ERTMS deployment in Spain as a real demonstration of interoperability. Near future challenges

J. Iglesias[1], A. Arranz[1], M. Cambronero[1],C. de la Roza[1], B. Domingo[1], J. Tamarit[2], J. Bueno[2], C. Arias[3]

[1]**ADIF. Spanish Railways Infrastructure Manager**
[2] **CEDEX. Research and Studies Centre of Ministry of Public Works and Transportation (Fomento).**
[3] **Renfe Operadora. Spanish Public Railways Operator.**

Summary: This paper 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. These challenges can be summarized in the following issues: 1) Execution of interoperability tests in a laboratory, 2) Reduction of up to now ETCS increasing costs by means of promoting a real open market and 3) Migration of lines in commercial exploitation to new releases of the specifications and 4) Cross acceptance issues and European corridors operational rules.

Index Terms: ERTMS, Interoperability, Signalling.

1. INTRODUCTION

In the early 1990s, the European Commission, with the objective of stimulating railway transport, started the definition of a common European signaling system with a double objective: in 1st place the breaking down of railway borders caused by the utilization of up to 15 national systems, and in 2nd place the opening of a market produced by the appearance of a standard system supplied by different companies breaking the captive markets that imposed the national signaling systems.

The process has been arduous and complex and has required, on one hand, a large economic investment, and on the other hand an effort by a large number of people both on the railways infrastructures and operators as in the European signaling companies, that have contributed to the creation of the system ETCS and its actual introduction into more and more European countries.

Spain, with the initial decision to introduce the European system in the high speed line Madrid-Lleida, a risky and difficult decision, while not understood initially has proved to be the correct one; it was one of the countries that initiated, in a more determined way, the development and introduction of the new system. Lastly and due to its introduction in all Spanish high speed lines and in all types of trains that circulate, Spain has been able to overcome all problems caused by the put in service of so many cases of interoperability, having converted itself into a world reference in terms of the commercial running of ERTMS.

The main issue of this paper is to show how the real interoperability among almost the totality of ETCS suppliers is being successfully tested in Spain, presenting the behaviour of lines in commercial operation for both L1 and L2 of ETCS, as well as the new lines opened during the year 2010. In fact at the time

being five ERTMS trackside suppliers (Ansaldo, Alstom, Dimetronic, Thales and Bombardier) and five on board unit suppliers (Ansaldo, Alstom, Dimetronic, Bombardier and Siemens) are in commercial operation in Spain.

This amount of different suppliers, together with the successful ETCS real deployment is a clear demonstration that nowadays the signaling rail interoperability is a fact, and this paper highlight the role played by the Spanish railways as pioneers in the real implementation of the system, solving the problems derived from the intervention of many suppliers, as well as for the non stability of the ETCS specifications.

However some real challenges are still over the table. The first one is the migration of all the lines and trains to the version 2.3.0.d. of the specifications, which will be, according to the EC decision, the version in which backwards compatibility will be assured. The second challenge will be the execution of interoperability tests at lab, in order to reduce L2 tests in lines with L1 in commercial operation. Third challenge is to reduce the ETCS cost in future projects once the system is being more stable and mature, and last but not least is the European cross acceptance based on a commonly defined set of tests which will guarantee the acceptance by all the European NSAs.

2. ERTMS DEPOYMENT IN SPAIN

At the time being Spain is one of the few world countries where ERTMS has been fully deployed and it is now being used in all the existing High Speed Lines (more tahn 2600 kms of double track at the end of 2010) as well as in the future lines which are now under construction. ERTMS is also being deployed in conventional lines and the first example of it is the installation of ERTMS in Madrid commuter lines.

Figure 1 show in a graphic way the current situation in Spain with five different suppliers for track subsystem and five different suppliers for the on-board subsystem. At the end of this year a new HSL of 470 km between Madrid, Valencia and Albacete has been put in service reaching the number before mentioned of more than 2.600 kms of high speed lines with more of 1.500 kms of them equipped with ERTMS. This Madrid-Valencia-Albacete line has been equipped with ERTMS by the Spanish company Dimetronic and the trains running over it (Talgo S-112/330 km/h and Talgo S-130 250 km/h) are equipped with Siemens ERTMS unit.

Also in December of 2010 the first international connection with France has been put in operation by opening the section between Figueres (Spain) and Perpignan (France) equipped with ERTMS L1 and 2 supplied by Ansaldo. This is a short section (50 km) of the future line from Barcelona to French border (160 km), but it represents an important step due to the fact that is the first connection between Spain and France by using the ERTMS system. The train running over this infrastructure ins the Dayse TGV train (Alstom) equipped on board by the Ansaldo ERTMS equipment (called bi-standard because also implement the French TVM system).

The first Spanish high speed line from Madrid to Seville is still operating with the initial signaling system LZB, but it is also planned to be equipped with ERTMS L2 in the near future. Anyway this line is not currently and inner barrier due to the fact that trains equipped with STM-LZB are daily operating allowing a complete interconnection of the whole Spanish High Speed network. In fact and without any doubt the current paradigm of rail signaling interoperability is the high speed train between Barcelona and Malaga in which a train equipped with Siemens EVC (102 and 103 series) runs over four different technologies: Thales (Barcelona-Lleida), Ansaldo (Lleida-Madrid). LZB system with LZB-STM on the train (Madrid-Cordoba) and Dimetronic (Cordoba-Málaga), running without stopping 1,185 Kms in 5 h 35 m and showing how in Spain a complete interoperability between different signaling suppliers has been achieved.

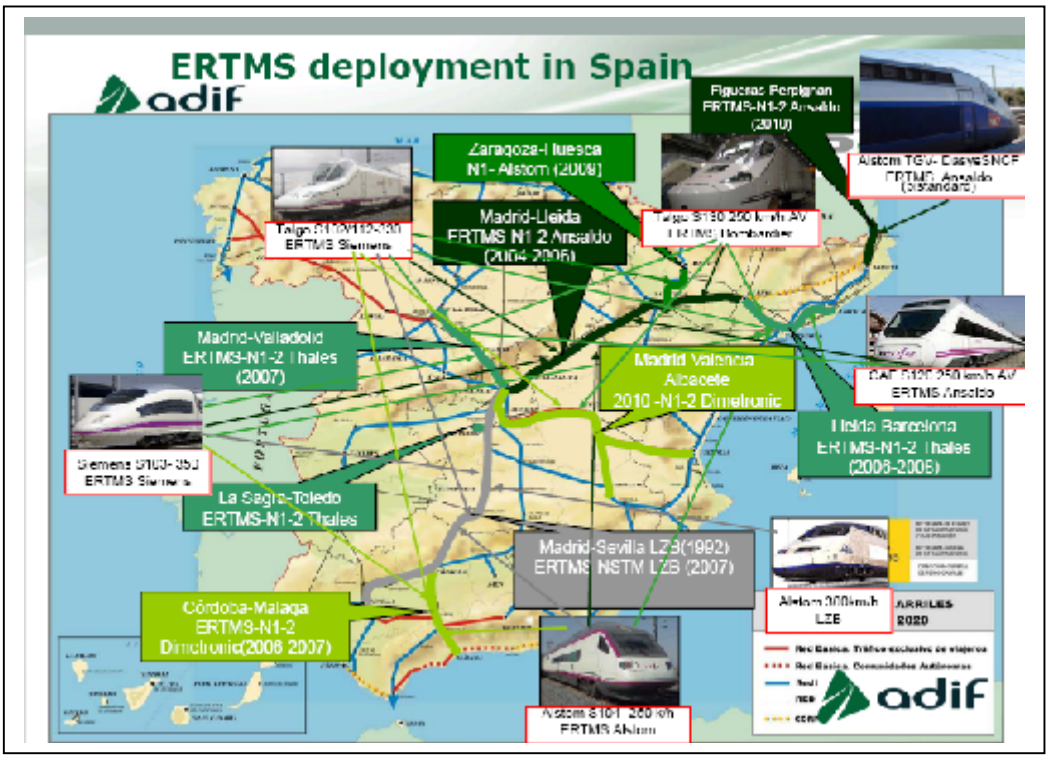

Figure 1. ERTMS Lines and Trains in Commercial Operation in Spain.

Up to now, and as a unique example in the world, Spain has demonstrated crossed interoperability, a track supplier and another on board unit supplier, in 16 different cases where all the existing ETCS suppliers have been involved: Alstom, Ansaldo, Bombardier, Invensys and Thales for the track subsystem Alstom, Ansaldo, Bombardier, Invensys and Siemens for the On Board subsystem.

As it is shown in Table 1 a), currently there are 12 cases of crossed interoperability in commercial operation, and 4 in process of testing. This large number of cases has been occurred because both Adif and Renfe Operadora ERTMS systems have been contracted with practically all the existing providers, in a scenario that clearly shows how, from a technical point of view, the open market is currently a reality.

CROSS INTEROPERABILITY IN SPAIN		TRACK EQUIPMENT					
		Alstom	Ansaldo	Bombardier	Dimetronic	Thales	STM-LZB
ON BOARD EQUIPMENT	Alstom S-104/114	14	7		9	8	10
	Ansaldo S [illegible]		5			6	
	Bombardier S-130		11			12	
	Dimetronic 252 and Circa			15 Pilot line	16 Mad. Comm.		
	Siemens S [illegible]	13	1		3	2	4
	Thales	No On Board Unit from Thales in Spain					

Table 1. Cases of cross interoperability

Table 2 shows some data related to the reliability of ERTMS during almost the four first years of commercial exploitation. This table demonstrates how the system has overcome the initial problems due to the youth of the system and the initial failure rate of some ERTMS components higher than the expected values. Once these problems have been solved table 2 shows how the punctuality and incidences of the system comply with the ratios initially defined.

YEAR	PERIOD	PUNCTUALITY (Delay <3')	Nº OF TRAINS (Kms)	DELAY DUE TO ERTMS(>3') (%)	Nº OF INCIDENCES DUE TO ERTMS (%)	Kms BETWEEN INCIDENCES
2006 (Mad-Lleida)	19/05-31/12	98,48%	3307 (1.551.940 km)	17 (0,51%)	221(6,6%)	7.022
2007 (Mad-Tarragona)	1/01-31/12	98,06%	7665 (4.139.100 km)	34 (0,44%)	659(8,5%)	6.280
2008 (Mad-Barcelona)	1/01-31/12	98, 8%	17075 (10.608.575 km)	59 (0,34%)	1047(6,1%)	10.127
2009 (Mad-Barcelona)	1/01-31/12	98,53%	32.143 (19.969.666 km)	79 (0,24%)	1150(3,5%)	17.358
2010 (Mad-Barcelona)	1/01-31/01	98,86%	2205 (1.369.305 km)	12 (0,54%)	104(4,7%)	13.166

Table 2. ERTMS Reliability in Spain

3. COMPLEMENTARY TESTS

The path taken to reach the current level of interoperability has been quite complex. This was due to he fact that the European specifications of ERTMS were not sufficiently mature and the gaps within them have had to be filled with the experience of the pioneer countries in ERTMS. Indeed, as an example we can highlight that ERTMS test specifications, were only defined at a component level (Test Specs for the On Board Unit, Subset 076 or Test Specs for Eurobalise Subset 085), but there were no test specifications for train-track integration. Subset-076 of Annex A of the TSI does not include any definition of tests relating to the engineering of the ERTMS track.

Nowadays, there is a collection of Subsets which contain the specification of tests for the complete system, taken as a whole (Subset 110, 111 and 112), but they are in an initial phase (edited in 2009 and 2010) and there are not yet a complete published test specification to verify the integration between track and train. That is the reason why the “Complementary Tests” were developed in Spain. The aim of these tests has been to prove the main functional qualities of each one of the high speed lines by means of a group of test cases (215 in level 1 and 260 in level 2). While they do not try to carry out exhaustive tests on the installation, this should be assured by the validation dossier of the manufacturer, it does test the more meaningful functional qualities on the more critical points on the line.

For more than 5 years the execution of the complementary tests have been detecting errors as well as different interpretations of the ERTMS specifications (SRS) that have been solved through the participation of expert teams from Adif, Renfe, CEDEX and Tifsa. Equally, these bugs were reported to the ERTMS User Group and the European Railways Agency for the corresponding clarification of the specifications.

As a conclusion we can state that, through the implementation of complementary tests, it has been proven that once corrected the detected problems in these tests, no relevant functional problem has appeared during the later commercial exploitation. This is the best indication of the usefulness of these aforementioned complementary tests in the deployment of the ERTMS in Spain.

4. ERTMS TEST IN LABORATORY

In this section will be highlighted the importance of performing train-track integration tests in a laboratory in order to reduce testing on real track with the associated reduction of cost and human resources. In Spain where most of the ERTMS lines are equipped with both L1 and L2, once L1 is in operation is extremely difficult to execute on the track the L2 Complementary Tests. In this paragraph we will first explain in detail the general references for testing and secondly it will be explained the way of testing in lab the specific applications deployed in the different lines.

4.1. References for testing.

4.1.1) Certification tests

The test specification for the certification of European interfaces affecting the communication between track and train are provided in the Subset-085 for Eurobalise (see Figure 5 Cedex Eurobalise Lab) and in the Subset-076 (see Figure 6 CEDEX Eurocab lab) for Onboard Unit. Both specifications are well consolidated and are continuously improved through their use in the certification of generic products.

Finally the Subset-094 defines the reference architecture for testing in the laboratory. This architecture allows the connection of Onboard ERTMS equipment under test to the reference tools through adaptors to pass the Subset-076 test sequences.

Two major issues difficult the assurance of interoperability at this early stage:

- The use by the companies of Module H in the Quality Assurance using internal test specifications different from the sequences defined in the Subset-076.
- The lack of European interfaces for the RBC and the consequent absence of common specification for certification tests. This implies a company specific approach for testing even when the tests are performed by an independent laboratory.

The use of independent laboratories is highly recommended at this stage to assure the interoperability of the projects in which these constituents are used.

Figure 5: CEDEX Eurobalise Laboratory.

4.1.2) Interoperability tests between suppliers. (IOP Tests)

These 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 Subset-111 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 a clear view on the status and to make them interoperable, that means to support cooperative tests between different suppliers.

The IOP tests between different suppliers alleviate the drawbacks underlined in the certification process.

4.1.3) Operational Test Cases

The infrastructure Managers grouped in the ERTMS Users Group are working in a set of operational test cases to be tested in specific projects, either when putting a new line or train in service either when integrating tracks in service with trains also in service but on different lines. These test cases specify in a harmonized way what has to be passed before putting a trackside or rolling stock project in service.

4.2. Testing Specific applications

All the work performed from this point is project-specific and is based on the layout of a specific infrastructure that is being put in service or is going to be used by a Railway Operator with specific trains.

4.2.1) Specific scenarios

The infrastructure Manager contracting the specific project allocates the family of generic operational test cases to specific segments of the line under test. Several test cases are concatenated to define a test trip along a specific segment of the line. This trip is a specific operational scenario. The operational scenarios are tested either on the line with a real train or in a reference lab using project data and real Onboard ERTMS equipment connected to the test bench.

4.2.2) Testing in reference laboratories

Adif and Renfe Operadora are promoting the use of the reference laboratories to simplify the process of putting in service tracks and trains. Both are using the CEDEX Eurocab laboratory (Figure 6) recommending the suppliers to provide project data and to connect real equipment.

This approach has been used with the Madrid-Levante line and the Commuter lines of Madrid. The EVCs from Alstom, Bombardier, Dimetronic and Siemens has been connected to the tools. Project data from Alstom, Dimetronic and Thales have been translated to a common format allowing the definition of scenarios using segments from different suppliers. This first approach have saved a lot of time and tests resources during the process of ERTMS validation of Madrid-Valencia HSL, and it has been one of the key issues of entering in commercial service in December 2010. This laboratory tests will be executed in the next lines to be built in Spain in order to drastically reduce the testing time in the real line. Up to now the lab is ready for L1 tests, and CEDEX team is hardly working in setting up the lab for testing level 2.

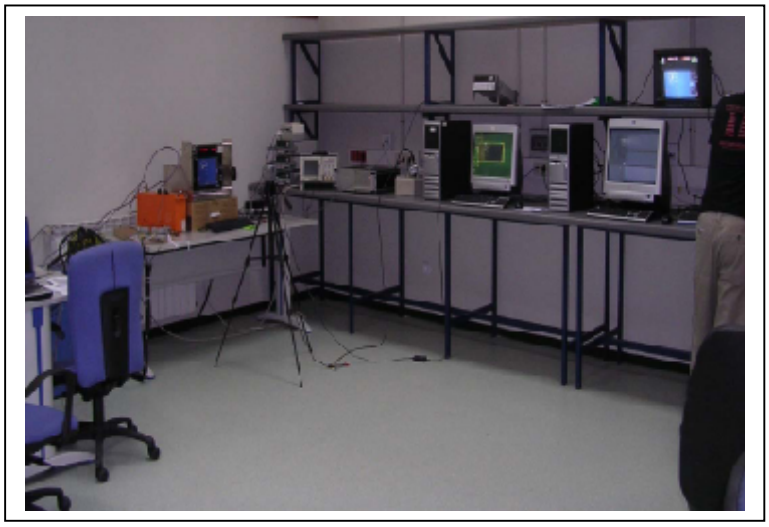

Figure 6: CEDEX Eurocab Laboratory..

4.2.3) Validation tools

CEDEX has developed two specific tools for the tests in laboratory, the GAE tool (Automatic Generation of Scenarios) and the JRU Decoder and Analyser.

The GAE tool translates the project data of each company to a common format in Windows data base and allows the elaboration of specific operational scenarios using the project lay-out and messages.

The JRU tool is an universal decoder and analyser able to provide decoded information of each telegram. This tool is easily adapted to each company by means of a format descriptor file. Once the record is translated to a common format, the analyzer can decode each massage according to the corresponding SRS issue.

A third tool has been developed during the elaboration of the sequences of the Subset-076. This tool is called Test Sequences Debugger (TSD). It is a functional model of the Onboard ERTMS used to debug the test sequences produced by the group of laboratories. This tool produced and maintained by ERSA is in continuous evolution with its use in certification and validation processes. The debugging of this debugger approaches the tool asymptotically to the full compliance. This is a key aspect of the feedback collection from commercial projects.

4.2.4) Complementary tests.

Once the infrastructure layout is defined by the supplier, ADIF assembles the test cases into test scenarios which are test trips on the line entering in service. These scenarios are split into scenarios to be performed in the CEDEX laboratory using project data or scenarios to be performed on the track.

The scenarios performed in the laboratory aim at the verification of engineering rules, functional interoperability and operational compatibility between train and track. The scenarios performed on the track aim at the verification of track layout, train dynamics and safety issues as well as ERTMS integration with adjacent systems, mainly the interlockings.

This execution of part of the Complementary Tests in the laboratory could reach a percentage up to 70% of the whole set of Complementary Tests. This percentage can vary depending on the line functionality but anyway will alleviate enormously the work performed in the real line with the associated cost reduction.

The use of the TSD in the laboratory tests allows the introduction of new testing strategy decoupling the validation of infrastructure project from the rolling stock project in three independent steps with great added value:

1. Off-line verification: Verification of engineering rules for infrastructure
2. In line verification: TSD against real data of infrastructure: Validation of the infrastructure project
3. Real EVC connected to the tools loaded with validated data of infrastructure: Validation of the onboard projects (several)

The translation of project data to a common format is quite suitable for the verification of the interoperability of corridors implemented by different suppliers using laboratory infrastructure data bases.

5. FUTURE CHALLENGES

In the following paragraphs we will describe the main pending challenges we have in Spain to fulfil the process of ERTMS deployment and complete the putting of service of L2 in Spanish ETCS lines:

5.1 Complementary Tests in Laboratory

The first 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 wont be a standard solution. For ADIF execution of L2 tests in the laboratory is vital because as the lines are in operation in L1 there are very few slots for testing on track.

5.2 ERTMS L2 in Spain

Another challenge that faces us currently is the put in service of the ERTMS level 2, which allows us to benefit from the advantages of this level as speed and capacity increase. It is also important to check the reliability of level 2 and in this way reduce the cost of future procurements by means of not installing both levels together depending on the functionality of the line. Adif, Renfe and Ministry of Fomento are strongly working together to achieve this target very soon. Currently the line Madrid-Ansaldo L2 is being tested in commercial simulation. This means that all the Complementary Tests have been successfully passed by both train and track and also the safety dossiers of both subsystems are fulfilled. Once enough reliability will be demonstrated the line will enter in commercial service. However the effort performed by Spanish Railways, both Renfe and Adif, to put in operation L2 should not be repeated any more. L2 process has suffered the impact of incomplete definition of the specifications, not fully support of the involved companies and many other issues that have caused an extremely high delay in the whole process. Just as an example the lack of European specifications in the definition of one element of the GSM-R chain as the modem, has caused a lot of discussions and delays.

5.3 ERTMS versions migration

Another important challenge, also caused by the complex European process, is the migration process of the current Adif high speed lines equipped with version 2.2.2.+ of the SRS (Versions SRS 2.2.2. with an addition of change requests), to the version 2.3.0.d. that will be the base and backwards compatible

version. At the time being all the existing lines are equipped with 2.2.2+ with the exception of the new Madrid-Valencia line equipped with version 2.3.0.d. In parallel all the existing trains are running with versions 2.2.2+

To open the Madrid-Valencia line some specific engineering solutions were implemented to allow trains 2.2.2+ to run over the 2.3.0.d. track, but this was possible only for L1, because for L2 some CRs already included in 2.3.0.d release make both versions fully incompatible. For this reason Adif and Renfe operadora are strongly working to define a strategy which will allow an ordered process of changing both the trains and the track to version 2.3.0.d. 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. However it has to be highlighted that after being one of the countries pioneers on implementing ETCS and that based on this risky exercise Spain has strongly contributed to show the feasibility of the system, we are now suffering a nightmare to reach a version backwards compatible.

5.4 ERTMS Costs reduction

The fourth challenge that we would like to point out is the utilisation of these tools, such as complementary tests execution at laboratory, that guarantees the technical interoperability and therefore allows us a completely open market in the ERTMS, to be able to reach the desired objective of a reduction of ETCS costs. All the effort made was going toward this objective and now arrives the time of collecting the benefits: the open market should necessarily produce a cost reduction. Adif has very actively participated in a Benchmarking led by UIC to compare the ETCS costs in different European projects and to share experiences with them in analysing together the cost structure of ETCS. Now is the time of reducing the R & D costs charged by the manufacturers because the system starts being mature enough. The opening of new markets for ETCS outside Europe-according to Unife data more that 50% of the contracted ETCS lines are out of Europe- will necessarily conduct to a costs reduction for future ERTMS implementations.

5.5 ERTMS cross acceptance

During December this year it has been opened the first international connection between Spain and France, which is the short section between Figueres (Spain) and Perpignan(France). This have been the first step of connecting Madrid and Barcelona with France once the section between Barcelona and Figueres will be finalised in 2012. The Spanish complementary tests have been performed to assure technical compatibility, but not any European specifications are ready to assure interoperability.

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 latter 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.

6. CONCLUSIONS

The path to arrive here has been long and hard, but the entire Spanish railway sector should feel proud of the work that has been carried out and the objectives that have been partially fulfilled, although at the beginning many of them seeming impossible. Presently Spain is the world reference in ERTMS. Now we are in the position of offering other railways our capabilities and all the accumulated know-how in integrating different supplier’s subsystems. By this way we can guarantee the level of interoperability initially foreseen when ERTMS was created. However as we mention in the previous paragraph, some challenges are still pending. Many of them due to the slowness of the ERTMS specifications consolidation, which is totally incompatible with the progress of high speed in countries like Spain. This

continue modification of the specifications has also caused some not acceptable issues like the versions migration we shall perform in Spain, causing a cost not covered by any body.

Acknowledgements

Our strong acknowledgment to the Infrastructure General Directorate of the Spanish Ministry of Fomento for the continuous support to ERTMS deployment in Spain.