The Institution of Railway Signal Engineers Inc

Australasian Section Incorporated

ELECTRONIC VIRTUAL TRAINSTOPS

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SUMMARY

As signalling technology moves from the world of the fixed signal to the world of Communication Based systems, one major issue which arises is how to deal with the legacy unfitted train.

Traditionally, the available answers to that issue have been:

- Don’t allow non-fitted trains to run on the relevant part of the network (the captive fleet option); or
- Build the Communications based System as an overlay on traditional signalling infrastructure including its fixed signals.

This second option in particular denies the railway any of the cost benefits associated with the new technology and acts as a barrier to its use.

This paper will explore the alternative – to make the signalling for the unfitted train an overlay on the underlying Communication Based Signalling, rather than the other way around.

The method for doing this will be explored via the example of the Electronic Virtual Trainstop. We do not have one of these right now, but we are in a position to develop its specification.

In a world where the signal engineer has involvement in defining the train’s on-board systems, this paper will explore three specific subsystems and the interfaces between them needed to achieve operability. One subsystem is part of the infrastructure, associated with the communications based signalling itself. The second is conceptually portable, but operationally part of the equipment taken on board the train. The third is the electronic virtual trainstop itself – the core on-board system.

The issue with defining an on-board system for an unfitted train seems apparent just looking at the terms. In reality, “lack of fitment” covers a range of possibilities, ranging from no fitment whatsoever, through a very basic system-independent facility (here we find the Electronic Virtual Trainstop) to a train fully fitted with somebody else’s Communication Based signalling. Each possibility will be discussed.

By defining the intermediate system and some basic open interfaces, the paper will show how the issue of interoperability can be managed for the full range of possible trains.

1 INTRODUCTION

When introducing communications based signalling to part of a network, the issue often arises of how to manage the “unfitted train” on the newly signalled portion of line.

At its core, this is the question of interoperability for trains running on a line provided with more than one signalling system over its length. The current most common scenario here is a line with lineside signals where part of that line is converted to CBTC operation. In the future (when there are fewer lines with lineside signals) a more common requirement may be for trains to operate in a network with multiple CBTC systems.

The common approach to that question in projects to date has been to leave the previous generation of signalling, complete with lineside signals, in place and implement the new Communication Based signalling as an overlay to that legacy system.

One problem with this approach is cost. The project tasked with providing the new signalling system is typically required to pay the cost of re-signalling the infrastructure fully with the legacy technology (“upgraded to current standards”), and then to pay the cost of implementing the Communications Based system as a brown-fields overlay as well. Thus, for the project, we get one signalling system for the price of two as it were.

This approach treats the legacy signalling system as the core and builds on top.

An alternative is to re-frame the question into one of inter-operability. The question becomes: “what is the minimum I need to do to allow a train fitted for another signalling system to run in an area fitted with my signalling system?”

In this approach the Communications Based Signalling System is treated as the core infrastructure. The task is to provide any support needed for signalling legacy trains as an overlay to that system. When framed that way, it can be seen that providing the whole of both signalling systems over the one bit of infrastructure is just one of the options, albeit an expensive option.

In the longer term, those industry players who are able to deliver true interoperability (ie the ability for a single train to run over diversely signalled infrastructure) will do better than those which can’t.

The following sections will explore the options available for achieving this level of interoperability.

2 NOTATION & ABBREVIATIONS

Abbreviations are as follows:

ARO	Accredited Rail Operator
ATP	Automatic Train Protection
CBTC	Communications Based Train Control
DMI	Driver Machine Interface
EMU	Electric Multiple Unit
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
EVT	Electronic Virtual Trainstop
GPS	Global Positioning System
GSM	Global System for Mobile
ITU	International Telecommunications Union
SIL	Safety Integrity Level
TPWS	Train Protection and Warning System
VDU	Visual Display Unit
VR	Victorian Railways
VTC	Vital Tablet Computer

3 WHERE DID WE COME FROM?

We are just coming up to the centenary (May 2019) of the introduction of electrification and its accompanying power signalling into Melbourne.

This signalling, which represented the leading edge of technology in its time, relied on track circuits to detect the location of the train, then fed this information to the signalling system which provided signals (electrically lit motor semaphores) which the driver could observe and use to control his train. It also featured a first generation ATP system which would ensure that a train would always stop safely, even if it passed a signal at stop.

Introducing his son’s book on VR signalling in 1922, H. Raynar Wilson wrote [1]:

> *“When I entered the railway service five-and-forty years ago, signalling, generally, was very primitive. Now it is almost perfect; the machine itself has reached perfection, but the man behind the machine is human and, therefore, frail.”*

The technological marvel he was referring to was the combination of the Essendon line power signalling and the modern Tait (named for the Victorian Rail Commissioner at the time) electric train (aka “Red Rattler” in a later era). And he was right. Both the Tait trains (final train withdrawn from service 1984) and the signalling (replaced in 2014) comfortably outlasted anyone working in the VR design office at his time of writing.

In his book, F Raynar Wilson provides a photo (figure 1) showing the ATP system [1]:

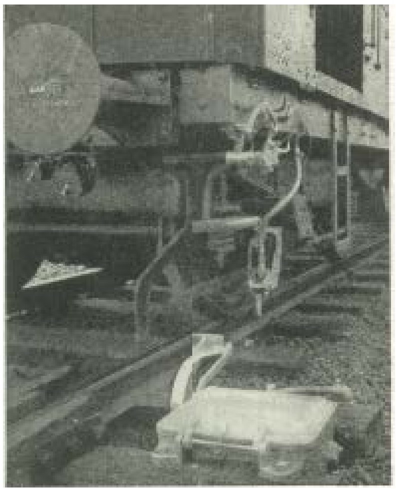

Figure 1: Trainstop and tripcock, Melbourne 1919

Not much has changed. I think I saw the trainstop mechanism in this photo still in service 5 years back. The tripcock mechanism, perhaps less familiar in its detail to signalling engineers, does not look quite the same on current generation trains as the one shown here.

Importantly for this paper though, at the interface between them, both the trainstop and the tripcock are exactly the same today as they were when this photo was taken. It is an example of a simple open interface. It is “open” in the sense that it has a well defined technical specification, and anyone is allowed to use it in their design (whether engaged in manufacturing trains or signalling systems). That the interface has remained stable for 100 years is remarkable, though perhaps not so remarkable as may appear at first glance.

The operation of the signalling in its key parameters and requirements under that generation of train and signalling is roughly described in the system diagram in figure 2.

[refer figure 2]

In this system view, the signalling system on the train is embodied in the driver. The infrastructure signalling communicates with the driver via the signal aspect utilising an open air interface, and it controls the train brake using the trainstop interface discussed previously.

The train driver must know location and speed in order to judge when to make brake applications and to comply with the speed constraints of the network.

In one respect, the original system fell a little short of perfection, as shown in Figure 3. To avoid the risk of providing the train driver with too much information, the Victorian Tait Electric Train (“Red Rattler”) was not fitted with a speedometer. The instrument on the left hand pillar is the ammeter.

Figure 3: Tait train cab

The train driver was expected to “learn the road” so as to apply consistent and precise power and brake settings at each point along each line. If the train is driven with consistency, it will not over-speed. This was the argument.

Many years and many generations of trains and signalling technologies have passed. Yet, provided you have a train and a signalling system fitted according to the above system diagram, you can run any of those trains on any of those signalling systems regardless of manufacturer.

The network features full interoperability at that level.

You can even drive a train between regions signalled with completely different operating rules and signal aspects. You just have to either swap out the driver between the two regions, replacing her with one qualified for the region being entered, or ensure that the driver on the train is qualified to operate in both regions.

In telecommunications terms, full roaming is supported. As a side note, it probably helps if the train is stopped when you swap out the driver.

4 CBTC REVOLUTION – THE REQUIREMENTS

Today, as we transition to Communication Based Signalling Systems, we face a revolution in signalling as great as that faced by the signalling engineers of 1919. Both Sydney and Melbourne have projects in progress intended to deliver CBTC signalled lines. The model in both cases is one of single signal supplier and captive fleet.

The thing that is lost is interoperability. The following sections of this paper will consider what is involved in getting that back. A later section will consider whether interoperability is a sufficiently important feature for us, as a signalling industry, to go after.

4.1 The system view

If we consider signalling infrastructure with no lineside signals, we can see that certain things are generally required to allow a driver to drive a train:

- The driver needs a method to get an authority to allow the train to go forward into the section. This requires a signalling system and a DMI.
- The driver needs to know how far he/she can safely drive the train before needing to stop or change speed for some reason. Each Communications based signalling system has its own regime and rationale on this issue. In common is the need for information about the train type, its location and speed.
- The train needs a way to stop or control itself safely if the driver does not control the train to avoid unsafe situations (this last can be considered optional in some cases). This requires that the signalling system can control the emergency brake.

Distilling specific needs from this functional list, the CBTC signalling system is able to help the driver with all of those things provided it can obtain the following things:

- An interface to the driver (DMI);
- Knowledge of the train’s identity and type;
- Knowledge of the train location;
- Knowledge of the train’s speed; and
- Ability to operate the train’s emergency brake.

With this information available, the signalling system is able define a “protection point” for the train and ensure that the train stops or slows (as applicable) before reaching it (leaving appropriate clearance). Various alternate algorithms are available within CBTC systems to ensure the protection point is protected.

To achieve our interoperability objective, we can add the requirement that the signalling brain on the train is portable. To achieve this here, we assume that it resides on a Vital Tablet Computer (VTC) System which the driver brings on board in her bag.

This could be just a tablet computer. But we don’t exclude that it has multiple components, including a vital computer which stays in the driver’s bag and has Bluetooth and other connectivity.

The system diagram shown in figure 2 is updated to that provided in figure 4 to show the operation of the new technology to provide the equivalent system:

[refer figure 4]

The driver is replaced by the tablet (VTC) in the system diagram, but the driver is still required to perform her function as will be seen in the next section.

Between the Train System and the VTC System, there are three “air” interfaces defined. These are all defined to be open. Apart from that, some functionality is transferred from being provided by the signalling system (or as a hybrid between train and signalling systems) to a system where the functions are split with clear interfaces defined.

On the other side, all interfaces between the VTC and the infrastructure based signalling system are defined as proprietary.

5 SYSTEM CAPABILITY TO DELIVER REQUIRED FUNCTION

The authority related information provided by the infrastructure is assumed to be (1) protection points where the train must stop, and (2) Protection points where the train must not exceed a defined speed. Each case is considered in turn.

A number of algorithms are available for providing train protection using the quoted parameters. This paper considers one of the simplest of these.

5.1 Case 1: Protecting stop point

Knowing the type of train, its location and speed, the signalling system can calculate the location where the emergency brakes would need to be applied in order for the train to stop ahead of the stopping point (taking into account measurement tolerances and providing other required margins).

This distance back from the Protection Point then defines the Target Stopping Point for the train. The distance between the Target Stopping Point and the Protection Point can be viewed as an enforced fully braked overlap (according to conventional standards).

In order to assist in calculating the various key braking parameters, it helps if the signalling system has available the static braking characteristics of the train (as loaded) and the static characteristics of the train's location and adjacent geography (grades and speed restrictions).

Figure 5 illustrates the relationship between the parameters.

[refer figure 5]

If the train passes the Target Stopping Point, the Emergency Brakes are applied.

Working back from the Target Stopping Point, the point can be calculated where maximum service braking must be commenced in order for the train to stop at the Target Stopping Point. This is the train's stopping distance.

If the train passes the "Commence Braking Point", an alarm (audible and visual) is provided to advise the driver that full service braking is required to stop at the Train Stopping Point. There is no enforcement of braking following the alarm.

If the driver applies the brakes, slowing the train, the signalling system re-calculates the Train Stopping point and the Commence Braking Point based on the new speed. With the train travelling slower, both these points move closer to the Protection Point.

We can envisage a driver who applies the service brake just before reaching the Commence Braking Point. As the train slows, new Train Stopping points and the Commence Braking Points are continuously calculated, with the train never quite reaching either before it finally stops just ahead of the Protection Point.

Figure 6 illustrates this process and shows the practical train braking rate which achieves the result.

[refer figure 6]

The purple curve is simply the locus of the "Commence Braking" points applicable for each speed in relation to the Protection Point. This represents the braking curve for the train which brings the train to rest ahead of the Protection Point without the alarm sounding.

In practice this braking rate is around half the emergency braking rate. The train takes longer to slow and stop than if it applied full service brake (approximately 10s longer to stop from 80 km/hr), but this increased stopping time affects neither headway nor timetabled travel time in this application.

This algorithm may be regarded as unnecessarily clunky. Practical CBTC algorithms can do better. Yet it can be seen that the system running even a clunky protection algorithm can deliver CBTC headways and run-times for non-fitted trains which are as good as those for fitted trains.

5.1.1 Degraded modes of operation

As the quality of location detection and speed detection degrade, perhaps due to poor or absent interfaces between VTC and train system, we can look at the impact this might have on the performance of our algorithm.

In the first instance, poor sources of information merely cause larger error bars and tolerances within the VTC. More serious is where some class of information is missing.

Where location is known to the train but speed information cannot be accessed, the train will stop at the originally defined target stop point. To progress beyond will require "forward route set" which allows the protection point to move forward. The result is a virtual 3 position signalling scheme.

Where location is known only via the infrastructure (track circuits typically) but the speed can be measured, the train will either stop one track circuit clear of the Protection Point (slowing in steps according to the track circuits provided) or move up to the protection point at a defined release speed. The result is similar to many speed based ATP systems in service today.

Where neither location nor speed are known except through the infrastructure, the train will stop at the track circuit which leaves a clear line speed to the protection point. The result is a fixed block 3 position signalling scheme.

It can be seen that the degraded cases mirror practical systems in service in various places today. This puts us somewhat along the road supporting an argument that even a poorly supported VTC is "no worse" than legacy 3 position fixed signalling.

5.2 Case 2: Protecting speed restrictions

An analogous algorithm is available to enforce the slowing of the train to a speed restriction at a point. Figure 7 shows the calculations needed for a train slowing to medium speed (40 km/hr) to pass over some points:

[refer figure 7]

Figure 8 shows the practical braking curve based on this protection algorithm which ensures that the train is not speeding at the points:

[refer figure 8]

As for the earlier case, the practical braking curve is approximately half the maximum service braking rate, but unlike the earlier case the lack of efficiency in the algorithm chosen is reflected in both journey time and headway.

For our simple case of slowing from 80 km/hr to 40 km/hr, this cost is around 5s. This may not be seen as significant for a practical railway. For high speed railways the time and headway costs are much larger and do justify the development of a more sophisticated algorithm (many are available) as well as higher speed points.

With an improved algorithm to hand, it would seem hard to justify not applying it to the lower speed case as well. Thus much of our 5s loss is recoverable using a practical (as developed) VTC system.

5.2.1 Limited information cases

For the speed enforcement functions, clearly the VTC must be able to access train speed information. So there are no cases where this function can be supported without the speedo being visible (or other method).

Speed enforcement without knowledge of train location is also difficult. Typically in infrastructure based schemes, speed enforcement can be made to work effectively for a single class of train. Compromises are then made for every other class or enforcement not provided for some of those others.

5.3 Moving between regions (Roaming)

Roaming, in the telecommunications world, is the ability to take your mobile phone into an area serviced by somebody else’s network provider and still have your phone make and receive calls.

In the railway world it is the ability to operate your train on somebody else’s infrastructure. We’ve had this with traditional signalling systems due to the simplicity of the interface between the driver’s eye and the signal aspect. As mentioned earlier the approach of swapping out the driver at network interfaces can also be used.

We have discussed earlier the issue of working between fixed signal and CBTC areas, which involves a type of roaming. The challenge left is the next generation step where trains will need to be able to move directly between different CBTC signalled areas (since the fixed signal areas are all gone). To date this challenge has been met with the imposition of extreme forms of “group running” and captive fleet. Selecting a different supplier for a future project can require full network replacement and full fleet replacement. To say that this results in inefficiencies is to significantly understate the problem.

This is the telecommunications equivalent of the world before mobile phones. GSM solved that problem by including a roaming requirement and defining some key system interfaces to be open and standard. Before that, you just had to have two phones.

For the VTC system, analogous options are available to achieve our roaming objective.

5.3.1 Separate VTC system for each CBTC system

Classically, we can conceive that the driver has two or more VTCs in her bag when she gets on the train, one for each CBTC system the train will traverse during its journey.

When the train has run through the area controlled by the first system and reaches the boundary, it will classically be facing an end of authority point and will need to stop.

The train driver will then reach into her bag, take out the tablet computer relating to the CBTC system about to be entered and replace the tablet in the standard VTC holder with the new one. Other VTC components may stay in the bag.

The new VTC will pick up the train ID, its location and other information, providing what needs to be provided across the interface to the new CBTC system, acquire an authority with a protection point.

The train can then proceed.

In the same way we like the train to be stopped when changing over drivers in traditional network roaming, we like the train to be stopped when carrying out this roaming exercise also.

To achieve this level of capability does not require compatibility or direct interoperability between signalling systems. It does require that a number of interfaces between train system and signalling (onboard) system be open, defined and standardised. More detail on this later.

5.3.2 Common VTC supports multiple CBTC systems

Another option is to have a single VTC system such that, as the train transitions from one CBTC brand area to the next, the VTC manages it, switching between proprietary systems in the background but managing the open interfaces to allow seemless transition between networks.

The air interfaces between VTC system and signalling infrastructure system would need to be made open to permit this outcome.

This presents no problems in the telecoms world, but is perhaps a “hope too far” in today’s railway world.

6 SIGNALLING SYSTEM COMPONENTS

For the “unfitted train”, the essential system component is a portable method for bringing the CBTC signalling system onto the train. This signalling system must then be able to communicate with the driver (via the DMI) so that the driver can drive the train.

Our fitment process is that the driver carries the system onto the train in her bag. The system includes the DMI, which is located on a tablet computer. Although the train is referred to as “unfitted”, this does not exclude some minimal fitment for providing standard brackets to hold the tablet computer (so the driver can view it) and possibly other equipment. It also does not exclude that the train will be fitted with a static device whereby the train can be identified uniquely for the purposes of the signalling system.

The system may (or may not) also include some additional equipment (considered part of VTC) which stays in the bag.

The VTC system is able to communicate with the signalling system using the proprietary (or otherwise) air interface normally available to the train-borne components of that CBTC system. This computer will have other capabilities also. These capabilities may include the ability to communicate with the train system using proprietary or open interface methods.

In all, it is necessary then to define specific sources of the data and the control function required for use in the protection algorithm described earlier. Where some data or functionality is specified as missing the degraded residual CBTC functionality available for the train can be defined.

The components, together with available sources of data and function are described in the following sections:

6.1 The DMI

The DMI will be provided by the tablet computer. Given this form, the look and feel may be the same or similar to the CBTC displays from the same provider for "fitted" trains running on the same line section.

Driver cabs come in many forms and layouts. The "Red Rattler" cab shown earlier is perhaps of the more basic variety.

Figures 9 and 10 show some more modern cab layouts, one from an Auckland EMU and the other from a Rockhampton loco. Whilst neither of these are likely to try to operate on the Melbourne Rail network without at minimum a bogie exchange, they do illustrate the issue of identifying a standard location for a bracket for the VTC's tablet computer.

Figure 9: Auckland EMU cab layout

Figure 10: Queensland diesel loco cab layout

In practice a separate position will need to be agreed for each cab type.

In addition, raising the issue of inter-operability, tablet computers vary in size between manufacturers and over time. Together with the standard "inter-operable' (and "future maintainable") bracket dimensions defined for the cab, it can be anticipated that system specific sub-mounting brackets might also be required.

At some point someone in the future could then propose to replace all of this with a VR headset (or similar) and this will raise a whole new set of issues to work through. The future-proofing issue suggests the positioning standard be kept simple.

A default position may be to mount the tablet in the clipboard (see figure 10) space. The clipboard is possibly the one piece of portable equipment currently with the most standardised space.

6.2 Train identity and type identifier

For a standard CBTC system where the train borne part of the signalling is fixed in cabinets, the infrastructure has a level of assurance that it is always talking to the right train. When the portable VTC is introduced, this level of assurance is not automatically provided. If the driver accidently gets into the freight train in platform 4 instead of the EMU in platform 3 and logs into the CBTC system seeking an authority, strange things may happen.

The CBTC system needs to know that it is talking to the right train in terms of its location. It also needs to know some other information about the train or make assumptions about them.

Table 1 summarises the parameters and which system and method may be the ultimate source for each:

[refer table 1]

For an urban railway with a limited number of train types operating with standard consists, the above may seem a bit like overkill. However, since the purpose of the VTC is to allow non-standard trains to operate on the infrastructure, a system design which did not allow for them could be seen as deficient.

Non-urban, particularly freight railways, have always needed to consider the above parameters when operating trains.

Figure 11 shows the current "VTC" equivalent for a typical freight train. The information here is provided to the driver as a hand written note as shown. The driver then uses his/her knowledge and experience to translate the information into actions and judgements for controlling the train during the journey.

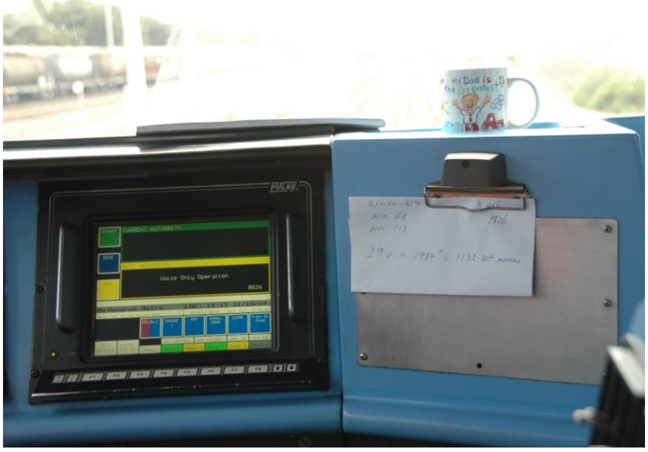

Figure 11: Train information stored in cab for driver processing

Signalling Engineers are not typically faced with dealing with these parameters in traditional signalling systems. CBTC systems provide the means to use them effectively within the VTC system to improve signal performance and headway.

With the introduction of CBTC systems comes the need for expanded horizons on the part of the signal engineer in accounting for such additional parameters.

6.3 Train location

From the point of view of the train, location can be determined by a number of methods to varying degrees of accuracy.

The CBTC system itself will have a method for determining train location. It may comprise balises placed at intervals with inertial or tachometer based data to determine location between balises. This may be supplemented by data from other sources such as GPS and knowledge of transitions between track circuits or axle counter sections. With the systems in place on board and VTC operating, these data sources provide primary location data for the train.

The question here will be which of these sources are available at what quality to our VTC system and the tolerance around any available location information.

The possibility exists that the train is fitted for a different, non-compatible Communication Based Signalling System, or with interfaces which allow the VTC system to obtain train system base data. If this is the case the train's own sensors may be capable of determining train location to a tolerance. The issue then will be for that information to be communicated in a standard format; or communicated in a format which is open.

Tolerance and reliability will be expected to be less for information generated by the VTC system in isolation than those derived with assistance from the Train System, but will be better than simply relying on track circuits or axle counters (with latencies).

Table 2 summarises the possible methods for determining train location and which system may be the ultimate source for each:

[refer table 2]

The VTC system generally amalgamates the various available sources of train location to produce a best estimate together with tolerances. In practice the system reports that the train is located within a defined region which includes the error-bars associated with the various tolerances.

Raw location is combined with network topology (static) and train path (dynamic) by the VTC system to produce location on the network.

Important here is the probability that the actual location of the train is outside of, or extends beyond the bounds of the error bars. This risk (normally assumed 0) needs to be acceptably small for the safety case.

6.4 Train speed

From the point of view of the train, speed can be determined by a number of methods to varying degrees of accuracy. A straightforward method is to use the camera in the VTC to view the train's speedo. In this way the information the system is working with is as good as that the driver has.

We could envisage a tablet computer mounting which allows the VTC accessible camera to view and interpret the actual speedometer – a clunky but simple option. Better would be an open interface to the system the train uses to generate its speedometer display.

More realistically, we could imagine a number of proprietary interfaces being developed: One for Siemens Signalling Systems to interface with Siemens trains, one by Alstom between their signalling system and train, and a third by Bombardier for their systems. No interoperability here.

Our objective needs to be an open interface to enable the train system to communicate the information to the VTC. This approach will be discussed further later in this paper.

Figures 12 and 13 show a couple of more modern trains and their speedometers:

Figure 12: Tokyo Keikyu line cab showing electromechanical speedometer (part hidden by driver).

Figure 13: Tokyo monorail cab showing VDU style speedometer including indication of authorised speed.

The VTC system itself will have generally have sensors internally which are usable as the basis for a method for determining train speed. This may comprise inertial guidance or GPS based data, which can readily be converted to measure speed. With the systems in place on board and VTC operating, these data sources provide primary location data for the train.

The question here will be which train based sources are available to our VTC system via an available interface and the tolerance around any reported speed.

The VTC system may be able to measure speed independently using GPS and inertial systems. Tolerance and reliability will be expected to be less than for train sourced data, but better than simply relying on track circuits and relay timers.

The possibility exists that the train is fitted for a different, non-compatible Communication Based Signalling System. If this is the case the train's own sensors may be capable of determining train speed to a high degree of accuracy (including data from tachometers and the same other sources which input to the speedo). The ideal objective then will be for that information to be communicated in a standard format; or communicated in a format which is open.

Table 3 summarises the possible methods for determining train speed and which system may be the ultimate source for each:

[refer table 3]

The VTC system generally amalgamates the various available sources to produce a best estimate together with tolerances. In practice the system reports that the train speed is between defined limits which include the error-bars associated with the various tolerances.

Important here is the probability that the actual speed of the train is outside of the error bars. This risk (normally assumed 0) needs to be acceptably small for the safety case.

6.5 Static data and System Specific Data

Network awareness and train characteristics comprise meta-static information sets. As such they can be held separately by the train, the signalling system and in the VTC. Input of each data set to each system can be carried out offline. The version of each data set should be checked to be correct prior to the commencement of the journey.

System Specific Data is data (which can be dynamic) which is needed but which does not need to be transferred between Systems via open interfaces.

Table 4 summarises the possible sources for static data and which system may be the ultimate source for each:

[refer table 4]

6.6 Interface to emergency brake

The final interface needing to be defined is the one which enables the ability of the signalling system to apply the emergency brake on the train when needed. This is the only control function defined in our set of interfaces.

Classically in Victoria, the emergency brake is applied by the signalling infrastructure by having the mechanical trainstop arm interface with the mechanical trip mechanism on the train to open a mechanical valve on the brakepipe. With a bit of luck the train emergency brake is thus triggered and the train brakes to a stop. We as signal engineers have intimate knowledge of the operation of the trainstop mechanism located in the infrastructure, but not so much on the train-borne systems it interfaces with.

The task of the interface discussed here is to bring that interface onto the train so it can be used by the VTC system. Since the train we are dealing with is “unfitted”, we expect this task to be a challenge.

Our approach is to define a device with a standard (or at minimum “open”) interface for performing this function on any train. By defining the function as a standard feature for all trains, the problem of non-fitment is avoided.

Noting that “unfitted” for a particular brand of CBTC may mean fully fitted for another brand of CBTC or fully fitted for ETCS, we will find that in the definition of this standard open interface lies the key to operability between CBTC systems.

Our objective here is actually less than true interoperability – it is merely roaming.

In our case, what we are after is a standard interface for an Electronic Virtual Trainstop (EVT) which can enable the control of the brake by our VTC system, regardless of supplier.

6.6.1 The Big Red Button

The use of standards in the operation of emergency brakes on trains is nothing new.

To operate the emergency brake, air is exhausted from the brake pipe by opening a valve. This can be achieved from the driver's cab by use of the brake lever or by pushing the “big red button” provided for emergencies.

Both of these items are standard features on all trains pretty much anywhere. Figure 14 shows a close-up of the Big Red Button associated with the Auckland train cab shown earlier in figure 9. Inspection of figure 12 will reveal a Big Red Button with the same function on a Keikyu line train in Tokyo.

Figure 14: The Big Red Button for an Auckland EMU

It is of the nature of standard interfaces that once you look beyond the interface itself, everything becomes different. In the old days the button would have been mechanical in nature and would have opened the brake pipe directly.

In more modern cabs this button is electrical (utilising a solenoid) rather than mechanical. An example is illustrated in figure 15 which shows the brake wiring for a loco used in Queensland.

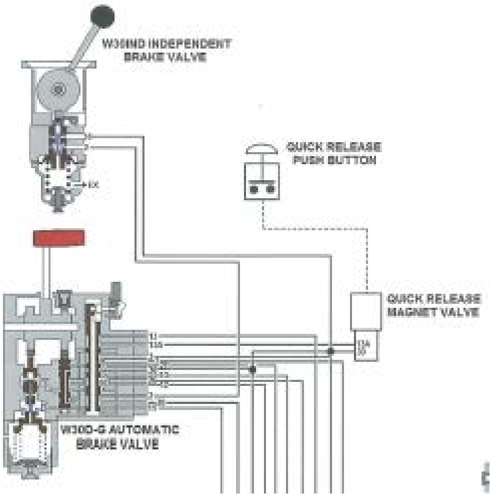

Figure 15: Locomotive wiring showing push button operating solenoid which in turn operates emergency brake [3]

It can be seen that there are many interfaces to the brake system defined within the train already. Most are part of the normal functioning of the train. Some are proprietary systems added on for various other purposes. A number of strategies are available for implementing the standard, open interface we seek.

6.6.2 Interface to emergency brake by other systems

If we look on board existing trains we find there is generally another system set up to apply the brakes automatically as a safety consequence. This is the vigilance system and we can learn from the approaches adopted here.

It has a number of methods for activating the brake.

The simplest of these is the “deadman’s pedal”. In this system a pedal must be kept depressed to hold off the emergency brakes. If the driver dies on duty, he/she stops applying pressure to the pedal, the emergency brake is applied and the train stops. The basis for operation here is a simple electrical switch.

Problems with this simple system have caused the development of more complex systems for achieving the same end. In one system there is a light followed by a sound. If the driver does not aknowledge by pressing a button, the brakes are applied. In this case the simple switch is controlled by some simple but reliable electronic logic.

More sophisticated still are systems which monitor the active control of the train by the driver. If the driver is actively controlling the train (by moving the throttle, applying a brake, working the horn, turning a light on or off, etc) then there is no vigilance test. If there is a period of driver inaction a vigilance test is applied. This option adds some more complex logic on top of the simple logic.

Top of the range are systems which actively monitor the eyes of the driver. A vigilant driver’s eyes behave differently to a driver who is asleep or dead. This system is able to distinguish between the states and either initiate a vigilance test or directly apply the brakes if the driver is judged not to be alert. At this level, supervision of the simple switch is controlled by a system on the fringes of artificial intelligence.

These systems can be highly sophisticated, but in the end the function is the same. If the driver is determined to be not adequately in control of the train, the system applies the emergency brake.

An observation to make for all these systems is the SIL rating required. BR 900 series relays are not found here, or in other similar systems. They are accepted as secondary protection systems.

If we look at TPWS, we find it certified to SIL2. This is our guide.

These vigilance systems represent the same functionality our electronic virtual trainstop (EVT) requires.

We can term it the “big red button” model for the virtual trainstop. We can imagine that the train manufacturers have provided a virtual big red button in the cab. Pressing that button (or releasing it, if you prefer that model) operates a valve which opens the brakepipe and operates the emergency brake. We can perhaps operate the existing big red button directly or we can have a method to attach to the solenoid device which the signalling system can cause to operate.

What we need is a standard interface to the signalling system which will allow the virtual big red button to apply the brake. Utilising the existing vigilance system, we could envisage that the same standard interface would have the capability of operating the brake. However, organising to modify the vigilance system to our need is likely to be complicated.

7 ELECTRONIC VIRTUAL TRAINSTOP (EVT) REQUIREMENT

The interface needs to allow the VTC system to operate the brakes. The brake control should be a train-borne system (defined and implemented by the train supplier). The VTC should be a signalling sub-system (defined and implemented as a proprietary system by the signalling supplier).

The interface between the two systems should be an open interface fully defined.

It should ideally support roaming. That is, the interface and both subsystems should be able to manage brake function across the transition between two areas controlled by separate CBTC systems (and potentially separate VTC systems – more on this later). The alternative (if roaming as an internal VTC function is not supported in an individual case) is that the transition must occur when the train is stopped (as with the changing out of drivers discussed earlier).

To achieve the desired outcome reliably, we need to avoid the pitfalls associated with trying to rely on signal suppliers to supply anything which features interoperability. Key here is to keep it simple and attractive.

7.1 Interoperability

To understand the pitfalls associated with specifying interoperability in interfaces between technology suppliers, it is useful to look at a case where it was actually achieved – GSM (2G) mobile phone systems. Below is the rough summary of a discussion you will find set out more fully in reference 2 [2].

For GSM, the impetus for European standardisation was driven initially not by the attractiveness of the benefits provided by rolling out interoperable open standards, but by the desire by the Germans and French to break in to a market up till then looking like it would be dominated by Scandinavians.

They were not fully successful since in spite of the huge amounts of money the French and Germans invested in producing a technology product which could selected as the endorsed European standard, the European Commission went ahead and selected the Scandinavian technology anyway. Good outcome, but driven by a failed strategy aimed in another direction.

Development to market of the common standards then required dealing with intellectual property rights. Top of the agenda for the European Commission was to open up the market and avoid unnecessary barriers being created. Top of the European manufacturers' agenda was to lock out the Americans and the Japanese.

The European Commission almost succeeded. As a condition for participation it forced the European manufacturers to sign up to an equal access agreement whereby patent rights made available to another player in the market had to be made available to every other player on the same terms. Dragged kicking and screaming as it were …

But it all came apart because one of the main technology owners – Motorola – happened to be American and was immune to European political pressure. Motorola, still quite interested in locking out other US and Asian competition, would agree to make available its patents only on a patent swap basis. The effect of this was to create a club of favoured suppliers who together were able to deliver GSM systems, whilst at the same time locking everybody else out.

It was not until the original patents had expired and the newer generations of system emerged that the situation changed.

The lesson for us here is that interoperability and open standards are not the favourite thing for your average technology provider. When it occurs it is often by accident and suppliers are more likely to be motivated by locking competitors out than by letting them in.

Having said that, if the right conditions are provided, interoperability and open standards can emerge.

7.2 Feasible approaches for EVT implementation

Feasible approaches for the implementation of EVTs generally fall into one of three categories. These are reviewed in the following sections.

7.2.1 Option 1: Mechanical interface to big red button

Figure 16 shows this approach – the true "bolt-on" solution.

[refer figure 16]

It involves fitting an overlay box fitted with a linear motor mechanism over the top of the big red button and providing fixings (the train system part of the interface) to allow it to be fixed to the console. In this concept the plunger in the linear motor physically depresses the button when required.

Bluetooth or similar connectivity to allow the VTC system to control the linear motor to operate the big red button when required.

Whilst this approach has the benefit of minimum change to the train, we quickly run up against issues of lack of standards. Although all big red buttons are big and red, beyond that they are all different, and differently positioned. The dimensions of the button, the force and length of travel required to depress the button, all differ from cab to cab. Thus designing a standard bolt-on unit is challenging.

It may be possible to have standard fixing points, but the bolt-on unit itself would be proprietary and each signalling technology provider would need a separate unit designed for each cab type.

The approach is a non-starter, even before we consider whether the bolt-on box would impede the normal operation of the button by the driver.

7.2.2 Option 2: Blue tooth standard interface

Having ruled out the mechanical interface, we are left with the electrical interface option. A standard alternate Bluetooth (or similar) interface is provided to a train system device which operates the solenoid which operates the emergency brake as shown in figure 17.

[refer figure 17]

In order to implement this option, a standard interface would need to be defined between train system device and VTC system. Since the required function is simple, the interface design would also be simple.

The train manufacturers would implement the device for their side of the interface (for each cab); the signal technology providers would implement their side of the interface and we would be left with full interoperability.

What could go wrong?

Firstly, there is no mechanism in the rail environment to define a standard of this type. In the telecommunications space, there is an International Standards Body (ITU), a European Standards Body (ETSI) and the European Commission (but only for Europe). Even with all those bodies pushing, it took 3 generations of technology to achieve worldwide international roaming for phones. As discussed earlier, the technology providers were not in the vanguard for this effort.

In the rail space we have none of those bodies. We have the European Commission (but only in Europe), then we have a Balkanised environment of rail operators, all trying to set international standards in their own engineering departments. Beyond that are the technology suppliers with the same interests exhibited in the GSM case discussed above.

In the GSM case, standards definition followed prototype demonstration (there was a competition conducted by the European Commission). This required investment by companies and governments and worked because the deal was that the winner became the standard. There was a prize.

In our case there is investment required, there is no one to run a competition and the prize is just interoperability. This is not always seen by the main players as much of a prize.

The second main issue with this option is how it manages (or doesn't) future obsolescence.

We have seen in the case of GSM-R for ETCS the selection and adaptation of a leading technology of its day for a rail application. Now as ETCS is rolled out we are faced with the impending technical obsolescence of this core component.

We have suggested a standard Bluetooth interface for the EVT. For how long will such an interface remain viable and what's our process for rolling out any upgrade? Even with a very simple interface, the processes of managing a standard in the absence of supporting infrastructure is daunting.

Implementing this solution is likely to be challenging.

7.2.3 Option 3: Plug replaceable standard interface

Some of the pitfalls of the above solution can be avoided by making the interface simpler and more robust against changes to technology.

This third option is essentially a hybrid between option 1 and option 2 where all functional components are left proprietary and only the plug form and basic connection details standardised. The ability to provide the electrical connection provided by the big red button to operate the emergency brake this way as shown in figure 18.

[refer figure 18]

The wiring provided within the train system is standard and simple to minimise cost and scope for confusion.

The interface comprises a standard plug and socket arrangement in or around the cabin console. Figure 19 shows a prototype plug which, in its developed form, would contain the Bluetooth connection supporting the proprietary interface, the voltage free contact and the battery.

Figure 19: EVT form

This device formally is part of the VTC system and is proprietary apart from the interface (which in this version is inexpensive and fully defined in a mature standard now).

In operation, when the driver gets on board the "unfitted" train, she puts the tablet computer in the bracket provided (or other agreed arrangement), plugs the proprietary EVT control into the standard socket provided in the train and the EVT function immediately becomes available.

Why will this work successfully to achieve interoperability where the previous approaches would not?

Firstly, the train system componentry and fitment is cheap and simple enough for a single rail operator to mandate in cabs running on its network unilaterally.

Secondly, although technology providers do not like much providing investing in systems which enable interoperability by others, they are generally quite happy to make use of interoperable components provided to them for their free use. In this solution all technology provider technology components remain proprietary.

To this extent the proposed solution ticks the boxes. It is feasible.

Where it is most likely to fail is that, due to the lack of a mechanism to set a national (or international) standard, every one of the 20 or more AROs around Australia will mandate a different form of plug and socket for its network. The requirement for a loco travelling interstate will become a room-sized panel full of sockets, and each technology provider will need to manufacture a separate plug for each one.

If Technology Providers don't much like interoperability, ARO's in Australia often like it even less.

This, after all, is how we got here in the first place. A topic for a future paper is how to fix that issue.

8 CONCLUSION

In this paper we have looked at the requirements for providing interoperability in CBTC infrastructure by use of mobile proprietary devices (VTC systems) in unfitted and otherwise fitted trains.

We have identified the need for open interfaces between train and VTC for:

- Train Identity
- Train Location;
- Train Speed;
- Emergency Brake Control (EVT)

We have shown that with just those parameters a full CBTC system can be provided using the VTC.

We have presented a practical solution for the EVT interface.

That just leaves the other three parameters to be developed into open interfaces. The prize is interoperability for CBTC systems. This provides the capacity to provide contestability in the CBTC signalling market, even after the first scheme has been installed on a network. It provides roaming capability – the ability of trains to run on multiple sections of infrastructure signalled with diverse CBTC systems.

Does anybody really want this?

Defining and providing open interfaces for Train Location and Train Speed is not a technically difficult task. Success depends on our ability as an industry to specify that such interfaces should be provided and that they should be open.

This is a step short of providing standards for such interfaces, but given the current absence of any signal standard setting bodies for the applicable subject matter, that would perhaps be a step too far.

Fortunately, as we have seen, even in the absence of all these open interfaces, the EVT alone can provide sufficient support to the otherwise unsupported VTC to allow a train to start roaming. Basic but safe.

9 REFERENCES

[1] Raynar Wilson, F. 1922, "*Railway Signalling: Automatic*";

[2] Bekkers, R. 2001, "*Mobile Telecommunications Standards: GSM, UMTS, TETRA and ERMES*";

[3] Moffat, F. 2015, "*He'll never stop that train in time. The evolution of the triple valve and development of railway air braking – an Australian perspective*".

AUTHOR

Peter Burns

Peter Graduated in Applied Science (Electronics) from Melbourne University in 1981.

He commenced as Professional Engineer with Victorian Railways that year in Signal Design., then progressed through various roles in Signal Design, Test and Development, Maintenance Management. He completed his MBA at Monash University in 1991.

Peter left PTC in 1994 to work for companies such as Alstom and Bombardier in places such as Sydney, Melbourne and Copenhagen.

In 2003, he joined with 2 colleagues to form *Rail Networks*, providing assistance over a number of years to Government as well as to Connex, the then franchisee for the Melbourne rail network.

Peter is currently director of the small consultancy firm "*PYB Consulting*" and as Chartered Engineer fills wide and various roles in rail organisations when they seek assistance. Recent projects have included RRLCMR and various Melbourne Grade Separation projects including the successful Burke/North/McKinnon/Centre Rd.

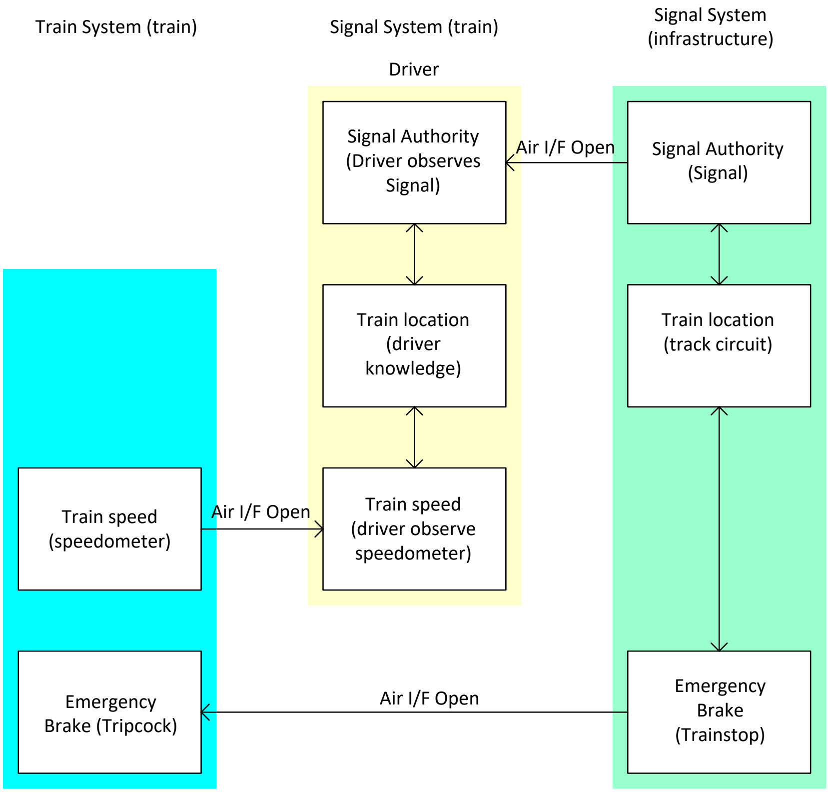

Figure 2 – System diagram 1922

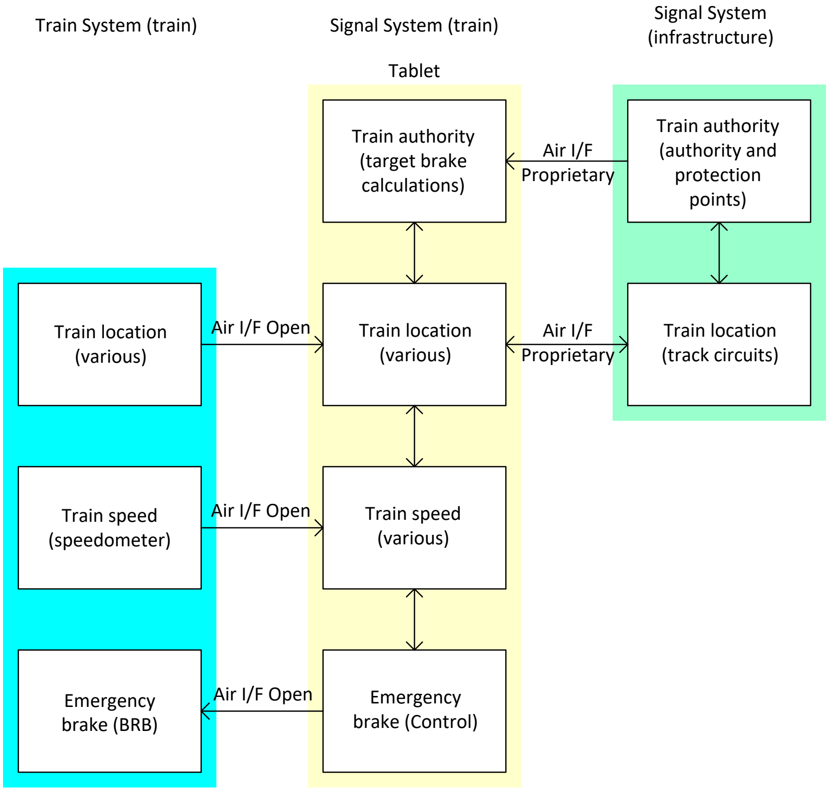

Figure 4 – System diagram 2022

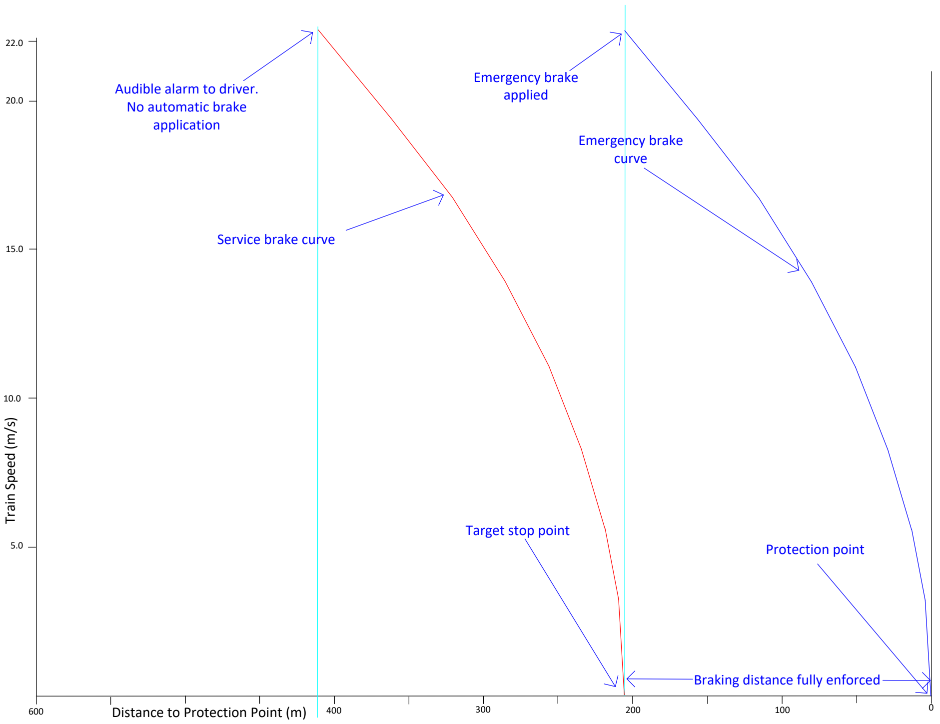

Figure 5 – Relationship between CBTC train protection parameters

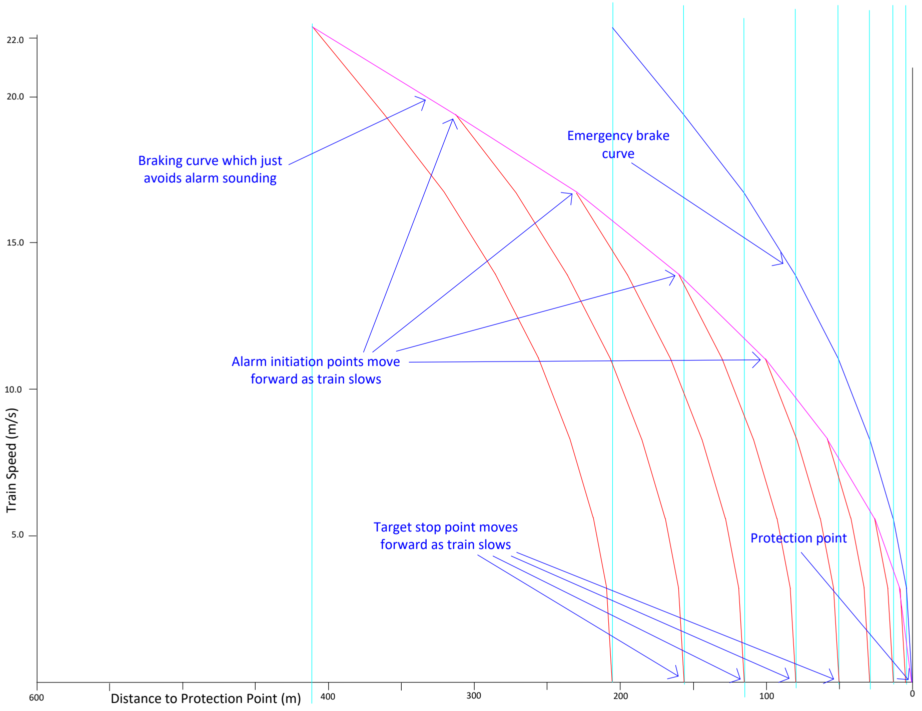

Figure 6 – process as train brakes; practical train braking rate

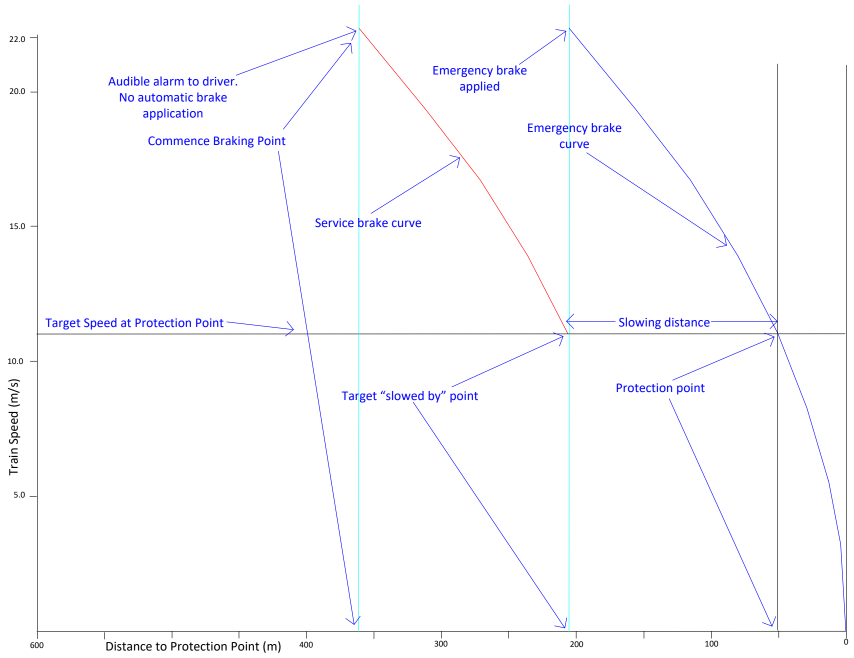

Figure 7 – calculations needed for train slowing to medium speed

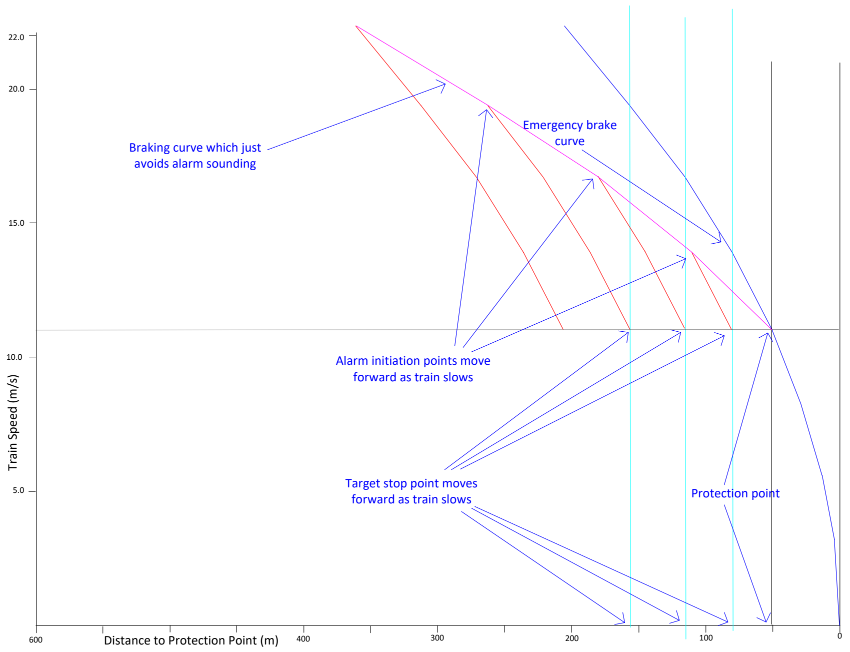

Figure 8 – practical braking curve based on protection algorithm

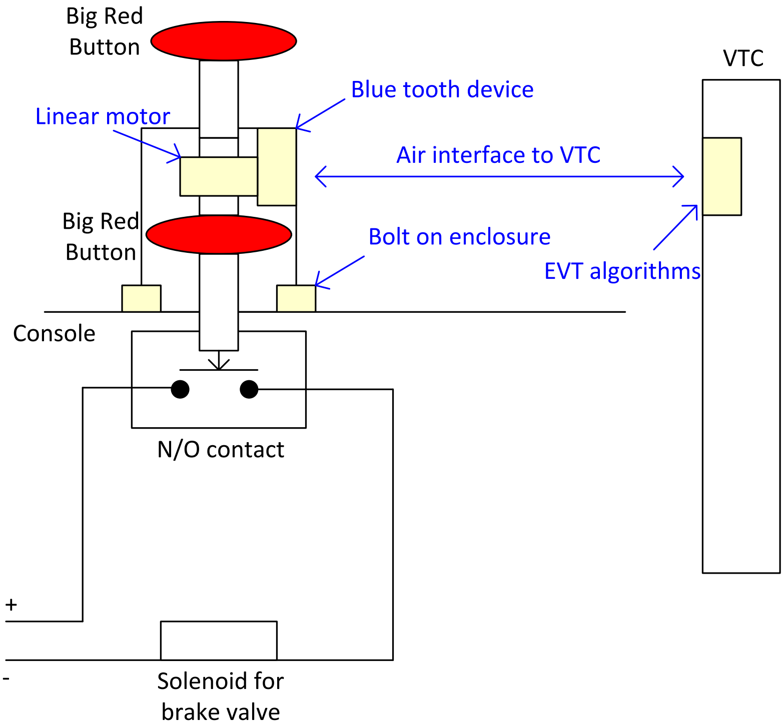

Figure 16: Mechanical Bolt-on option

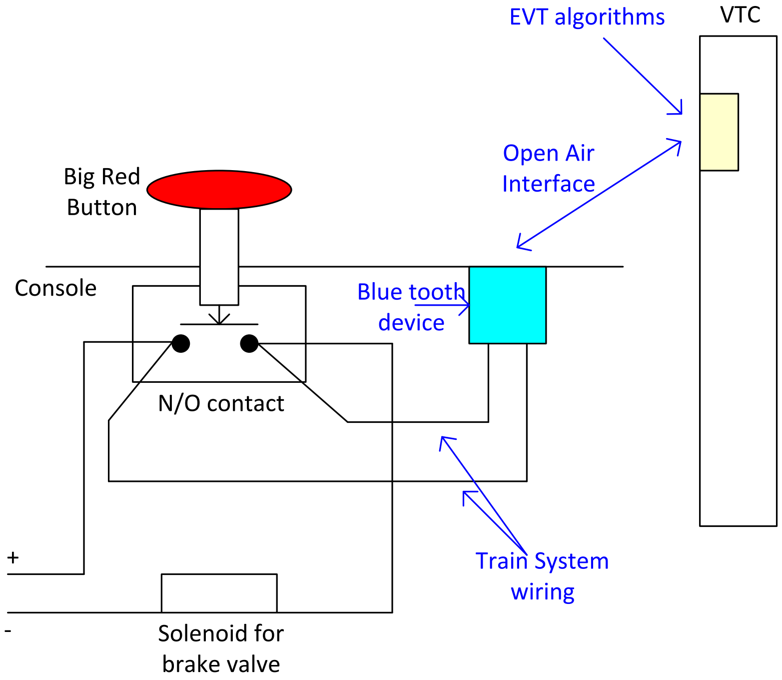

figure 17: Open interface to Console device

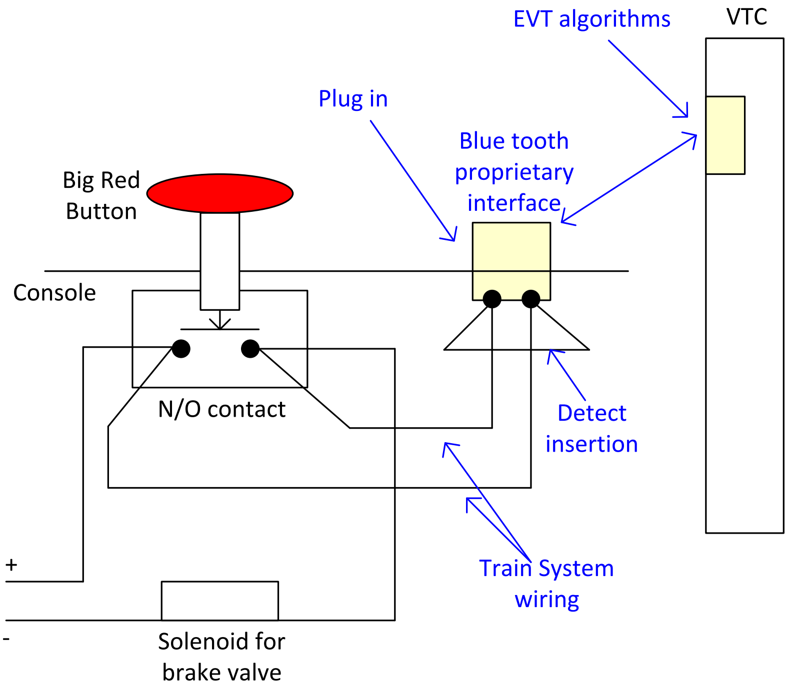

figure 18: Plug-in EVT interface device

Table 1. Train parameters and available sources

Parameter	Purpose and Default	VTC itself?	Train System?
Train Identity	Needed to uniquely identify the train and relate it to its detected location. No default.	Feasible. Manual entry of train id as currently occurs when logging in train radio. This is a non preferred method	Feasible. The train may be fitted with a tag, either in the form of a visual bar code (1d or 2d) or a static electronic tag which can be read by the VTC. Either interface is open or train is fitted with a separate tag for each type of CBTC infrastructure it may encounter.
Train type	Required to determine braking characteristics for calculation of target stop points and target braking points. Default is “worst authorised for line”.	Feasible. Manual entry of train type.	Feasible. The identity tag will enable identification of train type.
Train weight	Required to inform braking calculations. Default is “heaviest authorised for type”	Feasible. Manual entry of train weight.	Feasible. The train may detect and categorise its loaded weight. Information may be transferred to VTC by either open or proprietary interface (not discussed further here).
Train length	Required to position rear of train for signalling system when setting protection point for following train or authorising speed increase for train itself. Default is “longest authorised for type”.	Feasible. Manual entry of train length or train configuration which determines length.	Feasible. The train may detect and categorise its configuration or length using internal systems. Information may be transferred to VTC by either open or proprietary interface (not discussed further here).

Table 1. Train parameters and available sources

Table 2: Train location information sources

Method	**Signalling System?**	**VTC itself?**	**Train System?**
GPS	No	Feasible. A tablet can have GPS functionality provided it can see satellites	Feasible. The train may be fitted with GPS functionality. An interface to the VTC is needed.
Inertial Navigation	No	Feasible. The tablet can have Inertial Navigation Sensors and capability.	Feasible. The train may be fitted with Inertial Navigation Sensors and capability. An interface to the VTC is needed.
Electronic Tag	No	No	Feasible. The train may be fitted with one or more tag reader systems either separately or as part of a separate on-board signalling system. An interface to the VTC is needed.
Signalling System	Feasible. Track circuit and Axle Counter transitions are available sources. Other sources may also be available.	No	No
Odometer	No	No	Feasible. A train fitted with a tag reader system will often use an odometer for infill purposes.

Table 2: Train location information sources

Table 3: Train speed information sources

Method	**Signalling System?**	**VTC itself?**	**Train System?**
GPS	No	Feasible. A tablet can have GPS functionality provided it can see satellites	Feasible. The train may be fitted with GPS functionality. An interface to the VTC is needed.
Speedometer	No	No	Feasible. All modern trains are fitted with speedometers. An interface to the VTC is needed.
Inertial Navigation	No	Feasible. The tablet can have Inertial Navigation Sensors and capability.	Feasible. The train may be fitted with Inertial Navigation Sensors and capability. An interface to the VTC is needed.
Doppler Radar	No	No	Feasible. The train may be fitted with Doppler radar either separately or as part of a separate on-board signalling system. An interface to the VTC is needed.

Table 3: Train speed information sources

Table 4: Static and meta-static information sources

Type	**Signalling System?**	**Tablet itself?**	**Train System?**
Grade information and network topology	Feasible. The infrastructure owner is the ultimate source of this information.	Feasible. Needed to calculate location specific braking characteristics. Input from infrastructure owner.	Feasible. Not needed for this system architecture.
Permanent speed restrictions	Feasible. Can be used to calculate intermediate protection points. Information is then provided to Tablet via proprietary interface.	Feasible. Needed to calculate intermediate protection points	Feasible. Not needed for this system architecture.
Temporary and path related speed restrictions	Feasible. Used to calculate intermediate protection points. Information is then provided to Tablet via proprietary interface.	Feasible. Needed to calculate intermediate protection points	No.
Train Characteristics	No.	Feasible. Needed to calculate train specific braking characteristics	Feasible. The train manufacturer is the ultimate source of this data.

Table 4: Static and meta-static information sources

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