DOI: 10.36137/1931E

Integration Tests of ETCS On-board Subsystems Based on the Requirements of the Technical Specifications for Interoperability of the ‘Control-Command and Signalling’ Subsystem

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Summary

Achieving the interoperability of the European rail system in each Member State requires many measures to standardise the adopted technical solutions and relevant regulations. However, it is likely that there may be some incompatibilities between individual subsystems, even if these subsystems are designed in accordance with standardised requirements. Interoperable rolling stock may be unable to move freely over an interoperable railway line due to some incompatibilities and differences in the versions of the installed firmware in the ETCS system devices. The article discusses the compliance tests of the proper integration of the on-board subsystem with the trackside subsystem, carried out by the Railway Research Institute.

Keywords: interoperability, control-command and signalling, ERTMS, ETCS, TSI, CCS

1. Introduction

The railway systems operated in the various Member States of the European Union have developed independently and rely on different technical solutions. The multitude of control-command and signalling, power supply, and other systems hinders the free movement of people and goods across Member States. In view of the resulting technical barriers, the so-called “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system” has been drawn up, where the main priority for railway transportation is the standardisation of the adopted technical requirements. The underlying idea is to create conditions where trains are able to cross the borders of EU Member States without stopping. In order to achieve this objective, the interoperability of the European rail system must be obtained, which should translate into the creation of a single European railway area as a result. On account of the above, the railway system has been divided into structural subsystems [2]:

- infrastructure,
- energy,
- control-command and signalling and rolling stock.

and functional subsystems:

- maintenance,
- operation and traffic management,
- telematics applications for passenger and freight services.

This division has made it possible to establish the Technical Specifications for Interoperability (TSI) for the different subsystems, i.e. requirements that must be met in order to achieve the complete technical harmonisation of railways. The individual TSIs have the same structure, describing the essential requirements, basic parameters, interfaces with other subsystems, and the scope of checks and inspections to be performed to obtain an EC certificate of verification.

This paper discusses issues related to the structural control-command and signalling subsystem, as implemented by Commission Regulation (EU) 2016/919 [1] and its subsequent amendments on the technical specification for interoperability relating to the control-command and signalling subsystems of the rail system in the European Union, hereinafter referred to as the “CCS TSI”.

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2. Structure of the control-command and signalling subsystem

Pursuant to Directive (EU) 2016/797 [2], the control-command and signalling subsystem is divided into: "on-board control-command and signalling subsystem" and "trackside control-command and signalling subsystem". In the Directive, these subsystems are defined as follows: (…) *all the on-board equipment required to ensure safety and to command and control movements of trains authorised to travel on the network* (…) and (…) *all the trackside equipment required to ensure safety and to command and control movements of trains authorised to travel on the network*.

In the light of these definitions, both subsystems are separate objects of assessment when they are verified by competent notified bodies. It is also important to note that, in addition to the above-mentioned superordinate layers of the control-command and signalling subsystem, there is also a so-called basic layer. It consists of track occupancy control devices, switch equipment, station and line equipment. The requirements for the basic layer are defined by the relevant national regulations [7]. This is due to the diversity of the traffic regulations and technical solutions adopted by individual Member States. A subsystem's compliance with the requirements of the TSI is confirmed by awarding the subsystem an EC certificate of verification, which is issued by the relevant authorised body after it performs the necessary checks and inspections [10].

3. ERTMS

Whatever the case under consideration, interoperable railway vehicles and interoperable lines shall be equipped with the *European Rail Traffic Management System* (ERTMS), which is designed to meet the requirements of the control-command and signalling TSI, regardless of where it is implemented.

The ERTMS is classified as a so-called Class A system, and is subdivided into the European Train Control System (ETCS) and the Global System for Mobile Communications-Railways) (GSM-R). ETCS calculates and controls braking curves [5, 6]. These curves depend on a number of factors affected by both the vehicle and the track. When designing the system, the idea was to separate these factors into track-dependent and vehicle-dependent groups. As a result, vehicle data includes information such as vehicle weight, maximum single axle load, maximum permitted speed, and braking system parameters, etc.

Track data, unlike vehicle data (which is provided once before the start of the train run), is received by the vehicle throughout the entire running time. It changes both in time (depending on the traffic situation) and space (depending on the position of the vehicle). It includes, in particular, movement authorities, which consist of the maximum distance the vehicle can travel and the speed permitted as a function of the distance from the reference point. Together with the movement authority, or via some other transmission channel, the vehicle receives other information which determines the track-dependent factors affecting the braking curves calculated by the system. Such information includes track profile (downhill/uphill slopes), distance to neighbouring balises, and information about other track-vehicle transmission channels.

ETCS is based on the mechanism of digital track-vehicle transmission. Data can be transmitted via balises, short, medium or long loops, a digital radio channel, or special transmission modules. Track and vehicle description data is used to calculate static and dynamic speed profiles. The calculated profile is continuously compared with the current speed as a function of position. The localisation function required for the above operation is based on uniquely distinguishable (bearing unique numbers) and precisely localisable point transmission devices (balises or end-of-loop markers).

GSM-R can be implemented in two versions (baseline 0 and baseline 1). The control and supervision functions always work according to the same rules, regardless of the channel via which the information has been received from the track. Figure 1 illustrates the ERTMS/ETCS system architecture with its interfaces, and shows a clear division into trackside equipment, track-vehicle transmission, and on-board equipment.

The ETCS systems [6], both in the on-board and trackside variants, are applied across three levels and, depending on the requirements to be met, also in several models. GSM-R can be implemented in two versions (baseline 0 and baseline 1).

4. Different system versions

Depending on the project, on-board and trackside equipment is usually supplied by different manufacturers. In addition, individual hardware configurations may differ from each other in terms of the software versions, the interoperability component versions, or the components used because a given manufacturer's customer sheet may allow, for instance, the use of 4 types of modems or 5 types of odometry sensors.

Another important aspect is the collaboration of the rolling stock manufacturer with the suppliers of the on-board equipment, especially when it is necessary to optimally configure the ETC parameters for a given vehicle type [9]. Therefore, the ETCS system

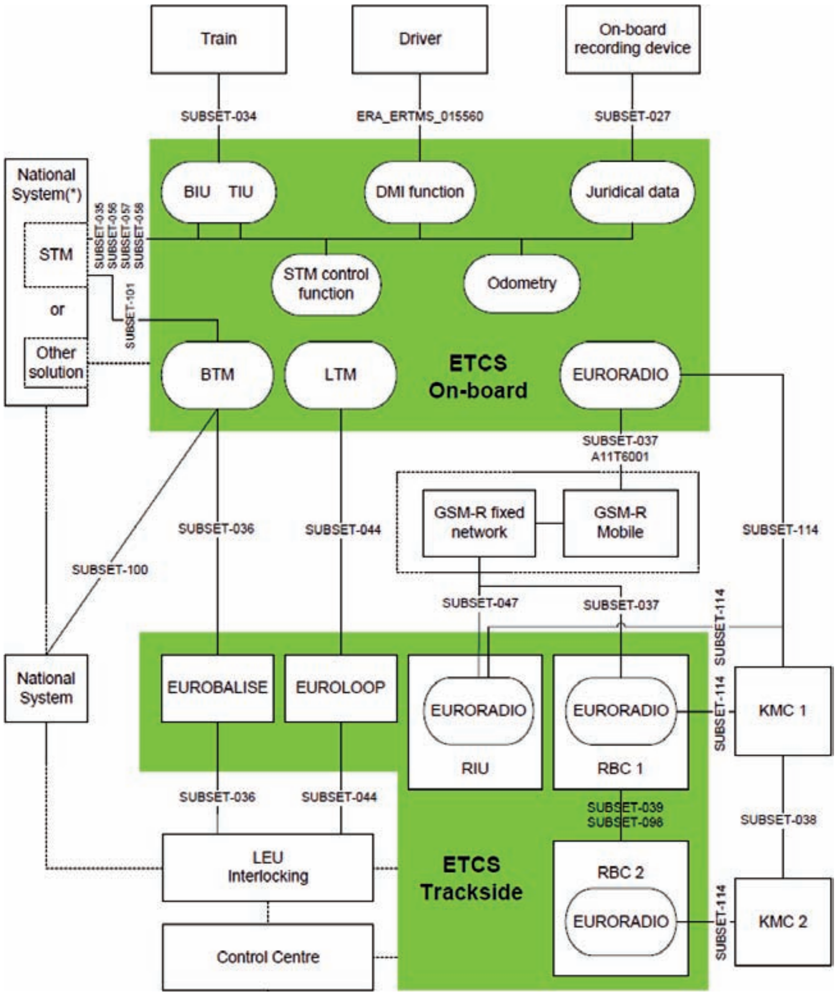

Fig. 1. ERTMS/ETCS system architecture with interfaces [4]

has to be implemented properly so that it communicates and interacts correctly with the train systems. Similar considerations also govern the trackside implementations of ETCS. There are challenges involved in the interfacing of the Radio Block Centre (RBC) with the interlocking systems (base layer) or with a neighbouring RBC, especially if it is manufactured by a different manufacturer.

Despite the adopted standardisation and unification of the requirements for the control-command and signalling subsystem, there are still many issues that need to be resolved. Tests carried out in laboratories in simulated conditions and the on-board subsystem manufacturers' start-up tests do not provide sufficient information on whether the on-board control-command and signalling subsystem has been integrated correctly with trackside equipment and other subsystems. This very issue is expressed at the very beginning of TSI 2016/919 [1], which reads as follows: (…) *Even a successful certification process cannot always exclude that, when an on-board CCS subsystem interacts with a trackside CCS subsystem, one of the subsystems repeatedly fails to function or perform as intended under certain conditions. This may be due to deficiencies in the specifications, different interpretations, design errors or equipment being installed incorrectly. A more coordinated way to perform compatibility tests should be introduced in order to help operators to take appropriate decisions* (…). In CCS TSI Table 6.2 [1], the aspect of assessing integration of the "On-board Control-Command and Signalling" subsystem with "Trackside Control-Command" subsystems and other subsystems clearly indicates the need to perform tests in conditions corresponding to the intended use, which should result in test run reports.

5. Operational test scenarios

In the light of the described situation, a need to verify the proper integration of the two subsystems in operational conditions was recognised, and individual EU Member States were required to develop appropriate operational test scenarios [Error: Reference source not found]. Pursuant to the provisions of point 6.1.2.2 of CCS TSI [1], an "Operational Test Scenario" means a sequence of trackside and on-board events related to or influencing the Control-Command and Signalling subsystems and the specified timing between them, aimed at checking and examining the assumed behaviour of the railway system operation in situations relevant to ETCS and GSM-R. The operational tests scenarios are based on the engineering rules adopted for the project.

At present, each Member State uses its own test scenarios, developed with local conditions in mind. In Poland, the body which defined the test scenarios is the Office of Rail Transport. The scenarios are published in the form of tables describing the individual test cases together with the possible actions of the driver, the expected response of the system, and the behaviour of the tested vehicle. An example of a test scenario is provided in Figure 2.

Every vehicle subject to EC verification, regardless of the adopted assessment module as described in Commission Decision 2010/713/EU [3], shall be tested for proper integration with the Trackside Control-Command and Signalling subsystem. Such tests have to be carried out by a competent and qualified body. Such a body is usually is a Notified Body (NoBo) or a Designated Body (DeBo) working with the NoBo. The Railway Research Institute carries out tests for the conformity of on-board and trackside subsystems as both the NoBo and DeBo, depending on the role in the EC verification process.

6. Tests of correct integration of subsystems

6.1. Testing grounds

The presented tests of proper integration of subsystems are based on the knowledge and experience gained by the Railway Research Institute's employees in the course of carrying out such tests on the Polish trackside ERTMS infrastructure. The main issue to be addressed when organising tests is the choice of the testing grounds, depending on the system levels to be verified. Since 2016, the Test Track Centre of the Railway Research Institute has been equipped with the ALTRAC 6413 ETCS Level 1 system, with a centralised structure (encoders installed in one room – a container). The system complies with the Functional Requirement Specification ERA/ERTMS/003204 ERTMS/ETCS FRS version 5.0 and the System Requirements Specification UNISIG SUBSET-026 version 2.3.0d [4]. The main equipment elements of the ETCS Level system used at the testing ground are: switchable and non-switchable Eurobalises, LEU encoders, and an ETCS-L1_IK signal simulator.

In the case of ETCS Level 2 tests, it is necessary to carry out these tests on a line belonging to the infrastructure operator, i.e. PKP PLK, which determines a number of formal conditions to be met in order to perform the required checks and inspections. The procedure starts with the determination of a specific test section compliant with the criteria of the adopted operational scenarios, followed by a technical and operational risk assessment carried out for the tested vehicle – taking into account

No.	Initial state	Action taken	Expected response
1.	The vehicle runs on a railway line outside the GSM-R and ETCS L2 areas, the on-board equipment runs with selected level 0 or STM SHP.	Passing over a group of balises announcing the vehicle's entry to the GSM-R area.	Establishment of the connection between the ETCS on-board equipment and the relevant radio network.
2.	The vehicle runs on a railway line within the GSM-R area and outside the ETCS L2 area, the on-board equipment runs with selected level 0 or STM SHP.	Passing over a group of balises establishing communication with the RBC.	Establishment of communication between the ETCS on-board equipment and the RBC, the train sends the relevant train data, the train receives the parameters for the reports, the train receives and acknowledges the relevant national variables.
3.	The vehicle runs on a railway line within the GSM-R area and outside the ETCS L2 area, after passing over a group of balises announcing the vehicle's entry to the ETCS L2 area.	Passing over a group of balises allowing enter to the ETCS L2 area. Signal on the semaphore associated with this group – permitting (movement authority).	The train reports the position, receives movement authority, change of the on-board ETCS level to Level 2, FS operating mode, speed restriction according to the speed profile for the vehicle and the line, sending information about the change of the train parameters.

Fig. 2. Example of a test scenario [source – Office of Rail Transport's study]

all of the parameters affecting the course of the tests to be performed. Next, in coordination with all the parties involved in testing the specific rolling stock, temporary traffic operation rules and regulations are drawn up, which serve as the basis to impose strictly defined track closures. Tests for proper integration are currently being carried out on the E-30 line, Legnica Wsch. – Miłkowice – Chojnów along with adjacent routes.

6.2. ETCS Level 2 test site characteristics

The Legnica Wsch. station features E-type signalling equipment. The Miłkowice and Chojnów stations have the EBILock950 version 4 computer-based interlocking system installed. On the Legnica Wsch. – Miłkowice section, traffic is managed with the use of a manual block system, while the Miłkowice – Chojnów section utilises an SHL-12 automatic block signalling system. The SHL-12 signalling equipment transmits secure information on the state of track sections from each block section to the EBILock 950 interlocking systems at the neighbouring stations.

There are category A, E, and B level crossings in the training ground area. Category A and E level crossings are located within the traffic post and are equipped with SPR-2 level crossing devices. The state of the signalling system of the devices at these level crossings is controlled on a continuous, ongoing basis by means of interlocking them on the train route. Category B level crossings on the Miłkowice – Chojnów section are equipped with SPA-4 devices. The level crossing devices are controlled by interlocking them with the LEU encoder and the switchable and non-switchable balises installed on the track.

The master system used to control the EBILock 950 version 4 interlocking system is the EBIScreen 3 remote/local control system, which is used by section station masters from the Bolesławiec local control centre to control and manage the traffic e.g. at the Miłkowice and Chojnów stations.

The major part of the ETCS Level 2 infrastructure is the EBICom2000 Radio Block Centre (RBC) equipment, which is an integral part of the complete INTERFLO 450 rail control solution. The RBC devices consist of two parts: the processing-execution module (RBU) and the ISDN server handling radio transmission. The RBC environment features external connections to: the interlocking system, the operator's panel (CMI), and the GSM-R network. RBC is to supervise the movement (traffic) of traction vehicles equipped with ERTMS/ETCS Level 2 on-board equipment. The supervision process involves sending radio telegrams with the movement authority (distance, permitted speeds, temporary speed restrictions, and emergency braking orders, etc.) to the vehicle and receiving information on the vehicle's position from the vehicle by radio.

Balises are an element of the ETCS Level 2 trackside equipment. They are installed on the track and generate data in the form of telegrams sent to the ETCS on-board equipment. The main function of ETCS Level 2 balises is train positioning. When passing over a balise, a train equipped with ETCS on-board equipment reads the identification data of the balise and sends it to the radio block centre. The RBC has information about the location identifier and the orientation of the balises (the order of the balises in the group) and uses such data to determine the location of the train and its travel direction. Balises are used to calibrate distance measurement equipment (odometers). The testing ground selected for tests was authorised by the relevant national safety authority (Office of Rail Transport (UTK)) in March 2016 to operate the trackside control-command and signalling structural subsystem in the scope of ERTMS/ETCS Level 2 (including interfaces to the control-command and signalling equipment and ERTMS/GSM-R system). The installed equipment complies with the relevant UNISIG specifications, including System Requirements Specification Subset 026 version 2.3.0 and Subset 108 version 1.2.0, in accordance with the technical specification for interoperability relating to the control-command and signalling subsystem of the trans-European conventional rail system (Decision 2006/679/EC as amended).

7. Tests and results

Testing the proper integration of the tested vehicle with the relevant trackside infrastructure is performed on the basis of the UTK operational scenarios as well as following a set of additional inspections developed by the Railway Research Institute. They involve carrying out test runs using the tested train in predetermined conditions to achieve a certain expected result. It is important to pay particular attention to the integration of ERTMS/ETCS with the relevant Class B system as this is the scope of the specific application for a given vehicle subsystem in a given country. The tests check the correctness of the transitions performed by the vehicle between the levels and modes of operation, the response to a change in the length of the *Movement Authority* (MA), the speed control, and the response to the occurrence of faults in individual components, etc. All tests are recorded using digital video cameras. All indications displayed on the DMI *(Driver-Machine Interface*, Figure 3) as well as the indications of the light signals from the second camera are recorded. In the case of Level 2 tests, a Railway Research Institute representative makes additional observations via the RBC operator's panel (Fig. 4).

The source of all data necessary to evaluate the results obtained is the *Juridical Recorder Unit* (JRU), whose memory stores all of the required train movement parameters (Fig. 5). Moreover, the so-called logs retrieved from the EVC (*European Vital Computer*) can also be used to verify the correctness of the telegrams read by the vehicle after receiving them from balises and RBC.

Fig. 3. DMI monitor during the tests [authors' own source]

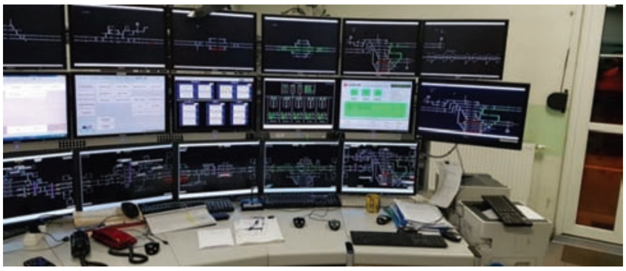

Fig. 4. Local control centre equipped with RBC [authors' own source]

The data collected from these sources, video recordings, in-person observations made by qualified staff, and knowledge of the testing ground make it possible to perform professional and reliable assessments of the integration of the tested on-board and trackside subsystems. In questionable cases, the assessment process is significantly prolonged because it is necessary to carry out a detailed analysis of the occurring error to eliminate this error. System errors causing a sudden stop of the tested vehicle (TRIP), wrong movement parameters (e.g. travel speed set lower than the travel speed required), incorrect measurements of the distance covered or of the distance of the antenna from the last balise passed are only a fraction of the difficulties encountered during discussed tests. In most cases, small changes made in the vehicle's software offer a solution to the occurring problems. In extreme situations, however, it is necessary to replace individual components.

8. Conclusions

The issues concerning the verification of the integration of the "On-board Control-Command and Signalling Subsystem" with the "Trackside Control-Command and Signalling Subsystem" discussed in this article are an important element of the type approval process of railway vehicles. This is the final stage of verification of the rolling stock prior to its authorisation for use and operation. Any errors or irregularities discovered may be eliminated by modifying the vehicle before the EC certificate of verification is issued.

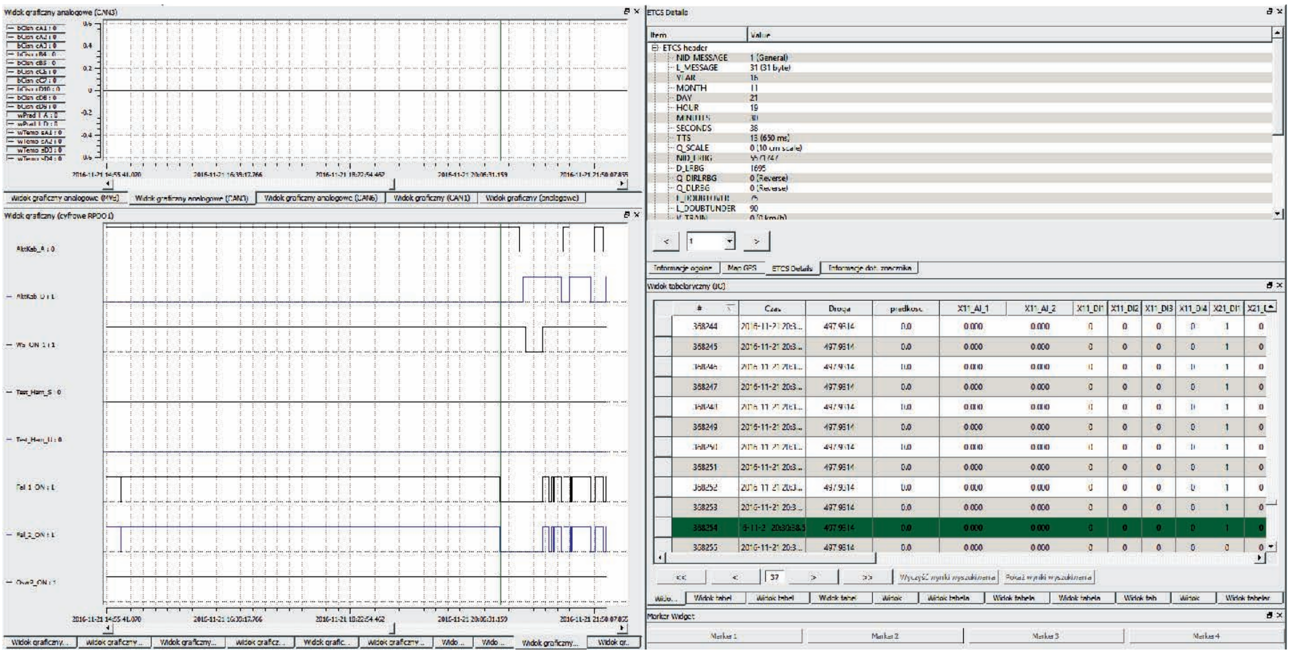

Fig. 5. Presentation of data from the JRU legal recorder in the application [authors' own source]

Every manufacturer of ETCS on-board equipment has a unique approach to the way in which they comply with the requirements of the relevant subsets and TSIs, which may eventually require them to implement additional measures aimed at making the relevant subsystems fully compatible.

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