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ANALYSIS OF THE POSSIBILITY OF IMPLEMENTING INTEROPERABILITY TESTS ON POLISH RAILWAYS

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Abstract:

Ensuring the greatest possible interoperability of rail transport, especially for railways in Europe, is one of the key projects to be implemented using the European Rail Traffic Management System (ERTMS), including the European Train Control System (ETCS) and the Global System for Mobile Communications-Railways (GSM-R). The ERTMS system aims to replace many different rail traffic control systems with one, common and unified European solution (Commission Regulation (EU) 2016/919, 2016), (Directive (EU) 2016/797, n.d.) Its creation was dictated by the desire to standardize the traffic control systems present in the territories of various European countries, at the same time extending their functionality and eliminating the existing technical barriers. The aim of this article is to present the possibility of implementation interoperability tests - IOP tests, on Polish railways. These tests are intended to provide a faster, more accurate and less costly demonstration of compliance with the ETCS interoperability requirements compared to field tests. The work defines the concept of interoperability tests as well as the purpose of their application. The general principles and procedures for conducting interoperability tests are presented. In the further part of the work, the operation of laboratories in the European Union is analysed. The laboratories functional in Switzerland and Spain were selected for this analysis. Following, the paper presents the validity of implementing interoperability tests on the territory of the Republic of Poland. On the basis of the pan-European procedure of conducting interoperability tests and the experience of foreign independent laboratories, conditions for the implementation of tests in the Polish railways were developed, which could be used in the future to introduce IOP tests in Poland.

Keywords: *IOP tests, interoperability, ETCS tests*

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1. Introduction

The increasing development of railways in recent years with the emergence of new traffic management systems such as European Rail Traffic Management System (ERTMS) means that both the railway infrastructure and vehicles must be equipped with European Train Control System (ETCS) and Global System for Mobile Communications-Railways (GSM-R) (Commission Regulation (EU) 2016/919, 2016), (Pawlik, 2015), (Girardi et al., n.d.). In some European countries, the GSM-R system is already being replaced by the LTE system for traffic guidance (CHRZAN, 2021). While in Poland is predicted that by the end of 2030, 6549 km of lines will be equipped with ETCS. Vehicles running on those lines, also have to be equipped with this system accordingly to KPW (KPW, 2017) and authorized under data published by the Office of Railway Transport, in Poland, out of 6 833 traction vehicles (as of 31 December 2019), only around 10 % are equipped with GSM-R radio. According to the Report (UTK, 2019), 215 traction units were equipped with ETCS at the end of 2018. Gathered numbers show that it is necessary to intensify the process of equipping traction vehicles with ETCS and GSM-R. The process of running vehicle and placing it in service must also be triggered, following by safety requirements. One of the most important steps in placing in service the vehicles is to perform the appropriate checks according to the operational scenarios developed. However, operational scenarios are already carried out on physical and implemented devices. Bearing in mind the costs of production, programming and maintenance of ERTMS devices, it is important that any irregularities and rules of interaction of individual elements of the ultimately coherent and compatible system are detected at the earliest stage as possible.
In order to achieve safe and reliable operation of the ERTMS system, numerous tests of all devices in the system must be performed (EN 50129:2003, n.d., p. 2003). However, the high cost of infrastructure and rolling stock makes it costly and time-consuming to put them out of normal use for testing and evaluation. For this reason, the use of laboratory simulations is even more than justified. Within the framework of railway simulations, we can find various functions such as driving and operational simulators and simulators for equipment testing and data analysis. Interoperability tests (IOP) are designed to check the technical and functional compatibility of the ERTMS between rolling stock and the rail network. They also provides a solution which reduce the effort required to put a new line into service and minimize the temporary decommissioning of infrastructure and rolling stock (by replacing test drives with simulation studies). Selected aspects of integration between ERTMS / ETCS on-board and trackside devices are presented in articles (Adamski et al., 2019) and (Karolak, 2021). Presented appliance can be used to carry out tests before a physical implementation of ERTMS on a new line as well as in advance introduction of ERTMS equipped rolling stock on a specific trackside implementation.
The aim of this article is to present the process of IOP tests and possibilities of implementation of IOP tests in Poland. The additional aim of this article is to encourage representatives of legislative authorities and authorities responsible for safety to use simulation methods in the process of authorization to exploitation.
This article is dedicated to the use of IOP tests for ETCS testing purposes to confirm the compatibility of on-board equipment with the track-side implemented equipment. The article aims to show how IOP tests are carried out in other countries and how such tests could be carried out in Poland. In addition, the article analyzes the requirements and solutions implemented in Europe in terms of standards and requirements in Poland. In the article, the analysis of introducing IOP tests to Poland was studied. The problem of organisation of IOP laboratory, assumptions for conducting IOP tests as well as their organisation and realisation were discussed.
In the first chapters of this article, IOP tests were defined and their implementation in different European countries was described. In the next part of the article challenges connected with introduction of IOP tests were described and scenarios of their implementation in Polish conditions were proposed. Then proposals for the organization of IOP laboratories, roles and responsibilities in the process of their creation and guidelines for their implementation are discussed.

2. Literature review

IOP tests are conducted to verify the correct operation of the ETCS system. The technical description of the ETCS system is presented in the ETCS system requirements specification, i.e. Subset-026 (ERA, 2016a). This is an essential document allowing to fully understand the functional aspects of ETCS system. However, demonstration that ETCS equipment complies with the requirements of the TSI is provided on the basis of:

– Subset-076-5-2 - Functional test case specifications (ERA, 2017b);
– Subset-076-6-3 - test sequence specifications (ERA, 2017c);
– Subset-076-7 - specification of the test scope (ERA, 2017a);

which specifies the tests to be used to confirm the technical compatibility and functionality of the on-board ETCS with the requirements of Subset-026 (ERA, 2016a).

It should be noted, that the ERTMS specifications give some leeway to the implementation of system functionality. Taking this into account, it is not 100% certainty that the on-board and track-side equipment is fully compatible with each other, even if both fulfill the applicable specifications (ETCS System Management Switzerland, 2014).

The approach to ETCS tests is described in the European Union Agency for Railways guide (ERA, 2017d), which presents the methodology in relation to the subset requirements - 076, while this document does not specify how interoperability tests could be carried out in individual countries. In particular, the scope of tests may take into account national requirements that may go beyond the TSI (Commission Regulation (EU) 2016/919, 2016).

Union Industry of Signalling (UNISIG) developed dedicated specifications in 2012:

– Subset-110 - IOP test guidelines (ERA, 2016c);
– Subset-111 - IOP test environment definition (ERA, 2016d);
– Subset-112 - Basics for IOP Test Scenario Specifications (ERA, 2016b).

These specifications define the laboratory tests between on-board system and the real conditions on the infrastructure before physically implemented. The first version of the mentioned above specifications was officially signed by the members of the organization in 2014. The current version, as amended, is from 2016.

A review of laboratories offering IOP tests in Europe indicates that they already operate in Spain, Italy, Germany (Website, 2019), (Jaschke et al., 2005), Holland, Belgium, Denmark or Switzerland (Le Borgne, 2019). The IOP tests are mainly aimed at ensuring interoperability and compatibility of ERTMS within each country. For this reason laboratories have different rules for: laboratory management, recognition of tests in authorization process, prerequisites for ERTMS subsystems, accepted operating scenarios, scope of the tests, or documents confirming the performance of tests.

One of the methods of conducting interoperability tests is the use of serial communication channels, as described in the article (Hwang, 2015) in which it was proposed a new interoperability test method and the tool to support it for the functional safety validation where the Ethernet and serial communication channels used by the actual train control systems are in common use. Another approach to interoperability tests is presented in the article (Barberio et al., 2014) where the results of research carried out under the ARTEMIS CRYSTAL project, which tackles the challenge to establish and push forward an Interoperability Specification (IOS) as an open European standard for the development of safety-critical embedded systems. ETCS requirements and compatibility problems are dealt with in the document (Holst Moller, 2021), which presents test examples.

The ETCS laboratory testing approach is also presented in an article (Solas et al., 2016) which discusses two novel laboratory tools that the EATS project (FP7-TRANSPORT-314219) has produced in order to overcome some of the problems those processes show and advance towards the “ Zero On-Site Testing ”paradigm - a method that assumes no field testing, only laboratory testing. On the one hand, saboteurs for the internal interfaces of the ETCS on-board system have been created. These saboteurs integrate seamlessly with the rest of the elements of the testing laboratory and allow to gather evidences regarding the safety functions of the equipment under test. On the other hand, the Wireless Communication Emulators have been also developed. These tools allow to put the wireless interfaces of the ETCS on-board equipment in the worst cases it will find in a real environment, by reproducing and injecting noise and interferer signals, and measuring the effect in the equipment under test. A similar approach was also presented in (Berbineau et al., 2021) and (Nardone et al., 2020).

While the authors of the article (Rosberg et al., 2021) indicate a number of problems identified in relation to ERTMS. They also recommend the use of simulation methods to predict and solve them, as methods with significantly lower costs than field tests, or to implement corrections after implementation.

The application of the simulation approach is now also more widely used, as it is also used for routing trains (Di Meo et al., 2020) and (Gago & Siergiejczyk, 2020), as well as for testing geolocation systems (Filip, 2020).

An important aspect that is the subject of many current publications is to propose formal methods for correctness testing, currently in the implementation phase, ERTMS level 3 (Di Meo et al., 2020), (Dghaym et al., 2020), (Arcaini et al., 2020), (Mammar et al., 2020), (Tueno Fotso et al., 2020) and in the field of cybersecurity (Abourahim et al., 2020).

However, none of the presented documents specifies the exact requirements for interoperability tests, let alone tests that could be used in Polish conditions. Each country has its own additional requirements, systems or units that have the required conditions for interoperability testing.

In view of these differences in the conduct of the IOP tests, the tests carried out in laboratories in Switzerland and Spain will be presented.

2.1. Interoperability tests – Switzerland

Three laboratories conducting tests for four existing ERTMS lines are currently in Switzerland. The laboratory is owned by ETCS trackside suppliers Thales, Siemens and Alstom. IOP tests are carried out on ETCS on-board (OBU) and track-side (RBC or L1LS) equipment. In addition, there are 15 infrastructure managers (IM) in Switzerland, which is important for testing. Despite of so many IMs, testing by suppliers of the track-side part of ETCS ensures an adequate level of verification of the compatibility of the whole ETCS. Consequently, interoperability tests are not conducted for specific railway lines, but for all ETCS implementations throughout Switzerland. These tests lean on Subsets-110, -111 and -112 developed by UNISIG (ERA, 2016c), (ERA, 2016d), (ERA, 2016b).

It should be stressed that tests in laboratories are a mandatory part of the trackside subsystem authorization in Switzerland and a part of the authorization process for railway vehicles.

In addition, there is a dedicated ETCS System Management Switzerland unit (SM ETCS CH) established by the national safety authority (in Switzerland it is the Federal Transport Office - FOT) to ensure and enforce ETCS interoperability. The studies, recommendations and requirements defined by this entity must always be taken into account and applied in the IOP tests.

IOP tests are an important part of a broader concept in Switzerland, adopted by SM ETCS CH. It is a safety concept for obtaining an ETCS system authorization (Le Borgne, 2019). It involves obtaining safety evidence for the track-side and on-board parts of ETCS by the suppliers at the various stages of implementation and for the integration of ETCS as a whole. The safety concept adopted ensures that any discrepancies in ETCS can be verified at a very early stage of implementation.

In the context of tests to verify the technical functional compatibility between the On-board and Track-side parts of ETCS (IOP tests), the interoperability of the system as a whole is a difference due to certain defects in the specifications dedicated to the different parts of the system. It should be stressed that according to SM ETCS CH, product faults that should generally be identified during product tests (verification of ETCS as an interoperability constituent) are often only detected during IOP tests (ETCS System Management Switzerland, 2014)

Figure 1 shows the participation of actors in IOP tests in Switzerland.

From the below figure, cooperation between track-side and on-board ETCS suppliers in IOP tests can be particularly stressed.

In advance of the starting tests in a Swiss laboratory, assumptions for IOP tests are required, which include in particular:

- information about the implemented TSI baseline and version, national requirements as well as the list of 'change request' implemented;
- the version of the Subset-091 specification defining the safety requirements for ETCS technical interoperability in levels 1 and 2 (ERA, 2015);
- declaration of any deviations from the specification and confirmation that these deviations do not cause any failure of the trackside or on-board equipment;
- a declaration by the supplier of on-board equipment confirming compliance with the applicable TSI requirements (as interoperability constituents);

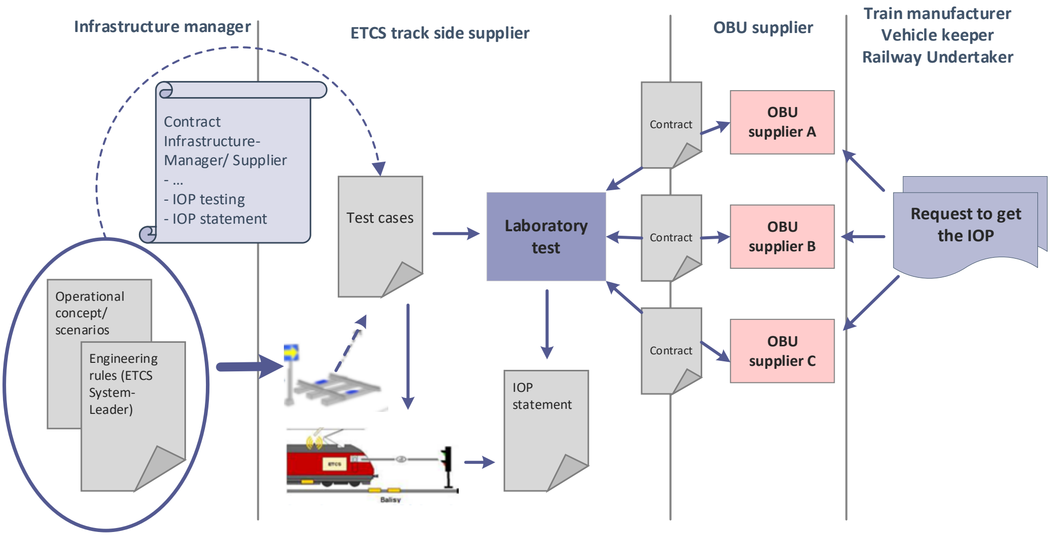

Fig. 1. Structure of participation in IOP tests in Switzerland (source: own study based on (ETCS System Management Switzerland, 2014))

– the operational aspects to be considered as a basis for selecting the implemented functionality of the equipment in consultation with the suppliers;
– certificates of track-side and on-board suppliers that define the status of ETCS equipment and the implementation of specifications (versions of specifications);
– how to build and run test cases (requirements);
– guidelines for defining test results (test protocols);
– how to handle and conduct tests in case of discrepancies, deviations;
– the scope of assessment of individual test results and the overall assessment for a given test.

The next step after the tests in the Swiss laboratories is to review the IOP certificate, which summarizes all verifications of compatibility of on-board equipment with track-side implementations for which interoperability must be demonstrated. The review shall cover any discrepancies that require specific non-technical fault handling, specifying additional operational rules, behavior and provisions that apply to them. The IOP testing process itself is relatively expensive. The costs of conducting tests include: costs of developing assumptions for IOP tests, costs of IT equipment delivered to the laboratory, adaptation costs, including costs of test tools, transport, etc.

2.2. Interoperability tests – Spain

ETCS, in Spain, is supplied by: Alstom, Ansaldo, Bombardier, Siemens and Thales, with Thales supplying only trackside equipment. The Cedex Interoperability Laboratory is an independent laboratory offering interoperability tests of on-board and track-side ETCS in Spain. The scope of the laboratory's activities includes the certification of individual ETCS components as well as the verification of compatibility between track-side and on-board subsystems. The tests that Cedex carries out are defined jointly by Adif (National Infrastructure Manager), Renfe (National Railway Undertaking), Cedex and the Ministry of Public Works and Transport.

IOP tests offered by Cedex consist of a developed complete catalogue of test cases (215 for ETCS level 1 and 260 for ETCS level 2 (Cambronero et al., 2011)). These test cases are designed to test the main functionality of the whole system, focusing on its normal operation. The scope of these tests includes: speed control and braking curves, level transitions, mode changes, temporary speed restriction management (TSR), drive permission management, odometry, ATO and predefined speed, DMI operation, national values.

There is a complete catalogue of test cases in Spain for testing track-to-train compatibility. This catalogue is constantly evolving, being complemented,

optimized and corrected with the experience gained during testing.
The article (Iglesias et al., n.d.) presents the real deployment of ERTMS in all the new Spanish High Speed lines. The paper shows not only the high level of interoperability reached in Spain, where almost all the ECTS suppliers are present in both track and on-board subsystems, but also the near future challenges that shall be overcome to continue a successful ETCS deployment. In addition, the article (Iglesias et al., n.d.) presents the conditions of laboratory tests that are carried out by the Cedex laboratory (Fig. 2).
Cedex offers five different test arrangement for ETCS implementation (Cambronero et al., 2011):
- new line and new rolling stock;
- validated line and new rolling stock;
- new line and validated rolling stock;
- validated line and validated rolling stock on another line;
- validated line and new rolling stock with software validated in another rolling stock.

Fig. 2. Traffic simulation Lab (CEDEX, 2019)

Depending on the configuration, the scope of test cases required for Cedex varies. For example, for the first case indicated, all test cases have to be performed, as this means that a completely new ETCS system is being implemented for both on-board and trackside applications. An in-depth analysis of each specific situation to be tested is carried out. Then, on the basis of the analysis of the expert group, a set of test cases applicable to a given configuration is selected, based on the characteristics of the rolling stock and the line and taking into account the functionality of the systems for the implementation. The tests are performed when the ETCS system is fully operational, i.e. independent EC verification processes have been completed.
It should be stressed that the process of verifying the functionality of the ETCS system does not end with testing itself. The tests require further analysis, which is mainly based on observation of the driver's cab data during the tests, track-side data recorded by the on-board equipment and information provided by the track-side and on-board ETCS suppliers. This is an important stage during which both, the system and functionalities are analysed in detail. A report on the verification of compatibility is then issued and assessed in order to obtain the placing in service of the rolling stock or line.
In the authorization process, in Spain, IOP tests are required by the relevant national legislation which sets out the test requirements for checking technical compatibility and safe integration. The tests are carried out after on-board equipment certification process and the relevant EC certificate of verification gained. Some of the infrastructure integration tests are carried out in the CEDEX laboratory, others are carried out on the line. Costs related to the tests are borne by the applicant (ETCS supplier).
Interoperability tests are being standardized by the signaling companies grouped in UNISIG to detect early problems in the integration of trackside (RBC-IXL and Eurobalise) and Onboard equipment (EVC) from different (or same) suppliers and to assure interoperability. The test architecture is defined in the Subset111 and the scenarios are specified in the Subset-112.
According to UNISIG the purpose of the standardization is to make IOP tests measurable and comparable, that means giving customers and organizations (especially National Safety Authorities, ERA and Notified Bodies) a clear view on the status and results of IOP test. So they

can be compared and mutually recognized by different laboratories and different suppliers.
The IOP tests between different suppliers allow for early detection of faults in the implementation of the ETCS system and the correction of any errors before its installation. (Iglesias et al., n.d.).
The tests developed in Spain could be a first approach to be considered by the European Railway Agency. A kind of similar tests should be defined by ERA to assure cross acceptance among different NSAs (National Safety Authorities). The Spanish approach of defining complementary test and later on executing this tests in a lab compliant with Subset-094 should be considered by the ERA as a good one to be included in the TSI (Iglesias et al., n.d.).

3. Research problem

The research problem of this paper is the analysis of requirements connected with IOP tests implementation and the proposal of tests implementation taking into consideration legal and technical conditions on European and national level.
Compliance of ETCS equipment with the requirements specified directly in the TSIs is the responsibility of the ETCS Providers and is a prerequisite for starting the relevant IOP tests. The main assumptions for IOP tests are:
– the boundaries for testing are defined by on-board ETCS and track-side interoperability constituents
– the on-board system and the trackside equipment come from different suppliers or from different product lines of one supplier;
– IOP tests are performed at interfaces which allow the user to control and observe the behavior of the system;
– IOP tests are visualized at ETCS interfaces, e.g. human-machine interface, protocol interfaces.

Figure 3 illustrates the scope of IOP tests for the integration of the on-board and track-side parts of ETCS presented by UNISIG.
It should be stressed that the guidelines for IOP tests alone should not refer to requirements set out in the TSI. The purpose of standardizing IOP tests is to make them measurable and comparable. This means that it is possible to provide users and organizations with a clear picture of performed tests and to ensure their interoperability, thereby promoting compatibility tests between different suppliers.
The one of the challenges for the near future are the implementation of the complementary tests in laboratory instead of on a real track. Although it has been mentioned in the previous paragraph the progress already reached, there are still some pending issues mainly related to the realisation of L2 tests in the laboratory. The lab updating is in progress but in this case the connection of the RBC to the laboratory simulated interlocking has to be done in a proprietary solution with each company. This is due to the fact that the interface between interlocking and RBC is not defined in the ERTMS specifications, and therefore shall be defined bilaterally between the lab and each company. This fact increases not only the time but also the cost of laboratory tests execution. The European project INESS (Integrated European Signalling System) will solve this issue but up to that time it will not be a standard solution (Iglesias et al., n.d.).
Another challenge is the migration process form ETCS version 2.3.0d to version 3.6.0 mentioned in the TSI (Commission Regulation (EU) 2016/919, 2016). There is no strategy that would enable an orderly process of changing both trains and tracks to version 3.6.0. This process is quite complex if we want to reduce the impact in the commercial exploitation. In this case the existence of both ETCS levels will allow completing the process by means of temporarily exploiting the line in one of the levels. In addition, it has not been established who is to bear the relatively large costs related to migration.

3.1. General assumptions for interoperability tests

On the basis of the IOP test guide - Subset-110 (ERA, 2016c) developed by UNISIG, it is possible to visualize the process of conducting IOP tests, as shown in Figure 4, together with determining the responsibility of entities participating in the tests.
As the figure 4 shows, the following stages can be distinguished within the IOP tests: preparation phase, testing phase and results reporting phase.
The preparation phase consists of configuring the test environment, i.e. defining a common set of data, ensuring equal test conditions for devices from different suppliers. Then, it is necessary to prepare the data of the developed project, which is an instruction on how to conduct IOP tests based on supplier implementation paths.

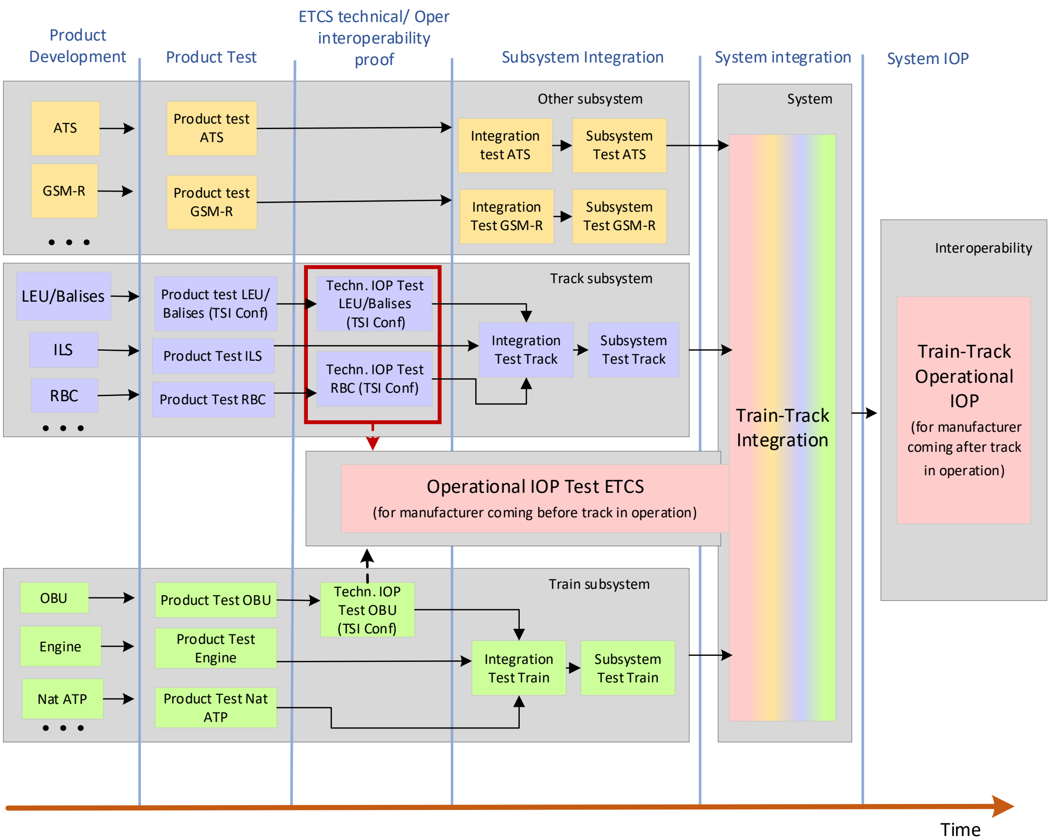

Fig. 3. UNISIG IOP test range (Subset-110) (source: own study based on (ERA, 2016c))

Then IOP test description is created, which is a specification of the overall test strategy and list of test scenarios related to the given project. In the next step, documentation defining test assumptions, including test case results and test environment specification, is developed. Then, it is necessary to define test scenarios that support the practical implementation of the test description and correlate them with previously defined test cases. The list of IOP test scenarios should be designed to include all specific test cases for a given project. Finally, the simulated environment is installed in accordance with the laboratory configuration assumptions. The test environment is considered ready after initial checking of all tested subsystems and successful passing of the test environment control and its documentation.

As part of the test execution phase, the implemented test cases are conducted according to a pre-defined schedule as well as test documentation and non-compliance reports. This information is the basis for analyzing the test results and for monitoring any problems

The final phase of IOP testing is results analysis and reporting. Based on documented results of performed tests, a detailed analysis is carried out to determine the correct operation of the system and the identified non-conformities. At the end of this phase, final test reports are issued.

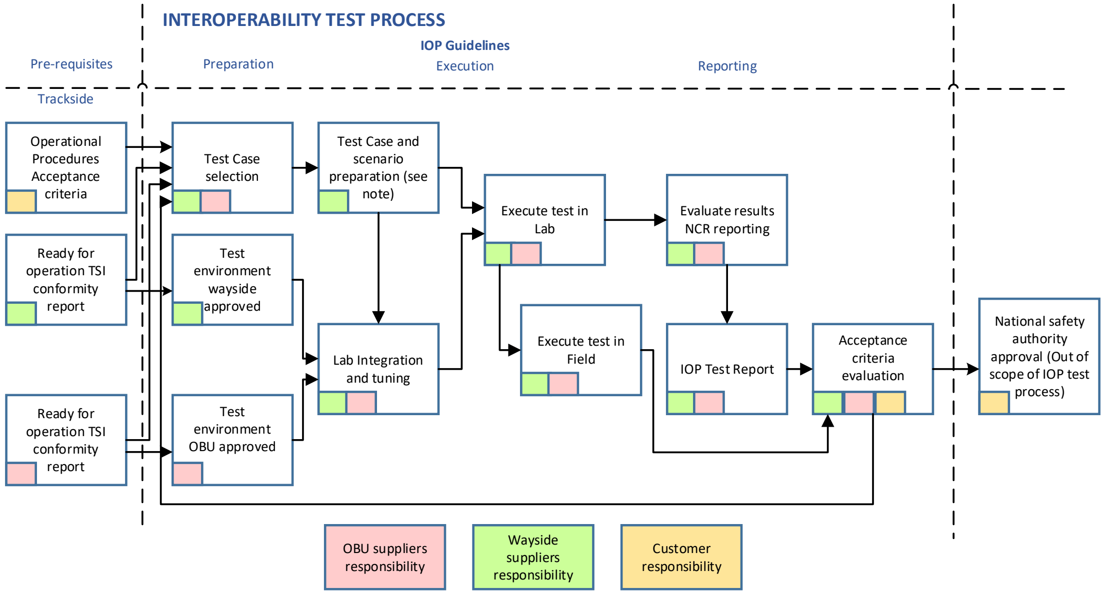

Fig. 4. The IOP testing process according to UNISIG (Subset-110) (source: own study based on (ERA, 2016c))

3.2. Interoperability Test Environment

According to Subset-111 - the IOP testing environment (ERA, 2016d), the test environment architecture should be as simple as possible to allow the implementation and testing of various ETCS system devices, but at the same time ensure easy combination of test environments supported by different on-board equipment and track-side suppliers. In addition, it is important that the architecture allows the connection of real ETCS system devices to the test environment, while ensuring the use of interfaces for different suppliers. It should also be universal enough to enable re-use of solutions already available from the previously performed tests. In addition, it should be possible to use additional, proprietary applications of a given provider (e.g. login or remote access to the user interface).

Continuous monitoring of the scenario should be ensured within the test environment. All data exchanged between the test environment and ETCS devices should be recorded on an ongoing basis. It should also be emphasized that the test environment should in no way refer to a specific version of the TSI CCS. As already mentioned, it is primarily to allow flexible and universal use. Of course, care should be taken to ensure easy maintenance, updating and modernization of this environment, but at the same time ensuring its constant universality.

3.3. Interoperability test scenarios

When developing IOP test scenarios, consideration should be given to defining the input data, its structure and content, i.e. general prerequisites, execution sequences and anticipated test results. In this area, it is crucial to define the content of the scenarios and to maximally simplify the understanding and evaluation of test scenarios operating in various IOP test environments. The format of the evaluation and the report should be harmonized to make it easier to understand between different sides of the tests, but also to maintain a uniform approach to the different tests. Such requirements are set in the Subset-112 specification - principles of IOP test scenarios (ERA, 2016b).

Testing scenarios should contain all information necessary to identify test itself and track changes, or clearly defined restrictions on its use. They should provide the best understanding, comparability and ability to easily maintain such IOP test scenario descriptions. Therefore, each test scenario should have

in particular identification data, including change histories; identified requirements, description and presentation of the scenario; configuration of the test environment for a given scenario; test prerequisites; execution sequences; expected results (verification steps) with a range of acceptable deviations; final conditions determining the status of on-board equipment and the condition of the infrastructure.
The principles of IOP test scenarios developed by UNISIG Subset-112 (ERA, 2016b) also define the parameters to be determined for the trackside and on-board ETCS layers for the purposes of conducting interoperability test scenarios. In addition, two forms were also developed under this specification: the interoperability test scenario form and the IOP test report form. It is extremely helpful material for creating rules for the implementation of the laboratory offering this type of test.

4. Results

4.1. Conditions for testing implementation in the Polish railways

Considering the pace of ERTMS system development and implementation plans, there is a need to implement interoperability tests in the Polish railway system. The described IOP test laboratories differ in both organization and scope of tests. Each of them has been adapted by individual countries to national conditions. In the conditions of the Polish railway market, which significantly differs from the ones analyzed (mainly due to national law, operating regulations and differences in railroad technology), it is not possible to adopt 100% one solution and implement it. It is necessary to take into account a number of important factors, such as the condition of the Polish railway network and rolling stock equipment with the ETCS system, organizational capabilities of the infrastructure manager, or even KPW (KPW, 2017), which will affect the shape of the laboratory in Poland. This chapter presents the conditions for the implementation of IOP tests in Polish railway conditions based on the analysis of existing laboratories conducting IOP tests.

4.2. IOP testing laboratory

In order to enable IOP tests, an independent laboratory should be created that will be available to all test applicants on an equal basis. The laboratory should be properly accredited to conduct IOP tests. In this regard, it is possible to use the procedures and experience of a laboratory operating in Spain which has such accreditation.
The IOP test laboratory should be understood as a set of dedicated tools, ICT devices, test procedures and competent personnel allowing to perform multiple tests of ERTMS devices in a simulation environment. The laboratory should be organized in such a way as to ensure the greatest possible flexibility of use. First of all, through the possibility of using real ETCS devices as well as through their simulation in a test environment. The test environment architecture should meet the requirements of Subset-111 (ERA, 2016d), developed by UNISIG. Figure 5 shows the architecture of such a laboratory.

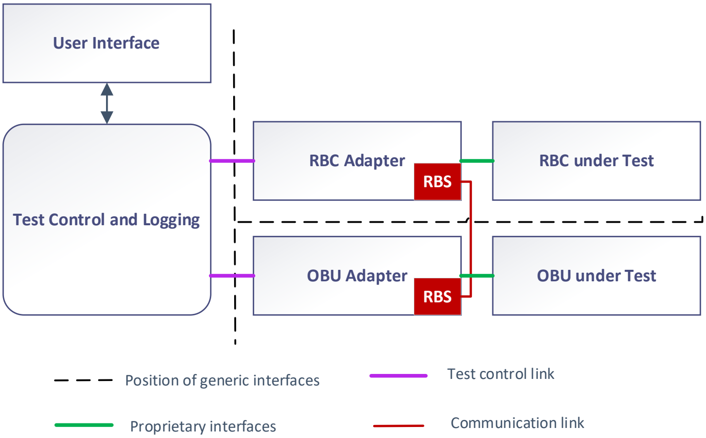

Fig. 5. Architecture of the test environment according to UNISIG (source: own study based on (ERA, 2016d))

The laboratory should be equipped with an adequate number of stands where IOP tests can be conducted. Each laboratory stand should be equipped with appropriate IT tools, connections and designated assembly points for real ETCS system devices. IOP test benches should be located in such a way that the test equipment is not affected by any external interference that could falsify test results. Each workstation should also meet the relevant ergonomics requirements, including handling of manipulators in the case of e.g. use as part of actual DMI display testing.

It is also crucial to ensure that all tests for specific devices are carried out in one test stand without the need to change the configuration of devices during the entire procedure. Access control should also be provided for each test stand, thanks to which only the person responsible for conducting IOP tests on given devices will be able to access during the test procedure. The IOP testing laboratory should provide a high level of test automation.

4.3. Preliminary assumptions for IOP tests

To conduct IOP tests, an IOP test manager should be designated - the person responsible for conducting IOP tests for a given project, who should be supported by: infrastructure manager (e.g. by verifying and creating new test scenarios, sharing design data of each implementation), ETCS trackside and onboard part suppliers and rolling stock manufacturer (e.g. by providing test items and commissioning IOP tests).

IOP tests should be based on operational scenarios and individual trackside implementations - in this area it is also necessary to base and use guidelines to confirm ETCS System Compatibility (ESC), which is to be defined by the infrastructure manager. Tests should be carried out on devices representing relevant parts of actual track-side deployments. Only tests that cannot be performed in a laboratory environment should be carried out in real conditions - on the network, which is decided by the infrastructure manager in consultation with the other parties participating in the tests taking into account the risks of not carrying out field tests.

It should be emphasized that IOP tests (carried out during the subsystem implementation phase) are not intended for testing the generic compliance of a product with the TSI, i.e. EC verification of the syntax or checksum of telegrams generated by interoperability constituents. Both the on-board and trackside parts of the ETCS system for which IOP tests are to be carried out must be strictly in accordance with the requirements of the CCS TSI (on generic level), which must be confirmed by the EC verification certificate issued by a notified body with competence in certification in this area.

Tests may be carried out at the level of the interoperability constituents or subsystems. Testing should not be made dependent on a fixed configuration for a particular vehicle. However, to determine the full compatibility of the devices in the target conditions it is required. From the specific configuration and working environment on the vehicle of the ETCS system there are certain dependencies of operation, such as braking curves, which depend on the percentage of braking mass, determined by the manufacturer of the railway vehicle. Here, the key is whether IOP tests are to demonstrate ESC compatibility

4.4. Legal conditions

In order to ensure the effectiveness of the implementation and conducting of IOP tests, they must be introduced as mandatory in the process of applying for an authorization for placing in service (placing on the market) for a type of railway vehicle what should be included in the act on rail transport (UoTK, Dz. U. 2003 Nr 86 poz. 789 as amended, n.d.) and the interoperability regulation (Regulation 1042 of 9.06.2021, n.d.). These tests give the opportunity to increase the coordination of suppliers and customers of the ETCS system, as well as easier comparison of the quality of systems from different manufacturers, and above all they can be used to demonstrate ESC compatibility. Another argument for including IOP tests as required in the authorization process is the need to perform ESC tests and enter the ESC compliance parameters in the European Register of Authorized Types of Vehicles (ERATV) (Commission Regulation (EU) 2016/919, 2016). Therefore, most tests should be carried out in laboratory conditions in order to reduce the costs of test implementation, which is also allowed by (ERA, 2021) and (PKP PLK S.A., 2021b), (PKP PLK S.A., 2021a).

4.5. Roles and responsibilities in IOP tests

Infrastructure Manager

An infrastructure manager should participate in the organization of the laboratory. This is crucial because the infrastructure manager has all the data necessary for conducting IOP tests regarding individual implementations of the ETCS system on the network it manages. As already mentioned, the infrastructure manager determines the ESC types for ETCS implementations on the infrastructure it manages. It is important that the manager must also guide engineering principles on his infrastructure in order to maintain technical uniformity of trackside solutions. This is crucial to ensure an adequate level of stability for certain types of ESCs that on-board equipment manufacturers and railway vehicle manufacturers must meet.

With regard to conducting IOP tests, the manager should provide all implementation data to map reference conditions for individual ESC types. Works with the IOP test manager and provides all necessary information to maintain test devices in accordance with specific ESC types and modifications. It should be emphasized that it should be the infrastructure manager's responsibility to develop and / or verify the IOP test list for testing, taking into account the reference conditions for specific track-side implementations.

Entity applying for IOP tests

The following entities may apply as an entity applying for IOP tests: supplier of on-board ETCS system equipment, railway vehicle manufacturer, infrastructure manager, railway vehicle owner or modernization contractor. The catalog of entities presented corresponds to the ESC assumptions. In the process of obtaining authorization for placing on the market of a railway vehicle type, the applicant for authorization is responsible for conducting ETCS compatibility verification (ESC) for a given area of use of the vehicle.

The entity applying for the IOP tests must provide certified equipment and software of the on-board part of the ETCS system and specify a representative configuration for the given IOP test together with the ESC types for which it applies for confirmation of compliance, in accordance with the conditions specified in the IOP testing process. It equips the test stand with testing equipment in a laboratory environment and with interfaces that meet the technical requirements contained in Subset-111.

IOP test manager

It is the IOP test coordinator who is responsible during the test for ensuring trouble-free running of the given IOP test from the point of view of technical settings of devices, simulation and reporting of results. It must also ensure the maintenance and necessary updating of IOP testing tools. The coordinator must have extensive knowledge of the design and programming of the ETCS system.

Notified Body

The notified body is responsible for verifying that the technical compliance checks have been carried out in accordance with the technical document published by the Agency. Based on the IOP test report, and if required, the ESC test report, the Notified Body shall confirm that the report has considered all complete tests and has identified all non-conformities and limitations (if applicable). At this stage, the notified body no longer verifies in any way the interoperability constituents and their groups for which an EC declaration of conformity was issued before IOP tests.

4.6. Conducting IOP tests

Conducting IOP tests should be in accordance with the guidelines set out in Subset-110, -111, -112 (ERA, 2016c), (ERA, 2016d), (ERA, 2016b). IOP tests should focus on network-specific (given ETCS deployment on the network) interface problems, including existing transitions. In particular, tests should cover all relevant operating procedures, mainly in degraded conditions (e.g., failures, defects).

Operation of the ETCS system is based on the constant calculation and control of braking curves, that is, calculating of the maximum allowable speed as a function of the road, constantly monitoring it and ensuring a safe system response in the event of exceeding (Gruba et al., 2018). The scope of IOP testing should include:

– speed control (in individual driving modes)
– braking curves;
– transition between ETCS levels on the railway;
– entry / exit to / from the area equipped with the ETCS system depending on the given level of

ETCS and baseline implemented on the vehicle and on the infrastructure;
- driving in individual modes and changing the driving mode;
- establishing connection and maintaining communication with RBC by the on-board equipment;
- management of temporary speed limits (TSR);
- monitoring of driving authorization data, including testing the system's response to an unexpected shortening or extension of a driving authorization;
- track conditions (e.g. checking the system response to REC message, checking operation in the event of loss of balis group, checking system behavior in the absence of STM / SHP mode);
- DMI work, including testing the proper display of all messages required by the ETCS system in real time;
- implementation of national variables.

The examples listed above are, of course, not a catalog of closed verification that can and should be carried out as part of IOP tests - they are only a general outline. Each determination of test cases should first of all be analyzed in detail by the infrastructure manager in consultation with the suppliers of the ETCS system in relation to the specific implementation on the line and traffic conditions on this line, taking into account the required ESC checks.

Each item listed above should be approached in detail and its correlations and relationships with the others should be analyzed. Specific test cases should be precisely determined for individual ETCS system functions and possible traffic situations, their connections in various configurations, but also in the absence of complete data or in the event of equipment failure. As the example of the Spanish Cedex laboratory shows, 260 level test cases implemented during IOP tests were developed for ETCS level 2.

Examples of test cases implemented in the laboratory as part of IOP tests may be:
- Entry to the ETCS area of the given level and baseline - on-board equipment in level 0 or STM / SHP;
- Stopping the vehicle before the end of the driving authorization in full supervision mode when driving in the ETCS area of the given level and baseline;
- Speed control in full supervision mode while driving in the ETCS area of the given level and baseline;
- Omission of the end of the driving authorization in full driving supervision mode in the ETCS area of the given level and baseline;
- Display of appropriate messages by the DMI in given circumstances, including the information displayed at the driver's request, but also the order in which the messages are displayed;
- Entering the ETCS area (appropriate level) without confirmation by the driver;
- Operation of ETCS on-board equipment after receiving information about electroless areas or with driving without stopping areas.

Above are only examples of test cases to demonstrate ETCS system compatibility, including ESC checks. Undoubtedly, it is also fully justified to use an independent laboratory for the purpose of verifying the operation of the new trackside ETCS system before its physical implementation on the railway.

5. Conclusions

The ERTMS system is already a well-known, efficient technology used all over the world. However, there is still a lack of flexibility in the area of authorization and certification. The key to the system's success in the future is both cost reduction and simplification of system verification and authorization procedures. This applies to the implementation of a new subsystem, and even more so to new versions of software related to already functioning subsystems. Currently, the process of placing ETCS equipment and subsystems in service requires a large number of tests due to the complexity of signaling systems and various engineering principles. Shift2Rail (Shift2Rail – European Railway Program for Innovation of Railway Products) multi-year action plan states that the expenditure and time spent on testing on the web is at least 30% for each specific project (Molina et al., 2018).

This article demonstrates the relationship between ESC compatibility and IOP tests that should be considered as the only valid form of demonstrating ESC compatibility, as well as interoperability to which IOP tests will contribute.

Assuming that the developed simulated IOP testing environment fully complies with the ETCS system specifications and CENELEC specifications, as well as exactly the same interfaces embedded in the actual equipment have been integrated in the laboratory development process, it can be guaranteed that the behavior of the simulated and actual system equipment is absolutely identical.

It can be concluded that despite the considerable costs of developing this type of tool, the cost of track tests is reduced, as the number of field tests is minimized, which reduces the use of infrastructure and rolling stock. What's more, laboratory tests allow you to perform multiple checks, which helps build confidence in the compatibility of implemented parts of the system.

The analysis carried out in this work has shown that IOP tests are a tool that gives the opportunity to prove ESC compatibility. In addition, IOP tests ensure the interoperability of the ETCS system by various ETCS suppliers on various system implementations and on different lines within the country without long and costly tests on rail lines. Tests in laboratories can be carried out easier and faster than in the field, they do not require booking track closures, they do not affect the capacity on loaded lines.

There is currently no laboratory in Poland offering IOP testing to prove the compatibility of the ETCS system, as it is implemented in other countries. Considering the pace of ERTMS development, as well as the advance of laboratories offer IOP tests, the release of this type of tests in Poland should be given priority, at least at a level equal to the implementation of the ERTMS system itself.

The article critically analyses the experience of other countries that have already implemented IOP tests, on the basis of which it presents a model adapted to Polish conditions. Clear guidelines for the organisation of such tests at both the national and executive level are given. Arguments for the implementation of IOP tests in the country are presented. The analysis conducted in this paper can be used by legislators and infrastructure managers to implement IOP testing in the country by introducing appropriate regulations and instructions. The article is therefore an analysis of the possibility to introduce IOP tests in Poland.

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