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The efficient structure of the rail industry**

A decade of change in the European Rail market; Influence on Innovation and R&D:

Toward a new equilibrium in the railway sector

Dr Guillaume de Tilière
ALSTOM TRANSPORT
33 rue des Batelliers, F-93400 St-Ouen
guillaume.de-tiliere@transport.alstom.com

Dr Staffan Hultén
Ecole Centrale Paris
Laboratoire Stratégie & Technologie
hultens@cti.ecp.fr

ABSTRACT

The harmonisation and liberalisation of the European rail markets launched in the 1990s aim at lowering national barriers and promote interoperability. To achieve this double goal, the EU commission has both acted to increase competition and to create pan-European railway standards. The strongest action to increase competition is the decision to demand of the member states that they should separate infrastructure and operations to promote a higher degree of competition between operators. Most of the EU efforts in technical harmonisation is directed towards developing a pan-European train control system. For example, the commission has set up the European Rail Traffic Management System (ERTMS) to establish support for the standardisation of the European train control systems.

The changes above affect the whole European rail industry, from suppliers of infrastructure and rolling-stock to operators. One important result of the drive toward harmonisation and liberalisation is that the railway industry's innovation models are changing. The new organisation of innovation has led to much more innovative activity in the rail industry, and to that the roles of the actors in the railway system have changed. The EU harmonisation and liberalisation are not the only forces that have changed the innovation activities in the railway sector. During the last 20 years member states, for example the Great Britain and Sweden, have on their initiative changed the regulatory structure much more than demanded by the EU. One outcome of this is a move from a monopoly to a workable competition of many operators. We have also witnessed a merger wave in the railway supply industry, for example rolling stock and signal systems, that has resulted in three firms dominating the European train industry – ALSTOM, Bombardier and SIEMENS.

This paper describes and analyses the changes through two case studies: First in how passenger trains are developed today as compared with before the 1990s, and second in the changes that affects the development of signalling technologies . This paper partly draws on out earlier research of authors (Whitelegg, Hultén and Flink, 1993; Hultén, 2000; Hultén, 2003; de Tilière & Garrison 2001; de Tilière 2002 and de Tilière, Curchod & Emery 2003).

This research underlined the shift from a national rail market equilibrium before the 90's to another pan-European one. This article aims at understanding innovation processes in both cases and describe the differences between the two Innovation Models that have been worked out:

- The National Rail Innovation Model (before the 1990's)
- The European Rail Innovation Model (after the 1990's, with the new European framework)

The analytical issue to be explored in the paper is to compare this shift of the innovation system in the production of passenger trains or in signalling technologies with the present stage in the process towards harmonisation and liberalisation.

The question this paper attempts to answer is if the regulated national system with close collaboration between state owned national operators was more efficient¹ than the system of today with European and global players selling to a variety of operators in different European markets. For example for rolling-stock, we measure efficiency as the time it takes to bring a new train to the market, the costs of developing new trains, and the price the operators pay per train-seat.

The empirical material consists of case studies of a few innovation processes and statistical data (costs per train-set, novelty of the train etc.) from comparable passenger train projects or signalling ATP systems in the last 20 years.

Keywords: Rail systems, Innovation, R&D, competitiveness, European harmonisation & deregulation.

¹ For instance, concerning the rolling-stock, efficiency is measured as the time it takes to bring a new train to the market, the costs of developing new trains, and the price the operators pay per train-seat.

Table of content:

1.	Introduction	6
2.	Lessons from the development of key Railway Technologies	6
2.1	Co-operation Operator-Manufacturer: Limiting the risk when introducing systemic innovations	7
2.2	The case of HSR technologies: The role of lead users in the development of the railway technological trajectory	7
2.2.1	Sustaining and Disruptive Technological Change	10
2.2.2	The X2 case	12
2.3	The case of Signaling technologies: Technological standards & national market barriers	14
2.3.1	The non standardization as a way to sustain the national industry	14
2.3.2	The key role of operators in R&D funding at the national level.....	14
2.3.3	The role of Operators in leading R&D and securing the related market risks	15
2.4	Case of the National Rail Innovation Model (up to the 90's).....	16
2.4.1	The role of national industrial policies:.....	16
2.4.2	Case of the National Innovation Model for Railway technologies	18
2.5	The problem of non-standardisation: toward the end of the “national Rail Market” Equilibrium	21
2.5.1	from the economical point of view: the need of cost efficiency	21
2.5.2	from technical point of view: the need of Interoperability.....	21
2.5.3	The change of paradigms: towards more harmonization	21
3.	Case of the new European Framework: Toward a New Innovation Model of Railway technologies.....	22
3.1	A new Institutional framework:	22
3.1.1	Toward a new European Institutional & organizational System.....	22
3.2	Case of a systemic innovation in the new European framework: ERTMS.....	23
3.2.1	New priorities for improving the European Rail Market	23
3.2.2	Case of European Rail Traffic Management System (ERTMS): birth of a European technology (Annex 2)	23
3.2.3	ERTMS versus previous national ATP : What changes in the innovation Process?	25
3.3	Case of the new Rolling-stock technologies: The Swedish Regina project.....	26
3.4	The New European Innovation Model of Railway technologies.....	27
3.5	Toward a new equilibrium of the rail market: New challenges for the Rail Industry	29
3.5.1	Impacts on operators & the role of infrastructure owners.....	29

3.5.2	Impacts on the Rail manufacturing industry	29
4.	Conclusion.....	30
5.	References	32
ANNEX 1:	Interoperability problems on EU international corridors.....	35
ANNEX 2:	Innovation and standardisation / ERTMS development	38
ANNEX 3:	Case of Swedish trains: the time to develop X2 and Regina trainsets.....	42

1. Introduction

The introduction of the European norm EU 90/440 introduced a new transition phase in the rail industry, aiming at increasing interoperability among rail systems in Europe to improve efficiency and competitiveness in front of air or road traffic. This included a separation between operators and infrastructure owners, as a pressure to shift from national rail markets to a single European open market for rail operation. Such institutional and organisational changes also impacted the rail manufacturers, from the organisational and technological point of view.

The aim of this article are to identify the main changes of the innovation process in the railway industry emerging out of the transition from national to a European market, and to outline toward which new market equilibrium it will converge.

This paper is based on a number of case studies, mainly looking at key innovations in railways such as high speed rail (HSR) systems (TGV, ICE, X2000, AGV) and signalling systems (KVB, LZB, ZUB and ERTMS). Observations leads to define the transition between two market equilibrium, which are analysed in terms of innovation models.

First case studies allows to draw out main characteristics of national rail innovation system before the 1990's, and see why this market equilibrium was running to its end. Then recent examples also analysed in the case studies allow to understand the new European framework and to work out the new European Rail Innovation Model. Benefits and disadvantages are discussed based on the case studies results; underlying the new challenges of the innovation actors.

2. Lessons from the development of key Railway Technologies

In this section we will analyse the development of railway technology from the point of view lead-users, standards, technological trajectories, and sustaining and disruptive technologies.

As with all large-scale projects, transportation systems involve complex decision-making processes, as well as a lot of technologies and processes that are combined from the design to the implementation phases (Figure 1). The difference between rail systems and road or air systems is the strong path dependency of rail technologies as infrastructure and rolling-stock are closely embedded in each other. This has resulted in national specific technologies, being the outcome of choices dealing mainly with the problem of national sovereignty and military considerations.

The national innovation model gave as a result that the principal innovative technologies were developed for national use firstly, involving a close cooperation between a national operator and an manufacturer during the whole innovation process.

2.1 Co-operation Operator-Manufacturer: Limiting the risk when introducing systemic innovations

In most cases of successful systemic innovations, institutions and operators were vertically integrated and working in close or exclusive cooperation with one manufacturer for a defined scope (see §2.2 for HSR: TGV, ICE and X2000 and §2.3 for signalling systems). The innovation process involved both parties during all stages and processes, allowing to secure R&D investments as the operator's (lead-user) role and involvement significantly reduced commercial risks. National operators (and governments) were used to give "study contracts" for the development of technologies to national manufacturers. This allowed to create national platforms for the validation of technologies (national network), used as a basis for export sales.

2.2 The case of HSR technologies: The role of lead users in the development of the railway technological trajectory

Operators were the key players in the development of HSR technologies. It began in Japan, with the Shinkansen that was developed under the direction of the JNR. This project was followed a decade later by project in many European countries. France developed the TGV, a collaboration between the operator SNCF and ALSTOM and other French railway engineering firms. Great Britain unsuccessfully tried to develop a tilting high speed train during the 1970s using the existing railway infrastructure, this project was under the control of British Railways. Sweden took a more cautious approach and eventually put a high speed tilting train on the existing railway lines in 1990. Italy and Germany opted for a mixed strategy with new trains running partly on old track and partly on new lines. In both countries the railway operator cooperated closely with the national industry. In Germany DB involved Siemens, Thyssen, Brown Boveri and other railway engineering firms in the development of ICE. In Italy the national railway operator FIS cooperated with FIAT in the development of a tilting train, Pendolino, and with Breda in the development of a high speed train without tilt. (see de Tilière 2001 & 2002 and Whitelegg et al, 1993).

The French, German, Italian and Swedish HSR technologies were successful mainly because the innovation process was involving both the operator and industry from the beginning. The operator took care of every validation cycle and put pressure on political institutions for the diffusion of the technology (see for example the battle between TGV and Aerotrain in France during the 1970's).

This way of organising R&D resemble 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. See figure 1 in which the first project step the recognition happens at the operator level.

The costs and risks of the producer was low, because of the national operator's high degree of commitment for the new technology. The operator committed itself in many different ways. 1) by cooperating with a manufacturer or a consortium of manufacturers. 2) by lowering the manufacturers R&D expenses as most of these programs were conducted under "Study contracts". 3) The operator initiated project also carried a higher probability of implementation. This Innovation Pull Model at a national level increased the chances of reaching a critical mass of adoption of the technology in the national market. Subsequently

the national supplier of trains could compete for export sales using the technical expertise and market knowledge acquired in the home market (see Figure 2).

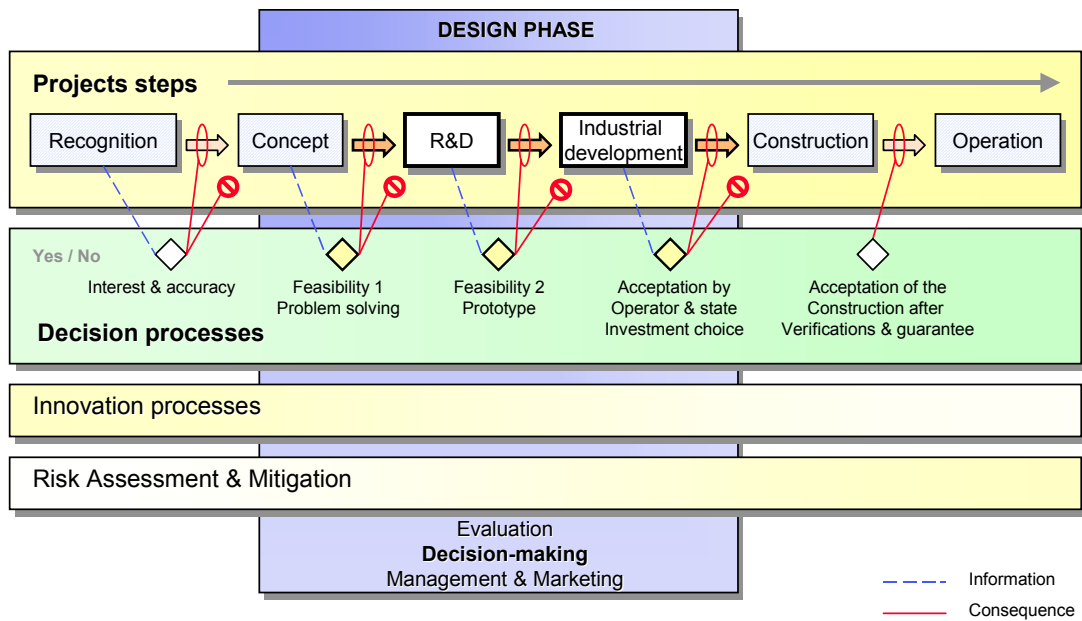


Figure 1: Typical project phases and decision-making processes for systemic rail innovations.

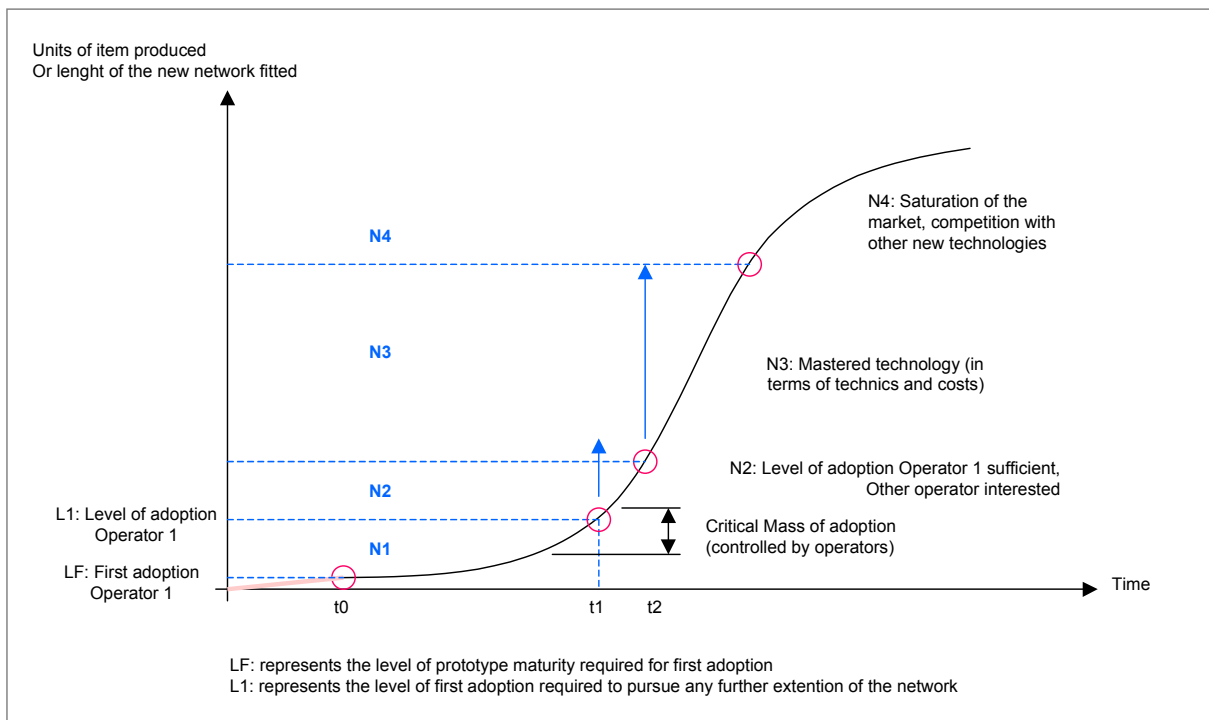


Figure 2: Critical threshold of adoption & the role of national operators

To understand the role of operators regarding innovation in high speed train systems, one must remember the quest for high-speed that took place with the birth of the Shinkansen in Japan in the 60's. The paradigm of the need for high speed resulted in major investments in

HSR technologies (France, Germany, Italy, UK, and Sweden) and three technological trajectories were developed on a national basis: Maglev high speed trains using new lines or high speed tilting trains using old railway lines.

However, Maglev technologies have been commercially losing the battle, as operators as lead-users continued to impose the rail standard for 2 reasons:

- The rail path dependency is strong due to compatibility issues (networks): flexibility requires to keep the same standards for interoperability on a national network.
- The impact on economies of scale is important: increasing the standardisation of products

As the critical threshold for the diffusion of Maglev systems has never been reached, this technology is still waiting for a market. Only three Maglev systems have been put in commercial operation: 30 km in the Transrapid (Shanghai) in 2002, but China seems to prefer HSR for its future network. The two other Maglev systems the M-Bahn in Berlin and the Maglev people mover in Birmingham, have both be dismantled as they were too costly to operate and maintain in the long run.

The experience shows that in the past institutional framework, in the case of national transportation systems, the strong involvement of national operators with the support of government 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, as the close relation between national operator-manufacturer was significantly decreasing commercial risks.

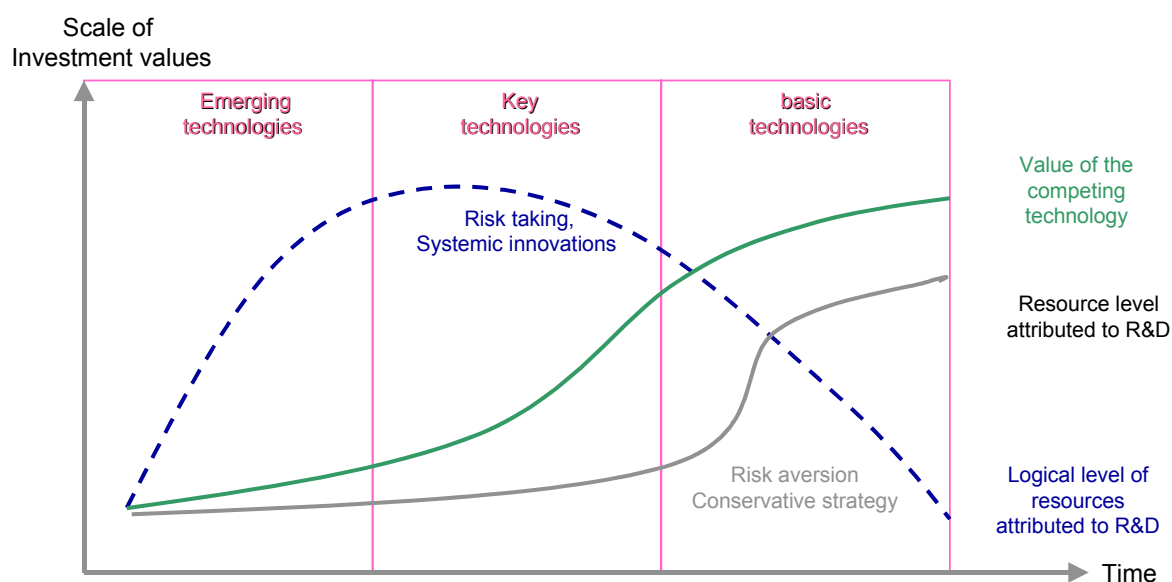


Figure 3: R&D investments strategies depending on Risk aversion

2.2.1 Sustaining and Disruptive Technological Change

A new technology produces major changes in the industry structure due to the fact that the established firms have difficulties in coping with the technological discontinuity. The new technology's capacity to transform an industry, in terms of marketing, technology and knowledge, is called the technology's transilience. Competencies developed about the old technology lose value and competencies about the new technology increase in importance. Knowledge about steam engines were of little value when electricity replaced steam, knowledge about electric trains can be of limited value if magnetic levitation becomes a competitive technology.

It is in this context of competition between an old entrenched technology and a new vigorous technology that firms and inventors refer to "windows of opportunity". If the new technology appears to early demand is disappointing because its relative attractiveness is not substantial enough. If the new technology waits too long the market actors may prefer to wait for another technology that gives even bigger advantages.

Another reason why we might get a shift in technology is if a successful technology oversupplies the needs in the market. Christensen (1997) suggests that this creates opportunities for redefining the trajectory of a technology (Figure 4).

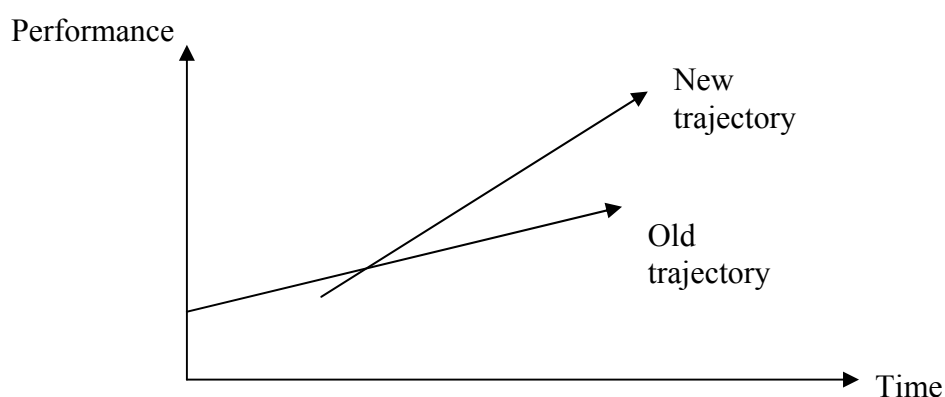


Figure 4. Discontinuous technology

According to Christensen the industry incumbents are very good at developing sustaining innovations driven by existing demand – even if these innovations are costly and technically difficult to develop. Sustaining technological changes are changes that help manufacturers sustain the rate of historical performance improvement that their customers have come to expect. An example from the high speed train field of sustaining technological change is the performance increases of the Japanese Shinkansen trains and the French TGV/AGV trains. The engines have become more efficient and faster, brakes have become more sophisticated, better streamlining gives less friction, and in AGV the utilisation of space has become more efficient (see Figure 5).

The disruptive innovation paradigm suggests that these types of successful technological improvements may undermine the industry from below. The reason for this is that the customers that are demanding more performance make the producers of the products blind for other ways of using the product.

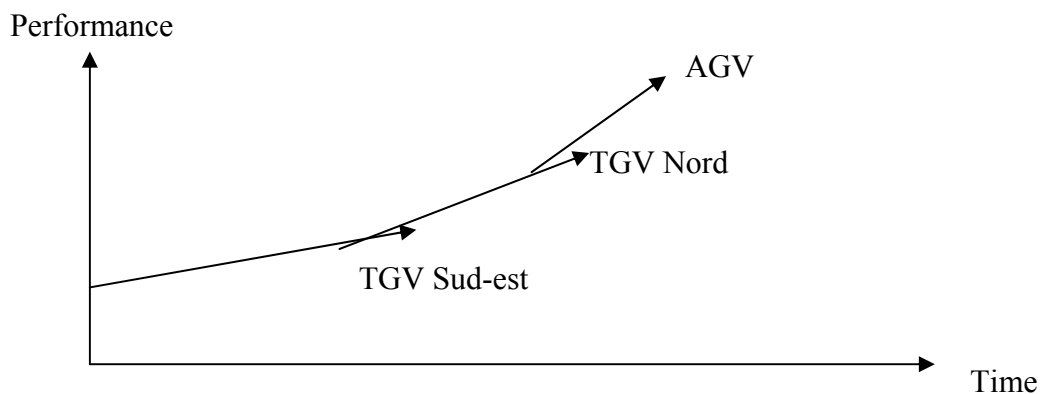


Figure 5. Sustaining technological change

In the railway technologies we can find one example of a disruptive innovation and that is the tilting trains that today seat fewer passengers, are slower and more expensive per train set than the very fast high speed trains of AGV/TGV type. However, tilting trains demand less investments in infrastructure and tilting trains with soft bogies can perhaps develop into very fast comfortable trains (for example the ideas to have tilt on TGV/AGV trains).

Hypothetically supporters of TGV/AGV trains will find it more difficult to justify the investments in new railway lines. The case of France is striking: it is getting more and more difficult to find profitable lines (see for example the French case study by Saubesty & Vernimmen, 1999). Tilting trains and fast regional trains on the other hand seem to be able to attract the necessary capital for investments in infrastructure and new rolling stock. They do this by finding new investors willing to invest in trains and the upgrading of infrastructure – regional authorities and countries that cannot afford to invest in new railway networks (see Hultén, 1999).

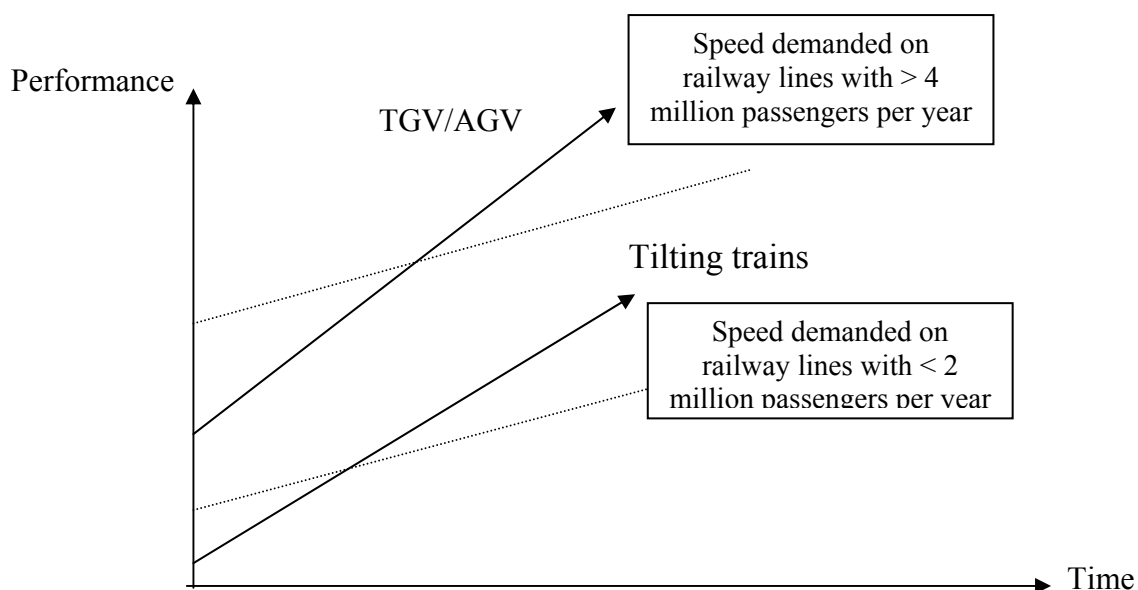


Figure 3. Disruptive technological change

In figure 3 we have depicted how tilting trains can act as a disruptive technology. The upper band shows the performance (for example speed) demanded at the high end of the market, and the lower band performance demanded at the low end of the market. Due to performance increases regional trains and tilting trains become possible to use on many more destinations.

Some important factors when actors decide on investments in rail technologies are presented in table 1: The data in the table draw on data from the case studies, Even if the position of high speed trains seems to be comfortable based on the information in table 1 it is often a sufficient condition for an attacking technology to perform better in only one dimension.

Dimension	Disruptive innovation - tilting trains	Sustaining innovation – TGV/AGV	Technological discontinuity – Transrapid
Price, costs	Cheap	Expensive	More expensive
Seating capacity	50-60 per coach	60-80 per coach	Limited seating capacity per trainset
Reliability	High	Very high	Unknown
Compatibility with old rail network	Very high	High	No
Speed	200-250 km/h	300-350 km/h	>400 km/h

Table 1. Comparison of the rail technologies.

The great advantages of tilting trains are their lower total costs and higher compatibility with existing railway networks. The most important advantages of magnetic levitation are its higher speed and its aura of modernity and high technology. The high speed trains have gradually diminished the speed advantage of magnetic levitation – from more than 50 per cent faster in 1980 to approximately 25 per cent faster in 2001. The speed disadvantage of tilting trains and fast regional trains is of no importance in the fast growing market for travel from 50-150 kilometres. Alstom's Arlanda Express covers the 40 kilometres from Stockholm to Arlanda in 19 minutes. The Transrapid that will connect Shanghai and its airport will need 10 minutes for 30 kilometres.

2.2.2 The X2 case

A study of high speed trains in Sweden was conducted during 1968 and 1969 in cooperation between the operator SJ and some Swedish industrial companies such as SAAB and VOLVO Flygmotor but notably not the railway manufacturer ASEA.

The main conclusions of the study were: 1) Since the high speed service has to include all main lines in Sweden, building new track, as in Japan, would be much too expensive. 2) New rolling stock that can overcome the comfort problem is required. 3) It was important that the high speed train service could start as soon as possible, preferably by 1976. A train developed and manufactured solely in Sweden was consequently out of the question, but it was still important that the Swedish industry and SJ could take part in the development. 4) The two possibilities were a) manufacturing of a foreign train on license or b) buying some parts from

abroad and developing some parts in Sweden. 5) The economy of the project was probably good. This study was followed by a commercial feasibility study.

The second stage, consisting of tests of high speed train equipment, in the development of a Swedish high speed train had actually started before the first stage was completed.

The practical tests started in 1969-70 by SJ's mechanical department and ASEA in cooperation. The two major issues were to gain insights in the construction of the tilting mechanism and to develop a bogie construction generating small dynamic forces.

In the first series of trials a derailed commuter train was rebuilt and equipped with airbags to achieve tilting. The trials were evaluated in 1973 and since this technical solution was considered uncertain further work was demanded. A contract for continued tests was signed in 1973 by the GD of SJ and the CEO of ASEA. The most important items in this agreement were: SJ and ASEA will share the development costs for a high speed train. ASEA is in charge of the development of key components such as the bogie and the tilting device. The decision on traction was to be decided later. SJ was responsible for the track, measure equipment and some other items. In case of export sales SJ should get a percentage of the revenues. It was believed that the development project should take two years to complete. A new train-set named X15 was constructed from the coach bodies from a train-set built in the 1940-50's and the bogies and an improved pneumatic tilting mechanism from the former experimental train-set. The rebuilding of the trainset was made internally at SJ. An intensive testing programme was conducted in 1975 and a Swedish speed record was set at 238 km/h. Despite the success of the technical tests no order was made in the late 1970's. The management at SJ including the GD was sceptical about the potentials of the project.

The direct costs of the project during the 1970's were estimated at 10-20 million Swedish crowns. These figures suggest that the investigation into high speed tilting trains was not considered to be one of SJ's most important projects. Other projects, i.e. the development and introduction of the ATC system, demanded and received much more resources.

A new GD was appointed in 1978 and he wanted to relaunch the high speed train project. Therefore, a new high speed train report was initiated, with the purpose of summing up the experiences so far from the trials and calculating the effects of high speed train service on society and for SJ.

The study was directed by the new director of the research and development department. The report, published in 1980, was designed more or less as an advertisement for a Swedish high speed train and was distributed to all decision-makers including politicians. To further strengthen the high speed train option was an extensive high speed train network outlined showing that nearly all Swedes would benefit from the high speed train services. The report also discussed the need for an upgrading of the infrastructure. In particular was the problem of the numerous road-rail level crossings noted.

Within SJ the positive political decision posed a problem, should they give the order to ASEA or could the firm find better alternatives elsewhere? It was decided that the train order was to be let out for bids. Request for bids were sent out to some 15 possible suppliers in 1982 with detailed specifications of the train. Bids were received from more than ten companies but no firm could fulfil the requirements, especially those associated with maximum axle-load and noise-level. The axle-load problem was caused by the demand for a trainset. No firm could offer a trainset with a sufficiently low axle-load. One reason why it was difficult to order a tilting high speed train was the fact that no such trains were in service in 1980-82.

The specifications were softened a little and sent out again in 1984. The most important change was to move from a trainset to a train with powered vehicles in the front and at the end. The incoming bids were still not satisfactory because two powered vehicles proved to be too expensive, and a third request went out in 1985.

Four firms made offers and SJ decided to continue discussions with two firms. SJ decided that the Swedish firm ASEA had presented the best offer. The new train got the name X2, in SJ's railway operations the train is normally called X2000. X2 commenced commercial operations in 1990.

2.3 The case of Signaling technologies: Technological standards & national market barriers

Signalling technologies provide a very interesting case, to understand innovation processes stressing the changes of innovation processes before and after the introduction of the European norm 90/440.

2.3.1 The non standardization as a way to sustain the national industry

Signalling technologies were mainly developed at national levels, leading to interoperability between national rail networks. Innovative signalling R&D programs destined to replace Automatic train Warning (ATW) systems were launched aiming at increased safety on main lines (See Curchod, de Tilière & Emery 2003). These Automatic Train Protection (ATP) systems were developed by national operators with manufacturers, as for instance SNCF-ALSTOM for KVB, SNCF-CSEE for TVM, DB-Siemens for LZB or ZUB, SJ-Ericsson for Ebicab ATC.

These R&D programs were conducted in the period 1975-1995, following several major railway accidents. Operators were looking for ATP systems for implementation on their national networks. Many operators as DB or SNCF have fully paid R&D of new national ATP systems. However, if one standard emerged, it was rapidly customised for each country, at the point that even for a single manufacturer as Siemens, its ATP (ZUB) was declined into several versions which were completely non-interoperable (ZUB 121 for Switzerland, ZUB 123 for Denmark etc). Each country followed its own path, operators looking for maintaining their network not accessible for foreign operators, and favouring their preferred national bidders for a sustainable cooperation. National industrial policy was always in the background, as the relation between operators, institutions and governments were very tight (see Dobbson 1994; Quinet 1999; de Tilière 2001).

2.3.2 The key role of operators in R&D funding at the national level

Before the 90's, all major innovations and new technologies have mainly been developed under the funding of operators. This funding from operators were done under "Study contracts" covering a R&D phase (up to an evaluation stage) and a complete validation of the technology through a pilot line, when a final standard was tested.

The first key innovation was done by Ericsson with the concept of communication between Balises (Track-side) and Antenna (onboard) first commercialised with Ebicab in Sweden, and

that influenced all national standards. Looking at the development of the French ATP (KVB) is interesting to understand innovation processes in the national frameworks at that time:

Case study: Development of the KVB ATP system in France (SNCF – ALSTOM)

- Learning through diversity: 1981-1985

SNCF gave a first study contract with ALSTOM (ex Jeumont-Schneider at that time), to develop an intelligent “crocodile” (upgrade the ATW system to an ATP). Meanwhile SNCF was also looking at other development abroad (Ebicab in Sweden), and SACEM or TVM in France. This first contract for R&D, fully paid by SNCF, covered feasibility, prototypes and tests of the technology. For each study contract, operators had the habit to award contracts for R&D to the best supplier in the field, or sometimes forced two suppliers to form a R&D consortium.²

In 1985, three signalling technologies were developed under “Study contracts” in the purpose of increasing safety: The TVM for TGV lines (CS Transport), the “Intelligent Crocodile” (ALSTOM) but not yet on the shelf, and another interesting system developed under the will of RATP: SACEM (ALSTOM- CS Transport – ex Matra Transport / Siemens now).

R&D and validation were included in the study contract and fully paid by SNCF. For the “Intelligent Crocodile” 10 locomotives and 100 signals were equipped between Blois and Tour.

- Selection and development of the national dominant standard: 1985-1988

Three severe rail accident on the SNCF network in the summer 1985, accelerate the decision of SNCF to implement an ATP system in order to reduce significantly human errors in system operations (drivers). SNCF look at the three systems above, plus the Swedish Ebicab. This last one was selected as the new future standard as it was the best optimised for main lines. TVM for high-speed lines and SACEM for regional trains (RER) were too expensive.

SNCF therefore asks ALSTOM that was in charge of the development of the ATP for main line with the Intelligent Crocodile to work out a pilot line with Ebicab. A contract under licence was signed with Ericsson, who supplied its balises and antennas. This new contract for study and realisation was paid by SNCF (1985-1987), and a new study contract (1987-88) was decided by SNCF, asking ALSTOM to re-configure the Swedish technology with the SNCF standards. In 1988 SNCF ordered the equipment of 3500 locomotives.

2.3.3 The role of Operators in leading R&D and securing the related market risks

In the National Rail Innovation Model before the 90’s, SNCF, as RATP, were strong technical specifiers, imposing technical options leading to a real customer-supplier partnership, close to a “co-development scheme”. SNCF engineering department had a strong influence on all R&D processes and therefore in the Innovation processes. Such a scheme for the development of new signalling technologies was common to other rail leading countries as Germany, UK, Belgium, Sweden, Italy etc. Therefore national markets were in some kind of market equilibrium, leaded by the paradigm of NIH.

² As for instance, the French RATP did for the development of the SACEM technology: consortium ALSTOM - CS Transport - MATRA (RATP split the study contract and funded 100% R&D and validation of the technology).

What benefit bring such a market equilibrium before the 90's and the European Institutional change? First the close cooperation operator/manufacturer as in the case of KVB, allowed to a manufacturer to manage its R&D programs funded by the operator and therefore without financial risks associated. R&D Financial risks were on the operator side, but this "equilibrium" was based on the principle that operators were giving directions for R&D according to their needs, and paying for it. Another key argument in this "model" was that operators as strongly involved in technological choices and in the development were mastering technologies, limiting the risks in implementation phases: According to the notion of "sticky" information (von Hippel, 1994), the problem of information bias was minimised in such a case, by a very high level of cooperation in all innovation processes. Operators were pulling innovation as lead-users (de Tilière 2001; von Hippel 1988).

In conclusion of this case study on the French KVB, that illustrate the development of national ATP technologies in Europe, the following conclusions can be drawn out:

- The role of operators as lead-users was determinant in new Technological trajectories and R&D, in defining direction and providing full financing.
- The tests and the complete validation of experimental technologies were also done under the study contracts. Which means that when a technology was developed, commercial projects only involved validated technologies, decreasing strongly the risks.
- If national markets reduced market opportunities globally for manufacturers, the national markets allowed to develop technologies under study contracts, knowing that behind the probability to have the specific market was really high. This resulted in strong captive markets for the manufacturers involved (as for TVM, SACEM or KVB, which continue to be de facto standards on their specific markets 10 years later).

These considerations can also be extended to rolling stock technologies as for the French TGV, the German ICE , the Swedish X2000 or the Italian Pendolino. New generations of trains were developed under study contracts, including R&D, prototypes and first series of trains. As for signalling technologies, this was fully paid by operators as design for their specific needs and under their will.

2.4 Case of the National Rail Innovation Model (up to the 90's)

Ten countries in the world were leading the development of railway innovations during the 1970s and 1980s in the railway industry. Seven of these countries were European countries. The leading countries developed national technologies, that afterwards were commercialised in other countries buying proven technologies. Innovation in the rail sector was strongly related to political issues: First concerning national transportation policies, and second concerning national industrial policies (export sales strongly related to political relations).

2.4.1 The role of national industrial policies:

As underlined by Dobbin (1994), national industrial policies played a key role in the development of rail innovations. The cases of the TGV and the ICE are interesting. For instance, Germany mainly bet on Maglev technologies up to the launch of the TGV which

was menacing the DB on its own network. Finally the ICE program was launch to stop the advances of the French competitor on the rail market (de Tilière 2002).

National industrial policies allowed to support R&D programs to support the development of new technologies up to the required performance level³ to enter in the market (see Figure 6). Such policies were strongly applied as it was the case for HSR and Maglev technologies (de Tilière 2001), even up to now.⁴ The case of national industries was a common case, as most of the systemic rail innovations have been achieved with “co-development” between operator & industrial.

For such new systemic innovation, the learning process takes some time and still high cost are required to solve youth defaults: operators alone are usually not decided to bear too much risk if not vital for their competitiveness. For this reason, industrial policies have help to start the innovation processes and helped operators to achieve their goals.

However, national R&D programs also resulted in a lot of wasted money as some R&D programs were cancelled at a late stage after decades of investments. Therefore one can argue that market rules should have avoided such wastes due to the trap of technological wonder.

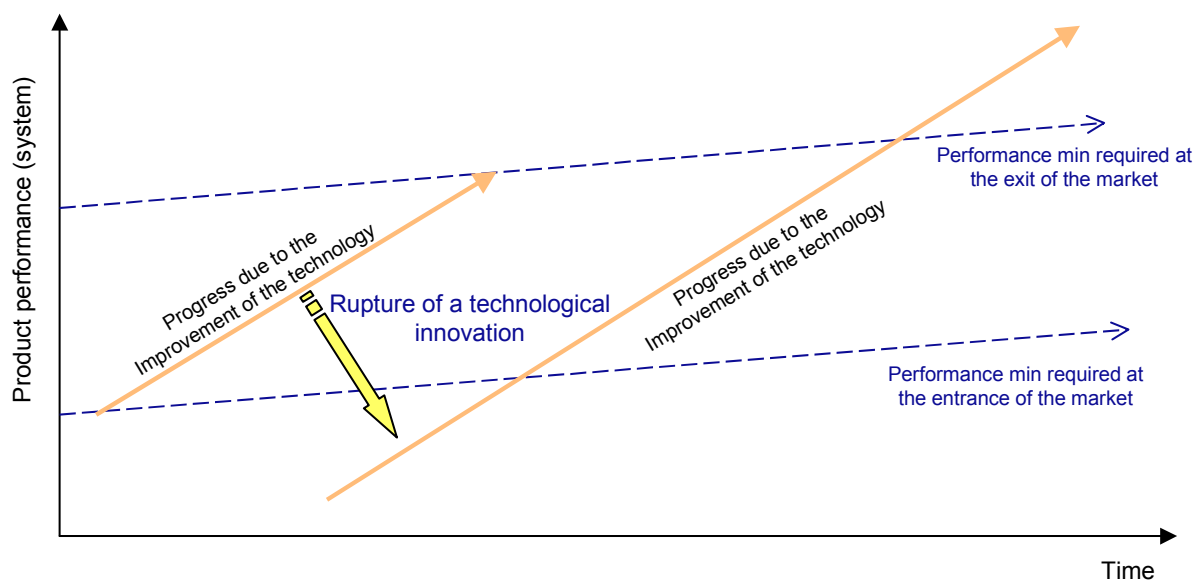


Figure 6. Technological innovation and Market entry level

³ Performances include many factors as reliability, speed, comfort, investments & operating costs

⁴ Case of the Shanghai Transrapid, partially financed by the German Government.

2.4.2 Case of the National Innovation Model for Railway technologies

- The Rail Market Equilibrium before the 90's (case of Rail leading countries): The "National Rail Innovation System":

Before the 90's, Rail leading countries mainly had a national market with a national operator working with a main manufacturer for a defined scope of supply (market share between national manufacturers according to key technologies).

The change agents for the system architecture were the duo operator-manufacturer, with the constraints and enablers of economic factors as well as of transportation and industrial policies

Innovations came from functional and specifications from the lead-user (operator). The manufacturer proposed technological specifications according to the degree of innovative solutions required by the operator (system level).

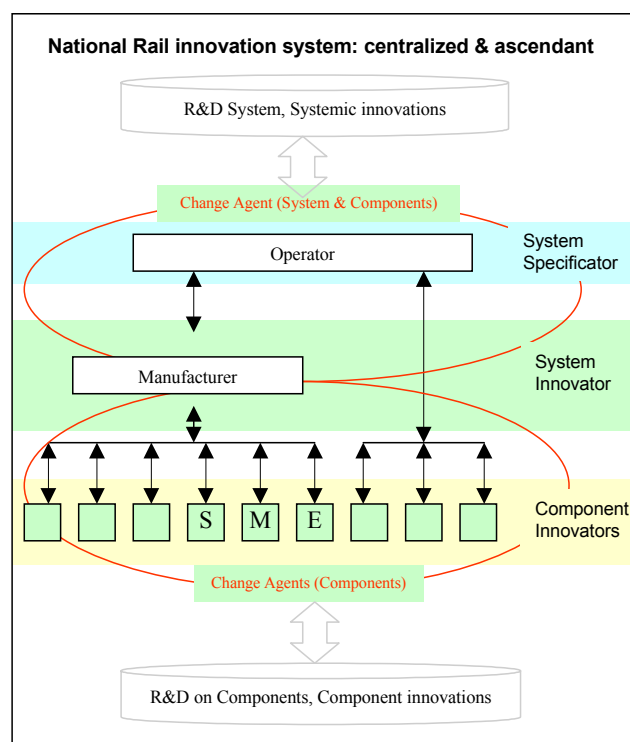


Figure 7. The National Rail Innovation System

Concerning roles in the innovation process, big manufacturers were more focused on systemic innovations, whereas SME who leads R&D more aggressively were focusing on component innovations. But the major characteristic of this National Rail Innovation System was the tandem Operator-Manufacturer, which allowed to develop technologies on a protected market, up to its maturation.

Therefore national markets were in some kind of market equilibrium, led by the paradigm of NIH. The European rail market was driven by these national strategies, which was before the 90's a kind of market equilibrium based on "National Rail Innovation Systems".

This model provided significant advantage to develop national technologies up to a competitive stage, that were after commercialised on the export market. This was a way for governments and institutions to sustain national industries, and therefore to support their national economy (de Tilière & Garrison 2001).

- The "National Rail Organisation & Institutional Model": Degree of integration & Paradigms

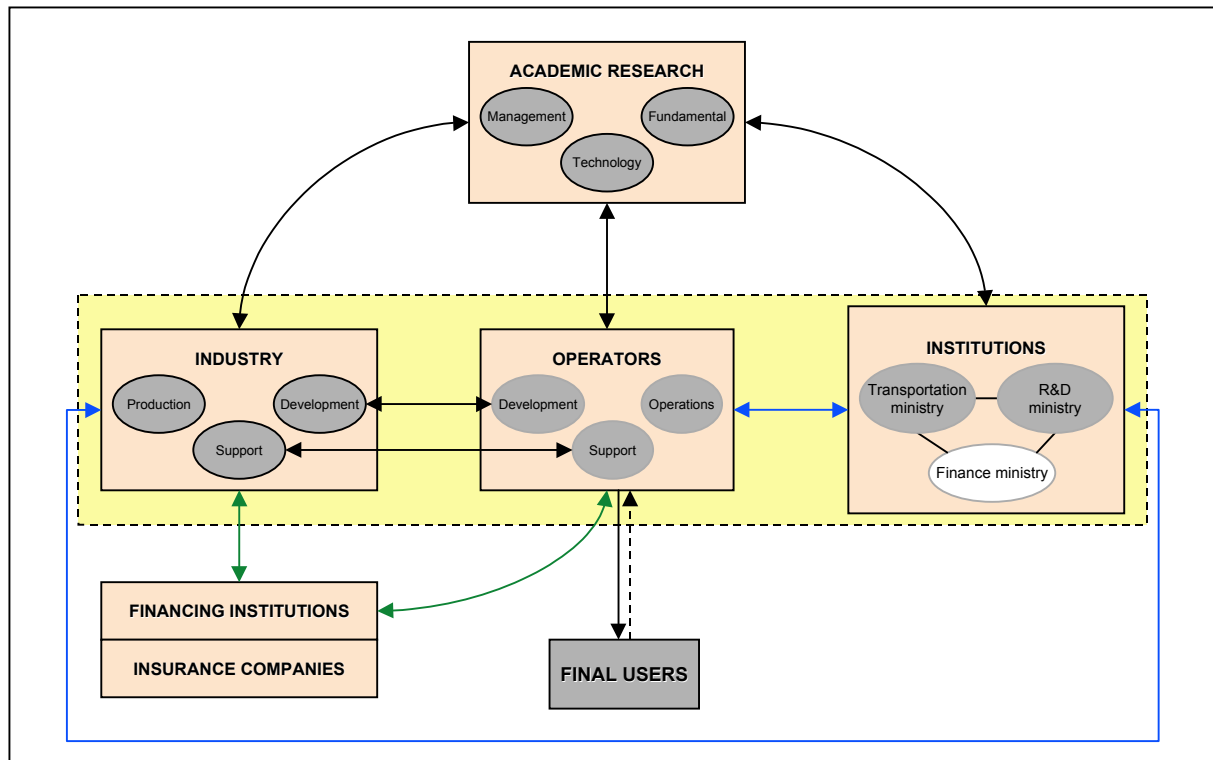


Figure 8. The integrated Institutional and Organisational Framework before the 1990's

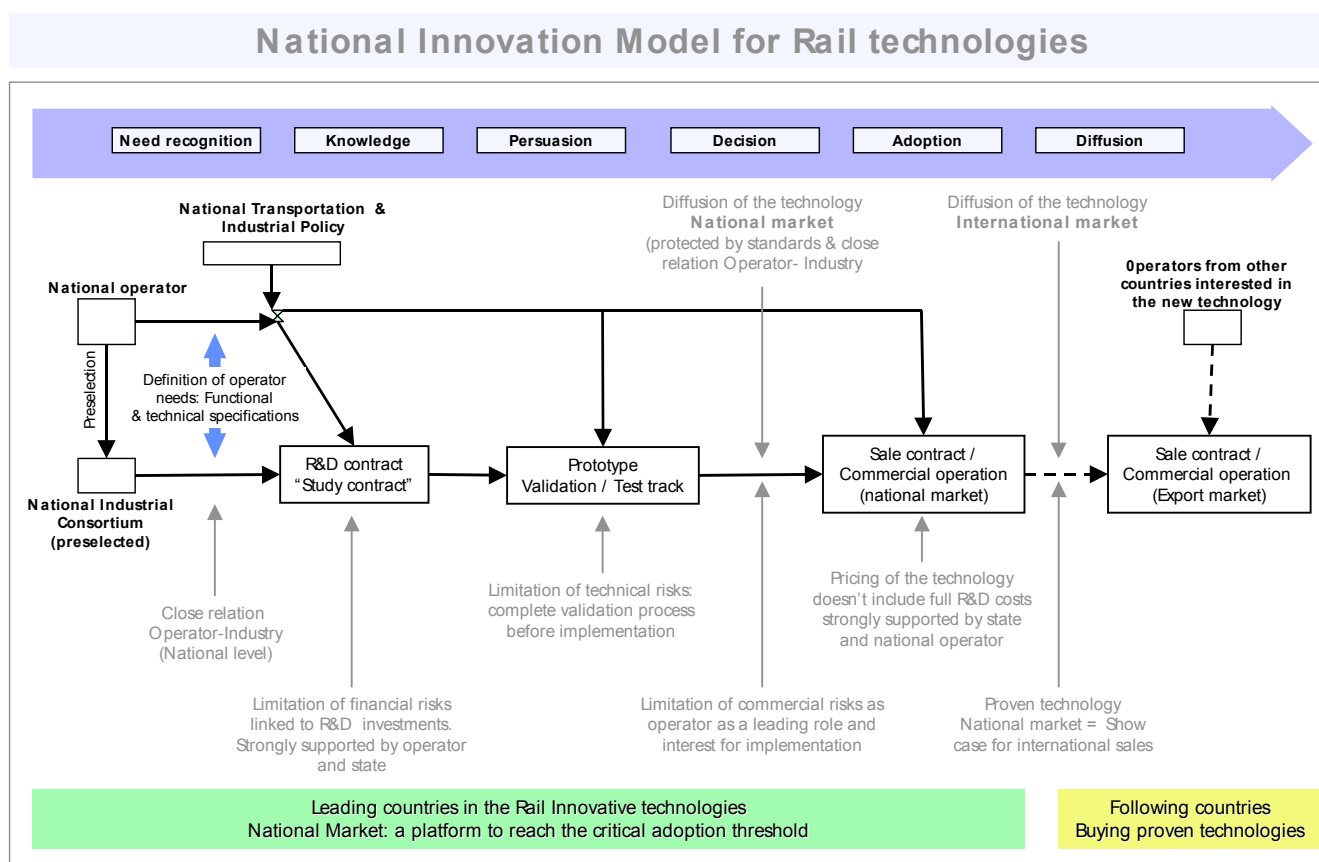
In this national innovation system, transportation policies were also at the service of industrial policies as underlined in the case studies. The needs of operators were also driven by paradigms that were shared by institutions, operators, manufacturers and governments at a national level. The convergence of such paradigms (such as the quest for speed between the 1960's to the 90's) allowed to mobilise adequate resources to launch or sustain technological trajectories. This convergence was also enabled by the integration of organisational and institutional systems (see Figure 8). Even the degree of integration was a strong factor in the ability to launch technological trajectories, as analysed in Quinet, 1999 or de Tilière 2001; centralised countries have been able to launch and sustain more quickly systemic innovations (incremental in this case) as Shinkansen and TGV.

- The “National Rail Innovation Model”: The key role of national tandems operator-manufacturer:

Case studies underline the predominance of the pull linear innovation model, that illustrates the birth of HSR technologies (de Tilière 2002) as the TGV in France, the ICE in Germany, the X2000 in Sweden as well as all national ATP signalling technologies.

This linear innovation model also constituted a basis for operators to impose their standards abroad. If they paid costly study contracts for the development of national technologies, providing to the selected manufacturer future rents of innovation in a captive market. These study contracts that were given to the best supplier in the field, were in fact the main gate to penetrate the national market for a specific technology. This promoted the paradigm of technological excellence, perhaps in detriment of cost efficiency in some cases (notion of national champions).

- Case studies developed in this paper allowed to draw a “National Rail Innovation Model” (see Figure 9):



The main characteristics of this Rail Innovation Model were the following:

- Tandem operator – manufacturer set up at a very early stage of the innovation process
- R&D funded mainly or fully by the operator through study contracts
- Complete validation of the technology by the tandem operator- manufacturer.
- For commercial contracts, the final technology was only priced by the manufacturer without including full R&D costs (national market & export sales).

Among the main advantages of this model were:

- Risks related to the direction and the cost of R&D were secured for manufacturers
- Technologies designed for specific national needs and purposes
- Limitation of technical risks due to a tight cooperation between the operator and the manufacturer (decreasing information biases to some extent): both were looking for long term cooperation and not “one shot” contracts.
- As soon as a study contract was attributed, uncertainties concerning commercial risks were also less than in open markets.
- In addition to commercial risks, an important point was the captive nature of these markets due to non standardisation.

2.5 The problem of non-standardisation: toward the end of the “National Rail Market” Equilibrium

2.5.1 from the economical point of view: the need of cost efficiency

If such national system's framework, that dominated the railway industry before the 1990s, allowed to protect innovations from too high competition in some cases, there was important disadvantages. Trains were produced in too short series due to national standards and regulations that effectively made each country a unique market. Foreign competitors were seldom in a position to win contracts in markets dominated by a national champion. A further complication, from a competitive point of view, was that the state railway operator gave preference to national suppliers by involving them in forward looking innovation projects, for example: the French TGV, the German ICE, the Italian Pendolino, the British HST, and the Swedish X2.

Regarding to this issue, the NIH syndrome (Not Invented Here) was really an important driving factor in reinventing the wheel at national levels asking for customisation of systems for national purposes. But as functional requirements are more and more convergent among Europe, it appears to be costly ineffective, especially now after merges that lead to pan-European manufacturers who are looking to standardise their product lines. The need for increased standardisation for both industries and operators lead also to open a bit more national markets.

2.5.2 from technical point of view: the need of Interoperability

Among lots of different political, social, human and technical hindrances to interoperability, one has to deal with 2 main problems: power supply and safety or train control systems (ATW/ATP/ATC). These non-interoperable issues are costly, especially on international corridors: this impact highly the rail competitiveness to the profit of road and air modes. Passenger trains are today often towed by multi-current/multi-system engines. Thalys for example, the high speed passengers train planed to link France to Netherlands and Germany, for example, is equipped according to this principle. It is able to run under four different power supply systems, what could be achieved without main difficulties thanks to recent developments in electrical components. It was a greater challenge for designers to find appropriate locations in the cab and enough space under power units to install at least seven ATP systems. (See Annex 1)

2.5.3 The change of paradigms: towards more harmonization

All the arguments described above, added to the strong trend of globalisation in the rail market (trend of merges between manufacturers since the 1980's, which was accelerated in the 1990's) gave less arguments to maintain national market barriers.

Moreover, the strong will of the European Community to solve transportation problem for passenger and freight along international corridors and promote European rail corridors ring the end of the “National Rail Markets” equilibrium.

3. Case of the new European Framework: Toward a New Innovation Model of Railway technologies

3.1 A new Institutional framework:

3.1.1 Toward a new European Institutional & organizational System

The links between rail actors as been completely redefined by the European Directive 91/440 (July 1991) imposing the separation between operations and infrastructure and the progressive opening of national markets for operation. As a first impact, the role of government & institutions in the rail sector has been transferred to some extent at the European level as underlined in the case of ERTMS (see § 3.2 and Annex 2). Main changes in the Institutional & Organisational Model are summarised below and also underlined in Figure 10:

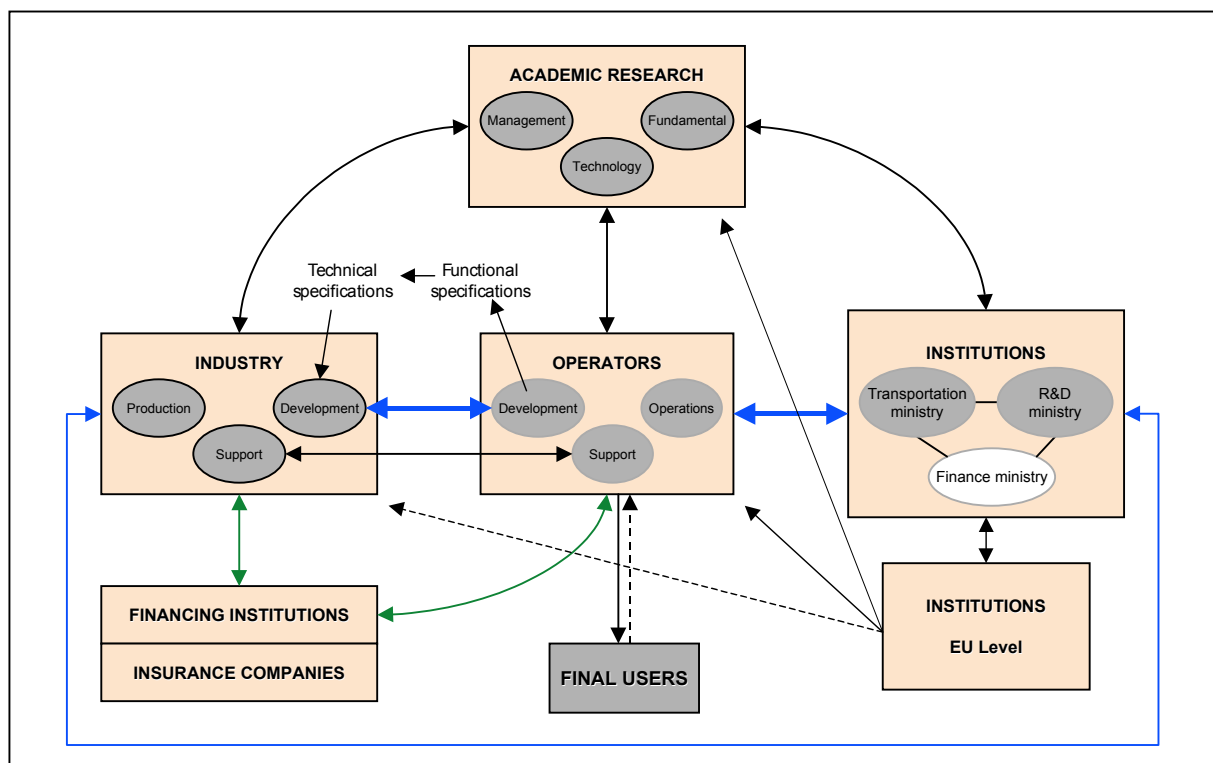


Figure 10. The new European Institutional & Organisational Model

- Separation between operations and infrastructure: This is the basis for the opening of operating markets. But this led to the transfer of all activities related to infrastructure from the operator to a new actor: the infrastructure owner. This last one invest and maintain rail infrastructure and rent tracks to operators.
- Vertical disintegration: The quasi integration between operators, infrastructure owners and institutions has been the norm until recently. The recent changes now open the door to private operators.

- Horizontal disintegration: This concerns the structure of the decision-making process concerning the development of transportation networks, which is more complex and multi-layered. Power of EC and regions have increase leading to a more decentralised model.
- Relations operator-manufacturer: The new institutional model breaks the former equilibrium and the tandem structure at national levels as it was practised before. Open markets don't allow anymore the allocations of study contracts as before. What is staying is the advantage of specific knowledge of national manufacturers on their specific market, or good relations that have with their traditional customer.

These deep changes impact the configuration of the rail market, and strongly reshape innovation processes. The new Institutional & Organisational Model lead to a change of the decision-making model which determine the type innovation model (de Tilière, 2002).

3.2 Case of a systemic innovation in the new European framework: ERTMS

3.2.1 New priorities for improving the European Rail Market

For a decade has the EC discussed the possibilities of constructing a European high speed railway network. The construction of the first purpose built international high speed railway connections (Paris-London and Paris-Brussels) revealed the true problems of interoperability. New European research organisations were created and inter-firm collaboration was supported. So far has the deregulation of railways had little impact on the standardisation of the high speed railway networks. The process is dominated by the harmonisation ideal with much efforts directed towards ensuring competition between different producers on the future European market.

The high costs related to the building of new high-speed railways increased the interest in finding ways to harmonise the existing networks. Thereby could the high speed trains run both on the dedicated high speed networks and on other lines. It is difficult to assess if the EU can wait for long before implementing the European standards. Until now most of the European standardisation in the railway sector has been made in pilot projects.

Railways have now to have to promote interoperability and adapt themselves very fast to the new technology (commercial projects) in order to increase their competitiveness along international corridors.

To understand how these new objectives as well as the new Institutional framework is influencing innovation processes (changes in partnerships for projects, R&D funding etc), this following case study will provide the main elements that will constitute the "New European Rail Innovation Model".

3.2.2 Case of European Rail Traffic Management System (ERTMS): birth of a European technology (Annex 2)

A first important step in the process to harmonisation of European Railways was the will to develop an common standard for signalling ATP, allowing interoperability along international

corridors. The institutional and market changes 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 Railways (UIC, ERRI)⁵ agreed the principles of tight co-operation in order to consider the requirement specifications as the base for industrial development. The project framework included:

- A new on-board equipment based on open computer architecture (EUROKAB)
- A new discontinuous system for data transmission, (EUROBALISE)
- A new continuous transmission system (EURORADIO)

In 1993, the EU council issued an Interoperability Directive and a decision was taken to create a structure to define the Technical Specification for Interoperability. The European Community (EC) defined in 1995 (beginning of the 4th Framework Programme) a global strategy for the further development of ERTMS with the aim to prepare its future implementation on the European Rail Network.

The UNISIG group, including all European Signalling manufacturers, led the definition of the specifications in partnership with European operators. The ERTMS standard was defined and improved until its last version 2.2.2 in 2002, with the aim to improve safety, capacity and cost effectiveness in the long run.⁶

- R&D and Pilot line funding: The notion of the rent of innovation

Financing schemes or funding is generally depending on the rent of innovation which is forecasted by operators and manufacturers.

Operators show for ERTMS an interest in this innovation, as decreasing some of their costs in the long term. But a short evaluation of the high investments required to shift from the national current ATP system (still up-to date in some cases) to ERTMS didn't push them to take the lead in this process until now.

Manufacturers saw to some extent a good opportunity to win new market shares, while still keeping for some time their national advantages to due remaining captive markets. They financed on their private funds all R&D meanwhile the EC planned to fund Pilot lines to validate interoperability, involving one operator and the infrastructure owner and two manufacturers for each pilot line, in order to demonstrate the interoperability (6 pilot lines were chosen in Europe). These test tracks provided industries and operators the experience to:

- Test the technology and the system integration
- Define possible standards improvements

- Role of actors in the innovation process

In the innovation process the leading role was held by the EC, initiating the process and funding the pilot line to go from the R&D to a demonstration (prototype of the complete system) stage. Manufacturers financed the R&D on their own, and operators were playing the role of the customer mainly involved in the process to attest the operability of the system. This represent a major shift in the innovation model, as before the operator was leading the innovation process.

- Uncompleted validation as a critical issue

⁵ UIC: Union International des Chemins de Fer, ERRI: European Rail Research Institute.

⁶ The cost of change is high for operators that have already developed their own ATP systems.

The validation phase is a major difference between the European rail innovation models before and after 1990. Now, for example with ERTMS, pilot line financed by the EU community were only to prove interoperability. But this was only a pre-validation phase on intermediate standards. This means that the complete validation of the technology has been done by manufacturers under the first commercial contracts were operators (customers) expected a implementation of “on-the-shelves products” (high risks for both manufacturers and operators).

Commercial projects were launched and partially financed by the EC (less than 10 up to now), and progressively the numbers of tenders is increasing. However, as test lines didn't allow a full validation of the systems with the a frozen standard, all these first commercial projects for each manufacturer and operator brings very high risks: First projects are in fact including the full validation of the system and the upgrade of the standard (as specifications were not completely frozen). Where operators were looking for on-the-shelve products, they see that manufacturers are still at a stage of prototype validation.

3.2.3 ERTMS versus previous national ATP : What changes in the innovation Process?

- For the industry:

In the new framework, manufacturers spent huge amount for R&D investments to reach the UNISIG 2.2.2 standard for ERTMS (between 30 to 100 ME by manufacturer). Test tracks have been financed by the EC, with around 10 to 20 ME for each project (for the complete system). Behind these investments stands the market opportunities, with globally 300 ME/year for the whole market. If we compare these figures with the case of ATP development as for KVB in France, it appears that R&D investments were fully paid by the operator, and that market opportunities were proportionally higher in annual revenue and much more secured (as national captive market).

So it leads to the fact that the new European framework lead to a new market equilibrium where there is more market opportunities (trend of open market), but significantly more risky as more competitors with the same standard basis.

- For the operators:

In the new European model, the lead-users are no more paying for new national standards where they play the role of technical specificators, but rather play the role of functional specificators. They took the leadership with infrastructure owners of the test lines funded by the EC, and look at the first validation step. However, as operators are not involved as before with national ATP systems (this is a will of the EC, and not firstly their own).⁷

- For the infrastructure owners:

They play in the new model a similar role as operators as lead-users, with the difference that they are more interested in ERTMS: This new technology allow to provide interoperability on tracks, allowing a competition between operators. Moreover, ERTMS decrease significantly trackside equipment, providing savings in investments and maintenance costs.

⁷ Operators still would like to make their past investments more profitable as their ATP systems were implemented in the 90's and are still efficient.

The case of ERTMS underlines the radical change in the innovation process for signalling technologies with the new European framework.

3.3 Case of the new Rolling-stock technologies: The Swedish Regina project

The X2 train eventually became the first train in a new generation of trainsets. The development of trainsets at ABB (ASEA merged with Brown Boveri in 1988) after X2 looked like this. The second train of this type was the Gardemoen train, that runs on the railway line between Oslo and the new airport Gardemoen and on inter-city connections in Norway. The Gardemoen train will exist in two models - one with tilt and another without tilt. This train is the most expensive of all trains built in Europe in the 1990's. The train is expensive because of very high power output per coach, a high top speed of 220 km/h and a high technical quality.

The third train developed from the X2 is the Öresund train. This train has no tilting equipment and has a top speed of 180 km/h. The cost per seat in these trains is much lower than in X2 and the Gardemoen train. One coach has a low-floor construction making it possible to enter the train with a wheel chair. An advantage of the Gardemoen- and Öresund train compared with the X2000 is that they can be built with a variable number of coaches because nearly all axles are equipped with power.

The experiences from these three train types have led up to a new type of trainsets at Adtranz (ABBs rolling stock firm merged with the German firm AEG in 1996). The new train type is called Crusaris Regina and has a top speed of 180-200 km/h. The most interesting and novel feature with this train is the extra wide body of 3,45 metres. This makes it possible to have five seats in a row and to comfortably seat nearly 200 passengers in a two-car trainset. The Crusaris train is an extremely flexible train. It can be ordered in the following constellations: two-car trainset, three-car trainset and four-car trainset. The trainsets can be coupled two or three together. This means that a Crusaris train can range from two coaches to twelve coaches. The extra wide body notion was developed at the Royal Institute of Technology in Stockholm in the mid 1990's. Less than five years after the idea emerged Adtranz got the first orders for this type of trainset in 1998. This order came from the regional transport authority, CPTA, in the Västmanland region west of Stockholm. In 2002 Adtranz, who had then been bought by Bombardier, had sold more than 50 Regina trainsets.

The idea to develop an extra wide body train emerged when a group of researchers thought about the possibilities of getting a lower cost per seat in a Swedish regional and inter-regional trainset. The practical possibility to order this train appeared when the Swedish National Rail Administration started to rebuild parts of the Swedish railway network to make room for bigger freight trains. It then appeared that the available space on the Swedish railway network could allow for 3,45 meters wide coaches. At the moment no complete investigation of the available coach space on the Swedish railway network exists.

The developments after the X2 introduction have given the following results: 1) New actors are purchasing high speed trains in Sweden, including private railway operators and CPTAs. 2) New actors like researchers develop ideas that are being adopted by railway manufacturers. 3) Regional authorities and private firms also participate in the financing of new railway lines. 4) The high costs per seat for the X2 triggered a search for lower costs resulting in cost savings per seat of more than 60 per cent compared with the first X2 trainset. 5) The success of X2 has partly contributed to a railway boom in Sweden. This has resulted in that many commercially attractive railway lines can be operated by high speed trains without tilt. The

new high speed railway lines all connect to Stockholm and are between 40 and 120 kilometers long.

In a twist of events in 2001 SJ selects an Alstom train to the new operations in the Mälardalen region Alstom trains will commence service in Mälardalen in 2004.

3.4 The New European Innovation Model of Railway technologies

- Toward the New Rail Market Equilibrium (case of Rail leading countries): The “European Rail Innovation System”:

As underlined with the new ERTMS signalling market or for rolling-stock technologies, the actors of changes are no more one operator and one or two manufacturers, but operators and manufacturers: The difference with old national tandems operator-manufacturer, the internationalization of both operation and manufacturing market put more pressure on standardization: Decrease of national market barriers (progressively, as technical interoperability is in progress).

This new innovation system induce more competition for the long term between manufacturers and also between operators. As a consequence, their role in the innovation processes have been impacted.

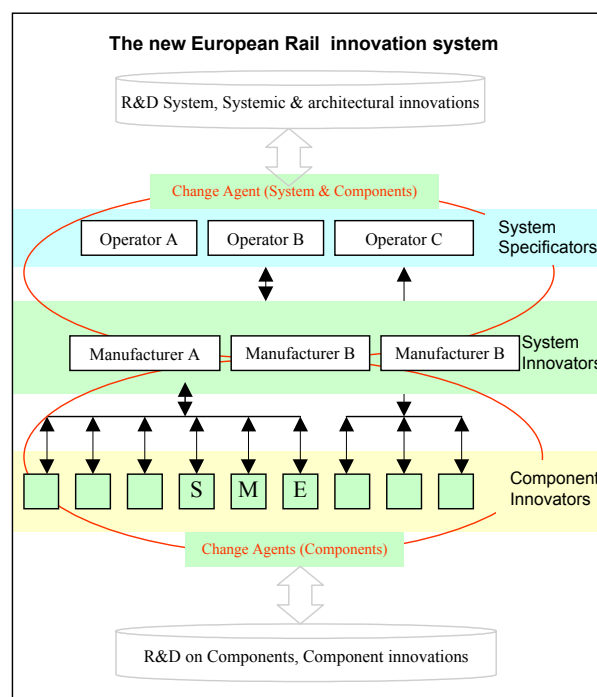


Figure 11. The New EU Rail Innovation System

- The new “European Rail Innovation Model”:

The case of the ERTMS, as well as recent examples of the development of new HSR generations allows to draw a “European Rail Innovation Model” (see Figure 12), which main characteristics are the following:

- Disappearing of the tandem operator – manufacturer: this fact leads to a dis-involvement of operators in early stage of the innovation process. Their roles remains now only in identifying functional specifications.
- R&D funded mainly or fully by the manufacturers (operator don’t provide anymore study contracts for generic technologies).
- Partial validation of the technology as operators not fully involved.

- For commercial contracts, operators are looking for fully proven technologies.
- The final technology should now be priced by the manufacturer including full R&D costs (which is not fully in practices for some businesses as Signalling technologies).

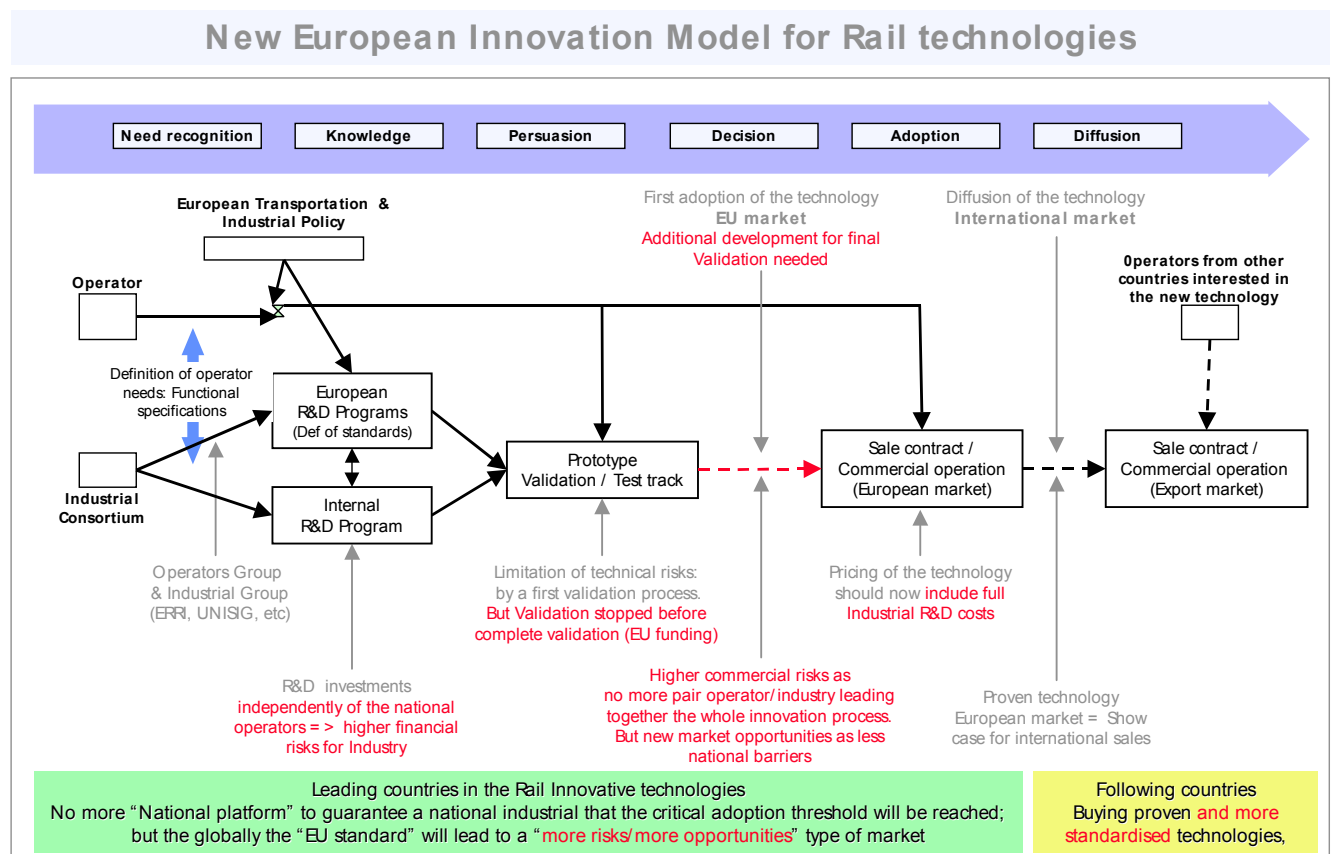


Figure 12: The New European Rail Innovation Model – since the 90's

The main advantages of this model are the following:

- Open market for standard product: Increased competition between manufacturers
- More efficient R&D efforts with increased value for operators (avoiding to reinvent the wheel in each country)
- More market opportunities as less national market barriers

This model as wanted by the EC provides an increase of economies of scale related to the standardisation. However these advantages are balanced by the several disadvantages:

- Higher financial risks for R&D investments (no more study contracts funded by operators).
- Risks related to the direction and the cost of R&D are no more secured for manufacturers, as none of them as the guarantee to have sales behind.

- Technical risks are higher as the operator has less role in the validation process (and not involved as before early in the innovation process). Therefore system integration done by the operator and the infrastructure owner is more complex than before (increase of information biases to some extent, as this open market favour “one shut” contracts).
- Higher commercial risks, as the captive nature of the national markets due to non standardisation will tend to disappear.

ERTMS is therefore a first systemic innovation to be developed according to this new European market configuration. This therefore provides, after 10 years of maturation, R&D and now the first commercial projects, a key example to understand the new European Rail Innovation Model. This trend to a new Rail Market Equilibrium seems to increase opportunities for manufacturers, but also Increase commercial risks, as they have no guarantee for implementation even on their own former national networks.

Looking at other technologies developed under this Model, new generations of HSR such as the AGV or the new ICE leads to the same conclusions. If a few markets continue to be protected to some extent, the overall European markets for passenger trains are much more competitive today than in the 1980s. Today firms are invited to give bids when a new train-set is being bought by an operator. Few purchases of trains are pre-captured by a supplier with an insurmountable knowledge advantage. Moreover, case studies underline that the new regime has resulted in substantially lower prices and shorter lead times, facts that are also confirmed by the key actors in the industry (both operators and producers).

3.5 Toward a new equilibrium of the rail market: New challenges for the Rail Industry

If a market equilibrium is to some extent always dynamic, in the case of the rail market the transition phase from the “National Models” to the “European Model” lead to new challenges, where operators, industries and institutions will have to restructured their processes (internally and externally).

3.5.1 Impacts on operators & the role of infrastructure owners

At national levels; operators have to shift from technical to functional specificators. They now are not anymore shareholder in the technology development as before, letting manufacturers doing their role in technological specifications. However this shift leads to a new challenge which now resides in the system integration: The number of partners and decision-makers is significantly increasing and therefore the implementation of systemic innovations such as ERTMS, is now more complex.

3.5.2 Impacts on the Rail manufacturing industry

After a decade of merges, the restructuring of the rail manufacturing industry is going a step further, adapting its processes to the constraints of the new market. A better definition of R&D programs has to be done, as it was before directed by national operator strategies (with study contracts). More than ever manufacturers have to identify the needs of operators and bring to the market efficient innovative solutions. However, one of the major difficulty it the fact that operators want in commercial projects proven technologies (problem with first ERTMS commercial contracts, where the technology was still in its validation process). Now

this has shifted to a consumer market, and R&D expenses have completely shifted in the supplier side. Operators or Infrastructure owners doesn't like to bear risks of innovative solutions and prefer of the shelves products: contracts acceptance are done on a performance basis. However, R&D support is also transferred at the EU level to support the development of new European standards, but the EC prefer to focus its support on non infrastructures rather than products belonging to the open market.

The main challenge for the industry is therefore to shift its mentality and include in the price of their systems the R&D costs, that were before taken by operators or states institutions linked to railways. To this extend the manufacturers will have to better sale their engineering through a better product pricing, knowing that the main difficulty in the rail market is to forecast sales.

4. Conclusion

The harmonisation and liberalisation trend that began in the 1990's induced an important shift in the Rail European Market. This paper analysed this main changes through two main case studies: the development of high-speed rail technologies and of Signalling technologies, before and after the introduction of the norm EU 90/440.

Before the 1990's, a National Rail Innovation System and Model have been drawn out, underlying the key role of operators in the development of innovations, with study contracts for manufacturers that were tightly linked to future captive markets. These innovation processes were also shaped by national industrial policies, using non-standardisation (or arguing for national specificity) for the in-vitro development of their own technology up to a competitive stage for export sales. Technologies developed with this model were the TGV, The ICE, X2000 for HSR technologies and the national ATP signalling technologies.

However, the globalisation trend for manufacturers and non-interoperability were pushing this National Rail Market Equilibrium to its end: The high cost of non-standardisation as the development of too short series of products (trains etc.) was expensive, leading to reinventing the wheel in each country. Interoperability and efficiency was therefore the new paradigm that lead the new transition phase launched under the impulsion of the European Community.

After the introduction of the norm EU 90/440, a new European Rail Market equilibrium was taking place, reshaping innovation processes and roles: the new innovation model lead to the shift of R&D expenses on the manufacturer side, letting operators to take some distance with the innovation process and focusing on functional specifications rather than technical specifications as before. This last model lead to more challenges in the system integration for the case of systemic innovations, as well as a more opportunistic / more risky type of market. This new framework should also avoid expensive R&D programs as done in the 70's with a higher selection rate of future standards, based on cost effective solutions. The purpose is also for all partners to reach a level of technology adoption that allows to increase know-how and return of experience, rapidly reinvested in a tailoring of the new system. However, the new Innovation model bring an increased complexity in the decision process, with the vertical and horizontal disintegration, added to the separation between operators and infrastructure owners.

To illustrate changes in the language of Rothwell's innovation models we have moved from first and second generation innovation model to a fifth or sixth generation innovation model. This new model is more complex as much more interactive, but leading to an increased efficiency when innovation processes are mastered by all the innovation actors. The main challenge for the rail industry is probably here, in their ability to adapt themselves quickly to this new market configuration and therefore to reach faster the more efficient configuration.

The Swedish case illustrates the benefits of this new Rail Innovation Model: The X2 demonstrated the potential attractiveness of railways and by creating bottle-necks in the old railway network. As faster and more trains are travelling on the Swedish railway network more bottle-necks appear that need to be removed (Hultén, 1999). It took 23 years to develop the first Swedish high speed train the tilting X2-train. Later trains have been developed in a much shorter time space. The radically new Regina train took a total of 12 years from the first ideas to develop a high speed (180-200 km/h) regional train with substantially lower running costs than the then used regional trains to delivery of the first train. Moreover, cost per seat is substantially lower than for X2.

The old equilibrium of national champions, close cooperation between the state operator and a big national supplier and technology driven long-term projects is moving toward a towards a more market oriented equilibrium. But, it is not yet the case for all rail market segments (some technological niches will remain captive for still some time). ERTMS is the first important experience for the case of systemic innovation. At the present stage we find market processes or networks of actors instead of bilateral cooperation. The former national champions are to some extent suffering from the more market like regime. Technological change is increasingly being dictated by user needs: rapid development of fast regional trains, direct step in from platforms, more seats per coach for daily commuting etc. Changes are incremental rather than radical. But taken together technological change is perhaps faster than during the national era and more investments go into R&D.

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ANNEX 1: Interoperability problems on EU international corridors

Among lots of different political, social, human and technical hindrances to interoperability, one has to deal with 2 main problems: power supply and safety or train control systems (ATW/ATP/ATC).

Passenger trains are today often towed by multi-current/multi-system engines. Thalys for example, the high speed passengers train planed to link France to Netherlands and Germany, for example, is equipped according to this principle. It is able to run under four different power supply systems, what could be achieved without main difficulties thanks to recent developments in electrical components. It was a greater challenge for designers to find appropriate locations in the cab and enough space under power units to install at least seven ATP systems.

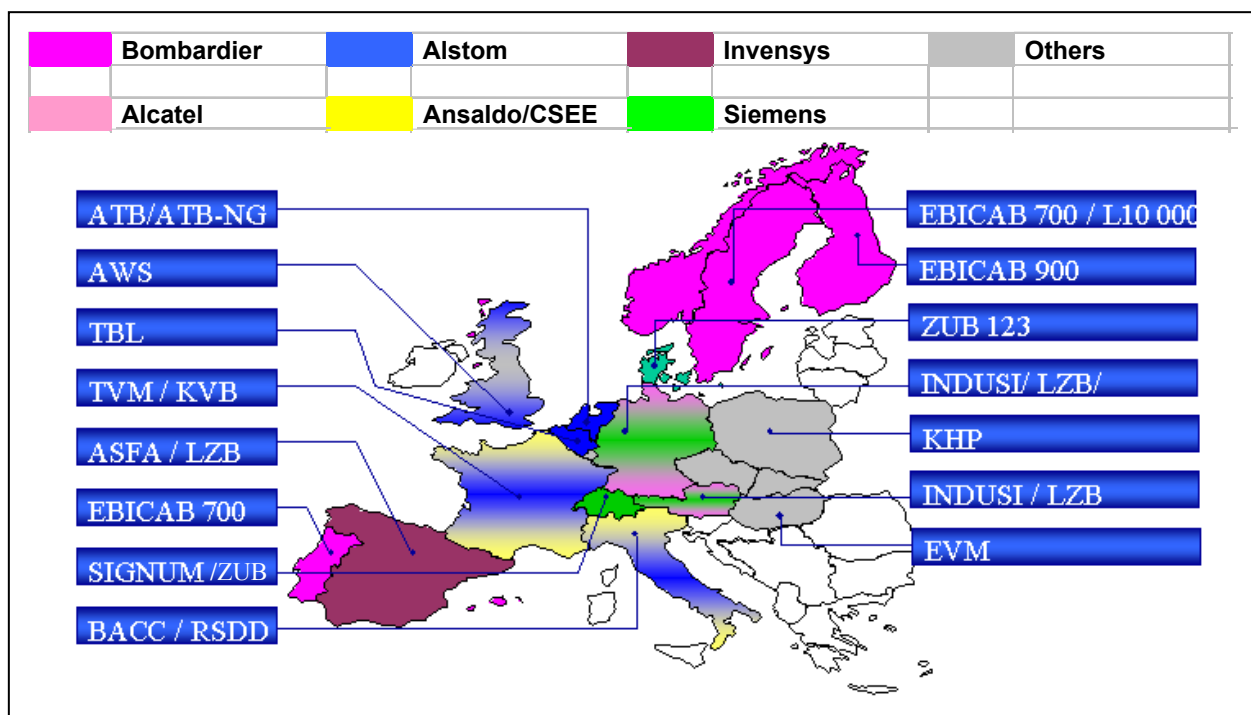


Figure 13: Different ATW/ATP/ATC systems through Europe

With regard with freight trains, locomotives are often not equipped with different power supply systems. and it is therefore necessary to change engines at border crossing stations.

If it is possible to equip locomotives with different power supply systems without great difficulty and to switch easily from one system to another, the problem is different with safety systems. In fact the instrument panel and the lineside signalling differs for each system and it is therefore necessary to change driver when going from a system to the neighbouring one.

These changes (driver or locomotive) are time consuming, specially for freight trains where resource allocation is not well planned. In reality, freight trains often spend several hours (even days) at border stations, waiting for a locomotive or a driver.

Interoperability problems therefore constitute a severe handicap in the rail competitiveness, for both freight and passenger traffic along international corridors.

The commercial success of high speed trains has put the question of common European railway standards on the agenda both for the EC and for the UIC (The International Union of Railways). Committees and research institutes are seeking to develop standards that will allow high-speed trains to run on international lines. Parallel to the building of a unified European railway network are some national railway networks being privatised and some railway operators being put under competitive pressure from internal competition. Both the effort to harmonise the national railway networks and the deregulation of networks are problematic because of the huge deficits in the operation of railways in the EU.

Also in earlier periods could passengers travel between European countries without changing trains. The compatibility problem was solved in two ways. First class TEE-trains overcome the incompatibilities by using diesel powered trainsets. Normal trains stopped at borders and changed locomotives. Such procedures continue to be used today on cross-border trains in Europe and on trains that run on national networks that are only partly electrified. This way of overcoming incompatibilities on international trains is feasible because the railway networks in most European countries have standard track gauge and conform to the UIC standard loading gauge.

When track gauges differ cross-border services become more difficult to arrange. Crossings between France and Spain are for instance more complicated because of the Spanish broad-gauge track. At this border have two different solutions been developed for managing rapid passage. The most well-known is the Talgo-trains with adjustable gauge that run both on the Spanish broad gauge and the French standard gauge railway networks. The other solution consists in lifting the compartment part of the coach from Spanish to French wheelsets.

The present compatibility problems are much more complex and difficult to solve. In this section we will discuss three critical technical dimensions critical for the interoperability of European high-trains:

- power supply,
- train control and
- loading gauge, see table 1.⁸

The variety in solutions that is evident from the table is the result of local and national decision making during a century or more that seldom made international considerations.⁹ Total variety is also underestimated because all the narrow gauge lines are excluded from the table.

The most complete standardisation has been achieved in the track and loading gauges. In the track gauge used the national railway administrations the same reference - the standard gauge reference derived from the stage coaches. In some regions forced military considerations neighbouring countries to chose different track gauges - for instance between Spain and France and between Russia and most of its neighbours.

Standardisation of the loading gauge was facilitated by international agreements, but the cost of potential conversion in Great Britain has prevented that country from adopting the international standard (Puffert, 1993). The broader loading gauge is less problematic since it

⁸ The EU concept of interoperability and interconnection of national networks distinguishes eight sub-systems to be considered. Five concern technical harmonisation: infrastructure, energy, maintenance, rolling stock and inspection/control. Three aim at improving services: operation, users and the environment. See P. Pourcin, Senior officer at UIC in IRJ, July 1995.

⁹ Ibid

doesn't exclude trains from countries with narrower loading gauge, but it poses problems for the nation that uses the broad loading gauge. This has for example hampered the German high-speed venture. The first generations of the ICE-trainsets are too wide to run on other railway networks and the German railway operator has therefore been forced to develop a special trainset for the PBKA-network that connects Paris-Bruxelles-Cologne-Amsterdam.

Table 1. Dimensions of diversity among European railways

Country	Loading gauge	Electrical power	Train control, ATC systems	High speed trainsets
Belgium	1435	3 kV DC	TBL and Belgian Crocodile	Eurostar, Thalys and ICE-2.2
Denmark	1435	1.5 kV DC, 25kV 50 Hz AC	ZUB	IC3
France	1435	25kV 50 Hz AC	KVB, TVM and French Crocodile	TGV Sud-est, TGV Atlantique, Thalys etc
Germany	1435	15kV 16 2/3 Hz AC	LZB, Indusi and ZUB	ICE-1, ICE-2, ICE-T and ICE-2.2
Great Britain	1435	750V DC; 25kV 50 Hz AC	AWS, Selcab and TBL	Eurostar and IC225
Italy	1435	3 kV DC (future lines 25kV 50 Hz AC)	BACC and RSDD	ETR450, ETR470 and ETR 500
Netherlands	1435	1.5 kV DC	ATB	Thalys
Spain	1668 (high speed 1435)	3 kV DC (25kV 50 Hz AC)	ASFA, LZB and Selcab	AVE standard and broad gauge
Sweden	1435	15kV 16 2/3 Hz AC	Ebicab	X2000
Switzerland	1435	15kV 16 2/3 Hz AC	ZUB	TGV Sud-est, Series 2000, ETR 470

Note: This table is adapted from Puffert (1993). Additional information is added from IRJ, July 1996

The power supply problem is to a high extent a problem of the choice of current and to some extent a problem of the geometry of the pantograph and the catenary. Both 25kV 50Hz and 15kV 16 2/3 Hz traction power are used for high speed trains. Other power systems are not well adapted for high-speed rail but are frequently being used until a proper high-speed network has been built. This is for example the case on the line from London to Brussels that use both the English third rail power collection 750V DC and the Belgian 3kV DC. As regards the pantograph there exist a proposal for a European pan head. This consists of a compromise between the smaller current collector bows used by Italian, Swiss and French railways with the wider bows used particularly by German, Danish, Dutch and Belgian railways.

Most of the EU efforts in technical harmonisation is directed towards developing harmonisation as the restrictions imposed by the national standards are not insurmountable only costly to circumvent. The Eurostar passenger train needs 16 on-board sensors for use with six ATC systems. The Thalys train operates on four networks and has 28 on-board sensors for ten ATC systems.¹⁰

¹⁰ Ibid (IRJ, July, 1996)

ANNEX 2: Innovation and standardisation / ERTMS development

A. Case of European Rail Traffic Management System (ERTMS): birth of a European technology

Two major changes occurred in the rail market since the 1990's and led to more pressure toward harmonisation in standards:

- Globalisation and concentration of the rail Industry (manufacturers).
- Trend toward the opening of the national markets in Europe for rail operations (harmonisation and separation between operation and infrastructure).

As Railways have been developed on national basis, trains such as the Thalys today are equipped with up to six different navigational systems. Each is extremely costly and takes up space on-board. A train crossing from one European country to another must switch the operating standards as it crosses the border. All this adds to travel time and operational and maintenance costs, before institutional and market changes 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 Railways (UIC, ERRI)¹¹ agreed the principles of tight co-operation (defining EUROCA, EUROBALISE, EURORADIO future standards). In 1993, the EU council issued an Interoperability Directive and a decision was taken to create a structure to define the Technical Specification for Interoperability. The European Community (EC) defined in 1995 (beginning of the 4th Framework Programme) a global strategy for the further development of ERTMS with the aim to prepare its future implementation on the European Rail Network.

The global strategy described in the "Master Plan of Activities" included the development and validation phase. The objective of the validation phase was to perform full-scale tests on sites located in different countries. First specifications were finalised in 1998 (Class P SRS) and evolved until a first agreement in 2000 by all members of the UNISG group (Class 1 SRS).

Then Tests for interoperability such as the Olten-Lucerne test track in Switzerland, Vienna-Budapest, the Test Track Italy or the Test Track France, allow to improve the experience and the technology (specifications SRS class 2.2.2 in 2002).

There are now a number of commercial projects at varying stages like the West Coast Main Line, the HSL-Zuid, Rome-Naples, Switzerland (SA-NBS), Berlin-Halle-Leipzig, Athens and Madrid - Lleida, that have been awarded and partially financed by the European Community.

B. The key benefits of the ERTMS innovation for operators¹²

The ERTMS innovation was driven by four main arguments summarised as follows:

- Countries in the middle of Europe need cross-border Interoperability improvement.
- Where no ATP exists or is becoming obsolete, improving Safety is of paramount importance.

¹¹ UIC: Union International des Chemins de Fer, ERRI: European Rail Research Institute

¹² J. Poré, *ERTMS/ETCS; Investments and migrations*; IRSE Conference, London Feb. 2003.

- Where traffic punctuality is capital, the global Availability is a main requirement.
 - Some operators (freight only, passenger regional traffic, ...) want as few On-board devices as possible and Low Costs (installation, operation, maintenance).
- In other words, ERTMS/ETCS return on investment will come from three types of sources:

- "Standard" sources:

- improved operational safety of the railway
- higher safety at the level crossings
- operation and maintenance costs saved on signalling

- New areas for signalling systems:

- better productivity of the rolling stock
- energy savings
- maintenance saved on rolling stock

- More unusual, advanced, aggressive areas:

- savings on track works
- contribution to the increase of freight traffic
- contribution to the increase of passenger traffic

Knowing that uncertainties concerning the forecast of the costs induced by the transition phase (migration) are difficult to apprehend, the following table gives an estimation of positive impacts of ERTMS implementation (source J. Poré 2003):

ERTMS/ETCS ROI savings (all figures in M Euro per year)	Europe	ERTMS/ETCS impact
"Standard" sources:		
• safety of the railway	> 200	+++
• safety at level crossings	> 300	+++
• maintenance of signalling	> 2,000	+++
New areas for signalling:		
• productivity of the rolling stock	> 1,000	++
• energy savings	> 200	+
• maintenance saved on rolling stock	> 600	++
More unusual areas:		
• savings on track works	> 200	+++
• increase of freight traffic	> 1000	+
• increase of passenger traffic	> 1000	+

C. Interoperability along international corridors (and neighborhood)

One advantage of ETCS is that the MMI (Men Machine Interface) is the same all over the lines equipped with ETCS level 2. Moreover, if a part of the line is not equipped with Eurobalise, the on-board ETCS computer can receive information from the markers of the national or regional system. By means of an interface, it translates national system messages into ETCS information format. It is so possible to only use ETCS MMI's, even on non ETCS equipped lines. In addition, ETCS and ETCS MMI may provide a great help to solve language

problems. Any MMI can easily be customised for numerous languages, the current one being chosen by the driver. Even when running in Germany, for example, a French driver could receive all written messages in French. Audio radio messages could be limited to very important information, using key words in order to suppress the risk of misunderstanding between people speaking different languages.

With such a system, it will not be necessary any more to change locomotives or drivers at the border. It will therefore be possible to improve the optimisation of human and rolling stock resources, for example to organise better integrated depots, to share resources between different railway corridor or lines, etc. In addition with the disappearance of custom barriers, this resources optimisation will allow to a commercial speed increase, giving to railways traffic more competitiveness.

New European Train Control System Level 2 (ETCS L2):

- Long term compatibility with other European railways by use of Eurobalise beacons;
- On-board signalling by use of radio transmission with the GSM-R protocol;
- Minimum amount of devices in the track, what reduce time and costs for track maintenance.

D. Pilot lines funded by the EU community: a first step for the system validation

The EU community funded 6 test lines in Europe in UK, Netherland, Germany, France, Italy, and Spain in order to prove interoperability between suppliers (two suppliers were selected for each test line). These test tracks provided industries and operators the experience to:

- Test the technology and the system integration
- Define possible standards improvements

However, none of these Test Track was done with the last standard¹³ and fully validated at the same level as before for national ATP systems: Operators were not leading the process as before, but following the will of the DGVII. The only pilot line that have been implemented for a complete validation as been achieved by SBB on the Pilot Line Zofingen-Sempach (32 km track on the Olten-Lucerne line), where the ERTMS system has been tested in full-scale operation on a daily commercial service basis. But the first commercial project in Switzerland was won by another competitor, which doesn't allowed SBB to use this advantage to reduce risks in its first commercial project.

The validation phase is a major difference between the European rail innovation models before and after 1990. Now, for example with ERTMS, pilot line financed by the EU community were only to prove interoperability. But this was only a pre-validation phase on intermediate standards. This means that the complete validation of the technology has been done by manufacturers under the first commercial contracts were operators (customers) expected a implementation of "on the-shelves products" (high risks for both manufacturers and operators).

The case of ERTMS underline the radical change in the innovation process for signalling technologies since the new European framework.

¹³ Pilot lines concerned standard UNISIG V2.0.0. or uses a subset of messages based on SRS 5A (older), as now commercial projects are based on UNISIG V2.2.2.

E. Standardization Process:

If the innovation process for ERTMS was led by the objective to set a European standard, the process of standardisation and specification development takes some time: Technological innovations produced usually a large spectrum of concepts before that the main standard emerge. In the case of ERTMS, standardisation has been (is) a major concern, which has been integrated in the innovation process since the beginning.

With the progressive ERTMS implementation, on test-tracks first, followed by commercial projects, shadow zones in specifications are getting smaller. In the near future it may evolve toward the dominant standard for the signalling of modern railways.

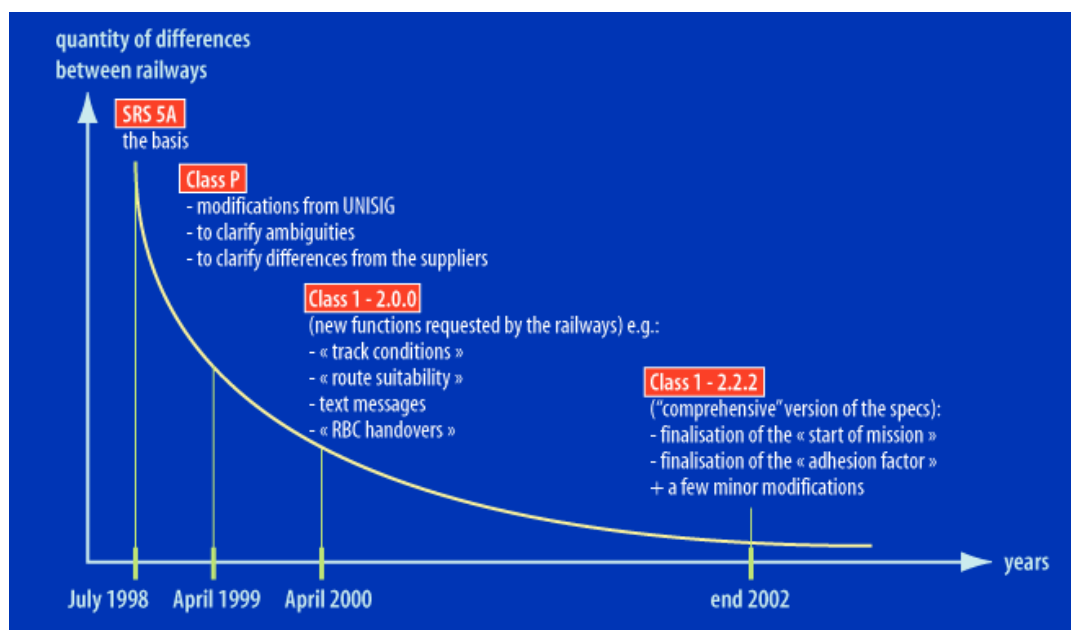


Figure 14: Standardisation process for ERTMS since 1998

Evolution of specifications and standards (Figure 14)

In the summer of 1998, UNISIG, comprising the European Signalling companies was formed to finalise the specifications. The Class P SRS was delivered on April 1999. With the final signature on ERTMS specification, Class 1, in April 2000, ERTMS has finally arrived providing substantially higher performance levels for the railways.

As the project of the Pilot line was launched in 1998, specifications were frozen at the SRS 5A. At this stage, the basis was frozen but ambiguities were remaining and few functions were missing.

In Switzerland, the SBB Pilot line required the development of a Generic safety cases, but with very limited opportunities for reuse, due to the specification changes that will be needed in the future (specs SRS 2.2.2). SBB intends to reuse the approval processes and the use cases for the application to the new HS line as currently for Mattstetten-Rothrist (SA-NBS) which is at the new standard.

ANNEX 3: Case of Swedish trains: the time to develop X2 and Regina trainsets

Year	X2	Regina
1	1968: Start of high speed train study	1988: Research project on regional trains start
2	1969: High speed train study completed Experiment with tilting train prototype	
3	1970:	1990: Regional train report completed
4	1971:	1991: Decision to build new lines in the Mälardalen region
5	1972:	1992:
6	1973: Second high speed train study completed Decision on cooperation SJ-Asea	1993:
7	1974: Construction of X15 prototype	1994: Seminar on a more efficient regional train
8	1975: New high speed record for X15	1995:
9	1976:	1996: Public bids for the Öresund train
10	1977: New experiments with X15	1997: KTH-book on efficient trains Öresund train ordered
11	1978:	1998: Regina train ordered by local public transport authorities
12	1979:	1999: Bidding process for new trains in the Mälardalen region starts
13	1980: New high speed train investigation completed	2000: Regina trainset delivered Öresund trains commence service
14	1981: Favorable decision in Swedish parliament	2001: SJ selects Alstom train to the Mälardalen region
15	1982: First round of public bid for tilting train	
16	1983:	
17	1984: Second round of public bid for tilting train	2004: Alstom trains will commence service in Mälardalen
18	1985: Revision of second round of public bid for tilting train	
19	1986: Asea wins public bid	
20	1987: GTO-tyristors became available	
21	1988: Separation of National rail authority from the operator SJ	
22	1989: Tests with first X2	
23	1990: Commercial service with X2	

Table Comparison of the time it took to develop X2 and Regina trains