Developing and deploying innovative technologies in a liberalized European railway system

Dr. Guillaume de Tilière, BG Consulting Engineers
Dr. Marc Laperrouza, Senior Research Associate, EPFL

Conference paper STRC 2009

STRC | **9th Swiss Transport Research Conference**
Monte Verità / Ascona, September 9. - 11. 2009

Developing and deploying innovative technologies in a liberalized European railway system

Dr. Guillaume de Tilière
BG Consulting Engineers
Lausanne, Switzerland

Phone: 41-79-314-4596
Fax: 41-32-724-0484
email: guillaume.de-tiliere@bg-21.com

Dr. Marc Laperrouza
EPFL
Lausanne, Switzerland

Phone: 41-21-693-0085
Fax: 41-21-693-0000
email: marc.laperrouza@epfl.ch

Abstract

In a network industry like railways, major systemic innovations and new technological trajectories are tightly connected to national institutional frameworks and policies. The major transformation occurring in Europe brought by the liberalization and harmonization of railways since a decade provides a fertile ground to study the link between innovation and institutions. This article aims at providing a structured framework to look at the innovation process in the railway sector. It focuses on institutional and innovation models before and after the railway sector's reorganization.

The article is based on the case study of the European Train Management System (ERTMS), whose development spans over a period of 15 years and thus offers a very good foundation to look at the evolution of innovation models. The various models that emerged underline the deep changes that occurred within the rail sector as well as their impacts. While they allow drawing some lessons on how to better manage the development and deployment of key innovative technologies in the railway sector, they also raise questions on how institutions shall adapt in order to cope with fundamental technological transformations.

Keywords

railways, innovation models, Europe, harmonization, institutions, technology

1. Introduction

With the development of railways, innovations in signalling technologies were aiming at increasing safety, network capacity and cost efficiency. In the development of international corridors, interoperability between networks became a major problem for rail competitiveness – both for passenger and freight traffic. At the beginning of the 1990s, the European Community launched its harmonization policy aimed at increasing the performance of the European railway system. The policy was embedded in a strong wish to harmonize future technologies as well as to dismantle national technological barriers (for instance to avoid the juxtaposition of several national systems in locomotives)[1].

The European Commission's ambition to foster a competitive pan-European railway market rests partly on improving the interoperability of the heterogeneous national railway systems. To this end, it has been encouraging the development and deployment of a harmonized railway management system – the European Rail Train Management System (ERTMS) – across Member States.

The stakes of ERTMS development

The development of ERTMS is one of the most interesting examples of a systemic innovation carried out under the new European institutional framework. ERTMS will be the technological support for the development of the trans-European rail network, allowing interoperability between national networks. In the long term it will allow to increase the performances of rail systems in comparison to road and air transport systems. The case of ERTMS is particularly interesting since it encompasses both a purely technical dimension to innovation (functionalities, requirements, etc.) and a strong institutional dimension since its supranational nature conditions its development and deployment – the program originated around the same time as major institutional changes in European railways.

Main challenge of the ERTMS innovation

From a technological point of view, the development of ERTMS is a systemic innovation: it includes the development of trackside equipments (Eurobalise), onboard train equipments

[1] Eurostar requires 16 on-board sensors with six automatic train control (ATC) systems; Thalys trains operating in four countries have 28 on-board sensors for eight ATC systems. In his study on railroad innovation in the USA, Usselman (2002) notes that at the beginning of the 20th century signalling only diffused through the industry when government threatened railroads with mandates.

(Eurocab) and communication systems (Euroradio / GSM-R). One of the key challenges has been to develop a generic system, based on some plug-and-play sub-systems in order to allow as much as possible interoperability between the main blocks of the ERTMS system. From this point of view, ERTMS is a completely new concept, based on modularity and standard interfaces.

In order to reach such a consensus between the main actors, the development of ERTMS has required the emergence of a new European rail framework. The management of this technological innovation has necessitated an important organizational and institutional change, underlying the mutation of the European rail market, a decade after the adoption of the first European directives. Several stakeholders have emerged because of the separation between operations and infrastructure management, leading to a re-organization of the associations which co-ordinate the European railway sector (e.g. UIC, CER, EIM, EEIG, CENELEC, UNISIG groups, etc.)[2]. Harmonization of EU railway standards has focused on compatibility between railways in primarily engineering terms.

The difficulties in standardizing at the European level are not surprising[3]. Puffert (1994) notes that railways in Europe developed diversity in their technical practices because network integration at a European level was less important to railway administrations than the integration of each local sub-network. These technical differences in national railways hampered the process of interconnection of national networks and were (and still are) the main obstacle in the process of emergence of a European railroad network[4].

As pointed out by van Zuylen & Weber (2002) policy for technological innovations in transport is confronted with a highly complex decision situation. It has to deal with multilevel, multidomain political decision making, with transport as it is embedded in the economic and societal environment, with many different actors and competing technologies, etc. On a European scale, innovation policy for transport has to deal additionally with the question of an efficient ‘‘division of labour’’ between Member States and EU, as prescribed also by the

[2] The list is not exhaustive. Other associations include ALE, CER, EIM, ERFA, ETF, UNIFE, UIP, UITP and UIRR.

[3] Lundvall (1993) points out that in the case of continuous incremental innovation the drive towards standardization is limited: “Geographical and cultural proximity to advanced users and a network of institutionalized (even if often informal) user-producer relationships are an important source of diversity and of comparative advantage, as is the local supply of managerial and technical skills and accumulated tacit knowledge”.

[4] For most of its history, technical coordination has been achieved through international agreements, often a result of the activity of international organizations.

principle of subsidiarity. In Europe, the railways harmonization process involves a large and complex administrative structure, with many technical committees developing standards in CEN, CENELEC and ETSI; further technical work at a more general level developing Technical Specifications for Interoperability under the high speed interoperability Directive; and the further layer of administration in the development of Directives – in particular on railway interoperability and the single market.

While promising, the development of ERTMS currently doesn't provide a solution to all the interoperability problems that plague the European railway network. In fact, Baggen, Vleugel, & Stoop (2008) argue that compatibility problems on the Betuwe route in the Netherlands are mainly caused by the way decision-making took place, in particular with respect to the choice and implementation of ERTMS.

2. The ERTMS innovation process

2.1 The source of the ERTMS innovation

Stoop, Baggen, Vleugel, & Vrancken (2009) identify 3 historical phases in the development of railway signalling: 1) the dawn of the railway industry (early 19^{th} century) were signalling was modelled after the Napoleonic military organization, 2) enhanced automation with the introduction of Automatic train Protection (ATP) system, and 3) ERTMS. In the evolution of signalling technologies, several factors have pushed for innovative concepts in control command systems. The drastic increase of passenger traffic on some key corridors put current technologies at a high saturation level, forcing operators, together with industry, to think about innovative systems. At the same time, the availability of new technologies allowed the industry to think about new concept and systems.

Operators as lead-users of innovations

The increasing demand of operators was a driving factor in the constitutions of users working groups for two main reasons. First, the increasing need of efficient cross-border operation pushes for more common procedures (case of the Paris-Amsterdam HSL). Second higher traffic density on the main corridors required cost efficient solutions to regulate trains under degraded modes. For instance, the increase of speed from 300 to 350 km/h for TGV reduced the capacity of the lines (longer headways).Third, improvement of safety were required, including on secondary lines where traditional technologies were too costly to be implemented in comparison to the manual procedures in use on low density lines. The purpose was therefore to improve the homogeneity of the networks safety level, while allowing the easiest implementation.

A systemic Innovation based on new technologies

The evolution of technologies led to new possibilities to improve the performance of signalling systems in at least three areas:

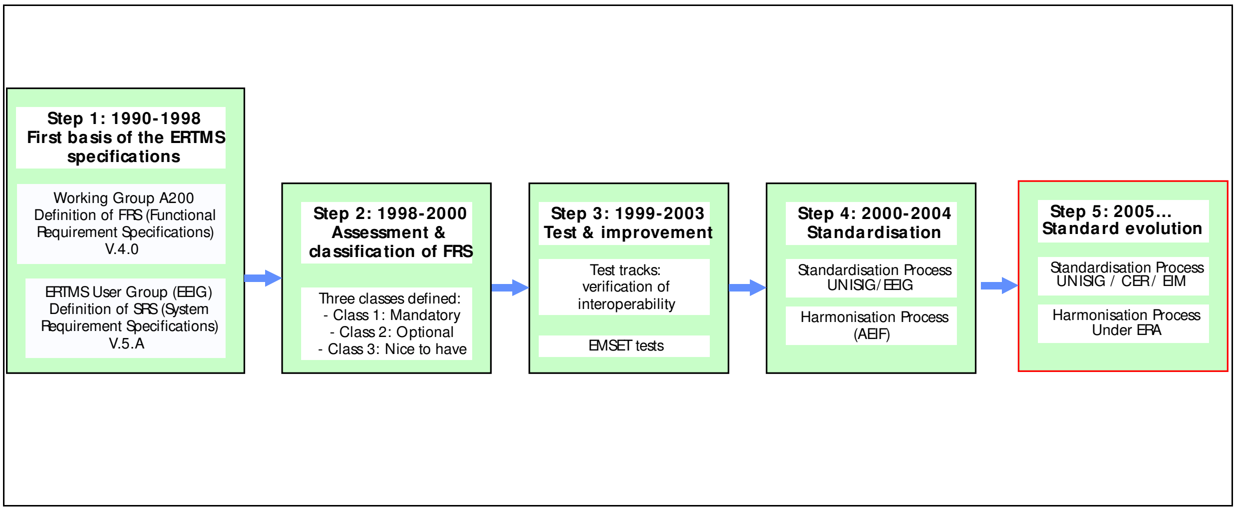
- Computing technologies allowed new support for operations previously conducted with intrinsic safety technologies; numeric technologies now allow to implement more sophisticated functions at lower costs;
- Communication systems – with the development of GSM networks also replacing analogue by digital technologies – provided a significant increase of data transmission capacity between onboard and trackside systems.
- Other areas of innovation, such as plasma screens which opened new possibilities for on-board cab signalling displays, or such as captors used for odometer systems (for instance coupled with Doppler radars for speed measures and onboard localization, which can now be done in compliance with the high rail safety standards).

2.2 Birth of a European technology: the ERTMS innovation process

A first important step in the process of harmonizing European railways was the wish to develop a common standard for signalling ATP, allowing interoperability along international corridors. Broad institutional and market changes at the European level opened the way to a new common technological path. Following the decision taken by the European Transport Minister in December 1989, a group of railway experts develop the requirements of ETCS. In June 1991, industry (Eurosig) and railway (UIC, ERRI) representatives agreed on the principles of tight co-operation in order to consider the requirement specifications as the base for industrial development.

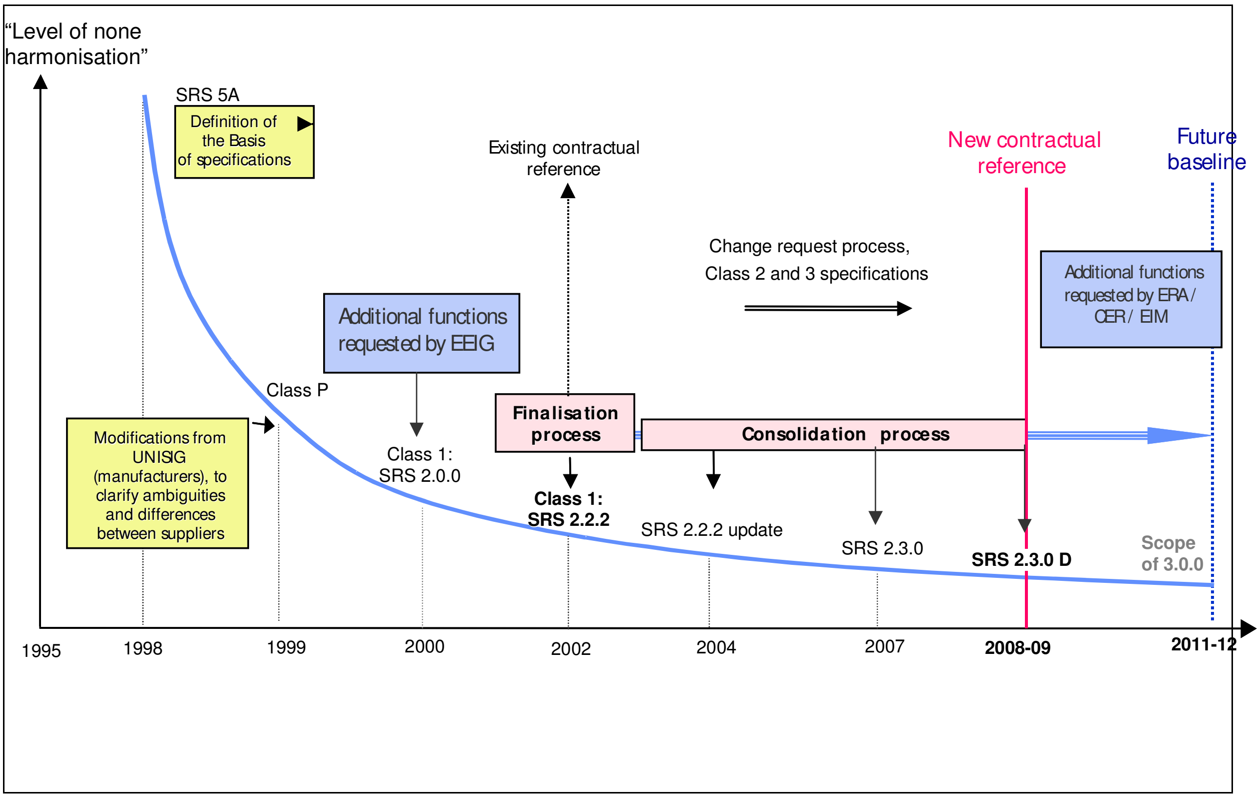
In 1993, the EU council issued an Interoperability Directive and a decision was taken to create a structure to define the technical specifications for interoperability (TSI). In 1995, with the beginning of the 4th research framework program, the European Community (EC) defined a global strategy for the further development of ERTMS, with the aim to prepare the future implementation of this technology on the European Rail Network. A user group was formed in order to define the technical specifications of the new ERTMS system. The EC brought a financial support of EUR 250 million until 2004 (Vinois, 2004), whereas the industry invested close to EUR 600 million to develop the technology. Formed in 1994, EUROSIG became UNISIG in 1998 and includes all European Signalling manufacturers involved in ERTMS. This group led the finalization of the specifications in partnership with European railways engaged in EEIG, as shown in the figure below.

Figure 1 SRS definition steps (adapted from UNISIG source)



The ERTMS standard was defined and improved until its last versions with the aim to solve interoperability issues, improve safety, capacity and cost effectiveness in the long run[5]. First versions of the specifications were updated up to version V5.a in 1998-99 (a first basis for test tracks like the one in Switzerland between Zofingen and Sempach). Then version SRS 2.0.0 was released in 2000. It served as the basis for several other test tracks in Europe and was funded by the EC in order to assess the specifications. The process allowed improving the specifications based on the feedback from several operators and industrials equipment suppliers (see Figure 2). Following this process of consolidation, the release of SRS 2.2.2 in May 2002 was been the first important step for commercial applications. It was completed by an EC decision in April 2004.

Figure 2 SRS definition and consolidation process



A number of gaps creating interoperability issues had to be solved throughout the process – in the first projects between 2004 and 2008 as well as in the SRS 2.3.0 release in 2007. Consolidation works led to the SRS 2.3.0 D that was issued mid 2009 and now constitutes the baseline for corridor operations as stated by ERA and the sector (even if some corridors such

[5] The cost of change is high for operators that have already developed their own ATP system early in the 1990s.

as Corridor A with Germany and Switzerland that prefers to wait for SRS 3.0.0 in 2012 in order to have some more functions they want, as the so called limited supervision)[6].

After a decade of experience, we can now identify three phases: a definition phase from 1998 to 2004 and a consolidation phase between 2004 and 2008. Since 2009 ERTMS entered a phase of "normal" mode of standard evolution, with recurrent work focused on new functionalities (objective of the SRS 3.0.0).

Pilot lines as a validation step: key learning

The Class 1 specifications were a good basis and a necessary step before the validation of the ERTMS concept on test lines. The six operators of the users group (EEIG) started in 2000 the deployment of pilot lines based on the SRS 2.0.0 and later 2.2.2 standards in order to demonstrate the interoperability[7]. Each line involved an operator, the infrastructure owner and two different manufacturers (one for on-board and the other for trackside). In total, nine lines were tested in seven countries[8]. They were partly financed by the European Commission, with on average EUR 10 to 20 million funding for each project (for the complete system)[9].

The aim was to provide to industries and operators the experience to:

- Test the technology and the system integration;
- Define possible standards improvements (specification improvement);
- Harmonize operation and contractual references;
- Validate a common interpretation of the TSI;
- Consolidate of the certification process.

It was part of the validation and consolidation phase of SRS, paving the way to issue the technical specifications of interoperability (TSI) as a basis for the ERTMS deployment. The test results allowed improvement of the specifications (leading to the SRS 2.2.2 version in 2002). A change request process has been tailored during this phase and served as a good

---

[6] 2.3.0 D constitutes currently the unique and interoperable technical reference to ensure the interoperability of all ETCS equipment deployed in Europe. However, a number of infrastructure managers and rail undertakings requested the introduction of new functionalities, in particular with a view to facilitating the swift deployment of ETCS on existing conventional lines (NERA, 2000).

[7] Only the first pilot line deployed by SBB with Bombardier in Switzerland (Olten-Luzern) was based on the former SRS 5.A standard. It provided a first experience in full commercial operation, but the system was dismantled as not upgradeable to the SRS 2.2.2 version.

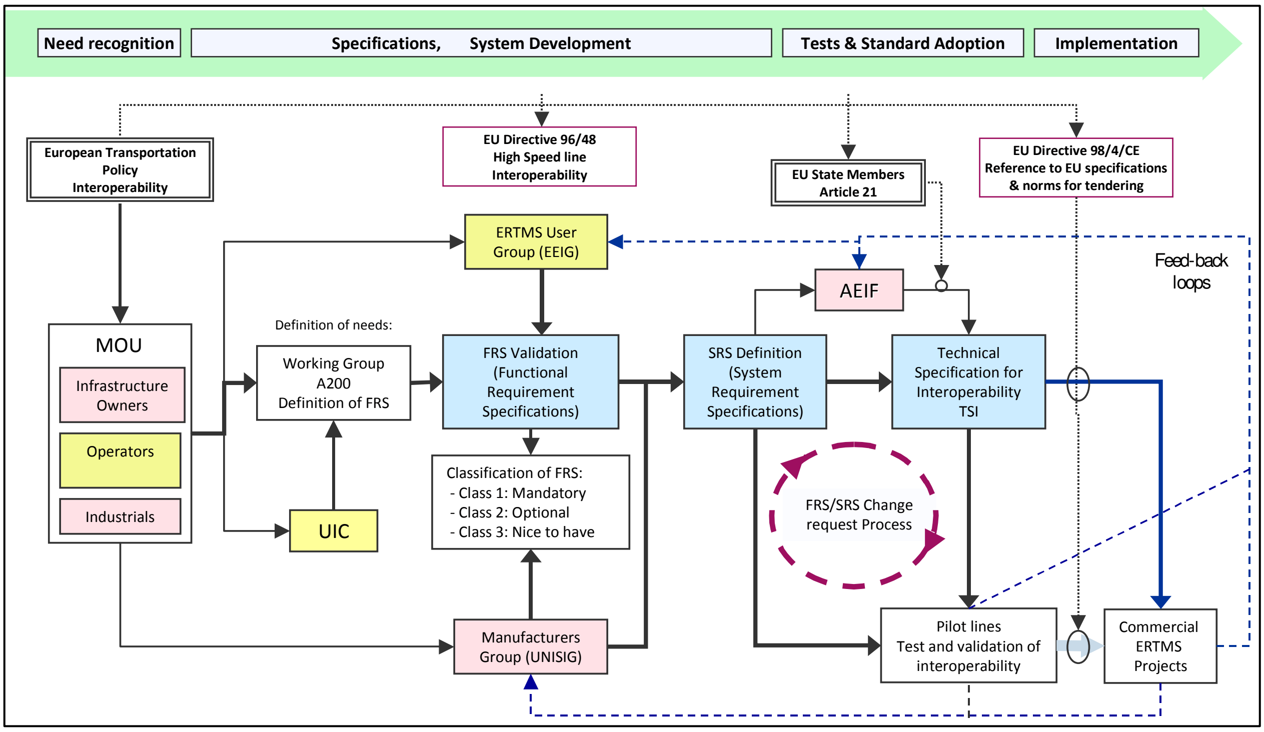
[8] Austria, France, Germany, Hungary, Italy, the Netherlands and UK.

[9] Curchot, Emery & de Tilière (2003).

basis for the organization of the consolidation process (Vinois 2004). It also allowed to support the definition and the validation process of the technical specification for interoperability (TSI).

Experiences gathered from the pilot lines provided both operators and manufacturers with a first important experience. They reduced to some extent the technological risks in addition to demonstrating interoperability. However, the project's organization and financing of test lines didn't allow a full validation of the systems with a frozen standard in output. Therefore, test lines have been closer to a partial validation (whose purpose was to validate the ERTMS concept). As a consequence it increased significantly the risks on the first commercial projects between 2002 and 2006[10].

Figure 3 The ERTMS innovation process up to end 2005



EMSET project: formalizing the test and certification processes

The EMSET project has been focusing on assessing the viability of the ERTMS system through the definition and realization of tests of ETCS components of each supplier. It has

[10] A lot of improvements based on feedbacks from field tests were necessary for a stable basis of the specifications.

been done by the CEDEX in Madrid and followed by the group of six ERTMS Notified Bodies[11]. This step allowed the definition of a standard approach for test specification at the product level, with common methods and test tools, in order to achieve a cross certification process between European countries. These results have also been included in the ETCS TSI. However this first step was limited in terms of results as homologation processes were limited to the products only. Until 2008 processes for system homologation at the project level were still done at the national level. Now this harmonization is tackled by the European Railway Agency (ERA) via a new working group started in January 2009 and gathering railways, national safety authorities and the industry.

ERTMS deployment: learning from the first commercial contracts

Manufacturers spent huge amounts on R&D investments to reach the UNISIG 2.2.2 standard for ERTMS (between EUR 40 and 120 by manufacturer). Commercial projects were launched and partially financed by the EC – there are now over 10 ongoing implementations of ETCS infrastructure projects despite the fact that the standard was still not free of interpretation gaps (leading to some interoperability issues). In Switzerland big efforts were done to close these gaps between 2004 and 2007 (as well as in Spain to some extent between 2005 and 2006).

Deployment of ERTMS now seems underway with an increasing number of ongoing projects and tenders. The UIC (2003) had forecasted deployment of ERTMS on around 16000 km of tracks in Europe for 2009, not far from the current deployment statistics (16'947 km)[12]. ETCS is therefore becoming the first standard for control command systems, a world premiere for railway systems. Even non-European countries are interested, seeing there an opportunity to work with more standardized and performing solutions (UIC and Winter, 2007). For instance, China is now looking for ERTMS solutions, South Korea is deploying it on 700 km of tracks, and Algeria, Turkey are planning to do so as well. ERTMS is also extended to other segments of guided transportation systems (low-density lines, urban transit systems).

2.3 Technological innovation and organizational changes

The development of ERTMS has been relatively long, lasting more than a decade before its first implementation. This period of time has been necessary to build up all the organizational and institutional networks necessary to support the ERTMS development (see Figure 3 and Figure 6) – the mechanisms and processes for such a systemic innovation required an

[11] ERTMS Notified Bodies include ADAF, AEA, EBC, Certifer, RFI and Railcert.

[12] Deployment statistics on http://www.ertms.com/2007v2/deployment.html.

appropriate institutional structure with a dedicated network of specialized organizations and the clarification of roles and relations through formalized processes.

With hindsight only such a dedicated innovation process was able to support the ERTMS development up to a stabilized maturity and to its deployment stage. In fact, the process really started when the responsibilities were clarified in 1998: UNISIG (representing manufacturers) was in charge of defining and issuing technical solutions while the EEIG (representing operators and users) was in charge of issuing the functional requirements. This constituted a deep transformation in the European rail market, allowing the emergence of a European standard. The long time required for the development can also be explained by the high number of actors involved in Europe: the multi-stakeholder environment increased the number of tasks, their complexity therefore creating delays[13].

[13] The main changes that occurred are highlighted and detailed through the Innovation Models in the section below.

3. From the National to the European Rail innovation model

3.1 The National Rail innovation model

To understand the challenges that the European rail market is facing, the analysis of the innovation process before the 1990s is relevant. Signalling technologies were mainly developed at national levels. Innovative signalling R&D programs destined to replace Automatic train Warning (ATW) systems were launched aiming at increasing safety on main lines (Curchod, de Tilière et al., 2003). These Automatic Train Protection (ATP) systems were developed by national pairs of operator-manufacturer, as for instance SNCF-ALSTOM for KVB (conventional lines), SNCF-CSEE for TVM (high-speed lines), DB-Siemens for LZB or ZUB, SJ-Ericsson for Ebicab ATC etc.

These R&D programs were conducted between 1975 and 1995 in the aftermath of several major railway accidents. Operators were looking for ATP systems for implementation on their national networks. Many operators, like DB or SNCF, fully funded the R&D of new national ATP systems. However, whenever a "standard" emerged, it was rapidly customized for each country, at the point that even for a single manufacturer like Siemens its ATP (ZUB) was declined into several versions, which were completely non-interoperable (ZUB 121 for Switzerland, ZUB 123 for Denmark etc). In other words, each country followed its own path: operators attempted to maintain their network inaccessible to foreign operators and favored their preferred national supplier/manufacturer for a sustainable co-operation. National industrial policies were always in the background, as the relation between operators, institutions and governments were very tight (Dobbin, 1994; de Tilière and Hultén, 2003).

The case study of the development of national ATP technologies in Europe brought the following conclusions (de Tilière and Hultén, 2003):

- The role of operators as lead-users was determinant in new technological trajectories and R&D, defining direction and providing financing. This was made possible by the setting-up of co-development programs between the operator and a manufacturer (the "national champion") at a very early stage of the innovation process (long-term co-operation programs, rather than open market philosophy);
- Some operators had also a strong role as technical specificators in addition to functional specificators (something that has now completely changed);

- Tests and the complete validation of experimental technologies were also done under study contracts. This decreased strongly the risks related to technical innovations during the implementation of commercial projects[14];
- On one hand, national markets reduced market opportunities globally for manufacturers. On the other hand, they secured strong captive markets because of high technological standard barriers (the case for most of ATP technologies until the late 1990s). The reduced size of market for a national standard was compensated by quasi-monopolistic situations on specific products. R&D investments were also more secured, like those for the technical specifications of an operator under study contracts. Such ATP technologies as TVM, KVB, LZB, EBICAB were still de facto standards on their specific markets 10 years later.

The role of national industrial policies

In this national innovation system, transportation policies were also at the service of industrial policies. It was the case for the development of high-speed rail technologies or signalling technologies. The needs of operators were also driven by paradigms that were also shared by institutions, manufacturers and governments at the national level. This allowed a convergence in the decision-making process that was intended for increasing success chances in the development of such systemic innovations.

The strong involvement of national operators with the support of governments allowed the development of systemic innovations once a manufacturer was selected for a research program. Therefore more risk-taking and future-oriented strategies were possible for R&D, promoted by a philosophy encouraging more long-term co-operative strategies. At least one of the advantages of such a framework has been to reduce the initial time-to-market of such technologies since only a very reduced number of actors were involved.

A linear innovation pull model

This way of organizing R&D resembles the first generation of innovation model according to Rothwell (1992). Basically, a simple linear model in which the R&D is initiated by a need pull, in which the first step (need recognition) happens at the operator level. The role of operators as lead users in the development of the new railway technological trajectories was central since they defined both functional and technical specifications.

The costs and risks of the producer were lowered by the high degree of commitment of national operators in different ways:

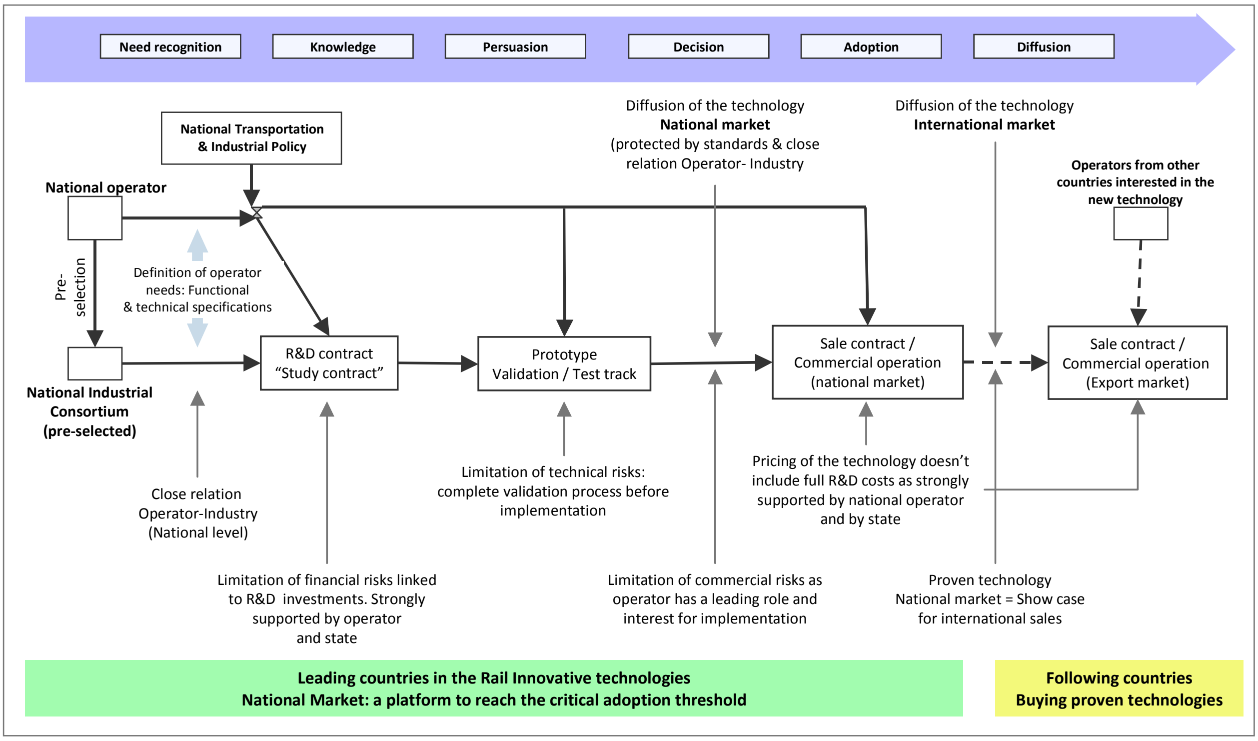
- By cooperating with a manufacturer or a consortium of manufacturers;

---

[14] The objective was to reach at the end of the test phase a sufficient threshold of system maturity, before its commercial deployment.

- By lowering the manufacturers R&D expenses as most of these programs were conducted under "study contracts";
- With the operator initiating a project, thus providing higher probability of implementation.

Figure 4 The National Rail innovation model – up to the 90s



This innovation model increased the chances of reaching a critical mass of adoption of the technology in the national market. Subsequently the national supplier could compete for export sales using the technical expertise and market knowledge acquired in the home market. But this model – driven by the paradigm of national industrial policies and "national champions" – brought so many obstacles and market barriers that in the early 1990s it was no longer compatible with the emerging European goals of creating a single European railway market.

3.2 The new European Rail innovation model

For a decade, institutional changes in Europe have led the innovation process in the transportation sector to be driven by a harmonization ideal. Interoperability –the paradigm to achieve the future single European rail market – meant that many efforts had to be directed towards product standardization.

A new institutional framework

The relationships between railway actors have been completely redefined since 1991. The European Directive 91/440 imposed the separation between operations and infrastructure as well as the progressive opening of national markets for operation. As a result, the role of governments and institutions in the rail sector has been transferred to some extent at the European level

For instance, the management of the standard has been shifted from the national to the European level. Technical groups from EEIG (and now EIM, CER) and UNIFE/UNISIG were defining the proposal for technical specifications. The process was led by the European commission, and the TSI was then approved by the Member States. In 2005, ERA took the lead for managing and coordinating the specification work.

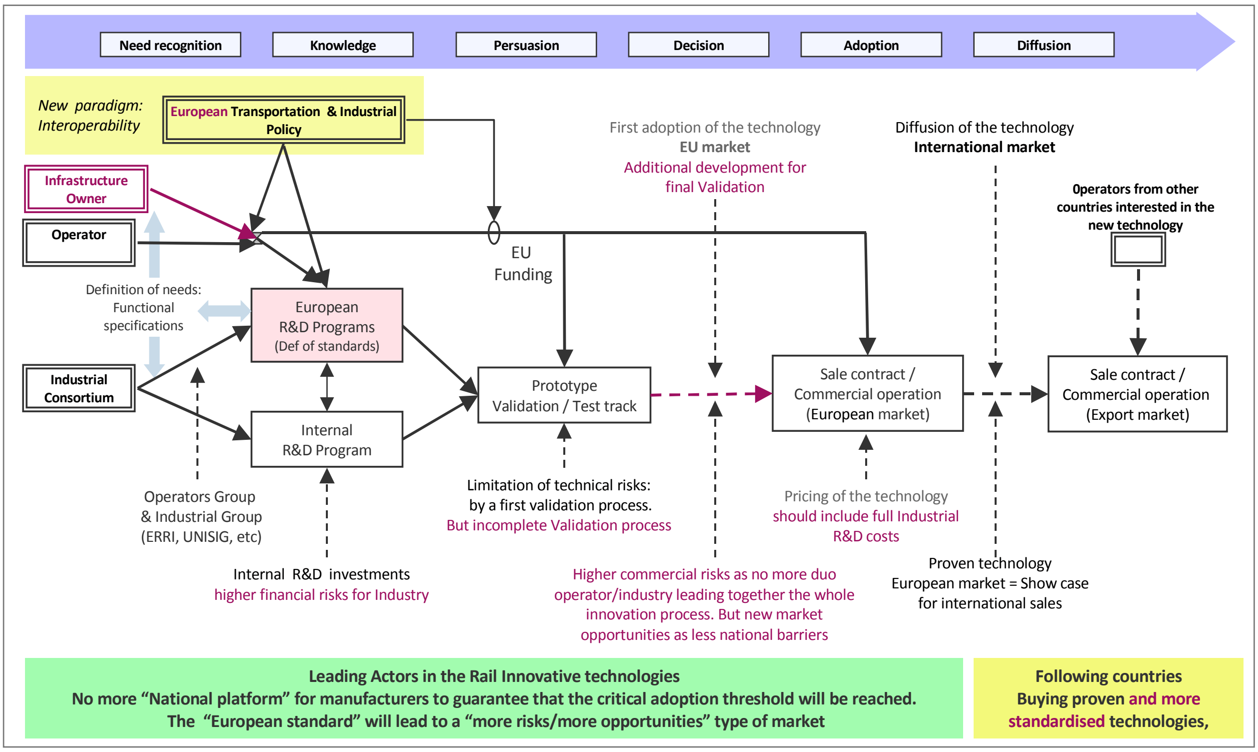
The changes in the institutional and organizational model defined in (de Tilière and Hultén, 2003) induced a radical change in the innovation model. Advantages are:

- Open market for standard products, increasing competition between manufacturers;
- More efficient R&D efforts with increased value for operators (to avoid reinventing the wheel in each country);
- Increased economies of scale due to standardization;
- Increased market opportunities thanks to decreasing national market barriers.

The new innovation model (see Figure 5) was probably the only way to achieve technical harmonization and the emergence of a European standard – allowing the birth of really interoperable rail corridors. However such changes brought several drawbacks which became key challenges for the sector in the first years of change:

- Higher financial risks for R&D investments (no more study contracts funded by operators as before, but open tenders with increased uncertainty);
- Technical risks were higher in first contracts, as the operator had a lesser role in the validation process as done in the past with the “lead-users”. The operator was not involved anymore as early in the innovation process; there were no more extended tests projects for validation before commercial operation;
- Higher commercial risks, as the captive nature of the national markets due to non-standardization had been reduced.

Figure 5 The new European Rail innovation model – since the 1990s



Towards an interactive innovation model

In the language of Rothwell's innovation models, we moved from the first and second generation of innovation models to the fifth or sixth generation of innovation model. The new model is more complex and much more interactive (as shown by the ERTMS development process), with an increased number of actors (2-3 actors in the National Rail Innovation model versus more than 20 in the new European Rail Innovation model).

The main challenge for the rail industry is probably the inability to adapt quickly to this new market configuration, and therefore to reach faster a more efficient configuration. In other words, building up the process and redefining roles is the critical step and the more complex to manage.

About the role of operators and infrastructure owners

ERTMS has shifted the role operators from technical to functional specificators. They are not any longer as much responsible for the technology development and let manufacturers fill this role of defining technological specifications. They are now responsible for the definition of functional specifications – a role split between operators for on-board equipment and infrastructure owner for track-side equipment[15]. This separation of roles was a condition for the opening of rail markets. However it created a challenge for the system's integration. The number of partners and decision-makers has significantly increased. Therefore the implementation of systemic innovations such as ERTMS is much more complex, especially in the decision-making process.

Impacts on the rail manufacturing industry

After a decade of mergers, the restructuring of the rail manufacturing industry is going a step further, adapting its processes to the constraints of the new market. A new approach of R&D programs has been defined. More than ever manufacturers have to identify the needs of operators and bring to the market efficient innovative solutions. However, one of the major difficulties lies in the fact that for commercial contracts, operators want proven technologies[16]. In this new environment, which has shifted to a consumer market, R&D expenses have globally shifted towards the supplier side as operators or infrastructure owners don't like to bear risks of innovative solutions and prefer on-the-shelves products.

The role of the European Community to support R&D and implementation

In order to support the development of new European standards, the EC provides support at two levels:

- At the specification level, where the EC, through EEIG and UNISIG, funded a maximum of 50% of the specification efforts (FRS and SRS);
- Through incentives to favor the deployment of ERTMS. First, by funding partially the pilot lines up to 2002, and then by funding some deployment projects in Europe according to the Commission's decision, via national deployment plans[17].

Conclusion on the transition between the two innovation models

During the last decade, a new European rail market equilibrium has emerged, reshaping innovation processes and roles. The new innovation model leads to the shift of the definition

---

[15] All ERTMS tenders are making reference to the last SRS standard, and operators clarify or define specific functional requirements.

[16] This has been a criticism from operators in ERTMS test-tracks as well as in the beginning of first ERTMS commercial contracts, when the technology was still in its infancy

[17] One of the incentives of the European commission is its intention to provide more support to first projects, and then reducing the support for later implementation.

of technical solutions on the manufacturer side, letting operators focusing on the definition of functional specifications. It also leads to more challenges in the system integration in the case of systemic innovations, as well as a more opportunistic and risky type of market. The new framework should avoid expensive R&D programs (as done in the 70s) with a higher selection rate of future standards, based on cost-effective solutions. However, it brings an increased complexity in the decision-making process. This is mainly due to the vertical and horizontal disintegration of the actors' organizations, in addition to the unbundling of operators and infrastructure owners.

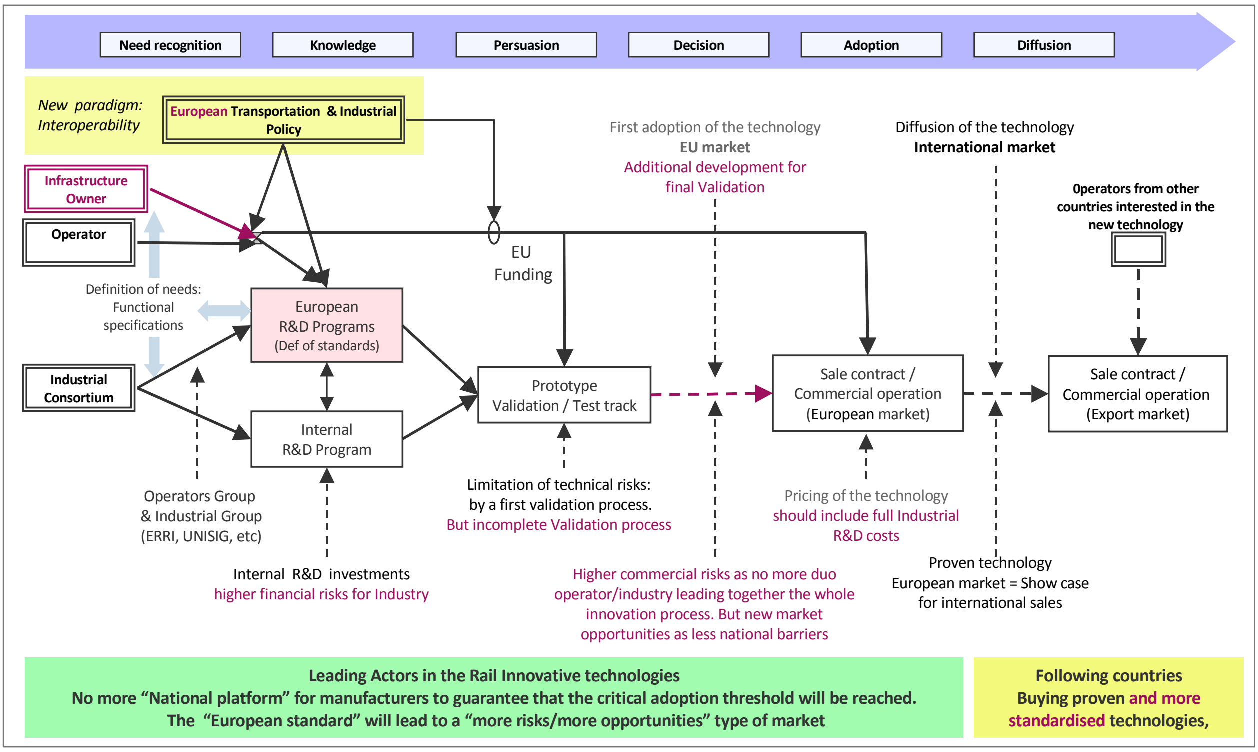
However, it is not yet the case for all rail market segments, as some technological niches will remain captive for some time. ERTMS is the first important experience for systemic innovations. Technological changes are happening faster than during the "national" era are increasingly being dictated by user needs. One can also notice a more efficient allocation of R&D investments.

3.3 ERTMS: setting the path for a new innovation process

The ERTMS innovation process has required all actors of the European rail sector to redefine their roles. More than a decade has been required to build the appropriate organizations and tailor all the processes (e.g. change requests and validation processes). One very important step was the creation of ERA decided in 2004. A new framework was initiated early 2006, under its lead with a new ERTMS Unit (see Figure 6).

A long specification work has been conducted for ERTMS, through interaction with the sector and feedback from some major project achievements. The current transition phase has been very important and led to the successful evolution of the TSI. The latest standard to be published mid-2009 (the SRS 2.3.0 D) is considered as stable. However the transition is not yet at its end: to cope with the current challenges as well as the political pressure surrounding the European corridor deployment, some improvements in the organization are still discussed (role of Art. 21 Committee replaced by the RISC, CER, EIM, UNIFE/UNISIG). For instance, the EC decided to create the TEN-T agency to fully focus on the European Transport corridors. ERA is planning in 2009 to act in some more technical areas and to tackle new subjects to solve the remaining bottlenecks for the most efficient deployment of ERTMS. Those latest changes will be effective during the specification phase planned for the next ERTMS Baseline 3, whose official release is expected in 2011-2012.

Figure 6 ERTMS specification process after 2006



To summarize the changes currently occurring, two steps shall be differentiated in the innovation process: the development phase and the deployment phase, both of them being very important for the success of the innovation:

- In the first step coherence between technology and institutions in the case of ERTMS development is somehow nearly achieved in term of processes (after a decade of intensive efforts). This first step related to the emergence of the standard is one where the institutions could focus on efficient leverage to reach this critical step with the sector, with reasonable financial incentives as well as the right enforcement (European mandatory specifications, the so called TSI). That said, coordination of national safety authorities (NSAs) and cross-acceptance procedures are still the part missing today – a gap that must be filled until 2011;
- The second step of corridor deployment or innovation diffusion is more complex. If the goals are reached too slowly, there are strong worries on achieving initial deployment targets in time. The amount of investment in question is huge, and so far the national interests are still predominant in decision-making, especially regarding financing schemes. This aspect is mainly related to the fact that railways always required massive financing once a transition to a new technological trajectory has to be managed (very strong infrastructure path dependency). Therefore the European Commission and ERA have to work on improving the leverage and the institutional framework to reach a reasonable objective – knowing that the initial plans won't be matched in time. This focus will at least be a key objective for 2009-2010, hoping that new ideas will allow a better definition of the means to be put in place to succeed.

4. CONCLUSION

The case study of the ERTMS development helps us understand the deep changes affecting the European railway market. The development of this new systemic innovation was a key element of the European harmonization policy. Its first emphasis has been on international corridors to solve interoperability issues and increase the competitiveness of the rail sector.

From this point of view, ERTMS brings increased performances for safety, capacity and allows interoperability – great achievements from the technological side. However, the big challenges have been the management of innovation processes as well as the institutional and organizational changes:

- Only a suitable institutional framework has enabled the ERTMS innovation to become a standard in Europe. The creation of ERA was a corner stone in the European policy and the adaptation of its institutions. But even more than defining a new innovative standard, the key role of ERA is to manage the long-term sustainability of the standard. For this, a strong and neutral arbitration of interests in the multi-stakeholder environment is necessary, each actor having its own interest in terms of functions, timing etc;
- If the institutional framework is sometime a prerequisite for the emergence of such systemic innovations, additional leverage and means must be defined for the deployment or the diffusion of the standard. If things are clear when building new lines, the key issue for ERTMS remains the renewal of existing infrastructures to ensure interoperability. Here railways still don't find always a business case matching the planning of the European Commission – a problem for the deployment of European corridors. New ways shall be developed to find better means to proceed for a better overall performance of the European rail networks. This will no doubt require national bodies to better include full consideration of cross-border impacts in their decisions.

The two innovation models described in this article, as well as the ERTMS innovation processes, point out to the radical changes of the European railway framework and explain why more than a decade was necessary before the first commercial deployments. Such changes have implied a redefinition of the roles of each actor (operators, infrastructure owners, manufacturers and institutions), and ERTMS has been a driving case for this process. This leads therefore the path for new potential systemic innovations in order to improve the European Transport Network, with an increasing efficiency as actors gain more and more experience. The next challenges are for instance the cross-acceptance of international projects or the decision-making for international corridors based on a high-level approach rather than a segmented and national basis. Those are questions, which are related to institutional models and organizations. More research shall be done in this direction to support the improvement of transportation systems and railways to build efficient and sustainable networks for the 21st century.

5. References

Baggen, J. H., Vleugel, J. M., et al. (2008) 'Towards interoperability on Northwest European railway corridors: signalling on the high-speed railway Amsterdam-Antwerp', 11th International Conference on Computer System Design and Operation in the Railway and other Transit Systems. Toledo, Spain.

Curchod, A., de Tilière, G., et al. (2003) *Managing Systemic Innovations in Rail Systems: The case of ERTMS technology*. 3rd Swiss Transport Research Conference. Ascona, April.

de Tilière, G. and Hultén, S. (2003) *A decade of change in the European Rail market; Influence on Innovation and R&D: Toward a new equilibrium in the railway sector*. First conference on Railroad industry structure, competition & investment. Toulouse, 7-8 November 2003.

Dobbin, F. (1994) *Forging industrial policy : the United States, Britain, and France in the railway age*. Cambridge [England] ; New york, NY, USA: Cambridge University Press.

Lundvall, B.-A. (1993) ' User-producer relationships, national systems of innovation and internationalisation', in D. Foray and C. Freeman (eds), *Technology and the wealth of nations : the dynamics of constructed advantage*. London; New York: Pinter. pp. 406p.

NERA (2000) *Safety regulations and standards for European railways*. London: National Economic Research Associates. A Report for DG Energy and Transport.

Puffert, D. (1994) 'The Technical Integration of the European Railway Network', in A. Carreras, A. Giuntini and M. Merger (eds), *European Networks, 19th-20th centuries; New approaches to the formation of transnational transport and communications systems*. Milano: Università Bocconi.

Rothwell, R. (1992) 'Successful industrial innovation: critical factors for the 1990s', *R&D Management*, 22 (3): 221-240.

Stoop, J. A., Baggen, J. H., et al. (2009) 'ERTMS, deals on wheels? An inquiry into a major railway project', *Safety, Reliability and Risk Analysis: Theory, Methods and Applications, Vols 1-4*: 1519-1524.

UIC (2003) *Implementing ETCS: Opportunities for European rail corridors*. Paris: Union Internationale des Chemins de Fer.

UIC and Winter, P. (2007) *Global Perspectives for ERTMS*. Paris: Union Internationale des Chemins de Fer.

Usselman, S. W. (2002) *Regulating railroad innovation : business, technology, and politics in America, 1840-1920*. Cambridge, U.K. ; New York: Cambridge University Press.

van Zuylen, H. J. and Weber, K. M. (2002) 'Strategies for European innovation policy in the transport field', *Technological Forecasting and Social Change*, 69 (9): 929-951.

Vinois, J.-A. (2004) 'ERTMS une opportunité sans précédent pour concrétiser l'interoperabilité du réseau ferroviaire communautaire', *La signalisation européenne ERTMS, Revue Générale des Chemins de Fer.* 9-13.