITE state of the art analysis has shown that some of these tests are already executed in labs-mainly CCS Interoperability Constituents (IC), balises and onboard units. Some of them are always executed onsite (eg GSM-R). The operational test cases of the TSI CCS [R4] and the integration tests have been identified as the area where the shift from on-site to lab to onsite can be greater. There are also examples of current test campaigns run entirely in the lab to debug the system and subsequently run onsite. This identification is a first step in the process of moving the tests from the test site to the lab.

Regarding integration tests (route compatibility, IOP, etc…) - that is the final tests where track and train can be observed together in their interaction – there is a feeling among experts that the process should be more exhaustive. Product errors are often detected at this later stage and the user's (RUs and IMs) would like to see evidence that any combination of information possible to be sent from trackside has been tested. This exhaustiveness is impossible to be met onsite.

Another area of improvement identified concerns monitoring of the systems in service, in particular the possibility to better define the testing scenarios relevant for operation and to obtain data for reproducing them in a simulated environment.

Based on the above considerations, VITE has proposed three main pillars on which a new test process framework can be built with the aim of facilitating the shift of CCS testing from on-site to the lab. These are:



1 Use of uncertainty principles to increase the confidence in lab

- A-priori tools, to assess which tests can be considered as best candidates for the laboratory
- A-posteriori tools, to identify based on quantification of test uncertainty indicators, the CCS aspects that do not need to be tested onsite if they have been tested in laboratory

2 Exploit added value of lab testing

- Increase coverage regarding monitoring, i.e. detail monitoring for constituents and improve the monitoring stage of the authorisation
- Test reporting can be optimised in laboratory testing by including expert external conclusions, more complete interface analysis and easier complete traceability between results and the requirements under test
- Test automation

3 Specific requirements

- Quality of input data shall be improved in the laboratories by harmonising the format and including digital marks that ensure configuration monitoring
- Conditions for the execution of the tests in the laboratory shall be equal to onsite conditions with specific focus on system interfaces

Fig. 2 Core of the test process framework

2.1. Uncertainty methodology applied to CCS

In engineering, an important way to build up confidence in a test process is to gain information about its accuracy. In fact, accuracy means precision (repeatability/reproducibility) - i.e. accurate test processes will give similar or identical results when repeated under different conditions - and trueness - i.e. accurate test processes will provide similar results if compared with reference test results obtained through other trusted means (see e.g. ISO [R2]). However, this analysis requires a large effort for complex systems and is seldom done for routine jobs.

In the VITE project, the recourse to the analysis of uncertainty - which is the quantitative aspect of accuracy - is performed with the objective of providing analytic and quantitative information regarding issues that with the current state of the art are often only provided in qualitative form (e.g. laboratory tests are more controllable, more repeatable, than on-site tests). It is useful for a research project to perform this effort and explore these aspects quantitatively, so that subsequent routine projects may benefit from the methods and results developed.
The methodology adopted in the project is represented by the VITE Test Accuracy Framework.

The Test Accuracy Framework is a part of the Test Process Framework that is based on the quantification of test uncertainty indicators.

The starting point for its definition has been the Uncertainty Framework of the TrioTRAIN projects (an example is described in Licciardello et al. [R3]), which was applied to three different assessment processes - two associated with 'EC' verification of subsystems (rolling stock aerodynamics and running dynamics) and one associated with conformity of an interoperability constituent (pantograph). The structure of the framework, comprising five elements (definitions, objects, parameters, methods, references) has remained the same and has been tailored to the needs of the VITE project.

The objects of analysis, according to the VITE's scope, are the technical assessment processes identified in TSI CCS [R4] - operational test scenarios (TSI §6.1.2), assessment procedures for CCS interoperability constituents (TSI §6.2.1), assessment procedures for CCS subsystems (TSI §6.3). The objects of the framework are not to be confused with the test objects, which are in the case of VITE the devices/software subjected to the tests defined in the above assessment processes. The references are represented by the TrioTRAIN deliverables and papers as a starting point, VITE deliverables (D2.2), this paper, and will grow in number as VITE progresses.

The definitions from TrioTRAIN have required slight modifications. For VITE, the assessment quantity is a "single (Boolean) variable that must meet a specific pass/fail criterion as a necessary condition for the overall assessment to be passed". For the topic under analysis, the appropriate level identified for this purpose is the "scenario" level (see Fig. 3). As an example, a scenario might examine whether the "handover" of the European Vital Computer EVC on the moving train between two Radio Block Centres (RBC1 and RBC2) takes place correctly in the ETCS Full Supervision mode. For this to be verified, single Boolean variables (the parameters) such as ‘RBC1 sends announcement to RBC2’, ‘establishment of communication session EVC-RBC2’, ‘EVC sends position report to RBC1, RBC2’ all have to be 'true' or 'pass'. If this occurs, then the scenario/assessment quantity "Handover management. FS mode" is a 'pass'. The assessment uncertainty - i.e. as defined in TrioTRAIN "the uncertainty associated with the assessment quantity that is being assessed, represented, once the assessment method is proven, by the assessment-to-assessment variability", is not quantified by a range of "values that could reasonably be attributed to a measurand" as for mechanical measurements, rather by an uncertainty indicator such as the probability that a non-conform system would pass the assessment (probability of a "false pass"). Specifically for the example, this is the probability of a false pass of the handover scenario, the value being potentially different if the test is done on-site or in the laboratory.

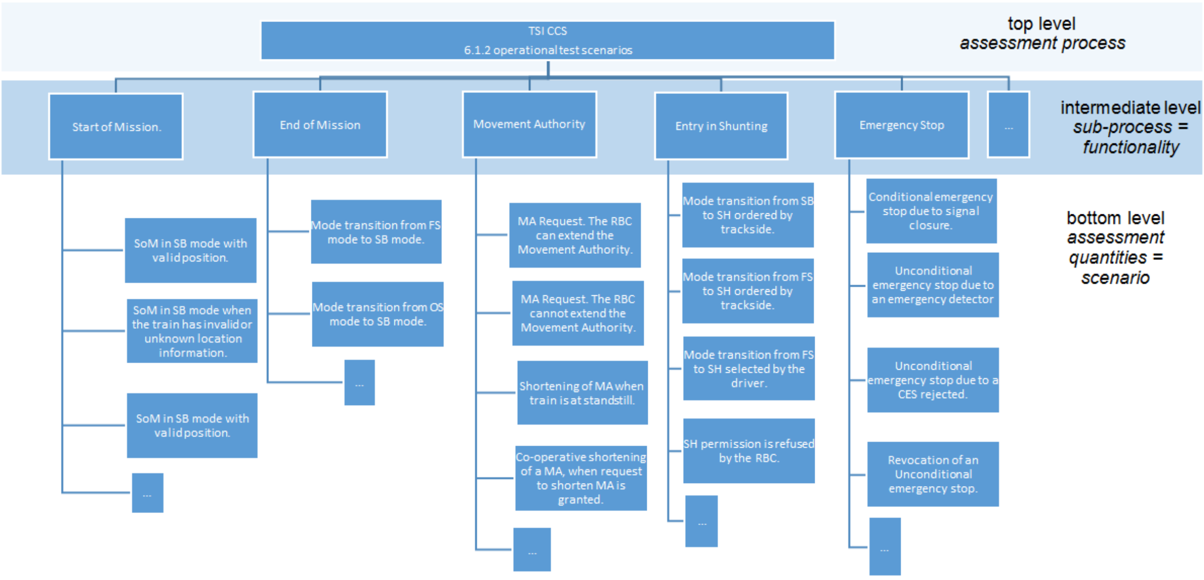


Fig. 3. Assessment quantities as defined for the scope of the VITE project (ERTMS/ETCS tests).

Ideally the purpose of the analysis is to quantify the uncertainty indicators (e.g. probabilities of false passes) for the different scenarios, based on the data available to the project partners as part of their background or generated during the demonstration activities. For this purpose, there are two basic categories of **methods** in the framework:

- the a-priori approach, in which the causes of uncertainty are identified, linked with the assessment quantity, and individually quantified so as to be able to quantify their contribution to the overall assessment uncertainty;
- the a-posteriori approach, in which the causes of uncertainty are not considered, and the quantification of assessment uncertainty is gained through the knowledge of test results - e.g. the numbers regarding passes and fails for each scenario.

The above approaches may be implemented in different ways, from very simple techniques to very sophisticated statistical and probabilistic analyses. In the VITE project we start from the simplest techniques.

With the a-priori approach, the first step is the identification of the sources of uncertainty and how they are linked.

A tentative graphical representation for the tests within the scope of VITE is given in Fig. 4. A first step is to distinguish between sources of uncertainty that vary during the tests and those that vary only from test to test. Such an analysis will be further detailed during VITE

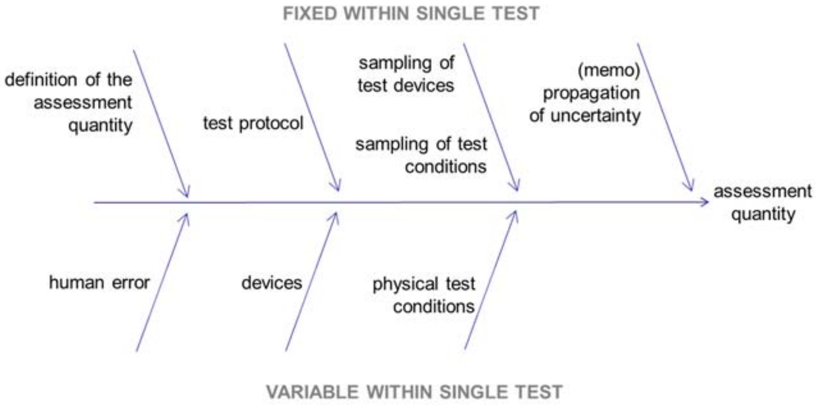


Fig. 4. Cause-effect representation (fishbone diagram) of the main categories of uncertainty sources.

The a posteriori approach for the handover scenario would be implemented, ideally, by repeating the scenario a number of times in the lab and on-site and comparing the results in terms of frequency of false passes. However, this is usually impracticable due to the large number of tests required, so other types of information have to be sought from the partners' backgrounds (e.g. how many times has the handover scenario failed? in the lab? on site? has it ever passed in the lab and failed on site?) and from the demonstration tests (how many fails of single parameters are recorded? for which scenarios? etc.). These are all indicators regarding the accuracy of the tests that can help, on the one hand, gain confidence in the tests which prove to be solid and, on the other, identify tests that might require improvement.

2.2. Exploit added value of lab testing

This pillar aims at maximizing the added value of lab testing by exploring and proposing actions for the following:

- Detailed monitoring for constituents and improve the monitoring stage of the authorization
  Test in laboratory are optimum to debug the system while maintaining a correct traceability of the SW configuration management of these changes
- Test reporting
  For acceptance by the stakeholders of the testing results performed in the lab there should be a complete and clear testing report. The test report should include not only what has been tested but also how it has been tested. These includes configuration information, traceability to requirements, number of tries, etc. There is also a minimum necessary description of the testing environment.
- Automated laboratory testing
  Minimising the effect of human error for the testers, by automatizing the tests, will contribute in the acceptance of the test results by all stakeholders

2.3. Specific requirements identified:

Finally, VITE has identified some specific requirements that will facilitate the shift to laboratory testing. Besides to what is written in section 3 there are some specific requirements that deal with improvements of the lab architecture and that are already being taken into account within the lab specifications.
The most recurring issues identified deal with configuration management, the quality of the input data and the conditions of the execution of the tests:

To improve configuration management possibilities and traceability for the laboratory testing, input data and configuration parameters shall be according to the latest validated data by the supplier and shall be supported by the digital signature of the supplier and include the version identification within the configuration management plan.

User’s see big added value in testing with the real equipment which is feasible as the CCS system is based on SW tools. Virtual equipment is also accepted if it can be demonstrated that the conditions are analogue to the on-site situation. In addition, labs shall be clear about the limitations that should be explained and annexed to the test report. Besides, tests shall be comparable and therefore need to be identified in harmonized interfaces.

3. Architecture

The VITE laboratory architecture is based on the UNISIG test environment, shown in Figure 5.

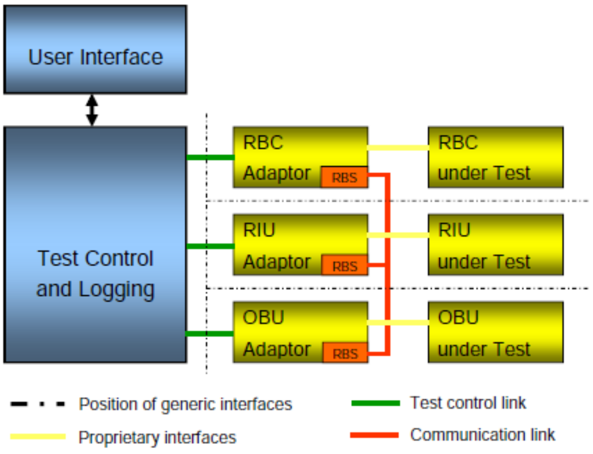


Fig. 5 Architecture overview of the UNISIG Test Environment

This architecture is described in a series of subsets, summarized in the following table:

Table 1. UNISIG IOP specification.

Document	Title
Subset-110	UNISIG Interoperability Test - Guidelines
Subset-111-1	Interoperability Test Environment Definition (General)
Subset-111-2	Interoperability Test Environment Definition (FFFIS for TCL-OBU Adaptor)
Subset-111-3	Interoperability Test Environment Definition (FFFIS for TCL-RBC Adaptor)
Subset-111-4	Interoperability Test Environment Definition (FFFIS for TCL-RBS Adaptor)
Subset-111-5	Interoperability Test Environment Definition (FFFIS for TCL-RIU Adaptor)
Subset-112	UNISIG Basics for Interoperability Test Scenario Specifications

The UNISIG IOP Test Architecture introduces a high level communication layer to coordinate the proprietary independent test benches for every interoperability constituent. This coordination task is managed by the module Test Control and Logging Unit (TCL). The documents in Table 1 describe the Test Control and the Communication Links shown in Figure 5, through the definition of a list of messages to be exchanged between the TCL unit and the external proprietary Adaptors.

3.1. Current status

However, the architecture displayed in Figure 5 has not yet been fully implemented. For the time being, the main shortcoming in the UNISIG architecture can be found in the definition of Subset-111-3, due to the difficulty to harmonize and implement the trackside part. On the other side, although Subset-111-2 is much better defined, it still needs customization for every particular case.

Despite these facts, it is still possible to overcome these limitations and perform track-train integration tests in the laboratory, even on remote premises. However, the possible solutions are very particular and are still far from being harmonized. In every solution, the degree of compliance to the UNISIG specifications in Table 1 varies, as well as the automation level to perform the tests.

In the following figure, two partial implementations of the UNISIG IOP specification are shown. These intermediate test architectures have been identified as Stage 1 and 2, respectively, in the VITE project. Their level of compliance to the UNISIG IOP specification, although incomplete, is increasing.

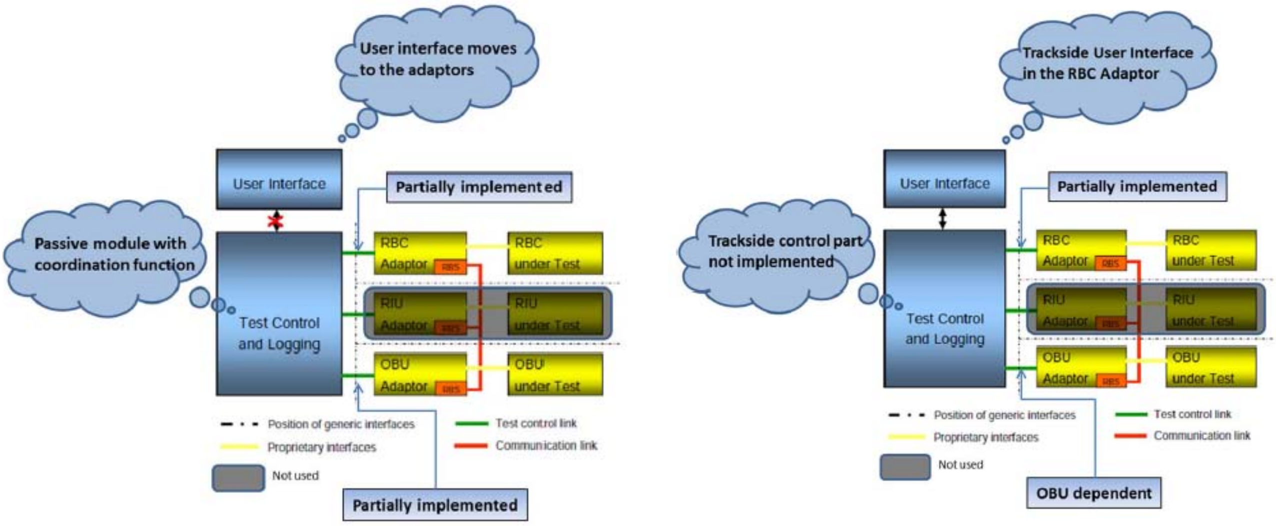


Fig. 6 Test Architecture – Stages 1 &2

In the end, the optimal solution goes through the improvement of Subset-111, in order to solve the lacks and the possible weaknesses in the communication between the TCL and the Adaptors. In this way, the customization effort would be reduced and the automation capabilities would be increased, but, to achieve this goal, it is necessary to go one step beyond and get into the adaptors. Only through a better structure and definition of the direct environment of the industrial components (both on-board and trackside), i.e. the Adaptors, it will be possible to solve the remaining open points in the Subset 111 architecture.

3.2. The OBU Adaptor

The structure foreseen for the OBU adaptor is based on the current Subset-111-2, although, in order to introduce a higher level of detail, the list of messages will be evaluated against the Subset-094 modules directly interfacing with the OBU.

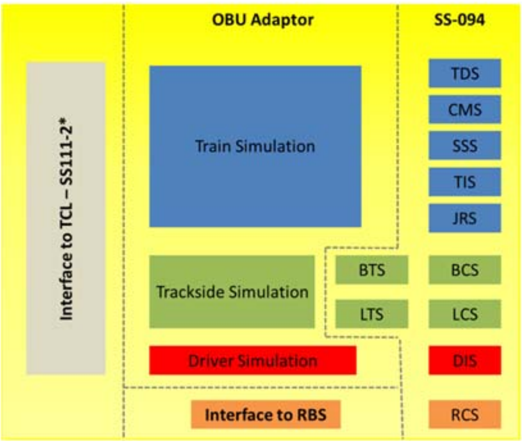


Fig. 7 VITE OBU Adaptor

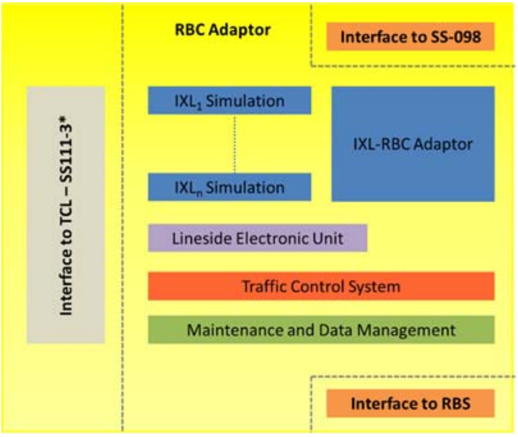


Fig. 8 VITE RBC Adaptor

As can be seen in Figure 7, the functionality associated to the OBU Adaptor is separated into three big virtual blocks, in the middle of the diagram:

- Train Simulation: The Subset-111-2 sections linked to this topic are the Movement Control and the TIU Control.
- Trackside Simulation: In this case, the corresponding Subset-111-2 sections are: Balise Simulation and Euroloop Simulation.

- Driver Simulation: The remaining Subset-111-2 sections are related to this topic.

With this modular approach, the ETCS OBU immediate environment (train, driver and track) is actually virtualized, as the key step to automate the interactions with the device under test.

This first classification is only the way to easily trace the Subset-111-2 messages back to the Subset-094 modules, in the right part of the OBU Adaptor. Considering that Subset-094 describes the complete interface to the OBU under test, this tracing exercise will help to check the completeness of Subset-111-2.

3.3. The RBC Adaptor

For the RBC Adaptor, the situation is completely different, since no official specification can provide some insight into the trackside signalling architecture. However, some recent initiatives [R5] together with the experience of the VITE consortium partners have facilitated to design the proposal displayed in Figure 8.

The modular architecture of the RBC adaptor includes the following trackside subsystems:

- The different Interlocking subsystems linked to the RBC under test. The interlocking might use the industrial hardware or a virtual one, but the logic inside must be the same than in the real track. Every signalling action on the IXL must be collected and evaluated against the Subset-111-3 messages.
- The Traffic Control System, including the function set/revoke Temporary Speed Restriction and the automatic route setting.
- The Lineside Electronic Unit System, to manage eurobalise telegrams built in real time (not preconfigured).
- The Maintenance and Data Management to get log records from the different subsystems, including the RBC under test.

Again, the key factor to fully automate the RBC environment goes through the use of a virtual track (topology and signalling elements) connected to the different interlockings and traffic control systems (virtual or not), as well as a virtual train dispatcher, managing the routes.

3.4. Stage 3 VITE Test Architecture

In this final stage, the main goal is not exactly the compliance with the current set of Subset-111 specifications but the improvements to be introduced in the architecture defined in the subset. The modifications will focus, one the one hand, in reducing the customization effort in the integration between the TCL and the OBU adaptor and, on the other hand, on improving the messages definition in the communication between the RBC adaptor and the TCL. Moreover, it is necessary to add another interface in the RBC Adaptor to permit the communication with another RBC based on Subset-098. The overall architecture is shown in Figure 9.

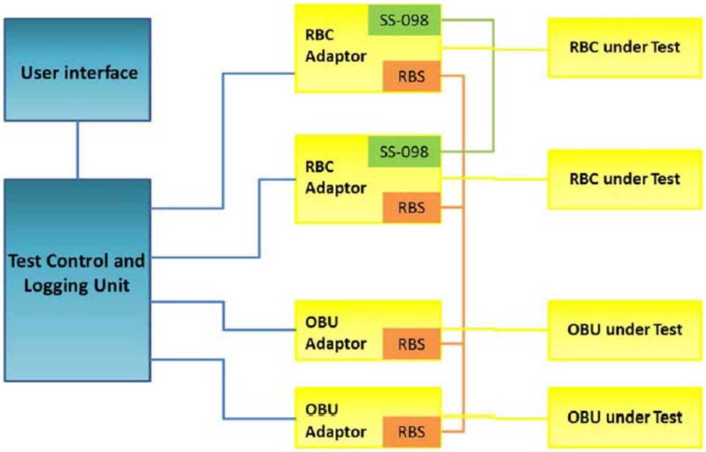


Fig. 9 Extended test Architecture

Regarding the architecture, its presentation in three stages, all of them based on Subset-111-1, expresses the natural implementation order in the evolution of the existing OBU and RBC test benches to allow harmonized remote interconnection. The current approach is an attempt to avoid the specific implementations and to solve the existing gaps in the UNISIG test environment specifications.

The extended architecture (stage 3) to be defined by VITE will produce an impact on the data format and the scenario format itself, which up to now have remained completely undefined. VITE will provide some guidelines on this definition.

4. Conclusions and next steps

VITE has identified three main pillars to support the shift from onsite testing to laboratory testing, which include the aspects considered as most useful by a wide range of stakeholders: infrastructure managers, railway undertaking, NoBos, engineering firms, university and laboratories. These are:

- The use of uncertainty principles to increase confidence in lab testing
- The exploitation of the added value of useful lab testing
- The identification of specific requirements to facilitate the shift to lab testing

VITE project continues to work on the three main pillars identified and expects to achieve its objectives at the end of 2018. The next steps are briefly described below.

To increase the confidence in lab results the test accuracy framework described will be practically applied: it will be further populated with data from ERTMS test reports in order to support the identification of the most suitable testing campaigns to be executed in the laboratory. Results will be an input for the lab architecture mainly regarding input and output data, test criteria, time attributes (duration) and simulation.

VITE will continue to work in maximising the added value of laboratory testing with a focus on the following issues:

- define the detailed architecture taking into account the requirements identified by assessing the best options for virtualisation while maintaining a similar behaviour to on-site testing.
- incorporate within lab architecture, execution and monitoring of test results the monitoring of a larger number of interfaces to provide a greater added value during test campaigns.
- focus especially on improving the test campaigns of the last stages before or just after authorisation since they are the ones where the partners foresee a bigger possibility of shift from on-site to laboratory testing.
- optimise laboratory test reports by incorporating all the extra information (mainly more observables and traceability) deriving from the tests being performed in the laboratory
- improve configuration management possibilities and traceability for laboratory testing
- set a clear guideline that can be accepted by NoBos with a classification of all test campaigns, if they are required to be executed on-site or could also be accepted if performed in the lab under certain conditions.
- Set the content of a test report that can be accepted by all stakeholders

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R4 TSI CCS: Commission Regulation (EU) 2016/919 of 27 May 2016 on the technical specification for interoperability relating to the ‘control-command and signalling’ subsystems of the rail system in the European Union

R5 EULYNX. www.eulynx.eu