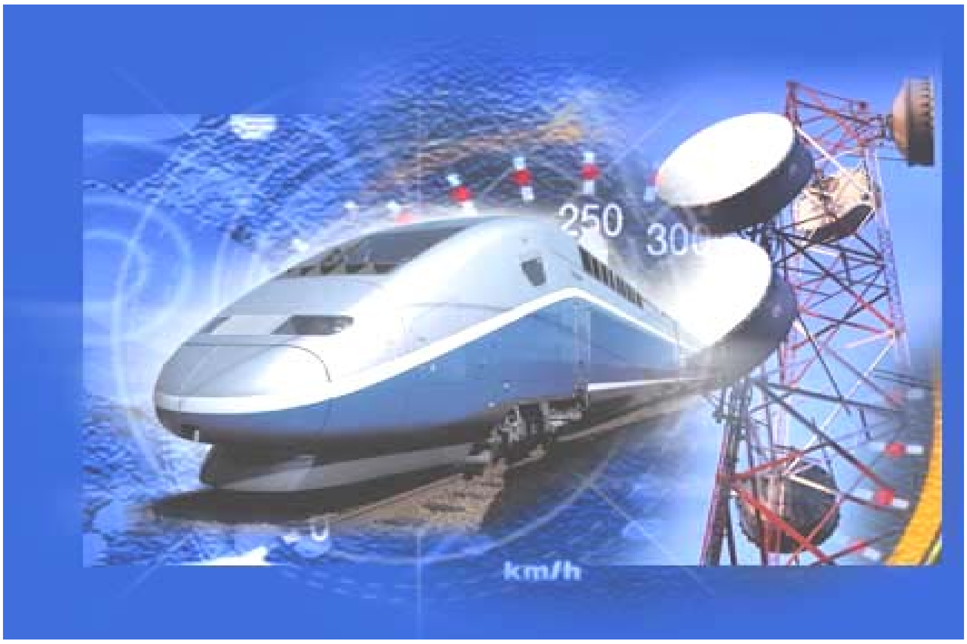

Managing Systemic Innovations in Rail Systems: The case of ERTMS technology

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ABSTRACT

Interoperability has become a keyword in the European Transport Policy, with the strong objective to improve transportation services. In the rail sector, this trend is embodied in technological innovations: A deep change in the communication and signalling system is taking place with the new ERTMS projects (European Rail Traffic Management System).

This new technology will constitute in the future an important improvement of performances of the rail transportation system, in term of interoperability between railways networks, in term of capacity and in term of traffic management. Such a systemic innovation is however a big challenge: It impacts equipment of infrastructures, rolling-stock, control centres as well as operating rules. Introducing such changes on a complex rail network with high traffic density is not an easy task: How implementing disruptive technologies in an incremental manner?

After a short presentation of ERTMS and its expected benefits, this paper examines the stakes of such an innovation through a case study approach, based on the recent experience of SBB and of the Industry (Swiss experience and international overview).

Keywords: Rail systems, Interoperability, new technologies, signalling, ERTMS, ETCS.

Table of contents

1. Introduction

In the past decade, the globalisation of the European Transportation Market has increased, with numerous merges of transportation industries as well as shipping actors or transport operators. This leads to an increased competition between transportation modes, where “national barriers” (in terms of standards) are falling down with a view to improve the whole European system performance.

In this way, the European community put more pressure on Railways to accelerate their harmonisation, as the rail system is suffering the most of national differences and barriers (in comparison to Airlines and Road). The European Rail Traffic Management System (ERTMS) is a systemic innovation which purpose was to set a new European standard, allowing trains to cross borders easily and therefore increase the competitiveness of railways on international corridors for freight and passengers.

ERTMS is a systemic innovation, in the signalling technologies impacting onboard and track-side equipment, communication technologies, control centres; but also operating rules and the complete certification process (safety issues).
Managing innovation is therefore a critical issue, in order to meet planning, quality and reliability targets. Moreover moving from national technologies toward ERTMS means to be able to deal with the transition from the current technologies to the new one. This last aspect is probably the most critical, as for railways the superposition of those technologies will add the difficulty to ensure the transition meanwhile the interference between both technologies has to be avoided. The work is therefore much more complicated than just implementing the new technology on a new track only, as at the beginning the network is still fitted with the former technology.

Behind the challenge of the ERTMS innovation, stand together the technological, organisational and managerial issues, that can enable the success of such projects. Switzerland is a pioneer in the implementation of this innovation, and this article will point out the main issues of this experience.

2. ERTMS: Technological innovation & Transportation services

2.1 History of 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)[1] 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 (EUROCAB)
- 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 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.

2.2 The key benefits of the ERTMS innovation for operators[2]

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.
- 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).

[1] UIC: Union International des Chemins de Fer, ERRI: European Rail Research Institute
[2] J. Poré, *ERTMS/ETCS; Investments and migrations;* IRSE Conference, London Feb. 2003.

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	+

2.3 Interoperability along international corridors (and neighbourhood)

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).

The current solutions to these problemS is generally different for passenger trains and for freight trains.

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.**

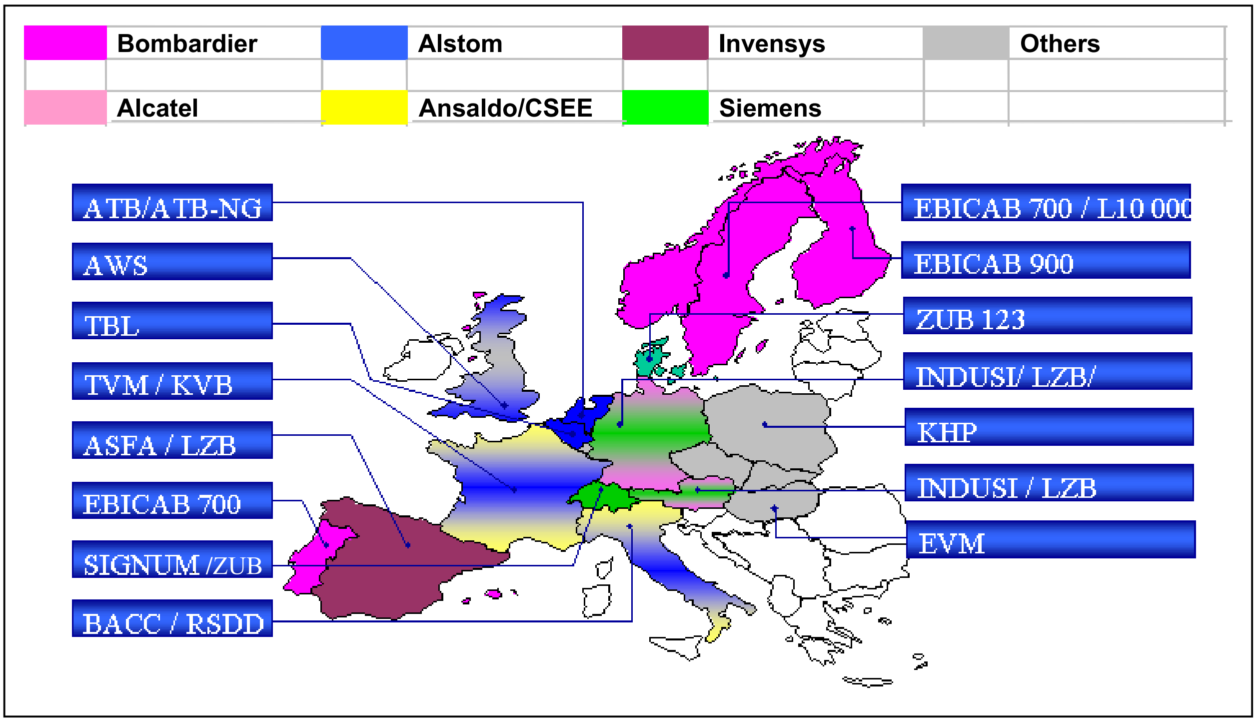

Figure 1: Different ATW/ATP/ATC systems through Europe

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.

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.

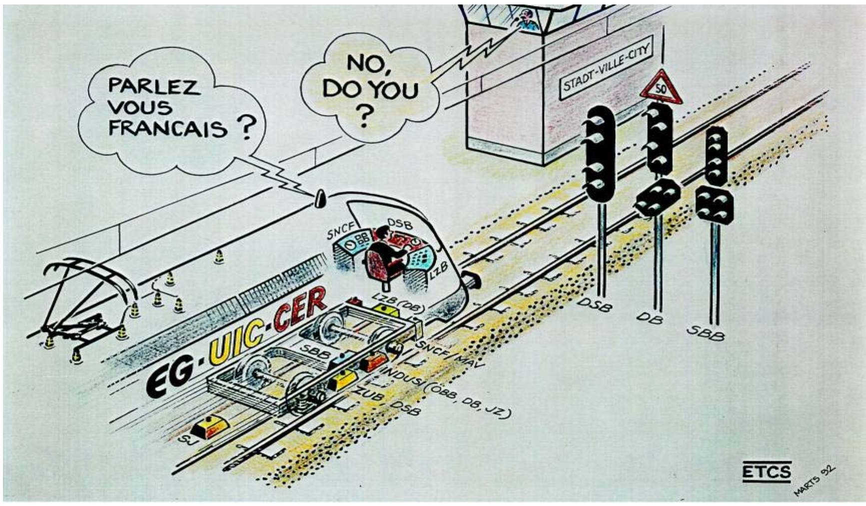

Figure 2: Comics on the problem of superposition of national systems on international corridors

2.4 Evolution of the Swiss Signalling & need of on-board signalling[3]

During many decades, signalling systems still had to be caught and decode by drivers, who finally had to obey information displayed by signals (encountered only in a couple a seconds). Safety issues was therefore a critical factor for the innovation in signalling technologies, as well as capacity issues.

The Signum system (Automatic Train Warning System –ATW) was the first in the Swiss Rail network to provide help or supervision to drivers. It allowed decades ago to significantly increase the safety with acoustic signals in cabins coupled with distance signals. However, this ATW system had no impact on network capacity. The French equivalent ATW system was the “crocodile” based on another technical concept, which of course was a problem to interoperability.

When Swiss Federal Railways (SBB) introduced new signals in the 1990’s, the ZUB system (Automatic Train Protection – ATP, with balises on the tracks) was introduced in order to control train braking curves and launch emergency barking when the train speed is to high in comparison to the maximum speed authorised.
Such a system was mainly implemented in German speaking countries, whereas in France for example it was the KVB. At least 10 different ATW/ATP systems were developed in Europe, rising a considerable barrier to Interoperability.

This system allows a high level of safety, but in terms of capacity it doesn’t fit to the future time tables for high density lines at higher speeds (200 km/h with 2min headways). This reason pushes SBB to implement ETCS Level 2:

Situated in the core of Europe, the SBB finally choose, only some years after ZUB implementation (cf. Annex 2) the brand new European Train Control System Level 2 (ETCS L2) which combines many advantages :

- 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.

This choice shows the SBB wish to contribute to more interoperability, in particular regarding North-South passengers and freight corridors.
Railways have now to have to promote interoperability and adapt themselves very fast to the new technology in order to increase their competitiveness along international corridors.

[3] See Annex 2 for more detailed explanations and examples.

3. Challenges of the ERTMS Developments

3.1 Status of experimentation and projects

Test tracks and commercial projects

The first step has been achieved to test the interoperability on EMSET and Vienna-Budapest trials. Test Track Italy has carried out trials in 2001, as well as the French test track in 2002. But one of the most significant test-campaign was 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. These test tracks provided industries and operators the experience to:

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

Finally, this test period allows operators to adjust their strategy for the ERTMS deployment on their networks. In this field the Swiss operator, SBB/CFF, leads the implementation of the ERTMS technology.

There are a number of commercial projects at varying stages (Figure 4) like Mattsteten-Rothrist (CH), the West Coast Main Line (UK), the High-Speed Line Zuid (NL), Rome-Naples (I), Berlin-Halle-Leipzig, Athens and Madrid - Lleida, that have been awarded and partially financed by the EC.

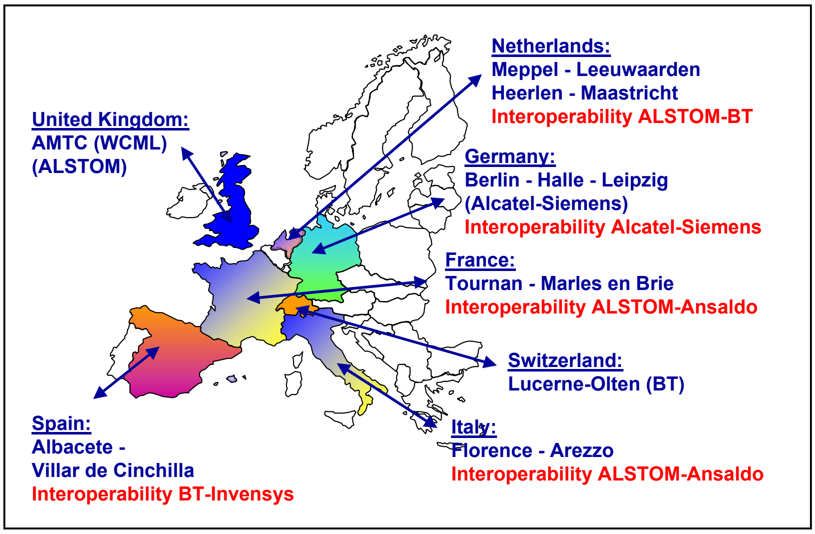

Figure 3: ERTMS test tracks (source: J. Poré/ATIS)

SBB leading the deployment of ERTMS :

SBB has achieved the most complete tests, and it has since 2002 launched the first commercial project for the SA-NBS line (Mattstetten - Rothrist). With its experience acquired on the pilot line, SBB is actually the operator who acquired the most experience in the operation of ERTMS systems: It now operates its line in Level 2 (see annex 3). The SBB Pilot Line is a 35 km of track; where 140 trains/day are in operation with a max speed of 125 km/h.

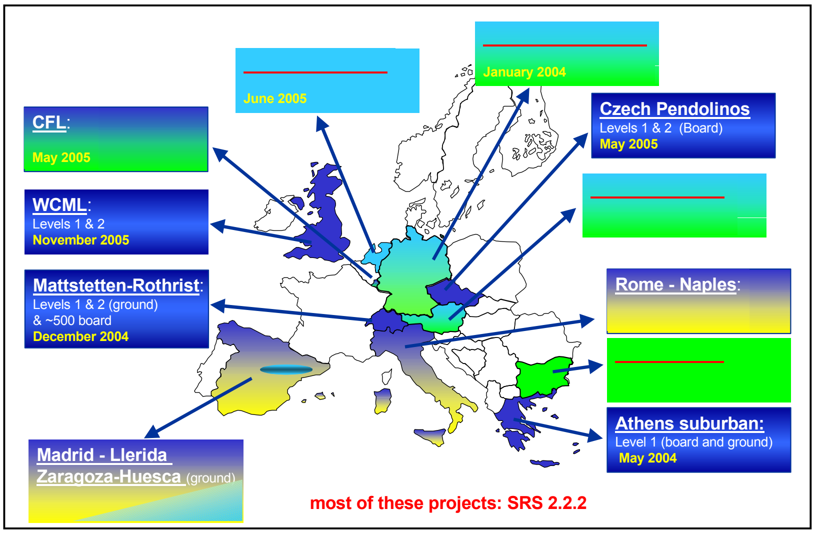

Figure 4: ERTMS Commercial projects (source: J. Poré/ATIS for the UNISIG presentation)

The test line does not comply with UNISIG V2.0.0. but uses a subset of messages based on SRS 5A. ETCS functionality was simplified for this first step (Lineside shunting signals are provided at stations). The purpose of this pilot line was to test the system before going straight to Bern - Olten.
The project was also a Pilot for the processes of CENELEC safety approval, which had not been used by SBB before.

The project was also a major training opportunity for drivers, and provided to SBB and to the industry the experience about technological and organisational aspects (through a common working group leaded by SBB).

3.2 Innovation, experimentation and learning curve

ERTMS technology is a technological innovation in the rail networks, based on new generations of the generic technologies such as GSM networks, electronic etc. This new system constitutes a radical innovation in the Signalling business, as the current national signalling systems has progressively to be removed for the ERTMS implementation on international corridors at least.

To succeed in Radical Innovations such ERTMS, actors must deal with the following challenges:

- Mastering the generic technologies ("infratechnologies")
- Handling the systemic architecture of the new technology (ensuring that the architecture and its interfaces are working successfully)
- Deploying the new innovation and develop an efficient learning process which goals is to rapidly set the technology to a sufficient mature stage.

Taking the example of the SBB Pilot line Zofingen-Sempach, this experience provides for the operator and the industry a good knowledge of the ERTMS implementation (see Figure 5). The learning curve includes both technological, organisational and knowledge management aspects.

For instance, the pilot line allowed the test of ERTMS components as well as operational rules and scenarios. The test runs allowed the improvement of the training of teams involved in the operation of the line (drivers, technicians, maintenance teams) through an appropriate "failure reporting & management organisation".

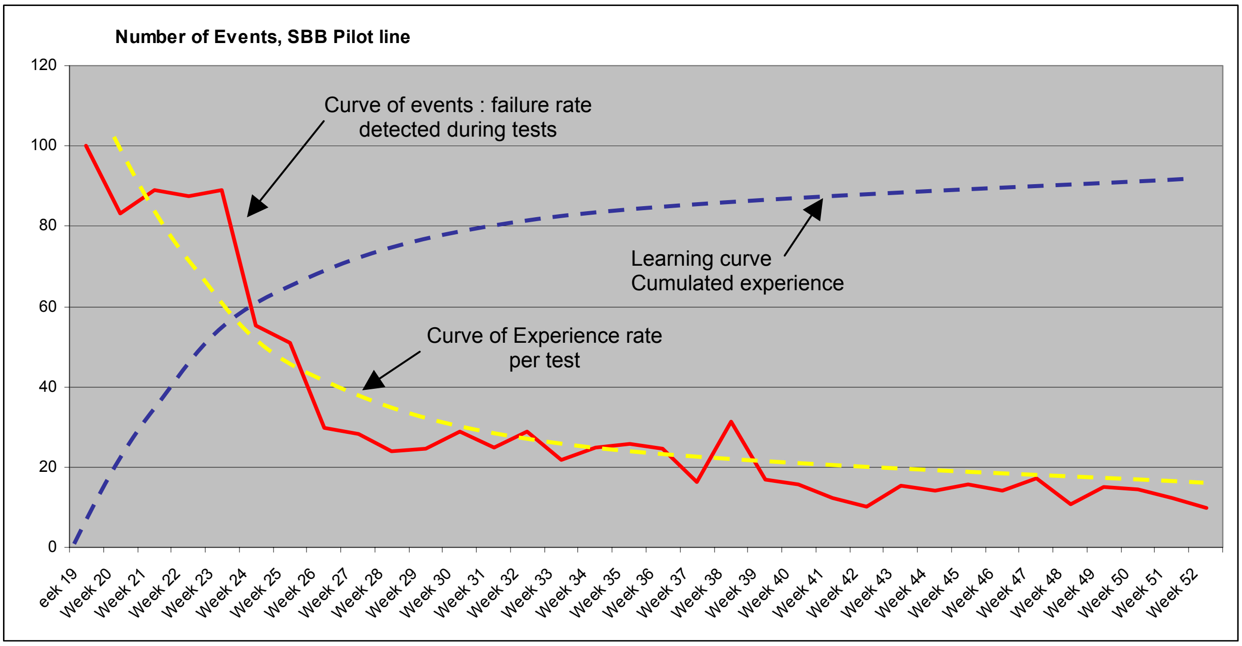

Figure 5: Learning curve based on the indexed number of failures detected during tests in 2002 (SBB pilot line Zofingen-Sempach – Source of the failure rate: SBB Jan. 2003).

Failure management & learning process:
The capitalisation of learning and knowledge in the experimentation phase is critical, and must be established in a joint organisation operator-industry. SBB put in place with Bombardier a reporting team tracing all failures and events, as well as a picket team (Hotline) to be able to support technicians and drivers to solve rapidly degraded situations.

Such a reporting and help-desk support team allowed a good learning process: In the pilot-line experience, the beginning of operation rapidly point two facts:

- Human failure & Mishandling was a critical issue for the 3 first months of the new system operation: personnel and drivers had difficulties to handle degraded situations. The main action should be to increase their training (problem of time and resource constraints).
- If the experience allowed to rapidly fix recurrent problems, in such a complex system a lot of failures happen only once every 1'000 or 10'000 trips, and their localisation is much more complex.

However, the reliability target fixed by SBB is about to be reached, even with 2 or 3 month delay. Now further analysis of the pilot line system design, processes and operation difficulties are under way in order to decide which improvement can be done such as an upgrade of this line to the SRS 2.2.2 ERTMS standard (see §3.3).

However, one of the biggest issue for operators is related to networks constraints: As corridors are usually in operations, the implementation of the new technology mustn't impact current operations. So the major challenge consist in working out strategies where the transition phase guaranties a minimum of disturbance (reducing risks during the learning phase).
In this matter, the SBB management opted for a "full insurance" strategy for SA-NBS (Mattstetten-Rothrist line) with the deployment of ERTMS temporary coupled with lineside signalling has backup for a transitory period. The investment of this backup is 31 Mio CHF, and it will allow to ensure that the maturity threshold of the new system will be reached without problem.

As Innovation brings inherent risks, other countries preferred to wait for more defined standards or more proven products before launching projects. For some of them, other arguments such as the competition with the technologies they developed is also behind, such as KVB in France or LZB in Germany: The networks which have been equipped in the last decade should be yet upgraded to ERTMS in the next future (investments conflicts).
Behind such arguments stand the problem of standard differences, where actors still fight to maintain their own standards as much as they can. But if ERTMS is already the future de facto standard, there is still work to be done to work on the shadow zones, which are now remaining.

3.3 Innovation and standardisation

If the innovation process for ERTMS was leaded 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.

Evolution of specifications and standards (Figure 6)

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.

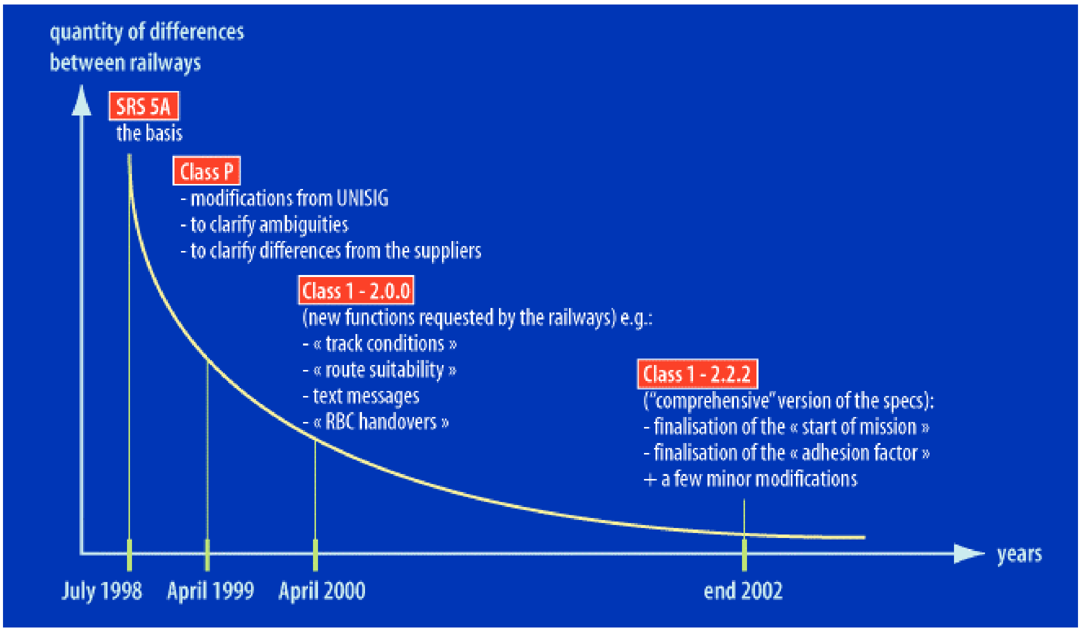

Figure 6: Standardisation process for ERTMS since 1998

Therefore, 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.

3.4 *The main challenges of the Swiss ERTMS experience*

An ambitious project of SBB:

Except Switzerland, ERTMS Pilot tracks were mainly done through projects separated from commercial operation constraints. Such test projects were all together really less significant that the Swiss Pilot line: they represent less than a total of 10'000 runs (non commercial operation), whereas the Swiss pilot line is now reaching 42'000 runs in commercial operation (140 trains per day).
Therefore, SBB is challenging simultaneously the testing phase of a new technology (which specification was not yet frozen), and its implementation on a line supporting daily commercial operations. This projects and especially both scope and planning were very ambitious.

Migration of the lines to new ERTMS standards

Understanding the complexity of innovation is difficult without reference to technological trajectories and compatibility between existing and new technologies (notion of path dependency). In the rail network, introducing a new technology (ERTMS) on a new track is one thing, but a large part of the difficulties comes from its superposition on the current technology (ZUB) in order to ensure the transition: Trains fitted with ETCS must run on other lines fitted with ZUB on other part of the network. Therefore, the problem of interference between the two systems which, increases the complexity and is the source of additional problems that must be handled during this transition phase.

Innovation and the certification/approval process
In railways, certification and approval process is costly and resource consuming for industries that have to make this in each country. In the case of Innovation, procedures have to be tailored and redefined by assessors (BAV in Switzerland, working closely with SBB). If for the Pilot line, the certification process was reduced, and generic safety cases were developed, but with limited opportunities for reuse (due to the recent standard update).
The SBB Pilot line project is a first experience for the processes of CENELEC safety approval, which had not been used by SBB before. Even with the new SRS specifications, the reuse of the approval processes and the use cases for the new HS line will be possible.
Finally, the great opportunity of the ERTMS standard will be to facilitate this process and decrease the costs related to such procedures, as in the Rail market, certification of products is mandatory in each country.

Risk mitigation & the “fallback” solution
If people in charge of the ERTMS deployment at SBB (XP) were rather confident in the system performance for SA-NBS, the SBB top management preferred to invest CHF 30 Mio more in a fallback solution. This consists in adding on the SA-NBS line a line-side signalling, which can be activated if problems of ERTMS arise, in order to ensure commercial operations in due time (End 2004).
However such a decision implies to implement both systems in parallel (the fallback), but extended tests has to be done to be sure that the fallback equipment doesn’t interfere with ETCS (cross-talk between antennas, or with beacons).

Main challenges for industries and operators
"The main difficulties in the profession came firstly from the fact that so many railways and suppliers had to work together, to exchange ideas that they were not used to share or to discuss with others. A common language had also to be used, in most cases English, but not all people were speaking and understanding the words and meanings in the same way. In short there has been quite a long learning process. This had probably been one of the (if not THE) major reasons for the somehow long development time of ERTMS/ETCS.
Other difficulties came from the necessity to get a consensus on most matters being discussed. This had been the case for standardisation (i.e. in CENELEC) and in UNISIG, ERTMS Users' Group, AEIF, etc.
The existing situation, the installed base for each railway in signalling in general and for ATC/ATP more specifically mean also that the migrations paths will necessarily be different between one country and another one. This fact may have already handicapped test projects; it will also be of paramount importance for the development and subsequent implementation of commercial projects.
The aspect of technology evolutions, past, present and future, has and will also influence ERTMS/ETCS. One such aspect concerns, from Level 2, the introduction of radio transmission for railway signalling i.e. GSM-R. The reliability of GSM-R, its implementation aspects, the ways to use and to maintain it are major points that are new for railways to work with.

4. Conclusion

The future of ERTMS/ETCS
ERTMS/ETCS is now coming as the new standard, increasing safety and capacity of railways in the long run. Various goals bring ERTMS/ETCS to the railways, one of which is to decrease national barriers on international corridors, as well as the higher cost of having simultaneously to many

different standards. The main objectives for the rail industry is to increase its competitiveness towards air and road.
The vision is to operate all high-speed lines and most other conventional lines through ERTMS/ETCS in Europe; plus several ones outside Europe as well. However, each railways fixes its own priorities, and will therefore find its own implementation strategy.

SBB as a lead-user
Among the 7 countries[4] that have launched ERTMS test track projects, the Swiss ERTMS experience driven by SBB is the most important, with the Pilot-Line and the current SA-NBS project. This advance in the implementation of this technology is due to the Rail 2000 and NLFA objectives, planning high density lines with high-speed: ERTMS is the only way to keep the 2 min headways planned in the time schedules.
As a pioneer, SBB will fix the de facto standard for specifications that were still unclear, and ask for change request at UNISIG. But leading this innovation deployment also induce more youth defaults to handle: Other operators are now looking at the Swiss experience to learn about technical and management issues in order to handle such transition/migration in the best way. This experience was a major test in operational conditions, providing also a significant training opportunity for design and technical teams, as well as for SBB drivers.

Managing systemic innovation
The Swiss ERTMS experience underlines the challenge of managing systemic innovation: SBB and industries are working together to implement this new technology, and more than only a technological challenge they also realise that major issues are related to organisational and management issues. Their efforts to try to implement an efficient project management and mitigation actions are a key issue in order to reduce risks for the transition/migration phase.

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ANNEX 1: List of key words and abbreviations

ATC: Automatic Train Control
Main Aim : Manage braking (and in some case throttle) in order to keep up specific speeds

ATW: Automatic Train Warning System
Main Aim : Remind the driver of restrictive indication

ATP: Automatic Train Protection System
Main Aim : Perform Emergency braking in case of exceeding specific speeds

BAV: BundesAmt für Verkehr (Federal Office of Transport)

DMI: Driver Machine Interface (on board equipment, interface for the drivers)

EC: European Community

ERRI: European Rail Research Institute

ERTMS: European Rail Traffic Management System

ETCS: European Train Control System
Main Aim : Common ATP/ATC System through Europe

GSM-R: Global Standard of Mobile communication – Rail

HSL: High Speed Line

IXL: Interlocking

KVB: Contrôle de Vitesse par Balise (Beacon based Speed Supervision)

LZB: Linien ZugBeeinflüssung (Continuous Speed Control)

MMI: Man Machine Interface (on board equipment, interface for the drivers)

NBS: Neu Bau Strecke (New High Speed Line)

NLFA: Nouvelle Ligne Ferroviaire Alpine (New alpine tunnels)

SBB : Swiss Federal Railways (SBB/CFF/FFS)

SFR: Swiss Federal Railways (SBB/CFF/FFS)

SRS: System Requirements Specification

UIC: Union International des Chemins de Fer

XP: SBB Infrastructure Division eXtended Process

ZUB: ZugBeeinflüssung (Train Supervision)

Continuous protection : train speed is checked permanently on the whole route

Point protection : Train speed is checked only at specific locations (mainly at main signal)

Semi-continuous protection : Train speed is checked permanently on specific parts of the route (mainly between distant and main signal)

ANNEX 2: Evolution of the Swiss Signalling & need of on-board signalling

During many decades, railway drivers had – and still have - to catch, decode and obey information from each lineside signal encountered in a couple of seconds.

No help or supervision was provided to the driver until 1933, when a major accident decided the SBB (Swiss Federal Railways) to introduce an Automatic Train Warning System (ATW) named Signum.

a) ATW/ATP system Signum

Coupled with a distance signal showing a warning indication, the Signum produces an acoustic alarm in the driver cab (ATW). The driver must answer back within the next few seconds in order to avoid an emergency braking.

Coupled with a main signal showing a stop indication, it immediately performs an emergency braking. In this case, it acts as an ATP system. However, start to brake only at main signal hardly avoid reaching the place to be protected. Signum is not a safety device because it is not built according to the fail-safe principle. Moreover, obeying signalling remains the entire driver's responsibility.

Nevertheless, his introduction has **significantly increased** the train operation **safety**. In lots of critical situations, this system has prevent bad consequences of drivers mistakes.

Since 1933 this system spread over the network. Nowadays, about 12,000 SBB signals are equipped with the ATW Signum system. As shown in figure 7, the introduction of the Signum only occurs tens of years after the first development of complex interlocking. One of the raisons is that interlocking – including block-system – is beneficial to both railway safety and capacity. In the first place, its development reduces drastically the causes of misunderstanding between operators (station managers, point-men, and signals-men). Secondly it speeds up route locking/release and reduces headways. On the other hand the Signum system has **no impact on capacity**.

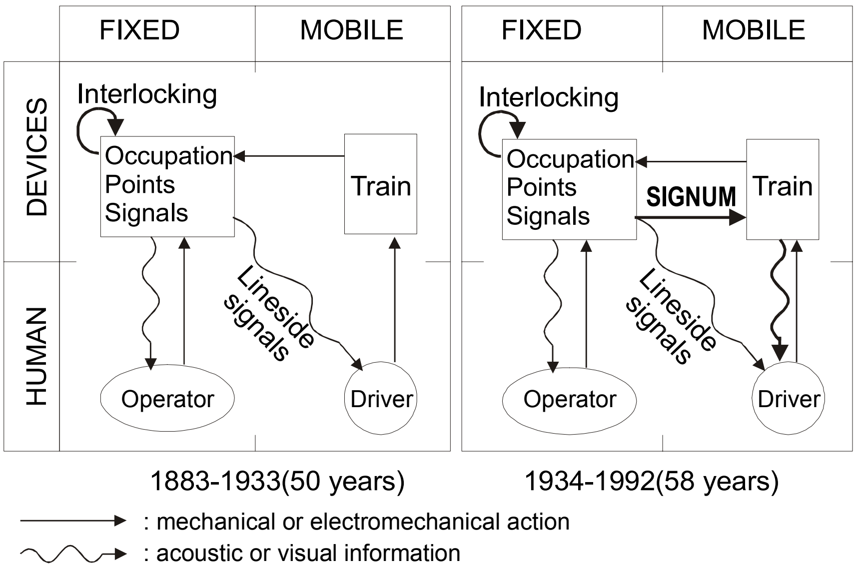


Figure 7 : A century of safety installation by the SBB

Based on an inductive technology, Signum could have been adopted by the French Railways. But, they generalised the "crocodile" system based on a physical track/train contact: one additional **obstacle to interoperability** was so added to the list !

b) ATP system ZUB

Noticing that the driver's response to the Signum acoustic signal indicating a speed reduction could become a conditioned reflex, giving no guaranties that the driver will really brake, SBB have tested an **ATP** system, the "ZUgBeeinflussungssystem" (**ZUB**).

ZUB makes use of beacons to supervise more specifically speed reduction and untimely departures. Coupled with a distance signal displaying a warning indication, the ZUB calculates two braking curves. As soon as the lowest one is encountered, an acoustic signal remember the driver he has to brake. If no action is undertaken in time, the second curve will probably be crossed, setting off an immediate emergency braking (ATP). The ZUB system is not a safety device because it is not built according to the fail-safe principle. Moreover, obeying lineside signalling remains the entire driver’s responsibility.

The driver must introduce some characteristics of his train in the ZUB device before its first running but ZUB needs no care during the progress of the train. Nowadays, about 2,000 SBB signals are equipped with the ATP ZUB system. The ZUB system was simply added to the Signum one.

A permanent supervision of the braking process usually avoid entering a danger zone. So, the **safety is guaranteed at a high level**.

In order to maintain capacity as the same level than before, in particular in degraded operation, ZUB require the introduction of some additional signals, beacons and cable loops. On the whole, **headways are not reduced by the introduction of ZUB**; they could even become larger.

ZUB has also been introduced in Germany, Austria and Denmark, but French Railways developed their own beacon based ATP system (KVB). Some other countries have also developed or installed other ATP systems. In addition to ATC-like systems (TVM and LZB), West Europe counts more than 10 different ATW/ATP systems, rising a considerable **barrier to interoperability.**

c) Swiss new signals

At the beginning of the nineties, the SBB introduce new signals. With only one light bulb shinning at the same time and possibly an auxiliary figure, signal information could be read and interpreted in a simpler way than before.

Old : Due to bad weather conditions, tiredness, lapses of concentration, the risk of confusing signals, misreading or misinterpreting their indications was great.
5/3* : Proceed at speed of 90km/h passing signal,
preparing to proceed at 60km/h at next signal
3/5* : Proceed at speed of 60km/h passing signal,
preparing to proceed at 90km/h at next signal

New : To reduce the risk of misreading or misinterpreting a indication, the number of signal lights is reduced to 3 (one per colour). A auxiliary yellow figure could give additional information on speed. Only the most restrictive speed is displayed.
5/3* : no reminder to proceed at speed of 90km/h passing signal,
but preparing to proceed at 60km/h at next signal
3/5* : Proceed at speed of 60km/h passing signal, but no information
about next signal

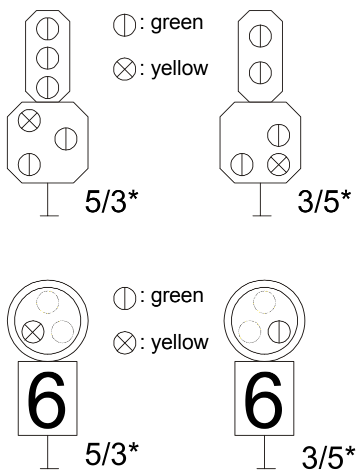


Figure 8: Example of misinterpretation of signals

This significant improvement of lineside signalling could cope with high speed as the braking distance could cover many block sections. However, high speeds in bad weather conditions could prevent the driver to read signal information correctly.

d) Need of onboard signalling for the "Rail 2000" SBB key element

The nationwide timetable project "Rail 2000" gave SBB the opportunity to search for a new signalling system, which offer simultaneously high level of safety at speed up to 200 km/h and headways down to two minutes.

Actually, the coordinated periodic timetable "Rail 2000" is based on travelling time just under a multiple of the time interval between trains linking two main railway stations, in order to offer connections from everywhere to everywhere at specific moments. To fulfil theses objectives, a new section of line is being built between and at Bern and Zurich, two main Swiss cities. The running time constraint demands a **speed of 200 km/h** on the new line, and good connections for a maximum of train in both stations requires **two-minute headways**.

Conventional lineside systems could hardly offer a good solution regarding safety and capacity as well. First, bad weather conditions can prevent the driver to read signal information at 200 km/h correctly. A new system for signal repetition directly in the cab would have to be provided, given that neither Signum nor ZUB could safely offer this functionality. On the other hand, two-minute headways could theoretically be obtained, but a slight delay of the first train will strengthen significantly the delay of the following ones.

Security and capacity, in strong correlation with **timetable stability**, were the two main reasons that have decided SBB to choose an onboard signalling system for the "high speed"(more than 160 km/h) lines.

Located in the core of Europe, SBB has finally chosen, some years only after ZUB implementation (cf. **figure 9),** the brand new European Train Control System Level 2 (ETCS L2) which combines many advantages :

- long term compatibility with other European railways by means of Eurobalise beacons;
- on board signalling by use of radio transmission with the GSM-R protocol;
- minimum amount of devices in the track, which reduce time and costs for track maintenance.

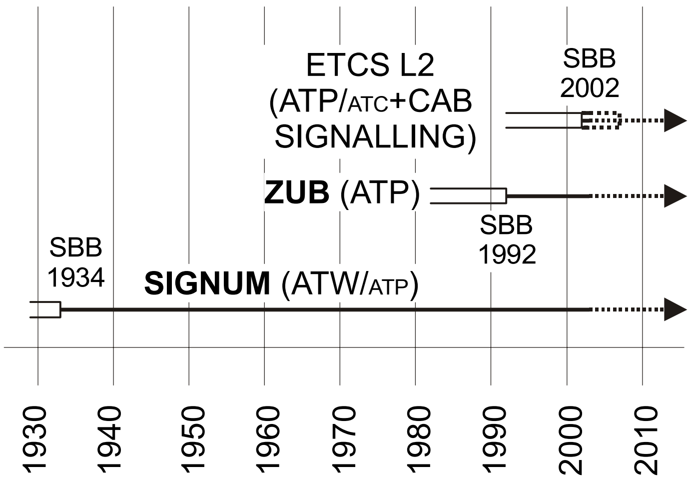


Figure 9: Evolution of ATW/ATP/ATC systems in Switzerland

This choice shows the SBB willingness to **increase the interoperability**, in particular regarding North-South passenger and freight corridors.

Railways have now to adapt themselves very rapidly to new technology and to promote interoperability in order to increase their competitiveness along international corridors.

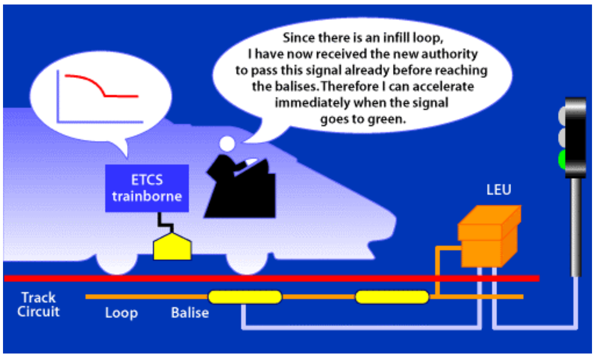
ANNEX 3: What is ERTMS

The European Rail Traffic Management System has been defined in 3 levels (presentation J. Poré – ALSTOM/UNISIG):

Level 1:

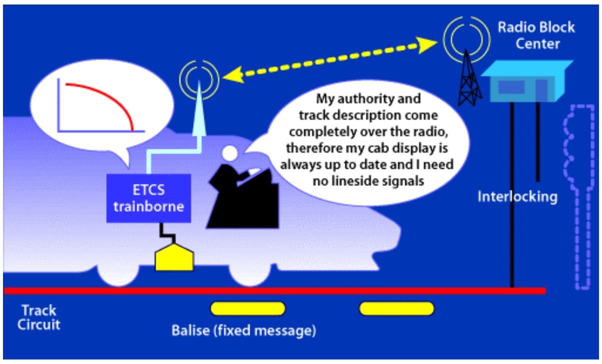
A. Eurobalises

- Overlay to Existing Signalling System.
- Movement Authorities through Eurobalise.
- Train Integrity & Position by Track Circuit.



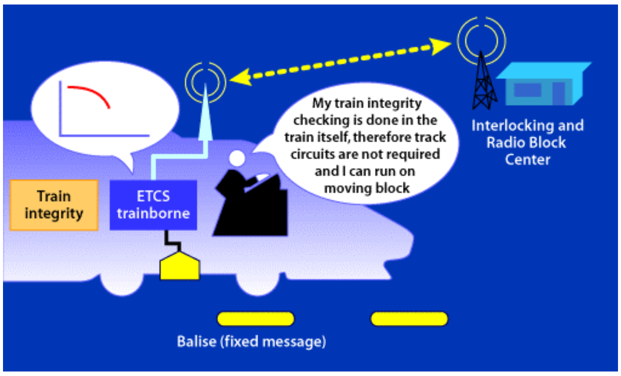
B. Eurobalises with unfill (Euroloop or radio or extra balises)

- Overlay to Existing Signalling System.
- Movement Authorities through Eurobalise.
- Train Integrity & Position by Track Circuit.



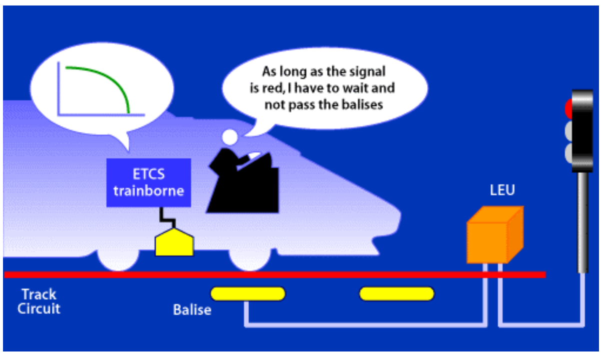
Level 2: Eurobalises + Euroradio (GSM-R) + RBC

- No more Trackside Signals Required.
- Movement Authorities through GSM-R.
- Train Position via Eurobalise.

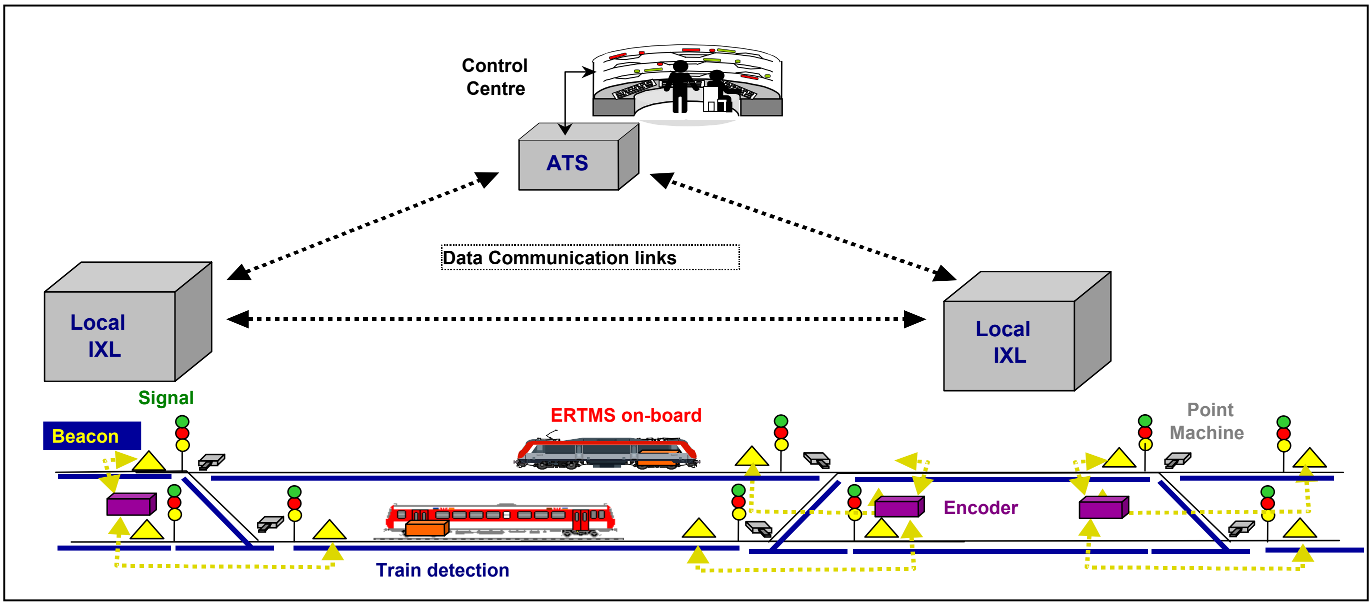


Level 3: Eurobalises + Euroradio (GSM-R) + RBC

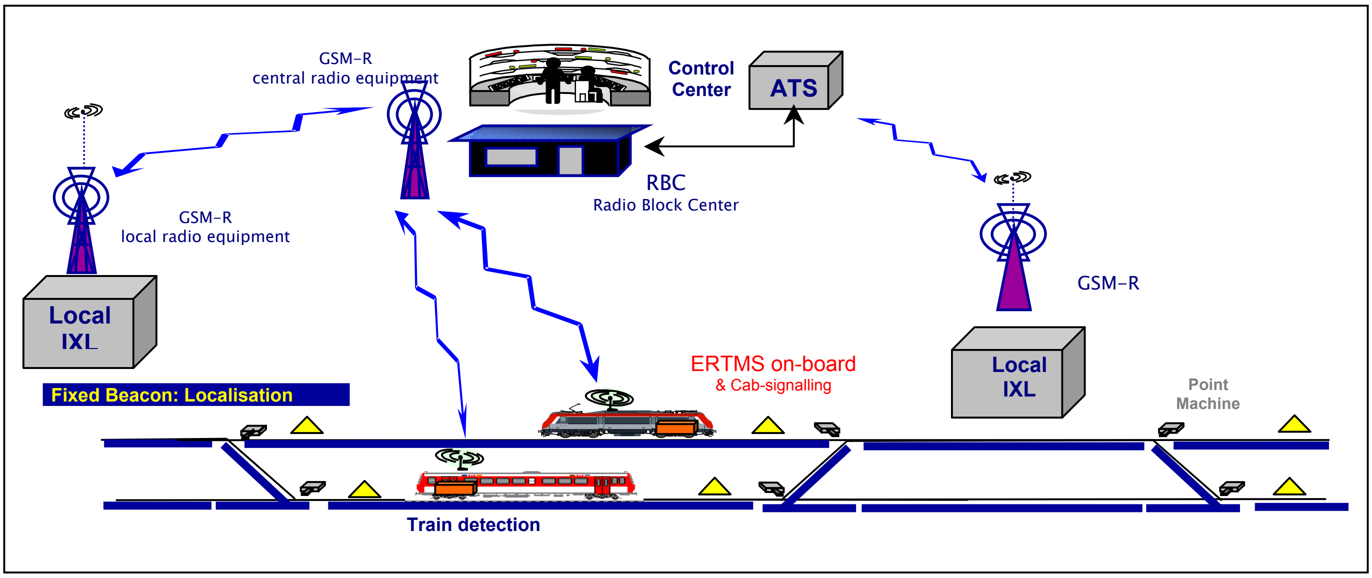
- Movement Authorities through GSM-R.
- Train Position via Eurobalise.
- Train Integrity Onboard. Moving Block.



ERTMS Level 1:



ERTMS Level 2:



ERTMS Level 3: