How capacity issues in large urban commuter networks in Europe are addressed by implementing modern train control systems

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INTRODUCTION

This paper provides an overview of the latest trends in Europe regarding the use of modern train control and signaling systems, such as Communication Based Train Control (CBTC) and the European Rail Traffic Management System *(*ERTMS), to resolve capacity issues in large urban commuter rail networks.

In addition to the various technical considerations, a transit agency's decision of whether to implement CBTC or ERTMS involves many factors, including: the operating needs of the railway, Life Cycle Cost, the risk tolerance of the agency and stakeholder management. Each of these factors will be discussed in this paper, and illustrated by actual re-signaling projects that are being installed across Europe.

Meanwhile in the US, transit agencies that own and operate large commuter rail networks have implemented, or are in the process of implementing, Positive Train Control (PTC) systems as mandated by the US congress in the U.S. Rail Safety Improvement Act of 2008. Although this legislation was implemented to improve safety, this paper will explore whether there any lessons learned from Europe that might be considered as a means to also improve capacity.

CBTC AND ERTMS OVERVIEW

CBTC and ERTMS are the latest generation of train control systems which are rapidly replacing conventional signaling systems all over the world and almost systematically implemented for new lines This latest generation of train control systems uses less wayside equipment, bringing more intelligence onboard the trains and using radio based communication media to transmit signaling data between the trains and the wayside computers.

Even though CBTC and ERTMS have similar architectures, they have been designed for different purposes.

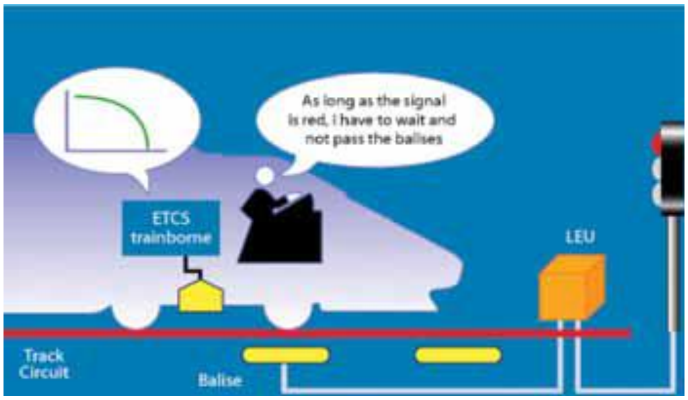
CBTC systems have been developed mainly to address capacity issues for metro type systems whereas ERTMS was designed as a standard system to address interoperability issues for cross-border service between European countries.

However, more and more, since ERTMS has become a standard product it is also chosen to reduce Life Cycle Cost (LCC) and in some cases to resolve capacity issues.

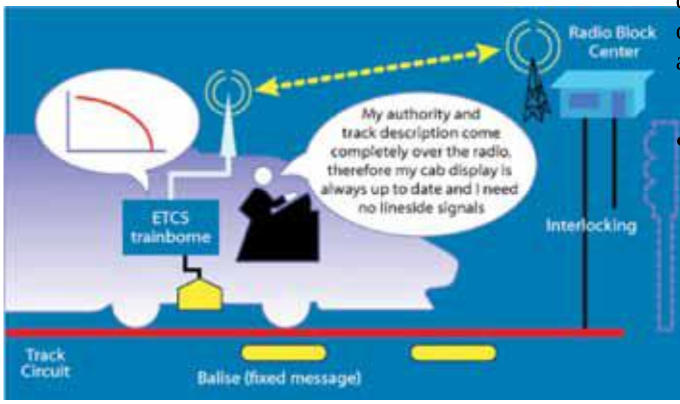
ERTMS system overview

ERTMS is an initiative started in the early 90s by the European railway industry to design interoperable train control systems in order to facilitate main line passenger and freight train movement from one country to another – eliminating the need for train operators and infrastructure managers to equip trains with multiple, national and legacy systems or switch locomotives at the borders. ERTMS is being offered in three different product levels with varying degrees of functionality:

- ERTMS Level 1, which provides a simple signal enforcement protection via a balise or a loop.



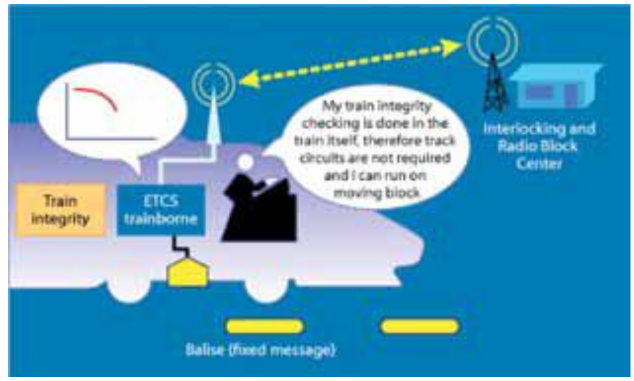
- ERTMS Level 2, which provides safe train separation and over-speed protection via movement authority information transmitted from the trackside to the train via GSM-R:



In theory, ERTMS level 2 would allow the removal of wayside signals as all the signaling information would be available onboard via a train driver display. It is noted, however, that ERTMS level 2 still uses the track circuits or axle counters for the train detection and for the train integrity monitoring function, unlike CBTC or ERTMS level 3 (see below).

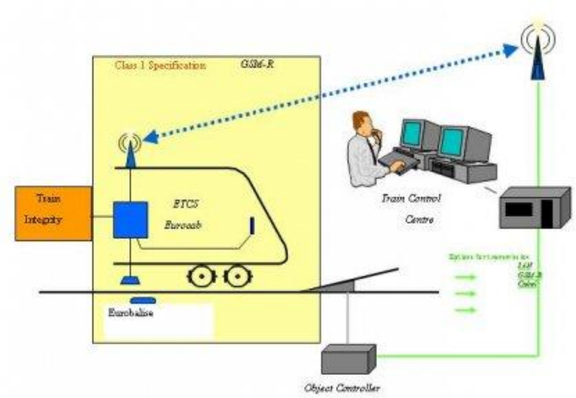
The train position is calculated by the on-board equipment for speed and movement authority control

- ERTMS Level 3 is similar to ERTMS level 2 except that the train detection function does not rely on track circuits but on the position calculated by the onboard equipment (as with CBTC):



The full version of ERTMS Level 3 is still in the development phase and has not been implemented yet. However a variant of ERTMS Level 3 called “ERTMS Regional” has been implemented in Sweden for a low density line (Västerdal Line). In this case the main reason of this implementation was the reduction of O&M cost and safety improvement.

- ERTMS Regional concept:



The concept of ERTMS regional is based on a centralized and combined interlocking / RBC (ATP) functions connected to a TCC (Control Center system). The TCC controls the field equipment via object controllers either thorough GSM-R of other media. The trackside and centralized equipment are compatible with trains equipped with ERTMS level 1 or level 2. Track circuits and signals between interlockings can be removed as the train calculates its own position. Only at a few locations track-circuits or axle counters may have to be installed for the train integrity function.

CBTC system overview

CBTC systems have been developed mainly for metro type networks to improve capacity and safety. Unlike ERTMS, CBTC has not been designed to be interoperable. Each CBTC supplier provides a unique solution with similar performance and functionality. CBTC systems can be rolled-out as an overlay of an existing track-circuit based signaling system or as a complete stand-alone system with no or limited fallback.

By default, CBTC systems are supplied with a high level of automation such as automatic train operation (ATO) and automatic train supervision (ATS) providing advanced regulation functionalities. These features significantly enhance the flexibility of operations.

The signaling industry (outside the US) shows a clear trend toward CBTC. Almost every transit agency in Europe and Asia chose to install CBTC to upgrade their signaling or when building new lines.

ERTMS and CBTC comparison

As discussed earlier, ERTMS and CBTC have been designed for different purposes. ERTMS is typically installed on main lines (regional, national networks) and CBTC on metro applications. For the purpose of this paper we are comparing CBTC with ERTMS level 2.

Characteristics	CBTC	ERTMS L2
Architecture	Wayside, onboard, radio communication, fixed transmission and control center level (ATS)	Wayside, onboard, radio communication
Train detection	Via onboard equipment and balises	Via wayside equipment (track-circuits or axle counters)
Train/wayside communication	Proprietary or standard solutions, usually operating around 2.4 GHz or 5.8 GHz frequencies. Short transmission times.	One standard: GSM-R. Longer transmission times.
Level of automation	Included (ATO or fully driverless)	Not included in the standard solution. For some applications (Thameslink) an ATO layer is being developed.
Capacity / Headway performance	High. Can reach 30 TPH or higher.	Limited due to track-circuit train detection and GSM-R performance. Simulations show that with ATO, ERTMS Level 2 can reach 24 TPH in certain cases.
Safety	High level of safety (safe train separation, continuous over-speed protection)	High level of safety (safe train separation, continuous over-speed protection)
Interoperability	None	Fully interoperable.
Reliability, Availability and Maintainability	High level of reliability, use of redundant architecture. Advanced diagnostics functionalities.	High level of reliability, use of redundant architecture.
Traffic Management System (TMS): regulation and supervision functions (ATS / CCR)	Advanced set of functionalities, included in the product.	Not included in the standard. Each application must interface with an existing TMS or develop its own.
Maturity of the available products	High	High
Main implementation risks	Depending on the application, the main risks are: - Too many changes in the standard	Depending on the application, the main risks are: - Too many changes in the

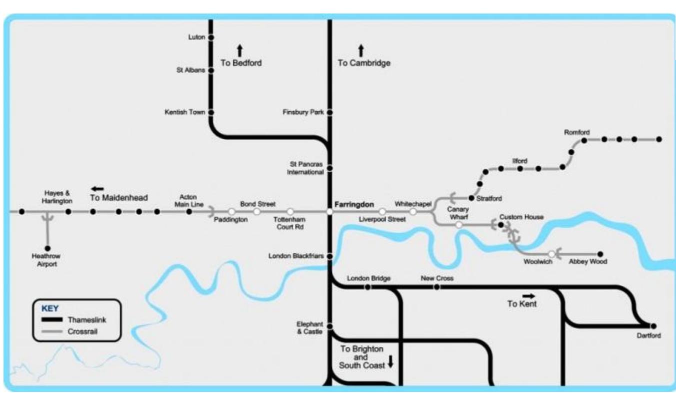
Characteristics	CBTC	ERTMS L2
	product due to specific project requirements - Onboard integration longer than expected - Migration disruptive to the service	standard product due to specific project requirements - Onboard integration longer than expected - Development of interface with existing Traffic Management System - The standard ERTMS product includes too many functionalities not used by the owner

CASE STUDIES

This section provides an overview of projects which have considered both CBTC and ERTMS as potential candidates for a new signaling system in order to improve capacity and reduce life-cycle cost.

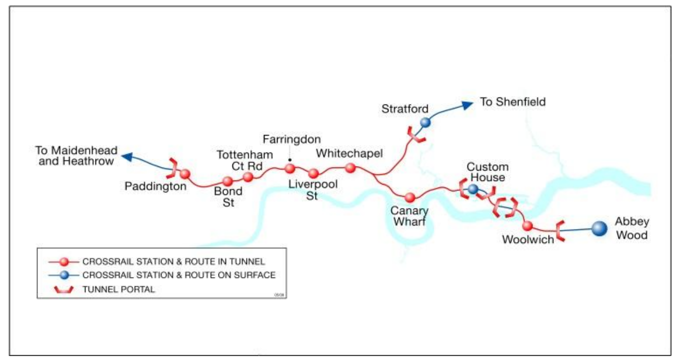
London:

In the UK, two major transport infrastructure projects are being delivered in parallel to improve the east-west traffic (Crossrail) and the north-south traffic (Thameslink) through London.



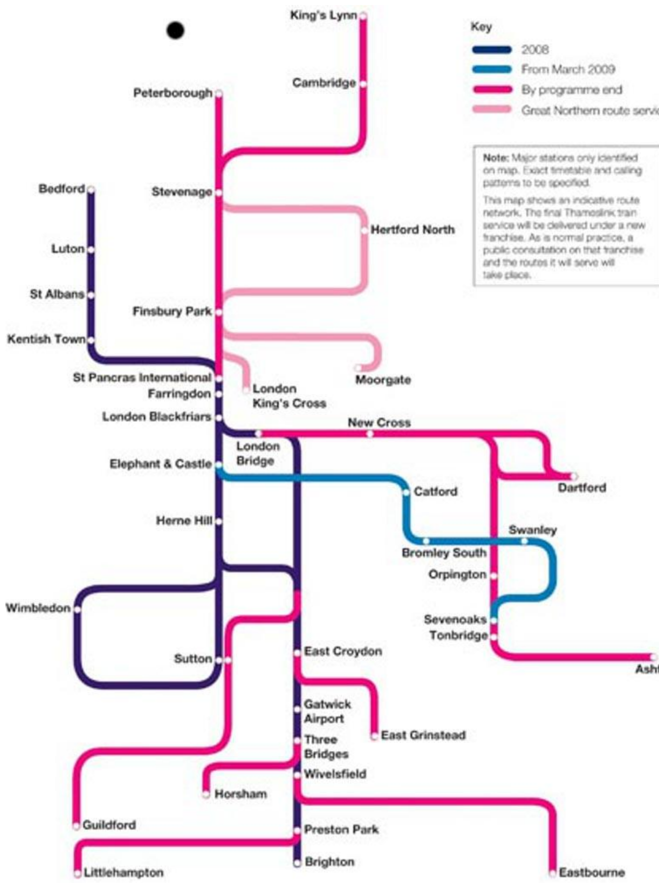
Crossrail is delivered by Transport for London (TfL) which owns London Undergound (metro), whereas Thameslink is delivered by the UK Department for Transport (DfT) in collaboration with the UK infrastructure manager, Network Rail.

Crossrail is the largest transportation infrastructure project in Europe, with total available funding of £14.8bn. It will run 118 km from Maidenhead and Heathrow in the west, through 21 km of new twin-bore tunnels under central London to Shenfield and Abbey Wood in the east. Revenue service is scheduled for 2018.



The central section of tunnel requires a 24 TPH headway with the potential to provide up to 30 TPH. The new tunnel will connect with the Network Rail surface routes. These surface routes are currently fitted with the UK legacy signaling system (AWS with TPWS); the western branch will be fitted with ERTMS level 2 in 2019.

In comparison, Thameslink is a £6bn program that affects a large portion of the UK mainline network and will offer more trains and better journeys for passengers on the existing Thameslink route running north-south through London.



Characteristics / Requirements	**Thameslink**	**Crossrail**
Characteristics of the central section	Existing railway, 4 km surface route, 4 stations	New railway 21 km tunnel, 8 new stations
Characteristics of wider network	16 services (hundreds of km)	4 services
Central section operation and headway	Dedicated new fleet, 24 TPH	Dedicated new fleet, 24 TPH
Level of automation	Automatic train operation	Automatic train operation with platform screen doors
Traffic Management System (RCC)	Several	Dedicated RCC
Future headway demands	Not known	30 TPH
Fallback signaling system for the central section	Wayside signals TPWS/AWS (legacy UK ATP system)	None
Other signaling systems fitted to dedicated trains	AWS/TPWS	ERTMS AWS/TPWS

As part of this vast program affecting hundreds of miles of track, a new signaling system will be installed in the central section in order to enable a 24 TPH headway.

These two projects have similar requirements in terms of headway for their central sections in London (24 TPH), and have similar types of interfaces with the main line network where ERTMS will be eventually installed. However. each project has taken a different direction for their choice of signaling systems.

Thameslink decided to install ERTMS Level 2 with automatic train operation (ATO) in the central section. This will provide consistency of operation by using the ERTMS technology throughout the Thameslink network.

Crossrail decided to install CBTC with ATO. The stations located in the tunnel sections will also be fitted with platform screen doors in order to control the dwell time and to operate more like a high-capacity metro.

The table below provides a comparison between the two projects:

The decisions to choose CBTC or ERTMS were not only driven by pure technical considerations. They were influenced by other factors such as outside stakeholders, railway organizations and the potential risks evaluated by each project.

With respect to technical considerations, it seems that only CBTC can satisfy the 30 TPH future capacity requirement for Crossrail, and TfL, who has significant experience in operating high capacity metro (LU) has also influenced the decision. And finally, the willingness of the project team to install a proven technology on its central section has been a determinant factor. The other alternative would have been to select an unproven solution using ERTMS Level 2 with ATO.

However, other risks emerge from this choice, such as the transition of operating modes between CBTC and the legacy signaling systems on the outer branches (TPWS/AWS). Eventually, when ERTMS is also installed on the branches, another type of transition will be required.

It is noted that provisions have been made in the Crossrail signaling contract to plan for the migration from the CBTC system to the ERTMS level 3.

Regarding Thameslink, the choice of ERTMS level 2 for the central section was mainly driven by the various stakeholders involved and the UK ERTMS rollout strategy defined by DfT and Network Rail. Once the technical hurdle of demonstrating the capacity of ERTMS level 2 with ATO to provide a 24 TPH headway in the central section was overcome, this technology was the logical choice.

Now the project needs to be fully focused on the integration risk between ERTMS and ATO – since this is the first application of its kind. An effective training program for train operators will also be required, as they will have to adapt to two operating environments: traditional mainline operation on the branches and metro-type operation in the central section using ATO.

One important aspect to be considered when choosing a new signaling system is the way in which the future railway will be controlled and regulated. Indeed the full benefits that are expected from the new or upgraded railway in terms of increased capacity, faster journey time, robustness and quick recovery in case of failure, can only be obtained if an adequate and efficient regulation tool is made available to the operator.

In some cases, railways have existing Traffic Management Systems in control centers or remote locations to control and supervise train movements. The introduction of a new signaling system in the core section of a large network raises the question of whether or not a dedicated Traffic Management System should be installed for the core section or whether the existing one(s) should be modified to interface with the new signaling system.

Paris

In Paris, the long awaited western extension of the existing RER line E (heavy commuter rail) is entering into the preliminary design stage. The EOLE project is managed jointly by the French rail infrastructure manager (RFF) and SNCF, the historical French rail operator, and in collaboration with STIF (the Paris region transportation authority).

The project is to extend the existing RER line E westward by creating a new 8 km tunnel between Haussman/St-Lazare (major railway hub inside Paris) and Nanterre (outside Paris) and to upgrade the infrastructure on 50 Km of existing line west of Paris up to Mantes-La-Jolie.

The main goals of the projects are to:

- Relieve traffic on the oversaturated RER Line A
- Provide better access to the Paris business districts from the western and eastern suburbs

The central section within Paris will be designed to operate 22 TPH initially and 28 TPH at a later date when the transport demand increases.

RFF/SNCF have decided to procure a CBTC system (code name NExT) for the central section. The fact that only CBTC can provide a capacity up to 28 TPH was a key driver in the decision making process. In addition, RFF/SNCF want to operate the central section like a high-capacity metro using ATO mode. The greater maturity of the CBTC solution versus ERTMS level 2 with ATO (only potential alternative) also played a role in the decision process.

Headway simulations have also shown that due to the topology of the line with steep gradients in the new tunnel under La Defense and Porte Maillot, ERTMS Level 2 with ATO could barely meet the 22 TPH capacity requirement. As a matter of fact, because ERTMS level 2 uses the track-circuits for the train detection function, the topology of the line can significantly impact the design headway as the braking distances have to be built into the fixed block layout – as for a conventional signaling system. The performance of the GSM-R also negatively impacts the headway performances (longer transmission times have to be taken into account).

As for Crossrail, the EOLE project will have to focus on the risk related to the transitions between CBTC and the French legacy signaling system (KVB) installed in the branches and in the future with ERTMS.

Unlike Crossrail, RFF/SNCF have planned to design a fallback system using track-circuits and wayside signals in order to move failed trains and also work trains during off peak hours.

It is envisioned that the core section will be controlled via a dedicated Traffic Management System – part of the CBTC solution. The services on the branches will be regulated by two future Rail Control Centers (RFF CCR projects) which will control two large regions west and east of Paris. Therefore the project would have to analyze the human and/or functional interfaces of the Traffic Management System on the core section and these future regional RCCs.

The main reasons for choosing CBTC were based on the performance requirements for the core section. Neither the project owners or their business culture – which is to operate main lines (regional, high speed), not metro – have influenced the choice of ERTMS. Hence there results a particular, interesting challenge for RFF and SNCF as they will have to adjust their operations and staff culture to operate the central section of EOLE like a high-capacity automated metro.

Madrid

An additional tunnel between Chamartín and Atocha stations was built in 2008 to increase the capacity of the commuter trains through Madrid. It was initially fitted with the Spanish legacy signaling system ASFA. The Spanish Civil Works Ministry has since started to install ERTMS level 2 in order to increase the capacity to at least 17 TPH and deliver a potential 24 TPH. The system has been in revenue service since March 2012.

Since the branches of the network were already equipped in ERTMS Level 1, the choice was made to stick with the same technology with an upgrade to level 2. This is the first time that ERTMS Level 2 system has been implemented in Europe, in a network with a high traffic density such as the Madrid commuter network. This is the first stage of a wider project to install ERTMS throughout the Madrid suburban network, with ETCS level 2 in the city center and ETCS level 1 in outer areas.

In this case the main factor that has determined the choice of ERTMS level 2 was the overall strategy at the national level to rollout ERTMS on the entire commuter network as it is also implemented on the high speed lines network.

Banedanmark Signalling Programme

Facing significant problems of reliability and punctuality due to near-obsolete signaling equipment on both their main line network (Fjernbane) and on the Copenhagen heavy rail network (S-bane), Banedanmark (the Danish rail infrastructure manager) concluded on a business case for a total replacement country-wide of their signaling systems.

Therefore in 2009 the Danish Parliament authorized funding for the 3.2 billion Euros “Signalling Programme”.

This program is managed by Banedanmark, in close collaboration with the different train operating companies (TOCs) in charge of train service on the different parts of the network.

In this case the choice of the new signaling system was different for the two types of network:

1. The main line passenger and freight services (Fjernbane) will be fitted with ERTMS level 2
2. The Copenhagen heavy rail transit system (S-bane) will be fitted with CBTC

The decision to choose two different systems was mainly due because the S-bane is a standalone system and does not share service with the main lines. The S-bane also operates today like a heavy rail metro (albeit in manual mode versus the future ATO mode).

The decision to install ERTMS level 2 on the main lines was mainly driven by the willingness of Banedanmark of adopting a proven and standard technical solution for the new signaling and with interoperability capabilities in order to ensure smooth cross-border service in the future with its neighboring countries, Sweden and Germany.

In both cases the choice of ERTMs level 2 and CBTC has been done with the goal of significantly reducing the maintenance costs for the life of the system by:

- Removing all existing track-circuits and wayside signals
- Specifying a minimal fallback system using axle counters and fixed signs markers
- Contracting the maintenance to the signaling suppliers for 25 years (for the infrastructure)

With this strategy, Banedanmark will be able to save at least 25% annually in maintenance cost for the infrastructure equipment.

PTC COMPARISON

PTC systems are being deployed in the US as mandated by the US Congress on all Class I railroads.

The main reason to implement PTC is to improve Safety.

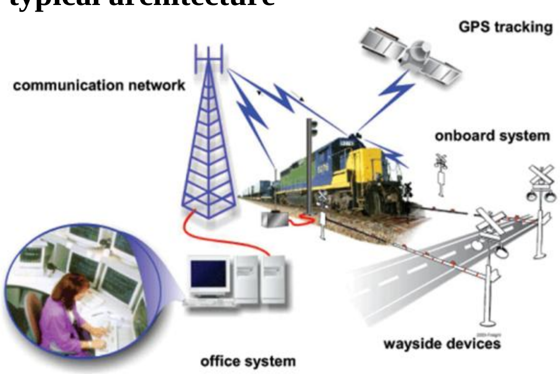
The Rail Safety Improvement Act of 2008 as enacted by Congress requires all Class I railroads and passenger rail operators to implement a mandatory Positive Train Control (PTC) systems by December 31st 2015. These systems must be installed on all main-line tracks where intercity passenger railroads and commuter railroads operate, as well as on lines carrying toxic-by-inhalation hazardous materials. The government-imposed deployment of PTC was prompted by a major train accident in Chatsworth (California) in September 2008 involving a head-on collision between a Union Pacific freight train and a Metrolink commuter train, and is intended to increase safety.

Any PTC system to be deployed must comply with the following requirements:

- All PTC systems must be interoperable
- The PTC system functionalities must prevent:
    - Train-to-train collisions
    - Over-speed derailments
    - Incursions into established work zone limits
    - Movement of a train through an improperly aligned wayside switch

PTC systems are overlays to existing signal systems (or manual block) and are intentionally not providing protection against low speed collisions when following a train.

PTC typical architecture



The PTC architecture is to some extent similar to CBTC and ERTMS:

- Back-office or central level equipment for the dispatching functions and sending the movement authorities to the trains
- Wayside computers interfaced with field elements / interlocking
- Onboard equipment
- Data communication: the current radio technology use the 220 MHz spectrum
- GPS technology for the positioning function (not the case for CBTC)

PTC differences with CBTC and ERTMS

There are fundamental differences in the design of PTC compared with CBTC or ERTMS, in particular for the radio communication and the positioning function. PTC uses the 220 MHz spectrum which seems to be sufficient–for now–to carry the required data between the wayside and the onboard. CBTC for example requires higher throughput via its communication link in order to perform its basic functions; and ERTMS has been developed around the GSM-R radio standard.

The positioning requirements for CBTC are more demanding than PTC, due to the high level of automation and specific functions such as accurate berthing at platform. Therefore GPS technology cannot be used for CBTC – not to mention the obvious that most metros where CBTC is deployed are in tunnels! On the other hand it would not be cost-effective to install transponders on thousands of miles of railroad track to perform the positioning function for PTC.

Another fundamental difference is that PTC is currently implemented as an overlay system to the existing signaling. With this approach, the capacity of the railroad cannot be increased and no cost benefits can be claimed as the railroads have now to maintain two systems. On the other hand CBTC and ERTMS can be deployed as stand-alone systems, thus enabling to increase capacity and reducing O&M costs.

CBTC installations have now reached a critical mass (more than 100 applications worldwide), thus reducing also the acquisition cost as the products are maturing and the competition between suppliers is quite intense.

The same can be stated for ERTMS as an increasing number of installations are in revenue service in Europe but also in the rest of the world (Asia, Middle-East and South America).

On the other hand, even though the railroads are putting a price pressure on the suppliers to deliver PTC, due to the very tight deadline the cost of acquisition may not be optimum right now (the owners may not have other choices to pay for additional contract changes only to meet the deadlines).

Lessons learned from ERTMS Regional implementation in Sweden

Sweden is the first country to introduce ERTMS Regional on the 143 Km Västerdal Line. This line has been identified by the Swedish Transport Administration (STA) as a suitable pilot line with low density traffic (16 trains a day) and no through traffic. The concept of ERTMS Regional was developed in close collaboration between the UIC (International Union of Railways) and the STA. The original specifications for ERTMS have been adapted to incorporate some new concepts (functional, operational and interfaces) for the ERTMS Regional version, especially for the trackside and central parts of ERTMS. The main reason to adapt the ERTMS specifications was that the current system (Level 2 or Level 3) was becoming too costly for low density lines.

In 2003 the STA launched an open tendering process in accordance with EU rules. After a period of evaluation Bombardier was selected to equip the Västerdalsbanan pilot line in 2005. The line was commissioned for commercial traffic in February 2012.

The main design concepts for ERTMS Regional are:

- Train detection based on train position report calculated onboard and fixed transponders on the track
- Use of virtual fixed blocks for train tracking
- Centralized and integrated interlocking and Radio Block Center for ATP functions
- Centralized dispatch and field control from a TCC
- Object Controllers along the line connected to turnouts or level crossing – these Object Controllers are connected via radio to the RBC/Interlocking
- Train integrity function performed by an onboard device
- Onboard equipment using the conventional ERTMS equipment (EVC and GSM-R)

One of the key concepts was to eliminate the use of local traffic control and to centralize the control and supervision of the line. By eliminating the track-circuits and wayside signals, ERTMS Regional reduces considerably the maintenance cost.

Due to the reduced number of field equipment to control, only a few Object Controllers had to be installed. The communication interface between the Object Controllers and the RBC/Interlocking uses open standards to reduce further the cost of investment.

The application of ERTMS Regional for low-density lines is somehow comparable to the US railroad’s “Dark Territory” or “Light Dark Territory”. The development of this system has benefited from the already developed ERTMS specifications and the strong support of the UIC and the STA. The industry will continue to work on the ERTMS Regional specifications to make them open to other potential users and suppliers.

CONCLUSION AND LESSONS LEARNED

Choice of the signaling solution

The trend in the signaling industry in Europe clearly shows that CBTC remain the first choice for projects with capacity requirements higher than 24 TPH and for metro type applications. The preferred choice of operation is ATO with the possibility of migrating to UTO.

In some cases, the choice is made by the infrastructure manager to implement ERTMS Level 2 on a high core section of a large and complex network with branches expanding within the national territory. With the use of ATO, ERTMS Level 2 can achieve throughput of

24 TPH and avoid of having a different signaling system than the one to be installed on the national territory.

In all cases the choice of a new signaling goes beyond the capacity issue, and other considerations are evaluated in the business case, such as:

- Life Cycle Cost reduction
- Obsolescence
- Other performance requirements: punctuality and reliability
- Interoperability
- Stakeholder management

System Approach

The general approach taken in the development of CBTC and ERTMS has been to define high level system functional and performance based requirements. European Transit and Railways operators have taken the stance to define how they would like to operate their network with the new signaling system, either CBTC or ERTMS, while fulfilling some key performance requirements (RAM, safety, headway, specific operational functions). This approach has enabled the suppliers to develop stand-alone solutions that can fulfill the owner requirements. In some cases, Transit or Railways have specified to maintain an underlay fallback system either based on the existing signaling system or new one, optimized but similar to the legacy system (fixed block with fewer wayside signals). This mainly is in order to address mixed fleet operations (equipped and unequipped trains) when the cost of equipping special vehicles is too expensive.

Using the new signaling system as a stand-alone system unlocks the capacity constraints inherent to the fixed block system. This is particularly true with CBTC that uses either moving blocks or virtual blocks. Even in the case of ERTMS level 2, which still uses the track-circuits or axle counters for the train detection function, the headway can be improved by optimizing the size of the fixed blocks. As the braking curves are calculated by the onboard computer (EVC) and based on the actual speed and characteristics of the train – as opposed to the worst case rolling stock characteristics and maximum speed for a conventional wayside signals fixed block signaling system.

It is acknowledged that in the current context of PTC implementation before 2015 and only to improve safety, it is difficult to take the time to define a system approach for PTC and to incorporate further requirements for the design. However PTC users and suppliers should consider, beyond 2015, working together to define a common high level functional set of specifications to include requirements addressing all the needs of the passenger and freight railroad such as: reliability and maintainability, capacity, LCC reduction, operations flexibility and enhancement functions (regulation and supervision) and interoperability. This latter requirement is of paramount importance for shared infrastructure and can have different interpretations depending on the type of railroad involved.

Some useful references or source of inspiration for a future common high level PTC system requirement specification could be the IEEE-1474.1 Standard for Communications-Based Train Control Performance and Functional Requirements and the ERTMS Technical Specifications for Interoperability.

NOMENCLATURE

ATO: Automatic Train Operation

ATS: Automatic Train Supervision

ATP: Automatic Train Protection

AWS: Auxiliary Wayside Protection

CBTC: Communication Based Train Control

ERTMS: European Rail Traffic Management System

PTC: Positive Train Control

TPWS: Train Protection Warning System

UIC: International Union of Railways

STA: Swedish Transport Authority