ERTMS REGIONAL AND NORTH AMERICAN DARK TERRITORY: A COMPARISON

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SUMMARY

Railways in both Europe and North America have developed control solutions for lines with low traffic density. These solutions are ERTMS Regional in Europe and "dark territory" in North America, in which conventional signalling is absent and which is now being equipped with Positive Train Control (PTC). To compare these solutions, this paper describes the control systems that have evolved on both sides of the Atlantic for lines with higher traffic density, and how the advent of data radio for safety-critical applications has spawned a new generation of wireless control solutions. Whereas the main objective of the European Rail Traffic Management System (ERTMS) and specifically its European Train Control System (ETCS) is interoperability of trains across national borders, the main objective of North America's PTC is to increase safety by enforcing movement authorities both under conventional signalling and in dark territory. The paper compares the implementation of these two systems, in particular the ETCS Level 3 that underlies ERTMS Regional and PTC-equipped dark territory. Both systems enforce movement authorities. But the philosophies underlying their designs are fundamentally different: whereas as in ETCS, enforcement is one of the core functions that ***ensure*** *safety, in PTC enforcement is an independent, "overlay" function that* ***improves*** *the safety of the core system. The paper also examines the potential for moving block and how the approaches for low-density traffic in Europe and North America provide a development path for small or new railways on other continents.*

1 INTRODUCTION

The railways of Europe and North America have evolved and still work in very different institutional, operational and technical environments. To ease comparisons, this paper uses the definitions in Figure 1.

Traffic control	*Generates* movement authority and *transmits* it to the train and driver.
Train control	Includes the train driver, who *executes* the movement authority, and the system (if any) that *enforces* the movement authority.
Traffic management	*Supervises* the traffic control system to fulfil business objectives.

Figure 1: Train control, traffic control and traffic management

Railways on both continents are now developing solutions for traffic and train control on lines with low traffic density – ERTMS Regional in Europe and PTC-equipped dark territory in North America. In the context of control systems for busier lines, this paper compares these solutions for low-density lines in terms of the history of their development, their technical implementation today, likely developments in the near future, and why railways on their respective continents consider them safe.

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2 NOTATION AND TERMINOLOGY

This paper's comparison tables use the notation in Figure 2, which should be self-explanatory in context.

Given the British roots and European base but worldwide membership of IRSE, we have made some compromises. The paper refers to *turnouts* instead of British *sets of points* or North American *switches*. We refer to ETCS *balises* more generically as *transponders*. We have adopted the North American *dispatcher*.

✓	Always – or almost
✓(✗)	Usually – but in some cases not
✗(✓)	Usually not – but there are exceptions
✗	Never – or almost

Figure 2: Notation for comparison tables

The term *railway* refers in this paper to both the integrated and mostly private railways of North America, which generally – but not always – run their own trains on their own rail infrastructure, and the European rail infrastructure operators, which nowadays offer their lines to more or less unaffiliated train operators. Self-contained networks like metros are excluded.

In line with popular if not universal usage, by *North America* we mean the U.S. and Canada only.[1] Although Canada has not mandated PTC, we speak of North American and not US signalling because of the ongoing, high degree of technical and operational integration of railways in these two countries.

3 SIGNALLED AND NON-SIGNALLED OPERATIONS

To understand the differences between ERTMS Regional and PTC-equipped dark territory, some background on the role of signalled and non-signalled operations on the two continents is crucial.

3.1 Signalled Operation: Almost Ubiquitous in Europe

In Europe, signalled operations, in which trains get their movement authority from signal indications, became standard on all railways in the course of the 20th century. This was due to Europe's traffic density – even today, the number of train-km per route-km is about five times higher than in North America – and population density, which allowed numerous staffed control stations along a line. In addition to signals, interlocking between turnouts and signals became a standard feature everywhere, often required by government regulation.

The introduction of centralised traffic control (CTC) did not change the principle of traffic control based on interlocking systems. Operators simply moved from local control stations to control centres.

Most European railways use different kinds of automatic train protection (ATP) systems that prevent trains from exceeding their movement authorities by passing stop signals. On high-speed lines, trains are controlled by continuous ATP systems that not only provide data for cab signals, but also continuously enforce the authorised speed. A very small portion of European lines are non-signalled and operate by dispatcher-issued track warrants like those of North American dark territory.

3.2 Much of North American Operations Still Non-signalled

In the late 1800s, North American rail operations came to be based on timetable rules and train orders. Dispatchers telegraphed and later telephoned train orders to local operators, who copied them and passed them to train crews. Later, voice radio allowed the dispatcher to dictate track warrants directly to train crews.

In the 20th century, on North American lines with higher traffic density, traffic control based on train orders or track warrants progressively gave way to CTC. The great advance of CTC was that instead of granting movement authority based on his knowledge of the situation, the dispatcher now requested the movement authority from an interlocking system, which relayed it to drivers via signals. This made overlapping authorities much less likely.

[1] Geographically, of course, the North American continent extends south to Panama.

Under North American rules, CTC is present when automatic signals authorise and govern movement on tracks whose normal flow is in *either* direction. Today, CTC covers about half of all North American routes. But a huge part of the continent's network – about one third – is still dark territory in which track warrants, not signals, communicate movement authorities and train crews operate non-interlocked, hand-thrown mainline turnouts.

The remaining routes – about a sixth of the total – are a hybrid of signalled and dark territory. On these routes, automatic block signals (ABS) authorise movement on a track whose normal flow is in a single direction. However, a track warrant authorises the driver to traverse the ABS route. Such territory is "light dark" because it signalled for the driver, but dark to the dispatcher, who cannot see the signal aspects.

This paper focuses on North American dark territory devoid of dispatcher-controlled or automatic signals.[2] In such territory, the dispatcher traditionally has granted movement authorities on the basis of operating rules, timetable instructions and a formal "train sheet" on which the dispatcher records train movements. Increasingly, simple conflict-checking software supervises the dispatcher's granting of movement authorities. Today, the dispatcher typically communicates these movement authorities (track warrants) to the train driver via voice radio. In the near future, the conflict-checking software will increasingly allow transmission of track warrants to the driver's cab via data radio.

3.3 Summary of Differences

Figure 3 summarises the differing proportion of signalled and non-signalled operations in Europe and North America.

Territory type	Medium for communication of movement authorities	Europe	North America
Signalled	Signals (or wireless equivalents)	Almost all	About half
Dark	Dispatcher-issued track warrants	Almost none	About one-third
"Light dark"	Dispatcher-issued track warrants to access routes with automatic block signals (ABS)	Almost none	About one-sixth

Figure 3: Proportion of non-signalled operations on the two continents

On both sides of the Atlantic, track work or operating incidents can force a railway to run trains over a line section against the normal flow or otherwise without the benefit of signals. In this case, "dark territory" operations take over: dispatchers grant movement authorities in the form of track warrants or an equivalent.

4 THE NEWEST GENERATION OF CONTROL SYSTEMS

On both sides of the Atlantic, the advent of data radio suitable for safety-critical applications has spawned new generations of solutions for traffic and/or train control.

4.1 In Europe: ERTMS and ETCS

ETCS seeks to **achieve interoperability** by replacing the national ATP systems and thus eliminating the need to equip driver's cabs with multiple signalling systems for cross-border operations. Improvements in speed, capacity and safety are not the main objectives of ETCS, since in most countries the conventional systems already perform very well. ETCS is part of ERTMS, which also includes the radio standard GSM-R, harmonised

[2] In some rare cases, local operators may still receive track warrants and set non-automatic signals to communicate them to drivers. This is also considered dark territory.

interlocking functions, and, as the name suggests, a traffic management layer to support international dispatching by exchange of train location and status data between control centres. ERTMS is therefore a traffic management system that incorporates traffic and train control in the form of ETCS.

Three levels of ETCS have been specified. All levels present the same cab display to the driver.

- In **Level 1**, ETCS works as an intermittent ATP system. The conventional signalling system transmits movement authorities to active ETCS transponders, which relay them to the train.
- In **Level 2**, ETCS works as a continuous ATP system in which GSM-R radio transmits the traffic control data. Passive transponders provide location reference points to the onboard train location system. Train spacing is still based on fixed block sections equipped with track circuits or axle counters.
- ETCS **Level 3** is like Level 2 except that it adds train-borne checking of train integrity to the system and eliminates the need for track circuits or axle counters.

ERTMS on mainlines is always ETCS Level 1 or 2. ERTMS Regional is a newer concept for lines with low traffic density. It is based on ETCS Level 3, but has a simplified interlocking system. In mainline ETCS, the interlocking system controls traffic by setting routes, and a separate “radio block centre” (RBC) generates movement authorities. In ERTMS Regional, in contrast, the same control unit both performs interlocking and issues movement authorities. Following development work started in 2005, the first application of ERTMS Regional began commercial service on a 143 km single-track line in Sweden on February 21, 2012.[3]

4.2 In North America: PTC

The main goal of PTC has not been interoperability, as in Europe, but rather to **improve safety** by offering a relatively economical way to enforce movement authorities, i.e. to implement the ATP function that until now has been missing on much of the network – including both signalled and dark territory. Another core function of PTC is protection of temporary work zones for maintenance forces. Although interoperability is not a focus of PTC, it is nevertheless a requirement, as trains often operate on “foreign” railways.

Although PTC had been under development for many years, a 2008 head-on collision involving a passenger train in Chatsworth, California, prompted the US Congress to require PTC on lines carrying passengers, dangerous goods or significant freight tonnage by 2015.

4.3 Summary of Differences

Figure 4 summarises the key differences between the control solutions of the latest generation on the two sides of the Atlantic.

As Figure 4 shows, a central difference between ETCS and PTC is that whereas ETCS both *issues* and *enforces* movement authorities, PTC is an independent, “overlay” system that merely *enforces* the movement authorities issued by pre-existing systems, i.e. either the signals in signalled territory or track warrants in dark territory.

Both ERTMS Regional and PTC-equipped dark territory thus depart from the technologies of conventional railway signalling in several ways. First, both systems transmit movement information to the driver’s cab by means of wireless technology instead of line-side signals. Second, these solutions do not rely on track circuits (or axle counters) for monitoring train position and ensuring train integrity. These solutions thus offer the basis for *Virtual CTC*, or CTC with almost none of the expensive and vulnerable line-side infrastructure of conventional CTC.

[3] Railway Gazette International newsletter, April 25, 2012.

	Europe	North America
Control solution of the latest generation	ETCS	PTC
Main rationale for development of solution	**Interoperability** between national rail networks	**Better safety** by enforcement of movement authorities
Medium for transmissions to driver's cab...		
...of movement authority (**traffic** control)	Transponders or GSM-R data radio	Signals or, in dark territory, track warrants transmitted by voice (or data) radio
...of data for enforcement (**train** control)	No separate transmission; enforcement based on movement authority	PTC data radio [4]

Figure 4: Differences in latest generation of control solutions

5 POINTS OF COMPARISON OF ERTMS REGIONAL AND DARK TERRITORY PTC

5.1 Elements to Be Compared

In order to more fully understand the similarities and differences between ERTMS Regional and PTC-equipped dark territory, we have compared them in the context of conventional signalling and wireless control systems (i.e. ETCS and PTC) on their respective continents. We make this comparison with reference to the elements in Figure 5.

One basis of traffic control is train **position monitoring**. This includes knowing where trains aren't (**track vacancy proving**) and that each train is still in one piece (**train integrity proving**). The position of **turnouts** must also be **monitored**. The **land-based control system** – including decisions by the dispatcher – uses all these inputs to decide when to **throw** and **lock turnouts** and when to grant and transmit **movement authorities** that the **driver** then receives by signals, wireless substitutes for signals, or track warrants. On-board equipment may also **enforce** the movement authority.

Let us examine each of these points of comparison in turn.

5.2 Train Position Monitoring

This has two essential functions: (1) in **traffic control**, to prove that a section of track is empty before *granting* a movement authority and (2) in **train control**, to monitor a train's location and speed for *enforcement* of the movement authority.

Obviously, position monitoring is also essential for the **traffic management** function as it goes about supervising the traffic control function to achieve business objectives. Position monitoring for this purpose lies outside the scope of this paper, however.

The conventional solution for train position monitoring for traffic control on both sides of the Atlantic is track circuits (or, increasingly in Europe, axle counters). As Figure 6 shows, newer technologies now helping monitor train position include transponders, odometry – i.e. keeping track of the distance run from a known point – and

[4] An exception is the Northeast Corridor between Washington, New York and Boston, where enforcement is on the basis of movement authorities received via transponders and codes transmitted through rails.

satellite positioning. A special case is the practice in PTC of inferring a train's track from the monitored position of a turnout it has traversed.

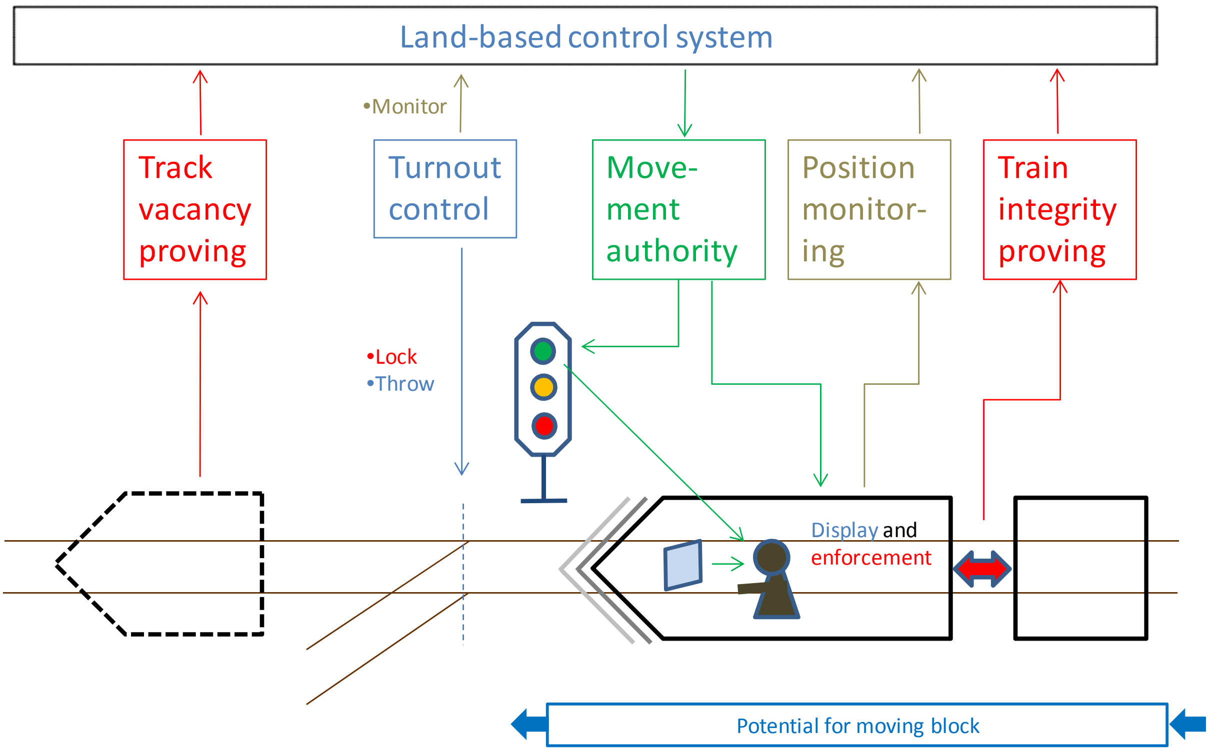

Figure 5: Points of comparison between ERTMS Regional and PTC-equipped dark territory

Track circuits (or **axle counters)** are central means of position monitoring for conventional signalling in North America and Europe, where they are also integrated with ETCS Levels 1 and 2. They *may* be used at junctions and passing loops in ETCS Level 3, which underlies ERTMS Regional.

North American dark territory does not use **track circuits** for train position monitoring. Instead, in former times, station operators reported passing trains to the dispatcher by telegraph and later telephone. Nowadays, in conventional operations in dark territory, a train crew typically reports its position periodically to the dispatcher by voice radio, for example when the train crew is requesting additional authority to advance.

	National European signalling	ETCS Level 1	ETCS Level 2	ERTMS Regional/ ETCS Level 3	NA signalled territory	NA signalled territory w/ PTC	NA dark territory	NA dark territory w/ PTC
Track circuits (or axle counters)	✓	✓	✓	✗ (✓)	✓	✓	✗	✗
Transponders	✓	✓	✓	✓	✗ (✓)	✗ (✓)	✗	✗
Odometry	✓	✓	✓	✓	✗ (✓)	✓	✗	✓
Satellite positioning	✗	✗	✗	✗ (✓)	✗	✓	✗	✓
Inference of train's track from turnout position	✗	✗	✗	✗	✗	✗	✗	✓

Figure 6: Technologies for train position monitoring

On both sides of the Atlantic, another traditional function of track circuits was to detect broken rails, and in North America it still is. Most European railways have changed their mind, however. Since track circuits fail to detect many rail faults that lead to broken rails, the railways concluded that other means, such as regular ultrasonic checks, are enough to guarantee rail integrity. European track circuits are thus losing their role in broken rail detection. In Germany, for example, track circuits have not been used in new installations for more than a decade. Instead, axle counters have become the lead technology for track vacancy proving.

Transponders and odometry for train location in ATP systems are generally used in European signalling, but are generally only used on North American lines with dense passenger traffic. The freight railways that own and operate most North American rail routes dislike track-mounted **transponders** because of their exposure to theft, vandalism, dragging equipment and track upkeep operations.

PTC is introducing **odometry** in concert with **satellite positioning** to provide its enforcement function in both signalled and dark territory. As Section 6 describes, Europeans consider that GPS **satellite positioning** offers too little self-checking for train control applications.

5.3 Train Integrity Proving

Before granting a movement authority, the traffic control system must check integrity, i.e. that all relevant trains are still in one piece. In conventional signalling on both sides of the Atlantic, track circuits (or axle counters) provide this function. If a line lacks these devices, it needs an on-board means of train integrity proving. Figure 7 illustrates.

	National European signalling	ETCS Level 1	ETCS Level 2	ERTMS Regional/ ETCS Level 3	NA signalled territory	NA signalled territory w/ PTC	NA dark territory	NA dark territory w/ PTC
Track circuits (or axle counters)	✓	✓	✓	✗	✓	✓	✗	✗
On-board train integrity proving only	✗	✗	✗	✓	✗	✗	✓	✓

Figure 7: Application of methods for train integrity proving

In national European signalling systems, ETCS Levels 1 and 2, and conventional North American signalling, track circuits (or axle counters) detect any part of a train left behind in a block. Both ERTMS Regional (which uses ETCS Level 3) and dark territory in North America lack such devices.

Such lines thus need some other method of proving train integrity. On both continents, modern passenger trains have a data bus that proves train integrity or could. In North America, an end-of-train (EOT) device allows the driver of a freight train to determine train integrity in both dark and signalled territory. EOT devices are being equipped with GPS so as to provide the position of the end of the train, prove train integrity and locate any cars left behind. The resulting level of train integrity assurance will be high – especially with the level of accuracy established by the Interoperable Train Control (ITC) group charged with developing the PTC standards for the US freight and commuter railways outside the Northeast Corridor. In addition, EOT devices are receiving accelerometers to verify the separation between the locomotive and the train’s rear end.

Another, longer-term solution for freight train integrity proving on both continents may lie in the data-bus cable required for electronically controlled pneumatic (ECP) braking.

5.4 Transmission of Train Position Information to the Control System

Once captured, position information must somehow be transmitted from the track circuits (or axle counters) or from the train to the land-based control system. Figure 8 shows the three basic technologies for doing so.

	National European signalling	ETCS Level 1	ETCS Level 2	ERTMS Regional/ ETCS Level 3	NA signalled territory	NA signalled territory w/ PTC	NA dark territory	NA dark territory w/ PTC
By wire	✓	✓	✓	✗	✓	✓	✗	✗
By voice radio	✗	✗	✗	✗	✗	✗	✓	✓
By data radio	✗(✓)	✓	✓	✓	✗(✓)	✓	✗(✓)	✓

Figure 8: Transmission of train position from track or train to land-based control system

In all conventional signalling and in ETCS Levels 1 and 2, train position information travels from the track circuits (or axle counters) to the ground-based control system by **wire**. In dark territory, North American railways currently generally use **voice radio** for position reporting. ETCS also reports the train's position by **data radio**.

As implemented on the large North American freight railways, PTC has four major components: a land-based control centre, data radio, an on-board system and GPS positioning. Once the PTC control centre has transmitted the parameters of a movement authority via **data radio** to the driver's cab, the on-board PTC system enforces the movement authority without reporting train position back to the control centre. As they install the wireless infrastructure required for PTC, however, the railways will increasingly use it for non-PTC location and speed reporting functions in both signalled and dark territory.

5.5 Remote Control of Turnouts

Over time, turnout control has evolved from (1) on-the-spot hand control to (2) local remote control by cables or rods from a nearby control station and more recently to (3) electric power and electronic control from a control centre that tends to be ever further away. All these control methods are still in use, however.

Figure 9 compares implementation of the three basic functions in remote control of turnouts: **monitor**, **lock** and **throw**.

	National European signalling	ETCS Level 1	ETCS Level 2	ERTMS Regional/ ETCS Level 3	NA signalled territory	NA signalled territory w/ PTC	NA dark territory	NA dark territory w/ PTC
Monitor	✓	✓	✓	✓	✓	✓	✗	✓
Lock	✓	✓	✓	✓	✓	✓	✗	✗(✓)
Throw	✓	✓	✓	✓	✓	✓	✗	✗(✓)

Figure 9: Functions for remote control of turnouts

Traffic control systems incorporate all these functions for the vast majority of turnouts on main (as opposed to yard and industrial) tracks in Europe and in conventional signalling in North America. In North American dark territory, however, hand-thrown turnouts are the rule. This will persist even after the fitting of PTC, which does introduce the monitoring of turnout positions and in some cases their locking. A potential function of PTC would allow the train driver to throw a turnout from his cab (instead of a manual throw by a train crew member on the ground) if consistent with the train's movement authority.

5.6 Transmission of Movement Authority to Driver's Cab

Once the land-based control system – at the centre of which sits the dispatcher – has granted a movement authority, it must transmit it to the driver's cab.[5] As Figure 10 shows, various technologies allow this transmission, alone or in combination.

	National European signalling	ETCS Level 1	ETCS Level 2	ERTMS Regional/ ETCS Level 3	NA signalled territory	NA signalled territory w/ PTC	NA dark territory	NA dark territory w/ PTC
Line-side signals	✓(✗)	✓	✗	✗	✓(✗)	✓(✗)	✗	✗
Coded track circuits	✗(✓)	✗	✗	✗	✗(✓)	✗(✓)	✗	✗
Cable loop antennas	✓	✓	✗	✗	✗	✗	✗	✗
Transponders	✗(✓)	✓	✗	✗	✗(✓)	✗(✓)	✗	✗
Voice radio	✗	✗	✗	✗	✗	✗	✓	✓
Data radio for **movement authority**	✗	✗	✓	✓	✗	✗	✗(✓)	✗(✓)
Data radio for **enforcement data**	n.a.	n.a.	n.a.	n.a.	✗	✓	✗	✓
Cab display	✓(✗)	✓	✓	✓	✗(✓)	✓	✗(✓)	✓

Figure 10: Transmission of movement authority to driver's cab

Line-side signals are involved in the transmission of movement authorities to the driver's cab in almost all conventional signalling in Europe and North America, with the exception of some high-density or high-speed lines. Line-side signals are absent by definition in ETCS Levels 2 and 3 (including ERTMS Regional) and in North American dark territory.

On high-speed lines in North America and some European countries, **coded track circuits** transmit movement authorities. Some European high-speed lines also transmit movement authorities by a trackside **cable loop antenna**. **Transponders** transmit movement authorities on some national European ATP systems and by definition in ETCS Level 1. In the Northeast Corridor, **coded track circuits** transmit movement authorities while **transponders** provide location reference and transmit speed-limit changes.

Today, **voice radio** is the usual means of transmitting movement authorities (track warrants) in North American dark-territory operations. As we have seen, on both sides of the Atlantic, even on sections normally controlled by interlocking systems, railways have to issue track warrants (or an equivalent) to trains in case of operating incidents or in order to establish work zones for maintenance forces. **Voice radio** is a main medium for the transmission of such track warrants.

[5] To be precise, and as we have seen, PTC does not transmit movement authorities to the driver's cab, but rather the parameters, also known as targets, needed for movement authority enforcement.

Trains receive movement authorities by **data radio** in all ETCS Level 2 and 3 implementations. In the near future, **data radio** will progressively replace **voice radio** in the transmission of track warrants in North America. This transmission will increasingly use the radio communication infrastructure the railways are installing for PTC. As we have seen, however, movement authority *granting* and *enforcement* will remain functionally fully separate from each other.

On both signalled lines and dark territory, PTC transmits the parameters of movement authorities – but not the movement authorities themselves – to the train via **data radio** so that the on-board PTC system can enforce them. It is the conventional procedure – either the **signals** or the track warrant delivered by **voice radio** or (increasingly) **data radio** – that delivers the movement authority to the driver, who is responsible for staying within that movement authority even if PTC fails.

Most national European systems tell the driver about the movement authority both via line-side signals and in some form of **cab display**. In conventional North American signalled territory, **line-side signals** are prevalent but **cab displays** less so. A **cab display** of movement authorities is a standard feature of ETCS, but within ETCS only Level 1 retains **line-side signals**. PTC provides a **cab display** of the *parameters* of the movement authority, so the driver knows when enforcement will occur.

5.7 Enforcement of Movement Authority (ATP)

A major difference in train control between North America and Europe is the prevalence of automatic train protection, which typically warns the driver and then stops the train to prevent it from exceeding its movement authority. In Europe, with its high average frequency of passenger trains, ATP is nearly universal. In contrast, North American railways have generally limited the fitting of ATP to lines whose traffic density and passenger counts resemble those typical in Europe. Figure 11 illustrates.

	National European signalling	ETCS Level 1	ETCS Level 2	ERTMS Regional/ ETCS Level 3	NA signalled territory	NA signalled territory w/ PTC	NA dark territory	NA dark territory w/ PTC
Automatically by on-board ATP system	✓	✓	✓	✓	✗ (✓)	✓	✗	✓
Driver, possibly with help of other crew members, with no ATP	✗	✗	✗	✗	✓ (✗)	✗	✓	✗

Figure 11: Enforcement of movement authority (ATP)

ATP is a standard feature of almost all national European signalling systems and certainly of all levels of ETCS. In North America, in contrast, with much lower average train densities and speeds and a much smaller proportion of passenger trains – even in signalled territory – railways have traditionally found ATP cost-justified only on high-density, higher-speed lines with a relatively high proportion of passenger trains. Indeed, the main purpose of PTC is much broader implementation of ATP in both signalled and dark territories.

5.8 What about Moving Block?

In principle, any traffic control system that does not rely on fixed blocks equipped with track circuits (or axle counters) offers the potential for moving block. In this mode, the traffic control system continuously monitors the position and speed of all trains and continuously feeds them movement authorities enabling them to follow at a safe stopping distance. This allows better use of line capacity than when fixed blocks maintain safe separation between trains.

If moving block is ever implemented, it would replace conventional signalling on high-density lines, which offer opportunities for savings and increased throughput. However, the focus of this paper is solutions for low-density lines – ERTMS Regional and North American dark territory – which have little or no need for moving block.

Indeed, whereas the traffic control functions in both ERTMS Regional and North American dark territory are much simpler than conventional signalling, the real-time nature of moving block makes it much more complex and technically challenging.

For low-density lines, the following advances can nevertheless increase efficiency and throughout:

- Communication of movement authorities via data radio. This is a basic principle of ETCS Level 3, which underlies ERTMS Regional, and will progressively be implemented in North American dark territory.
- Subdivision of sections of line covered by track warrants into shorter, virtual blocks allowing shorter headways between trains moving in the same direction.
- The concept of Virtual CTC, which would control traffic on the basis of virtual blocks.

These steps can increase throughput without the technical complexity and difficulty of applying wireless technology to achieve moving block.

6 DECIDING WHETHER IT'S SAFE

A precise technical definition of "safe" is beyond the scope of this paper. Roughly speaking, however, safety requirements can be stated as the probability of wrong-side failure per unit time (e.g. per billion hours).

In Europe, enforcement of movement authorities is one of the core functions that ensure safety. Its design must therefore lead to the same low rate of wrong-side failure as for the traffic control function. In North America, in contrast, the responsibility for safe operations lies with the traffic control function and the driver, who is responsible for operating within the movement authority. The enforcement function – where one is installed – is seen as an independent "overlay" whose purpose is improve, not ensure safety. Enforcement thus lies outside the essential circle that ensures safety: movement authorities issued by the traffic control system and executed by the driver. Figure 12 illustrates.

	Europe	**North America**
Traffic control and issuance of movement authorities	To **ensure** safety, design for very low rate of wrong-side failures[6]	→
Enforcement of movement authorities	↓	To **improve** safety, tolerate a somewhat higher rate of wrong-side failure in order to lower cost and justify installation

Figure 12: Differences in design philosophy

In the North American design philosophy, the driver remains wholly responsible for operating within the movement authority even if the enforcement function suffers a wrong-side failure. This means that the safety level of the enforcement system, in terms of the expected rate of wrong-side failures, can be somewhat lower than that of the traffic control system. Indeed, in North America, the designers of the PTC enforcement system are seeking an optimal, least-cost middle ground between:

[6] Arguably, this objective has been largely achieved: although the history of rail accidents shows that wrong-side failures do occur, their frequency is low and dropping.

- the risks and expected costs of accidents in operations without enforcement and
- the very high cost of an enforcement function with the same safety level as the traffic control function.

In Europe, in contrast, because the role of enforcement is to *ensure* safety, as opposed to just *improve* it, enforcement is designed to achieve the same very low frequency of wrong-side failures as the rest of the control system.

Despite this somewhat less stringent safety requirement, however, there have been persistent claims that in the form mandated by Congress in 2008, the costs of PTC far exceed its safety benefits in the North American context. The Federal Railroad Administration acknowledged this in its 2009 proposed rulemaking for PTC.[7]

6.1 Practical Implications

The North American and European railway sectors have both evaluated the safety of possible elements of control systems for low-density lines. Not surprisingly, given the underlying differences in design philosophies, these evaluations differ markedly. Europeans are less enthusiastic than North Americans about the following technologies:

- Train integrity proving based on end-of-train devices
- Use of systems other than track circuits and axle counters for track vacancy proving
- Turnout position as one indicator of which track a train is on
- GPS satellite positioning

The attitude toward GPS illustrates the difference in design philosophies. In the US, GPS positioning is an integral part of PTC, which *enforces* movement authorities, but not part of the system that underlies the *granting* of movement authorities. In dark territory, PTC uses a combination of GPS positioning, turnout position and odometry to determine where and on what track a train is. ITC is developing a precision train location (PTL) specification in which GPS should not fail to be accurate within 1.2 meters more than once in nearly 100 million determinations.

In contrast, Europeans consider that GPS offers too little self-checking for train control applications. European application of satellite positioning in train control will have to await the much-delayed Galileo navigation satellites, which unlike GPS warn safety-critical applications if the position information becomes unreliable.

The underlying reason for this difference of attitude towards GPS lies in the design philosophy of the two systems: In Europe, any positioning technology is an integral part of the core system that ensures safety, and thus must be designed with the same low expected rate of wrong-side failure as the traffic control system. GPS does not offer this performance and so cannot be used. In North America, in contrast, this same lower safety level of GPS is acceptable as part of the independent PTC overlay system whose purpose is merely to *improve* safety by enforcing movement authorities generated by the core traffic control system that – along with the driver – *ensures* safety.

6.2 A POSSIBLE PATH FOR OTHER CONTINENTS

This paper reveals opportunities for railways on other continents to benefit from experience in the control of low-density train traffic in Europe and North America. For example, a small or new railway in a developing country might want to consider the European and North American models for low-density lines for several reasons. First, capital investment is lower than for conventional signalling, and the wireless solutions leave far less line-side equipment in need of maintenance or exposed to damage, theft or vandalism.

[7] Federal Railroad Administration, notice of proposed rulemaking on positive train control systems, Federal Register, Vol. 74, No. 138, July 21, 2009, page 35952.

Second, once the wireless infrastructure is in place, a developing railway can scale up its traffic level without significant added infrastructure investments, as follows:

- At initial, low traffic levels, traffic control is possible on the North American model of dark territory, without ATP.
- As traffic grows, ATP enforcement can be added on the North American model of PTC.
- As traffic increases further, the railway can implement a control system on the models of ERTMS Regional or Virtual CTC.

7 CONCLUSION

In this paper, we have shown that traffic control systems on both sides of the Atlantic must provide the same basic functions, including train position monitoring (including proving of both track vacancy and train integrity), monitoring and control of turnouts, and transmission of movement authorities. Until now, a standard function in Europe has been missing on much of the North American network – including both signalled and dark territory: the enforcement of movement authorities, or ATP. PTC is being introduced to remedy this. Once PTC is fitted in dark territory, railways will take advantage of its wireless infrastructure to progressively replace voice radio with data radio for transmission of position reports and movement authorities.

On low-density lines equipped with ERTMS Regional or PTC-enforced dark-territory traffic control, railways can forgo the expense of installing and maintaining line-side signals and track circuits (or axle counters), but then need other ways of monitoring train position and proving train integrity such as end-of-train devices that can report position and movement. Differences in safety requirements for such solutions in Europe and North America will continue to reflect differences in average train speeds and the number of trains and passengers on the two continents. They will also reflect an underlying difference in design philosophy. On both sides of the Atlantic, the traffic control system that *grants* movement authorities *ensures* safety by means of a very low frequency of wrong-side failures. In ETCS, the train control system that enforces movement authorities is an integral part of this core control system. In contrast, PTC is an independent system that *improves* safety by enforcing the movement authorities issued by the core system. PTC can therefore be designed with a somewhat higher rate of wrong-side failures and therefore at a cost that makes its deployment feasible in the North American context.

Together, ERTMS Regional and PTC-equipped dark territory offer elements of a scalable development path for traffic and train control on small or new railways on other continents.