# *Annex 14 – Case study on ERTMS*

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# 1. Executive summary

The European Train Management System (ERTMS) is a major industrial programme aiming to replace the conventional signalling systems currently used by the European MSs to achieve a unique signalling system at Union level. The full deployment of ERTMS on the TEN-T network is one of the priorities of the European railway transport infrastructure development (**European ERTMS Deployment Plan**) and is expected to be achieved on TEN-T CNC by 2030 and on comprehensive network by 2050 (EU Regulation No 1315/2013). [1,2]

The capital investment required for the deployment of ERTMS on the entire TEN-T core network is significant, being estimated in approximately €20 - €30 billion. Out of this investment, the large majority will be released for the trackside installation of the ERTMS.[3]

Due to the strategic importance of ERTMS in creating an open and competitive European market, and the significant investment expected for its deployment,[4] a tailored analysis of ERTMS/ETCS[5] has been carried out in order to determine the unit cost.

A comprehensive review of the available literature as well as a number of relevant cases of ERTMS implementation in eleven MSs has been investigated. A unit cost range between approximately 60 k€ to over 370 k€ is observed for ERTMS trackside deployment[6], which primarily depends on the target ERTMS functional level and on the national deployment strategy:

- The unit cost for the trackside deployment of ERTMS increases with the increased complexity of works. From Level 1 to Level 2, the cost increase is, on average, in the range of two-thirds higher, due to the more complex technology applied. Whilst the unit cost of the ERTMS Level 3 is expected to be comparable to the unit costs of Level 2, even though not sufficient data were available to perform a quantitative analysis;[7]
- Generalising to the extent feasible, the unit cost of ERTMS deployment on the whole network is significantly cheaper, compared to single-lines deployment. Such reduction reaches levels of 45%, mainly due to economies of scale and stronger bargaining power from the contracting agency. Exceptions can nonetheless occur, as for the Danish case, which adopted a whole network deployment strategy, but showed a unit cost increase of 60% with respect to the other Countries, due to the complexity of the programme and unexpected difficulties faced by the Danish Signalling Programme.[8]

Supporting the quantitative assessment, a qualitative analysis was performed to evaluate other factors affecting the unit cost, such as standardisation process and risk of investment cost increase.

The current study is based on a sample of projects and provides a framework on the technical and economic factors affecting the unit cost of trackside ERTMS implementation and quantitatively evaluates the impact of these factors on the ERTMS unit cost.

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[1] www.ertms.net
[2] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[3] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[4] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[5] European Train Control System
[6] ERTMS cost can nonethteless reach higher costs per kilometre in a few sporadic cases.
[7] ERTMS level 3 has been deployed only in test projects at the time the analyses were performed.
[8] Banedenmark (2017) - The Danish Signalling Programme – where are we now?

# 2. Introduction

*The* ***European Railway Traffic Management System (ERTMS)*** *is a major industrial programme aimed to harmonise the automatic train control and communication system and underpin interoperability*[9] *throughout the rail system in Europe.*[10]

The ERTMS was initially developed by eight members of the **Association of the European Rail Industry** (UNIFE)[11] - Alstom Transport, Ansaldo STS, AZD Praha, Bombardier Transportation, CAF, Mermec, Siemens Mobility and Thales - in close cooperation with the European Union, railway stakeholders and the GSM-R industry.[12]

The ERTMS gradually replaces the conventional command and control systems (Automatic Train Protection – ATP – systems) enabling the achievement **a unique signalling system at European level**. The uniformity of the traffic management systems at European level is expected to increase the competiveness of the railway sector by enhancing the cross-border train operations.[13,14] Trains equipped with ERTMS should indeed be able to operate cross-border without interruption along railway lines. Additionally, the advanced technical features of ERTMS provide increased capacity, increased (commercial) speed and higher level of safety, reliability and punctuality than most of the existing national signalling systems.[15,16]

Currently there are in fact more than 20 different rail signalling systems in Europe. Since the 1980s, when the ATP systems were introduced in the railway sector, each Country implemented its own system, able to guarantee interoperation within the Country. Each ATP is a stand-alone and non-internationally-interoperable system, compliant only with the national requirements, technical standards and operating rules (e.g. BACC in Italy, TVM in France and ASFA in Spain). Thus, the trains operating cross-border are equipped with different signalling systems, only able to interact with the signalling systems of the countries involved.[17] [18]

In 1989, a project commissioned by the EC began the discussion on the development of a common European system. As a result, in 2009, the **European ERTMS Deployment Plan** was adopted and the retrofitting of ERTMS became mandatory on a number of listed lines (the six ERTMS corridors).[19] The following year the ERTMS deployment became mandatory on additional freight lines (Rail Freight Corridors) following the publication of the Rail Freight Corridor regulation (Regulation 913/2010). [20, 21]

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9 The DIRECTIVE (EU) 2016/797 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 May 2016 defines 'interoperability' as the ability of a rail system to allow the safe and uninterrupted movement of trains which accomplish the required levels of performance for these lines

10 Commission Staff Working Document (2017) – Delivering an effective and interoperable Europena Rail Traffic Management System (ERTMS) – the way ahead

11 Union des Industries Ferroviaires Européennes

12 www.ertms.net

13 PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report

14 www.ertms.net

15 www.ertms.net

16 PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report

17 Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system

18 PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report

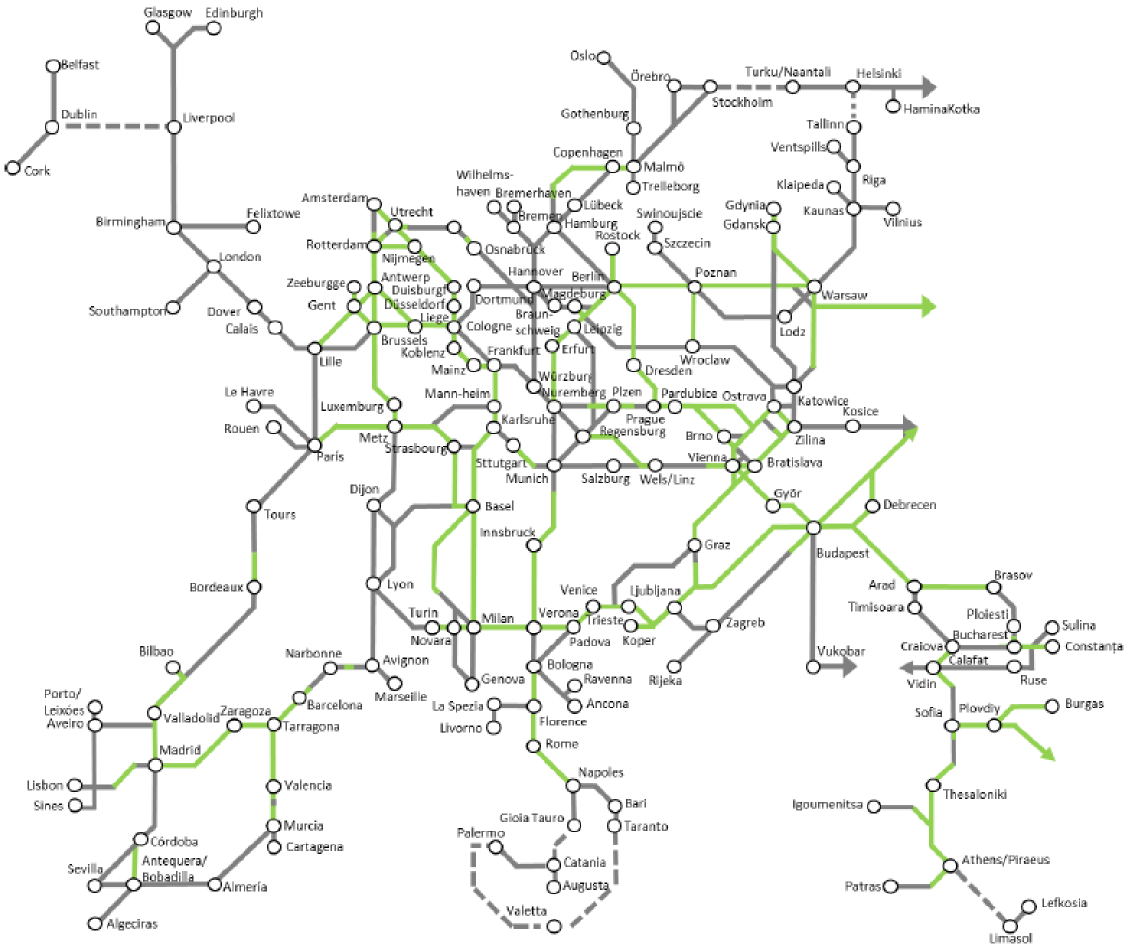
19 www.ertms.net

20 REGULATION (EU) No 913/2010 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 September 2010 concerning a European rail network for competitive freight

21 www.ec.europa.eu/transport

Today, the full deployment of ERTMS on the TEN-T network is one of the priorities of the European railway transport infrastructure development. The TEN-T Regulation No 1315/2013 requires the deployment of ERTMS on TEN-T CNC and comprehensive networks by 2030 and 2050, respectively. It was foreseen that **at the end of 2017 the ERTMS should have been operational on 4.500 km of lines on Core Network Corridors**.[22] The figure below shows the lines expected to operate with ERTMS by 2023 within the European network, which account for circa **30%-40%** of the all ERTMS on Core Network.[23]

***Figure 1: ERTMS in operation by 2023***




*ERTMS operational lines (either passenger or freight) shown in green on the schematic map of the Core Network Corridors. Source: Commission Staff Working Document (2017) – Delivering an effective and interoperable European Rail Traffic Management System (ERTMS) – The way ahead*

The **capital investment** required for the deployment of ERTMS on the **entire TEN-T core network** is significant: it was estimated of approximately **€20 - €30 billion**. Significant public (at EU and MS level) and private financial resources will be allocated in the ERTMS deployment projects, in the next decades, to support investments.[24] The large majority of the investment is required for the trackside installation of the signalling system, while only a minor part is necessary for the on-board installation of the ERTMS.

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[22] EC – Directorate-General for Mobility and Transport (2017) THE EUROPEAN RAIL TRAFFIC MANAGEMENT SYSTEM (ERTMS) DEPLOYMENT ACTION PLAN
[23] Kleine E. G. (2017) ERTMS Deployment/Migration Strategies of ERTMS Users Group members
[24] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report

**ERTMS: the global signalling standard**

In parallel with its European development, the ERTMS had a significant global growth since 2010 and became a worldwide standard. It is under implementation in more than 35 countries around the world, among the others: China, Taiwan, South Korea, India, Algeria, Libya, Saudi Arabia, Mexico, New Zealand or Australia.

ERTMS investments outside Europe represent more than 45% of the global ERTMS investment: more than 29.000 track km and approximately 2.900 vehicles are equipped with ERTMS worldwide. [25]

Due to the strategic importance of ERTMS in creating an open and competitive European market, and the significant investment expected in the future for its deployment,[26] [27] a detailed analysis of ERTMS/ETCS unit cost is deemed particularly relevant supporting the public decisors and the market players investing in ERTMS. It will ultimately support the sound development of the REGIO Rail Unit Cost Tool.

An overview of the ERTMS technical characteristics is reported below in order to clarify the impact that ERTMS features may have on deployment costs.

## 2.1 Technical characteristics of ERTMS

The ERTMS will provide a substantial change to the legacy of the ATP systems in terms of operations, components and technical characteristics. The ERTMS system consists of two main subsystems, namely the European Train Control System and the Global System for Mobile Communication for Railways:

- **The European Train Control System (ETCS)** is a train driving supervision system which is transmission based, acting between the track and the train, and is unified at European level. The ETCS is able to monitor the train speed and reduce it according to the restrictions on a specific line section, and to calculate the speed profile at all times. The ETCS is expected to replace the existing national ATP systems;[28, 29]
- **The Global System for Mobile Communication for Railways (GSM-R)** is a wireless system providing voice and data communication among the trains, the trackside and the railway control centres. It is based on standard GSM, transmitting at frequencies specifically reserved for railway operations in Europe (~900 MHz), with specific and advanced functions (e.g. fast call set-up for railway emergency calls, priority and pre-emption, functional numbering, location dependent addressing). [30, 31]

The current Study focuses on railway infrastructure only, therefore only the trackside elements of the ECTS are considered in the quantitative costs analysis, as both the on-board subsystems of the ECTS and the GSM-R, are excluded.

The technical specifications of both subsystems vary depending on the ERTMS versions (also called **Baselines**). The baselines are further divided in different **releases**.

Each baseline of the ERTMS/ETCS specifications is developed by one of the UNIFE company members, with an appropriate common migration strategy. The European Railway Agency (ERA) is responsible to set technical specification for the interoperability of the ERTMS system along the Trans-European rail

[25] www.ertms.net
[26] ~€20 - €30 billion estimated for the ERTMS deployment on the TEN-T core network only
[27] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[28] www.ertms.net
[29] UIC 2008 – ETCS Implementation Handbook
[30] www.ertms.net
[31] UIC 2009 – GSM-R Procurement & Implementation Guide

network.[32, 33] The large majority of the systems currently in operation follows the Baseline 2 specification (version 2.3.0d).[34]

Additionally, the ERTMS can be classified in different functional levels depending on the supervision modes for the train movement and the train-track data communication. The level of automation of the system enabling non-human supervision entails higher technical complexities and therefore higher costs. A comprehensive description of the main functional levels is reported below.[35]

## 2.2. ERTMS Signalling Levels

The ERTMS is characterised by three main functional levels. Level 1 is the basic level for ERTMS, while Level 2 and Level 3 are further improvements of the basic level.
The levels differ in the supervision mode for the train movement and the communication between signalling devices on trains and the trackside. In particular:

- The level of automation of the railway signalling increases while passing from Level 1 to Level 3. A higher degree of automation, implies a reduction of human intervention and therefore potential human error;[36, 37]
- The importance of the lateral signalling systems varies according to the different ERTMS Levels. For instance, whilst ERTMS Level 1 requires fixed lateral signalling system, the lineside lateral traditional signals are reduced in Level 2, becoming superfluous in Level 3. This phenomenon is due to the enhanced direct communication between the locomotive and the **Train Management System (TMS)** in Level 2 and 3.[38,39,40]

A detailed description of the main functional levels is reported in the following paragraphs.

### 2.2.1. ETCS/ERTMS LEVEL 1

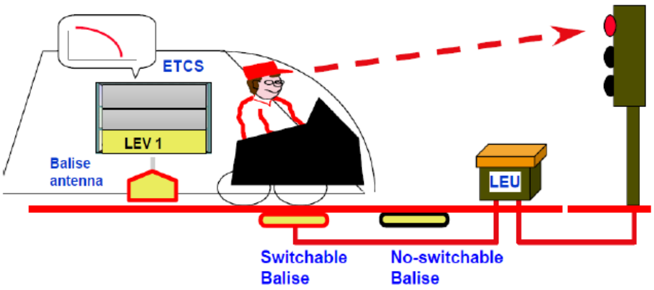
The ETCS/ERTMS Level 1 is a spot (or semi-spot) cab signalling system that can be superimposed to the existing lateral signalling system in place (e.g. national signalling system). It consists of:

- Trackside installation of **Eurobalises** (specific variant of conventional balises[41]) and train detection equipment, both linked to the Train Management System (TMS)**;**
- On-board installation of balise antenna[42] and ETCS subsystems.

[32] Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system
[33] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[34] Commission Staff Working Document (2017) – Delivering an effective and interoperable European Rail Traffic Management System (ERTMS) – The way ahead
[35] www.ertms.net
[36] Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system
[37] www.ec.europa.eu/transport
[38] The Train Management System is the control and communication platform which manages and controls the flow of information both on-board between the different sub-systems (i.e. converters, doors, heating, ventilation and air-conditioning) and between the train and tracks (www.bombardier.com)
[39] www.ec.europa.eu/transport
[40] Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system
[41] Balise is an electronic beacon or transponder placed between the rails of a railway as part of an automatic train protection (ATP) system (www.railsystem.net)
[42] Wire-less system to receive the balise signal on-board

The Eurobalise sends the location of the train passing over it to the TMS. The TMS receives the position of all the trains on the line and determines the **New Movement Authority (NMA).**[43] The NMA and the track data are encoded through **Lineside Electronic Unit (LEU)** [44] and sent to the Eurobalises. The train passing over the Eurobalises receives the NMA and the track data. The on-board computer calculates the speed profile[45] and the braking information for the NMA. The braking information is displayed to the driver.[46] [47] With the ETCS Level 1 the driver is still required to check the track-side signals.[48]

***Figure 2: ETCS Level 1 operational diagram***




*Source: Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system*

Infill loops or extra balises can be added to the track, ahead of the balises, in order to transmit in advance the NMA and the characteristics of the track ahead of the train passing over it. This advanced information allows the trains to regulate the braking phase, improving even more travel times and line capacity.[49]

## 2.2.2. ETCS/ERTMS LEVEL 2

The ETCS/ERTMS Level 2 is a radio-based continue signal and train protection system. The ETCS Level 2 does not require traditional lineside signals (apart from few indicator panels), as most of the signals are directly displayed to the driver through the on board computer. However, the ETCS Level 2 still necessitates on-track detection equipment, in particular:

- Trackside installation of Eurobalises;
- On-board installation of balise receiver:
  - ETCS Level 2 subsystems; and
  - **GSM-R radio system**.

The GSM-R radio system allows the on-board computer to directly communicate to the TMS and *vice versa*, without passing through the balises and LEU. All the trains automatically report their location to the TMS and receive back the NMA at regular intervals, through the GSM-R radio network. The on-board computer then calculates the speed profile for the NMA and displays braking information to the driver. The track characteristics are pre-programmed into the on-board computer.

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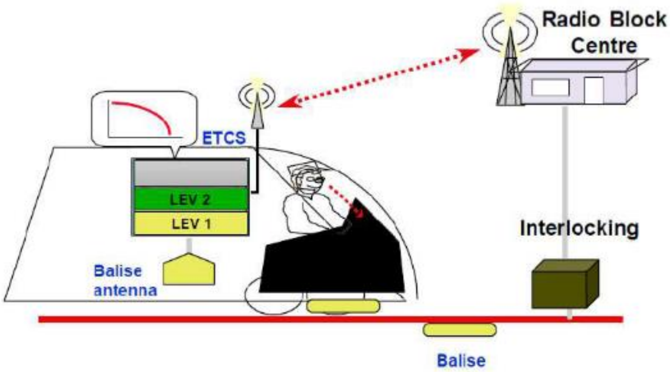
43 Permission to cross one or more block section - Palumbo M. (2014)
44 The Lineside Electronic Unit (LEU) is the equipment interfacing with TMS and other external systems, and the eurobalises. It sends the suitable ETCS messages to the Eurobalises, according to the information received from the TMS or other external systems.
45 The (static) speed profile is a description of the fixed speed restrictions of a given piece of track. The speed restriction are due the status of a section of the line, the curves, the tunnels, etc. (www.definedterm.com)
46 Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system
47 www.ertms.com
48 www.ec.europa.eu/transport
49 www.ertms.com

To ensure safe travel, both the on-board computer and the TMS continuously monitors the train position and checks the correct speed for the distance travelled.
The Eurobalises become autonomous and are simply electronic position markers, used to correct the distance measurement errors.[50]

***Figure 3: ETCS Level 2 operational diagram***

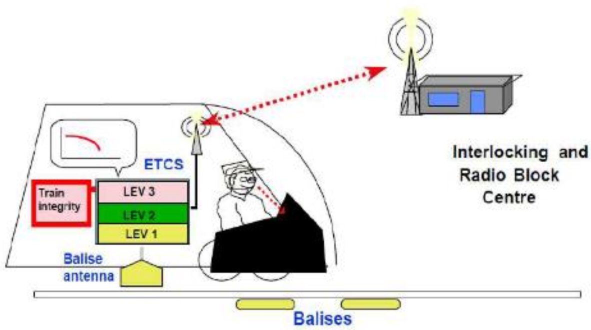



*Source: Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system*

## 2.2.3. ETCS/ERTMS LEVEL 3

The ETCS/ERTMS Level 3 is a full radio-based train spacing system. The signalling system is able to completely monitor the train location and integrity, with no need for lineside signals or train detection systems on the trackside, other than Eurobalises. On trackside, **continuous signalling loops** are deployed, in order to have uninterrupted signal between the train and the track. The on-board computer continuously determines the train position and checks if the current distance is correct for the speed travelled. The TMS receives the position of all trains on the line, by GSM-R and determines the new movement authority. The NMA is radioed to the on-board computer.
The route is no longer divided in fixed track sections, as ETCS Level 3 directly calculates the safe distance between trains.[51] [52]

***Figure 4: ETCS Level 3 operational diagram***




*Source: Palumbo M. (2014) ERTMS/ETCS signalling system - An overview on the Standard Europe an Interoperable signalling and train control system*

The ERTMS Level 3 is already defined in the CCS TSI, however its applications in operational services are limited to the EU.[53]

[50] www.ec.europa.eu/transport
[51] www.railwaysignalling.eu
[52] www.ec.europa.eu/transport
[53] Furness et al., (2017). ERTMS Level 3: the Game-Changer

2.3. # *Migration Strategies*

The EU MSs adopted different strategies for the ERTMS deployment which depends on technical and economical parameters.[54] The various deployment strategies have different impacts on signalling unit cost.

Three main deployment strategies have been identified:

- **Whole network deployment**: typical of countries with a small railway network or with an obsolete signalling system. The migration of the whole network simultaneously requires higher capital expenditure, whilst the marginal cost is reduced as a result of the creation of economies of scale;[55] [56]
- **Prioritised deployment:** several countries chose to deploy the ERTMS only in prioritised sections of their national network due to economical and/or technical difficulties to intervene on the whole network at the same time. In particular, the high speed lines of the TEN-T CNC and the interconnection lines between the corridors are considered of higher importance;[57]
- **Limited deployment**: Some countries are still lagging behind due to the scarce interest in international railway traffic and good performances of the signalling system in place.

There are two different ways of migrating towards ERTMS for each deployment strategy: the **dual trackside migration strategy**[58], which allows the interoperability with trains equipped with the legacy system and the **dual on-board migration strategy**[59], which instead allows interoperability with lines equipped with the legacy system. In some cases a **mixed migration strategy,** which combines the dual on-board migration to the dual trackside migration.[60]

An overview of the main migration strategies within the MSs is reported in the table below.

*Figure 5: Strategy/ migration path matrix*

| Strategy/ Migration Path | Dual on-board migration | Dual trackside migration | Mixed Migration |
|---|---|---|---|
| **Whole Network deployment** | Netherlands, Denmark, Luxembourg, Sweden | - | Belgium, UK |
| **Prioritised deployment** | Spain | Italy, France, Germany, Austria, Czech Republic, Slovenia, Hungary | - |
| **Limited deployment** | - | Poland, Ireland, Estonia, Lithuania, Latvia, … | - |

*Source: PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report*

The table shows a strict correlation between deployment strategies and migration paths: countries adopting a whole network deployment tend to opt for a dual on-board migration path. They generally have

[54] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[55] Kleine E. G. (2017) ERTMS Deployment/Migration Strategies of ERTMS Users Group members
[56] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[57] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[58] The dual trackside migration strategy consists on the trackside implementation of the ERTMS, while maintaining the legacy system during the migration period. The legacy system is maintained operative until all rolling stocks will be equipped with the legacy system
[59] The dual on-board migration strategy consists of equipping the trackside with the ERTMS only. Both the ERTMS and the legacy on-board subsystems are maintained operative for the locomotives that operates on both ERTMS and non-ERTMS lines
[60] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report

a smaller railway network and the whole fleet will be retrofitted at once, which will not require the trackside part of the legacy system anymore. Nevertheless, Belgium and the UK, combined a network deployment strategy with a mixed migration path.[61]

On the other hand, MSs adopting a prioritised deployment strategy tend to choose a dual-trackside migration path.  Indeed, they are characterised by an extensive railway network which leads to financial and technical difficulties in retrofitting the whole network at the same time. The only exception is represented by Spain which opted for a prioritised deployment and a dual on-board migration strategy.

The other countries, which implemented a limited deployment strategy, all chose a dual trackside migration.

[61] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report

# 3. Factors determining the cost of ERTMS

A thorough analysis of the relevant literature and the consultation of experts enabled to determine the factors having a stronger influence on the cost to deploy the ERTMS. The cost of the ERTMS is mainly influenced by the functional level installed, and the deployment strategies/ migration paths at national level.

Other factors affecting the ERTMS cost have been identified throughout the analysis. Among the others, the standardisation process and the risk of investment are recognised to have a not negligible impact and have been qualitatively assessed.

A qualitative description of all factors is provided in the following paragraphs.

## 3.1. ERTMS Functional Levels

The cost variation in ERTMS levels is due to the difference in both hardware and software components of the functional levels.

The number of hardware elements deployed on the track gradually decreases from Level 1 to Level 3. In particular, the ERTMS Level 1 and Level 2 require Eurobalise components, lineside lateral traditional signals and train detection systems, while the ERTMS Level 3 does not require lineside signals or train detection systems on the trackside, other than Eurobalises. The cost is expected to decrease from Level 2 to Level 3, as the trackside equipment is significantly reduced in Level 3. The cost saving achieved by level 3 will strictly depend on the system architecture adopted for the deployment.[62]

On the other hand, the technological complexity of Level 2 trackside subsystems is much greater than in Level 1. Thus, the installation cost of ERTMS Level 2 is significantly higher than in Level 1, even though the number of trackside subsystems is lower in Level 1.[63]

## 3.2. Deployment Strategies

The ERTMS implementation cost depends primarily on the deployment strategies at national level.[64]

The implementation of the ERTMS on the **whole network at once** would require a much larger financial investment whilst reducing the marginal cost and interoperability risk through more bargaining power and economies of scale. The **prioritised deployment** of the ERTMS enables to reduce the initial investment, however it leads to higher marginal costs and interoperability risks at national level. Both deployment strategies are strongly influenced by the strategies of the neighbouring countries. Indeed, the ERTMS projects can be considered as ***"open systems"*** where players cannot directly control their behaviour but they rather need to cooperate with the other players (often at international level).[65]

Additionally to these factors, other element that impact on ERTMS cost have been identified, which are presented below. However, the current analysis only focuses on the quantitative impact of the functional levels and the national deployment strategies.

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[62] Transport Research Laboratory (2010) – Final report: ERTMS Level 3 Risks and benefits to UK Railways
[63] UIC (2009). Final report: ERTMS Implementation Benchmark
[64] EC memo (2005). The ERTMS in 10 questions
[65] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report

## 3.3. Other factors

### 3.3.1. Standardisation Process

The standardisation process is an additional factor affecting the investment and maintenance cost. In particular, standardisation of the technology leads to lower investment and maintenance costs in the long term as well as to a more cost-efficient production system. [66]

### 3.3.2. Risk of investment costs increase

Another factor affecting the ERTMS deployment cost is the investment risk during the implementation phase. In particular:

- **Design risks:** are risks associated with the design of wrong ERTMS specifications which lead to lack of full compatibility and/or interoperability; and therefore an increase in costs.
- **Construction risks:** relate to the occurrence of unexpected events during the construction phase (e.g. the realised intervention does not fulfil with initial specification).

The main risks that may arise during the design and construction phase are:

- **Technological risk:** are risks related to the requirements for updates and new versions which might lead to system instability and non-backward compatibility between ERTMS versions. The technological risk impacts the RUs mainly, as they are responsible for the on-board installation of the ERTMS subsystems.
- **Interoperability risk:** are risks associated with the lack of compatibility between the specifications of ERTMS systems on different lines.[67]
- **Political risk:** relate to potential changes in the political support to the ERTMS during the implementation strategy, with strong consequences at national and international level.

- **Low market competition risk:** The ERTMS market is characterised by a low competition throughout Europe. Indeed, the development and upgrading of the system is entrusted only to eight Companies, part of the Association of the European Rail Industry. The low competition on the European market leads to high prices and lower efficiency level of outputs, as compared to other market structures.[68] [69]

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[66] EC memo (2005). The ERTMS in 10 questions
[67] PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report
[68] Lahiri S. and Ono Y. (2004). Trade and Industrial Policy under International Oligopoly
[69] Ellis K. and Singh R., (2010). The economic impact of competition – Overseas Development Institute, Project Briefing No 42

A summary of the main factors determining the cost and their impact is reported in table below.

***Figure 6: Factors determining the cost and their impact***

| Factors | Possible impact |
|---|---|
| **ERTMS functional levels** | Difference in hardware and software characteristics |
| **Deployment strategies** | Allocation of capital and marginal costs throughout the project |
| **Standardisation process** | Less and cheaper trackside equipment |
| **Risk of investment costs increase** | Occurrence of one of the risks described above or to unexpected costs, allocation of higher contingencies at design level |

*Source: Own elaboration on PwC and Leigh Fisher, 2015 – Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors – Final Report*

# 4. Analysis on a selected number of cases

In addition to a detailed literature review, a number of relevant ERTMS deployment cases have been analysed in order to determine the ERTMS deployment unit cost. The analysis has been particularly focused on the impact of the different ERTMS levels and the national implementation plans on the unit cost, which are deemed the main parameters affecting the unit cost.

## 4.1. Results

The unit cost for trackside ERTMS deployment varies from 60 k€ to 370 k€ per double track kilometre, in line with the unit cost range proposed by the Commission (30 k€/km – 300 k€/km). The cost range depends on both the deployment strategies and the ERTMS functional levels. [70]

The analysis was performed only on the projects stored in the database used for the analyses of the Rail Unit Cost study that relate to the deployment of ERTMS. The projects concerning the implementation of other signalling systems rather than ERTMS are not considered in this case study, as are not considered those projects for which the cost of ERTMS could not be clearly identified separating it from other costs – also relative to signalling.

It shall be noted that higher unit costs than those reported in this case study have been reported in works on lines that relate to signalling, although these were only generally referred to signalling works and not specifically identified as "ERTMS" deployment projects. Would these costs be considered, the maximum unit cost could significantly increase.

Hereunder, the variation in unit cost for the different functional levels is reported in table.

*Figure 7: ERTMS deployment unit cost per functional levels*

| Signalling Level[71] | Minimum [M€/km] | Quartile 2 [M€/km] | Average [M€/km] | Quartile 3 [M€/km] | Maximum [M€/km] |
|---|---|---|---|---|---|
| **Level 1** | 0.06 | 0.09 | 0.10 | 0.11 | 0.16 |
| **Level 2** | 0.06 | 0.15 | 0.17 | 0.19 | 0.37 |

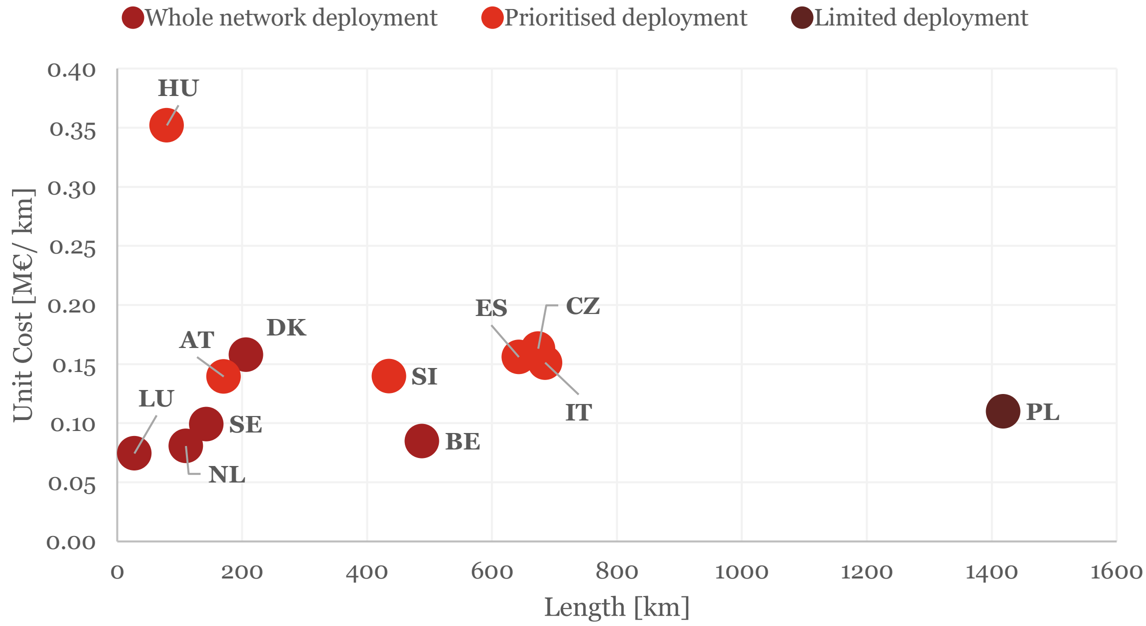
*Source: PwC own elaboration*

On average, the unit cost increases for an increase of the signalling level, as highlighted in the previous paragraphs. The unit cost for the deployment of ERTMS Level 2 is significantly higher than the deployment cost of Level 1. The data available is not sufficient to evaluate the unit cost of the ERTMS Level 3, however it is expected that the unit cost is comparable to the unit costs associated with Level 2.[72]

The different deployment strategies have been identified to impact on the unit cost of ERTMS deployment. The effect of the deployment strategies is reported in figure below.

[70] EC memo (2005). The ERTMS in 10 questions
[71] No data are available to calculate statistics on Level 3
[72] Transport Research Laboratory (2010) – Final report: ERTMS Level 3 Risks and benefits to UK Railways

*Figure 8: ERTMS deployment strategies per Country [M€/km]*




*Source: PwC own elaboration*

Generally, the ERTMS deployment on the whole network is cheaper (on a marginal level) than the prioritised deployment, due to economies of scale.[73] The unit cost for the ERTMS implementation in Belgium, Luxembourg, the Netherlands and Sweden is smaller than in countries which adopted the prioritised deployment. On average, whole network deployment countries incur in a 45% cost reduction compared to prioritised deployment strategies.

Denmark, which adopted a migration strategy on the whole network, but faced a unit cost for ERTMS deployment 60% higher than the average for other MSs that followed the same strategy, represents the only exception. It is due to the fact that Denmark adopted a singular National Implementation Plan, aiming not only to ensure the interoperability of the entire Danish railway network, but also to have a single Control Centre for the TSIs both on-board and trackside. The, so called, Danish Signalling Programme[74] faced unexpected difficulties and due to the approval and documentation task and other complexities, which led to delays and needs of re-planning.

Poland is the only country in the sample which implemented a limited deployment strategy although having an extensive railway network. Despite the fact that Poland adopted such limited deployment strategy, the polish railway has an ERTMS unit cost in line with the other countries as shown in Figure 8. It can be explained by the fact that the majority of the polish railway analysed deployed a Level 1 ERTMS which is cheaper than a Level 2 and therefore lead to a comparable unit cost with the other European countries.

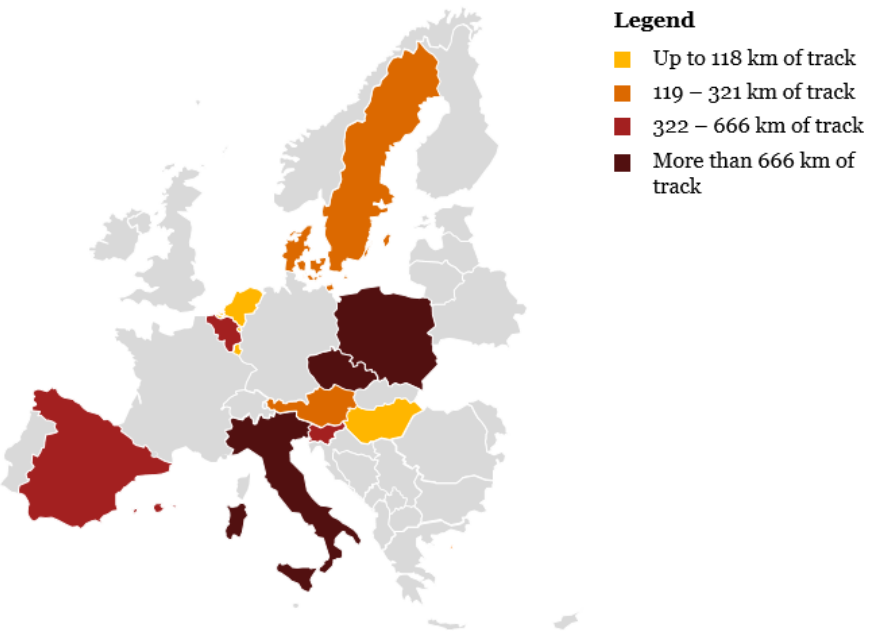
## 4.2. Technical characteristics of the cases investigated

The results presented in this case study derive from a sample of approximately 5.000 double-track kilometres equipped with ERTMS, spread in twelve MSs. The sample was selected in order to consider the difference in unit cost of the ERTMS levels. Nevertheless, different MSs have been considered to

[73] EC memo (2005). The ERTMS in 10 questions
[74] Banedenmark (2017) - The Danish Signalling Programme – where are we now?

investigate the effect of the national deployment strategies on the ERTMS unit cost. The geographical distribution of the tracks analysed throughout the EU is reported in the following table.

***Figure 9: Track kilometres deployed with ERTMS per Country [km]***




*Source: PwC own elaboration*

Italy, Poland and Czech Republic are highly represented within the sample analysed, with more than 650 km of track. The sample considered for the remaining nine countries under investigation, is on average 250 km of track deployed with ERTMS. The smaller sample is represented by Luxembourg and Hungary with less than 100 track kilometres deployed with ERTMS.

**Timeframe**

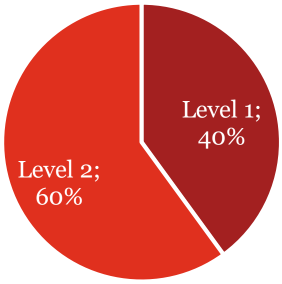
The timeframe considered varies from 2002 to 2016. The majority of the projects considered (approximately 80%) are from the period 2011 – 2016. Indeed, the introduction of the European ERTMS Deployment Plan, in 2009, significantly pushed forward the ERTMS implementation throughout EU.

**Technical characteristics**

The data collected throughout the study allows to assess the impact on the cost of the technological updates of both the functional levels and the deployment strategies at national level.

The data available allowed a consistent subdivision of the double- track kilometres between the different functional levels, as reported in the following chart.

*Figure 10: Double-track kilometres per ERTMS functional level*




*Source: PwC own elaboration*

The ERTMS Level 2 is the most represented within the sample, with approximately 3.000 double-track kilometres. Indeed most of the lines currently equipped with ERTMS are deployed with the functional Level 2. Level 1 represents 40% of the sample considered, with a total length of approximately 2.000 double-track kilometres. Level 3 is not represented in the sample as it is the newest technology which is not yet under implementation in most of the MSs.