Crossrail Train Protection (Plan B) - Railway Safety Regulations 1999 Exemption Application Report

1 Executive Summary

This report explains the reasoning and justification supporting Network Rail's application in association with Crossrail Limited and MTR Corporation (Crossrail) Limited for an exemption from the requirement under Regulation 3 of the Railway Safety Regulations (1999); that a train should be fitted with a train protection system (as defined by Regulation 2). This exemption applies between Paddington and Airport Junction on the Western Mainline where it is proposed the Train Protection will be provided by 'Enhanced TPWS' until European Train Control System (ETCS) is available. The exemption applies only to Crossrail services and will only be utilised should ETCS not be available for the start of Crossrail passenger operations between London Paddington and Heathrow Airport.

The planned Crossrail service with new Class 345 trains will offer significant passenger benefits outside of those considered within the Regulations making delivery of the Crossrail service a significant priority.

Delivery of ETCS, that will be fully compliant with the Railway Safety Regulations (1999) in time for the passenger operation of Crossrail services remains the primary objective of NR and CRL, this is Plan A.

A number of potential risks exist in delivering ETCS (Plan A) in the area between Paddington and Heathrow Tunnel Portal. Factors considered to increase the likelihood of delay to Plan A delivery include:

- Supplier /staff availability;
- Limited delivery experience of ETCS in the UK;
- Delivery in an area undergoing significant modification; and
- Existing complexity of rail infrastructure in the area.

For the reasons above a fall-back option (Plan B) has been developed in line with Network Rail's Governance of Railway Investment Projects (GRIP) and the Common Safety Method for Risk Evaluation and Assessment (CSM RA) framework (the European risk management process for the rail industry). To inform us in reviewing and selecting options we developed system definitions for all options in line with ORR guidance.

In development of the Plan B proposal we have –

- Developed a wide range of initial options for appraisal (including legally compliant options) on the basis of technical and operational limitations;
- Analysed each option against clear objective criteria;
- Undertaken a comparison of Great Western Automatic Train Protection (GW-ATP), TPWS and ETCS functionality;
- Developed an 'Enhanced' TPWS application capable of producing a comparable level of protection to existing GW-ATP for the Class 345 Crossrail trains; and
- Undertaken extensive stakeholder engagement.

From the range of initial options it was concluded that Enhanced TPWS offered the most viable solution for Crossrail operation as it would –

- Control similar levels of overrun protection for Crossrail services;
- Provide additional overrun protection for other services using TPWS;
- Offer a known and proven technology; and
- Be deliverable in parallel with ETCS without impacting the timescales.

A comparative train protection effectiveness assessment between GW-ATP and Enhanced TPWS was carried out. Extensive review, evaluation and quantification of the levels of safety offered by each option have been performed. Enhanced TPWS has been found to offer a similar level of signal overrun protection to the current GW-ATP/TPWS arrangements. Enhanced TPWS will provide benefit to more trains in the area, and as a result safety of the area as a whole is expected to show improvement.

Following analysis, our Plan B proposal is that with the provision of additional Train Protection Warning System loops (Enhanced TPWS) we can achieve a robust and deliverable fall-back option for the area between Paddington and Heathrow Tunnel Portal in the event that Plan A is unable to be delivered according to the Crossrail service schedule of activities.

Network Rail and Crossrail are keen to progress this application for exemption with the ORR, and will fully participate in any industry consultation that the ORR considers appropriate to ensure the best outcome for users of, and stakeholders in, the rail network.

Network Rail and Crossrail remain totally committed to Plan A; e.g. to deliver ETCS for Crossrail operation. The Office of Rail and Road is requested to grant a certificate for temporary exemption under Regulation 6 of the Railway Safety Regulations 1999 in respect of the train protection requirements of those Regulations. This is necessary to support the back-up plan developed as an abundance of caution in view of the schedule risk associated with Plan A. This exemption would be required to permit operation of Crossrail Class 345 rolling stock from 20th May 2018 to 31st December 2019 on the area of Western route below should ETCS not be available in readiness for initial operation:

- Paddington Station to Heathrow Airport Junction (0mp to 11m52ch), and
- Heathrow Airport Junction to Heathrow Tunnel Junction (11m 13ch to 12m 27ch).

Network Rail

August 2015

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2 Introduction

2.1 Purpose

This report summarises Network Rail's (**NR**) application under Regulation 6 of the Railway Safety Regulations 1999 (**RSR99**) in association with Crossrail Limited (**CRL**) and MTR Corporation (Crossrail) Limited (**MTR**) for exemption from the requirement under Regulation 3 that a train shall be fitted with a train protection system (as defined by Regulation 2).

This application is required to support a proposed fall-back train protection arrangement to be used for a limited period on Crossrail services to be operated in the area between London Paddington and Heathrow Airport on the Western route. This proposal may need to be implemented when Crossrail services using Class 345 trains replace the current Heathrow Connect services using Class 360 trains.

The exemption will be utilised by NR and MTR only if it proves necessary to implement Plan B, using Enhanced TPWS as the train protection system for all or part of the route from Paddington to Heathrow Tunnel Junction. An exemption will not be required if the planned ETCS (European Train Control System) is delivered and brought into service in time for the passenger operation of Crossrail services; this is Plan A, which remains the primary objective of NR and CRL.

The exemption, if granted, will mitigate the impact of any delay in delivery of Plan A. It is felt prudent by NR and CRL that we should secure such an option, so as to ensure adequate train protection is in place for the scheduled opening of Crossrail. ETCS provision is seen as challenging in a complex area that is being improved for Crossrail and Intercity Express Program (**IEP**).

2.2 Scope

This exemption application applies to Crossrail passenger services operating using new Class 345 trains in the following area of Western route: -

- Paddington Station to Heathrow Airport Junction (0mp to 11m52ch), and
- Heathrow Airport Junction to Heathrow Tunnel Junction (11m 13ch to 12m 27ch).

Exemption is not being applied for, or required in respect of, test operation of Class 345 trains that will be required prior to Crossrail service introduction for train protection system and train testing purposes.

2.3 Timescale

This exemption is required from the start of Crossrail passenger service operation on the Western Route until ETCS is in operation. Therefore, exemption is applied for from 20 May 2018 to 31 December 2019.

2.4 Abbreviations and Definitions

Abbreviations have been avoided as far as possible in this report, and where they are used they are defined within the text. The list below provides a summary of the abbreviations and definitions used:

ATO - Automatic Train Operation

ATP - Automatic Train Protection

Balise/Beacon (in the context of this document) - track mounted equipment in a specific position that communicates with an on train system. Balise is French for beacon

CRL - Crossrail Limited

CSM RA - Common Safety Method on Risk evaluation and Assessment

GW-ATP - Great Western Automatic Train Protection

CBTC - Communications Based Train Control

Enhanced TPWS – TPWS system whose effectiveness is improved by additional trackside equipment

ERTMS - European Rail Traffic Management System

ETCS - European Train Control System

EVC - European Vital Computer

HAZID – A Hazard Identification process

GRIP - Governance of Railway Investment Projects

HST – High Speed Train

IEP – Intercity Express Program

MAF-SD – Splitting distant, junction signal control

Main Lines - lines that are normally used for HST and non-stop trains to Heathrow

MAR – Approach release from red, junction signal control

MAY-FA – Flashing Aspect, junction signal control

Movement Authority – Indication to driver of permission to enter a section of line

MTR – Mass Transit Rail

NR - Network Rail

OL – Overlap. Safety zone beyond each stop signal

OSS – Over Speed System

Permissive move - movement of train into platform already occupied by another train

Perturbed operation - any time when the train service is delayed or disrupted from the normal operational timetable

Plan A - ETCS operating from Paddington to Airport Junction in time for Crossrail Services

Plan B - Fall-back proposal to implement Enhanced TPWS as a train protection system should ETCS delivery be at significant risk

PSR – Permanent Speed Restriction

Regulated PSR - Speed reductions of 1/3 or more and initial speed of 60mph or more.

Relief Lines - lines normally used for local services and stopping traffic trains.

RSR99 - Railway Safety Regulations 1999

Standard TPWS - TPWS fitted in line with current standards

SOD - Safe Overrun Distance

SORAT - Signal Overrun Assessment Tool

SPAD – Signal Passed at Danger

TfL - Transport for London

Tph - Trains Per Hour

TPWS - Train Protection Warning System

TSS – Train Stop System

3 Background

3.1 The Crossrail Route (overview)

Crossrail will deliver a major new suburban rail service for London and the South-East. It will connect the City, Canary Wharf, the West End and Heathrow Airport to commuter areas east and west of the capital (see figure 1 below).

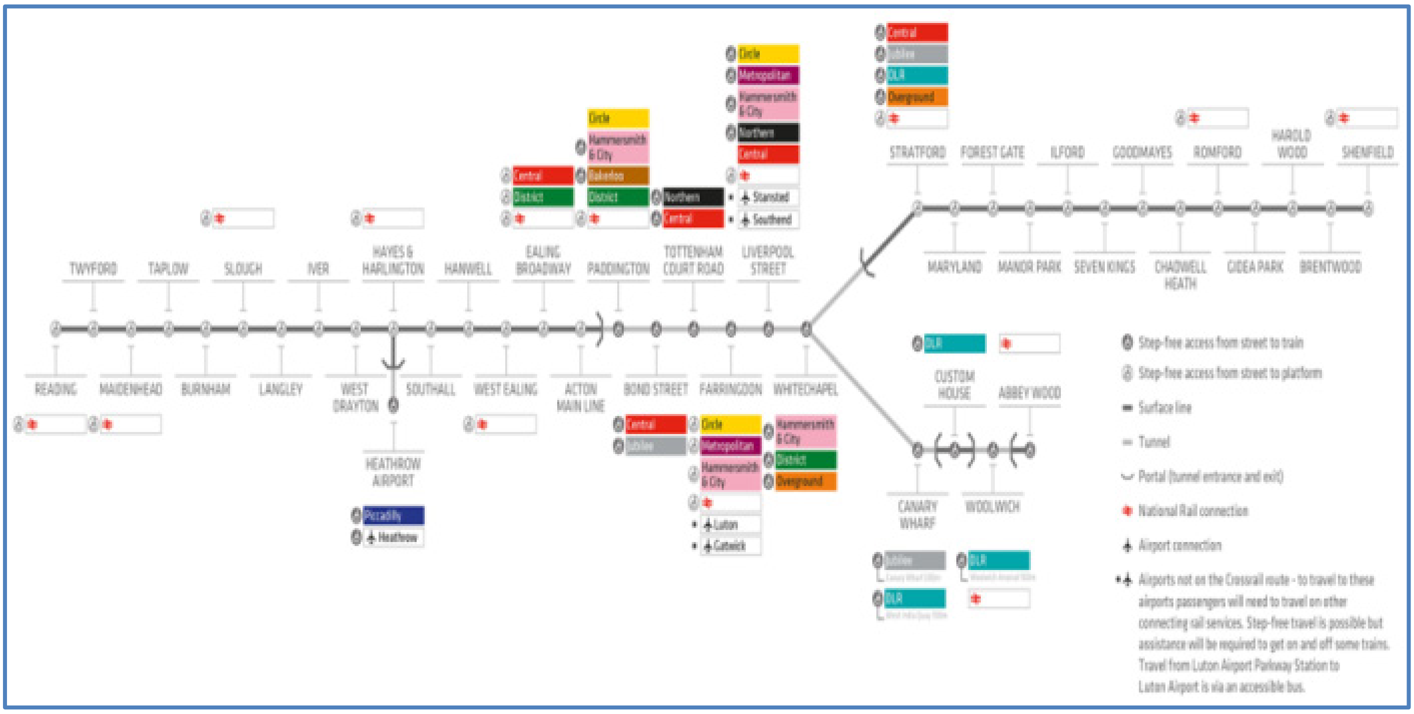


Figure 1

Crossrail will provide easier, quicker and more direct travel opportunities across the capital for the first time via new main line railway and tunnels. Crossrail will transform rail transport in London, increasing capacity by 10%, supporting regeneration and cutting journey times across the city.

Crossrail will not only provide London and the South East with a world-class, high capacity affordable railway; it will ease congestion on London's public transport system, provide better access to the capital and generate significant employment opportunities.

Introduction of Crossrail trains operating a 4 trains per hour (**tph**) service between Paddington and Heathrow from May 2018 will provide a significant increase in capacity, alleviating existing overcrowding on that section of route. Coupled with new features like Driver Only Operation (**DOO**) CCTV, the introduction of Crossrail services will provide significant safety and passenger comfort benefits.

3.1.1 Crossrail Service Introduction

The current planning assumption is that new Crossrail Class 345 trains will be introduced to run Crossrail services as follows:

- Liverpool Street to Shenfield – May 2017

- Heathrow to Paddington (Main platforms) – May 2018 (when Crossrail take over the Heathrow Connect service)
- Paddington (Low Level platforms) to Abbey Wood – December 2018
- Paddington (Low Level platforms) to Shenfield – May 2019
- Full through service (including services to Reading) – December 2019

3.1.2 Crossrail Central Operating Section

The Crossrail Central area consists of 26 miles of mainly newly constructed tunnel railway with 10 new stations. This section of the Crossrail route is not part of Network Rail's infrastructure. It will be owned and operated by Rail for London.

New Crossrail stations are being built at Paddington, Bond Street, Tottenham Court Road, Farringdon, Liverpool Street, Whitechapel, Canary Wharf, Custom House and Woolwich. A station is being rebuilt at Abbey Wood.

Crossrail station platforms will be 250m in length to accommodate 205m trains that will pass through each station, as well as enabling longer 240m trains to operate in the future as passenger demand increases.

The Crossrail Central area will initially be equipped with a Communications Based Train Control (**CBTC**) system capable of delivering a 24 trains per hour (**tph**) service.

3.1.3 Crossrail Route Train Protection

The Western and Eastern sections of the Crossrail route will operate on existing Network Rail managed infrastructure. The final train protection arrangements will require the Crossrail service to operate on a variety of train protection systems. Figure 2 below shows expected train protection arrangements for the Crossrail route in December 2019.

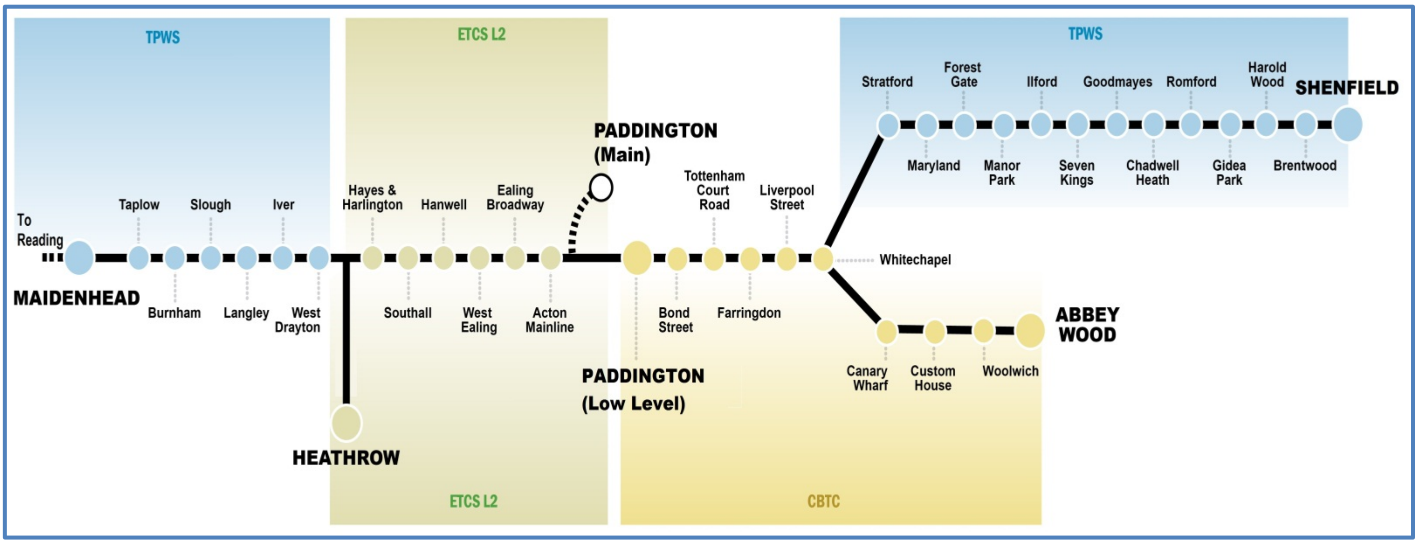


Figure 2

The existing train protection warning system (TPWS) installation is to be utilised on the Western section of the route from Airport Junction to Maidenhead (and onward to Reading) and the Eastern section of the route, from Stratford to Shenfield.

The planned train protection system to be used from Paddington to Heathrow is European Train Control System (**ETCS**) Level 2. This new system is planned to be delivered before Crossrail services operate to Heathrow in May 2018.

3.1.3.1 Crossrail Central Tunnel Area Train Protection

A Siemens Trainguard CBTC system, proven as a suitable train protection system on metro-type networks, is to be implemented in the Central area. It will be similar to those in use on London Underground's Jubilee, Victoria and Northern lines. This CBTC system is not suitable for typical mainline application. CBTC will provide Automatic Train Operation (**ATO**) which by default includes Automatic Train Protection (**ATP**).

As Crossrail is a new mainline railway, it is subject to the Railways (Interoperability) Regulations 2006 and as such European Rail Traffic Management System (**ERTMS**) is mandated by the Technical Specification for Interoperability (**TSI**) for the Central section.

As ERTMS is not presently capable of providing Automatic Train Operation (**ATO**) or moving block signalling to the required level of performance, Crossrail sought non-application of the TSI because application would compromise the economic viability of the project.

This was conditionally granted with a Commission Implementing Decision in January 2012 followed by a Department for Transport decision the following month. Provision has been made to plan for the migration from the CBTC system to an ERTMS system and enable ETCS Level 3 to operate in future.

3.1.4 Crossrail Trains

Crossrail trains will be over 200m long and will be based on tried and tested technology adapted to meet Crossrail's requirements, creating a world-class, high performing and reliable train fleet.

In February 2014 Transport for London (**TfL**) awarded the contract for provision of Crossrail's rolling stock and depot facilities to Bombardier Transportation UK.

The contract between TfL and Bombardier covers the supply, delivery and maintenance of 65 new trains and a depot at Old Oak Common.

The new trains will be manufactured and assembled at Bombardier's UK plant at Derby. TfL will be working with Bombardier on the final designs for the trains with the first due to be delivered in May 2017.

The new trains will be introduced to surface sections of the Crossrail route well before services start through Crossrail's Central underground section in December 2018.

The Crossrail Class 345 train is designed to be fully compliant with all modern standards including the Technical Standards for Interoperability (TSIs). Accordingly the train features an ETCS backbone as its core train protection system. In addition to ETCS the train will be provided with technical modules to support national train protection systems (TPWS/AWS) and also the Siemens Trainguard CBTC system deployed in the Crossrail Central Section.

The train will not include technical modules to support GW-ATP. No interfacing module exists to link this system to the ETCS backbone on the train and the development of such a module would present a significant technical challenge. There is insufficient space to provide for a further interfacing train protection system module on the train.

Crossrail trains will also utilise a bespoke Driver Only Operation (**DOO**) CCTV camera system developed from systems in use on London Underground. This system will provide a consistent image presentation to the driver whether at a surface station, or a tunnel station. The system is designed to improve the safe operation of the platform–train interface.

3.2 Exemption area (Overview)

The exemption application applies to the following areas of Western route (see figure 3 below):

- Paddington Station to Heathrow Airport Junction (0mp to 11m52ch); and
- Heathrow Airport Junction to Heathrow Tunnel Junction (11m 13ch to 12m 27ch).

Paddington Station to Heathrow Airport Junction is largely two Main Lines (primarily used by non-stopping passenger services) and two Relief Lines (primarily used by local stopping passenger services and freight).

At Heathrow Airport Junction the two tracks to Heathrow Airport join the Main and Relief Lines. These are used only by Heathrow Express and Heathrow Connect passenger services. On the approach to Paddington Station at Ladbroke Grove Junction, six tracks are provided, allowing trains access to all 14 of Paddington's platforms.

Freight services access a number of yards on the section of route, the main one being Acton Yard, at approximately 4½ miles from Paddington. Depots for FGW and Heathrow Express/Connect and a new depot for Crossrail are situated at Old Oak Common approximately three miles from Paddington. A new depot for IEP trains will be provided at North Pole, also at approximately three miles.

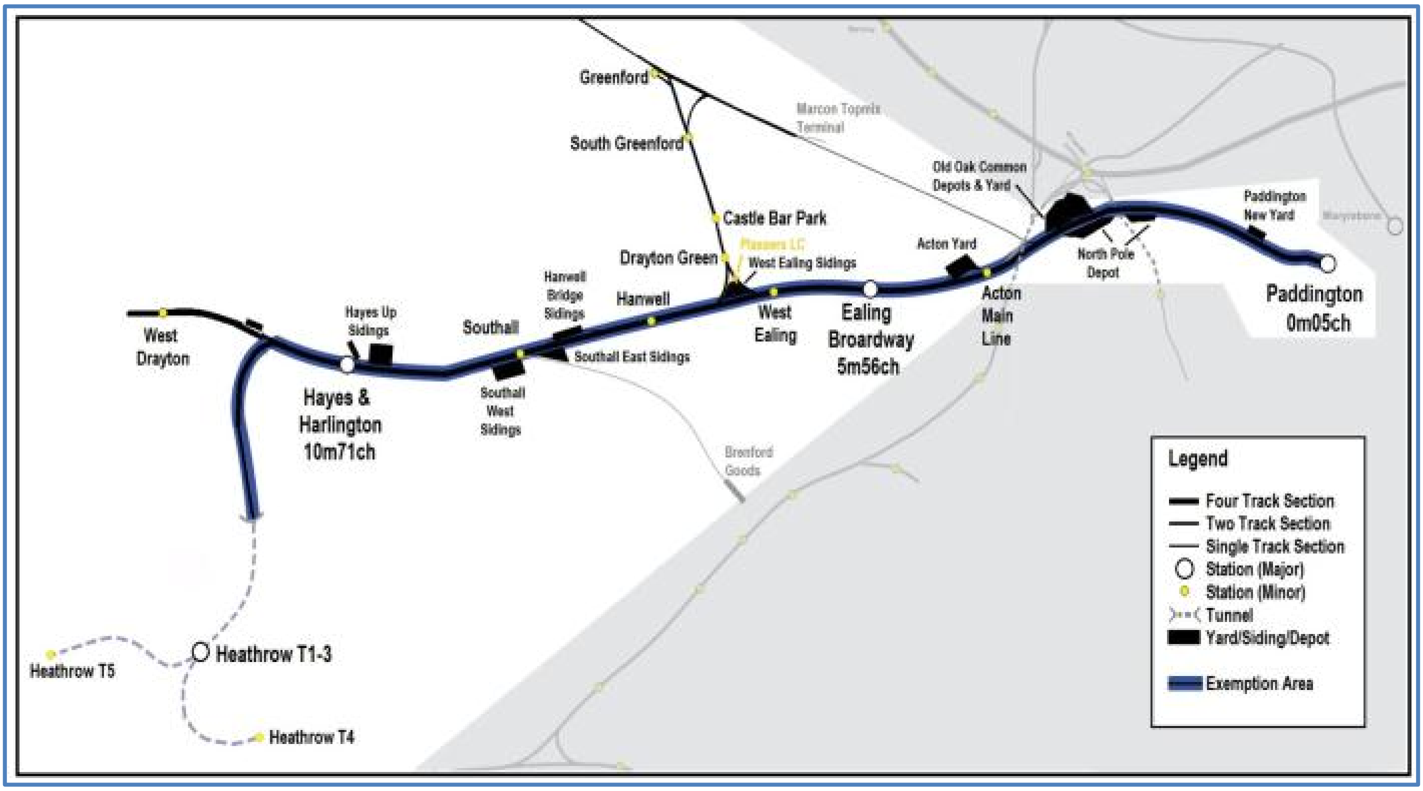


Figure 3

Maximum speed on the Main Lines is 125 mph, and on the Relief Lines 90 mph.

Trains that operate on the routes and are equipped with GW-ATP may run at speeds above 100mph.Trains operating on the section of the route between Paddington and Reading that lack GW-ATP may only operate up to the speed permitted by the TPWS system, which is nominally 100mph.

During perturbed operation and scheduled maintenance periods, all services may use either Main or Relief lines into Paddington.

3.2.1 Paddington to Heathrow - Train Protection

All Main and Relief Lines between Paddington and Airport junction are fitted with GW–ATP. It was installed initially as a pilot system on the Main Lines only in the 1990s to evaluate ATP for a high speed route. When originally implemented, only High Speed Trains (**HSTs**) were fitted with GW-ATP. Other trains and routes had no train protection systems at that time TPWS was fitted to the area as part of the national programme across all routes in 2003/4, following introduction of the RSR99, meaning all trains on the route were now covered by some form of train protection system.

In 1997 the Relief Lines from London Paddington to Heathrow Airport were fitted with GW-ATP, to coincide with the launch of Heathrow Express services.

The lines from Airport Junction to Heathrow Tunnel are only equipped with GW-ATP; only trains fitted with GW-ATP may run over this section of the route

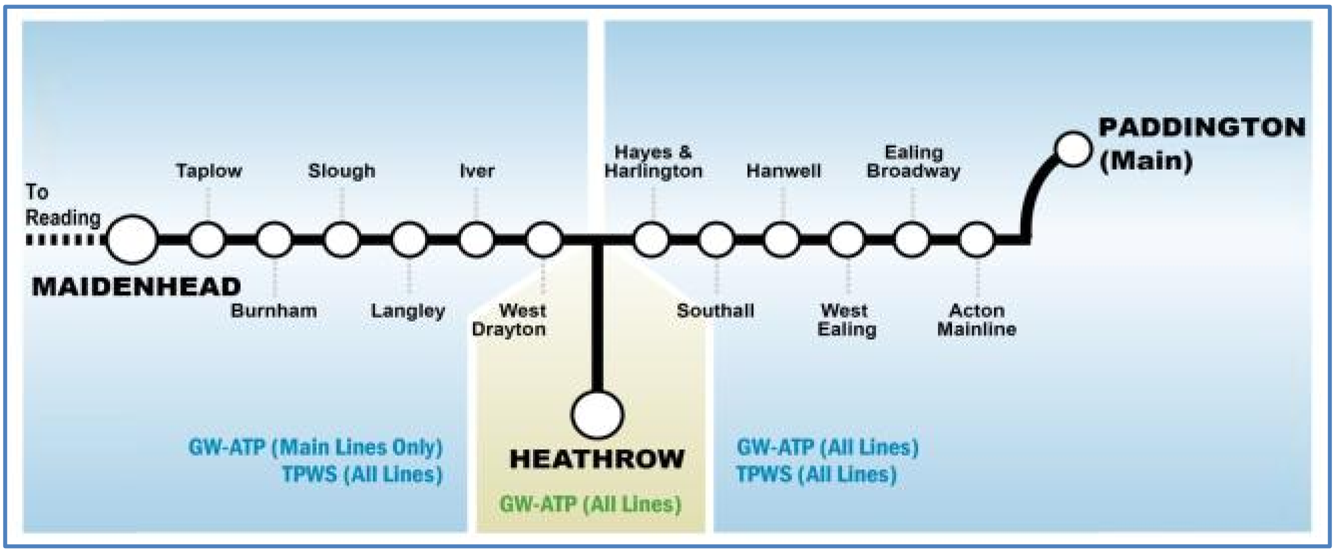


Figure 4

Additionally, Ladbroke Grove Junction benefits from enhanced signalling interlocking controls, designed to prevent junction collisions even if TPWS fails. These bespoke measures were introduced as part of a suite of improvements following the Ladbroke Grove train collision.

Currently the infrastructure in the relevant area supports both GW-ATP and TPWS. All of the trains using this infrastructure are equipped with either one or both of these solutions (see section 3.5, Train Types and Services). Figure 4 above shows the areas of availability for each system.

The system installed is a matter of timing and circumstance, with variables such as cost, regulation and technological development playing their part. Both systems are safe and compliant with the Regulations applicable to the routes on which they are used.

3.3 Regulations

3.3.1 History

Wide ranging recommendations were made in the report by Sir Anthony Hidden QC into the rail accident at Clapham Junction (1988 - 35 deaths) (**Hidden Report**).

The Hidden Report called for national implementation of Automatic Train Protection (ATP) to be completed within 10 years. This recommendation was made following significant and tragic rail accidents caused by signals passed at danger (SPAD) at Purley (1989 - five deaths) and Bellgrove (1989 – two deaths). Both these accidents and a spate of other near-misses would have been prevented by ATP.

Rolling stock design problems were also identified in the Hidden Report as a contributing factor to the number of fatalities suffered in accidents at Clapham Junction, Hither Green and Cannon Street.

In reply to the Hidden Report's recommendations two UK pilot schemes of ATP took place. British Rail and then Railtrack carried out extensive analysis and consultation into whether ATP should retrospectively be fitted nationally. Eventually it was decided by Railtrack, and accepted by the Government, that ATP would not be implemented nationally. Both ATP pilot systems remained in place but were not regarded as an essential part of the signalling system.

At Southall in September 1997, a High Speed Train passed a signal at danger (**SPAD**) and crashed into a freight train, resulting in seven deaths. The line on which this occurred was fitted with GW-ATP but the system was not operational.

At Ladbroke Grove in October 1999, again on a line on which GW-ATP was fitted, a SPAD resulted in a local passenger train proceeding without authority along the main line leading to a major collision with a HST. The collision resulted in 31 deaths, with many more severely injured. Although the line and HST were fitted with operational GW-ATP, the local train that passed the stop signal was not.

The Southall and Ladbroke Grove collisions acted as a catalyst for the national deployment of TPWS to both track and train, through the creation of the National TPWS Project. Ladbroke Grove raised the urgency of further legislation dealing with the issues raised in the Hidden Report, in addition to accelerating the provision of TPWS nationwide.

3.3.2 Relevant Regulations

Following the Southall and Ladbroke Grove collisions attitudes to regulation of the railway industry changed. Making installation of a train protection system mandatory was now seen as necessary to achieve full national coverage. Recommendations from several inquiries were rolled up into a single Statutory Instrument, which required what were by now considered a series of essential safety upgrades. The Railway Safety Regulations 1999 had three principle aims:

- compulsory use of a train protection system;
- prohibition of the use of Mark 1 rolling stock; and
- prohibition of the use of hinged door rolling stock.

Regulation 3 of RSR99 sets out the requirement to have a train protection system in service on a train, whereas Regulation 2 defines what this means:

Use of a train protection system

3.—(1) No person shall operate, and no infrastructure controller shall permit the operation of, a train on a railway unless a train protection system is in service in relation to that train and railway.

"train protection system" means equipment which–

(a) causes the brakes of the train to apply automatically if the train–

(i) passes without authority a stop signal such passing of which could cause the train to collide with another train, or

(ii) travels at excessive speed on a relevant approach;

(b) is installed so as to operate at every stop signal referred to in sub-paragraph (a), except a stop signal on the approach to an emergency crossover, and at an appropriate place on every relevant approach;

except that where it is reasonably practicable to install it, it means equipment which automatically controls the speed of the train to ensure, so far as possible, that a stop signal is not passed without authority and that the permitted speed is not exceeded at any time throughout its journey.

In broad terms (a) and (b) define the functions offered by TPWS and as such TPWS is a train protection system, but only if a system that automatically controls the speed of a train, ATP, is not reasonably practicable to install. So TPWS is a train protection system if it is not reasonably practicable to install ATP.

3.4 Train Protection Systems

Train protection systems act to prevent or mitigate the risk of a train exceeding safe limits. To achieve this systems automatically apply a train's brakes should a driver pass a stop signal at danger or exceed speed limits on approach to a signal. Systems can also prevent a train's speed exceeding that permitted on specific sections of the route and at junctions.

Train protection systems can be either "intermittent" (new information only available at specific sites) or "continuous" (information always capable of being updated).

- Intermittent - checks the movement authority and can check the speed of trains at predetermined locations. TPWS is an intermittent system. GW-ATP is also such a system, but is more continuous.
- Continuous - verifies the movement authority of trains through their entire journey, which can be changed at any time to stop a train if an unsafe condition arises (such as another train exceeding its movement authority) and requires continuous updated signalling system information to the train.

Train protection can be grouped into three broad categories;

- Basic (Train Protection) - protection at selected locations, can include selective speed supervision e.g. mechanical Trainstops and TPWS;
- Beacon based (ATP) - protection at selected locations, plus provides running profile (speed and distance) going forwards. e.g. GW-ATP; and
- Continuous (ATP) - Provides protection of speed and movement authority throughout. e.g. ETCS L2, CBTC.

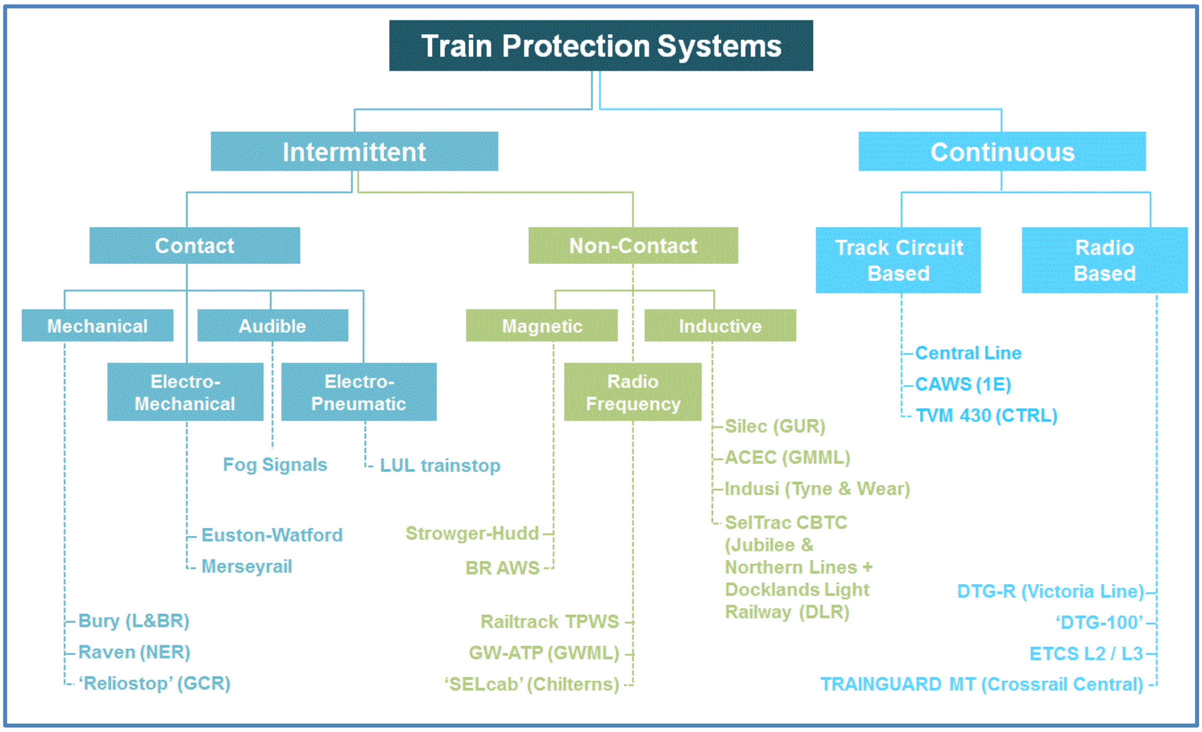


Figure 5

Figure 5 above shows various types of train protection systems in broad categories.

The term ATP (Automatic Train Protection) is applicable to systems that provide some kind of automated protection that stops a train that has exceeded the signalled movement authority (SPAD). These systems also can also prevent trains over-speeding; this is either on a location selective basis, or for the more advanced ATP systems continuous speed supervision is provided. Over-speeding either results in the train being brought to a stop, or being returned to the correct authorised speed.

Automatic Warning System (AWS) is in use throughout Network Rail. AWS primarily provides a warning to drivers of signal aspects that require the train to slow down or stop at a signal. AWS is fundamentally a warning system as brake application can be overridden by the driver. The warning acts as a driver aid to assist safe operation by requiring acknowledgment of a signal aspect that requires a driver to take action. Whilst AWS aids safe operation, it provides very limited train protection functionality as if a warning is not acknowledged the trains' brakes are applied, but is not considered a train protection system under RSR 99.

Another example of a widely used intermittent type system would be that which makes physical contact with a component on the train, such as the Trainstop/Trip Cock systems used on London Underground and some Network Rail lines. When the Trainstop on the track makes contact with the train's Trip Cock the brakes are automatically applied.

TPWS is an intermittent loop based system used on most of the UK rail network and is described in later sections of this document.

GW-ATP is a beacon based system, which is further described in later sections of this document.

CBTC and ETCS (Level 2 and 3) are continuous forms of ATP, which are also further described in later sections of this document.

3.4.1 TPWS – what is it?

In 1994, following the decision by British Rail not to retrospectively fit ATP across the network, Railtrack (now Network Rail) set up a project to examine alternative ways of preventing and reducing SPADs. An output of this work-stream was the development of the Train Protection and Warning System (TPWS).

TPWS is a system designed to reduce the number of, and in particular to mitigate the consequences of, SPADs and buffer-stop collisions. Pairs of transmitter loops are provided at each site that emits specific frequencies appropriate to their respective roles of "Arming Loop" and "Trigger Loop".(see Figure 6) An on-board aerial picks up the emitted frequencies as the front of a train passes over the loops and the receiver then determines whether to initiate a brake application on the train. Brake demand is based upon the specific frequencies detected and the time interval between receiving them.

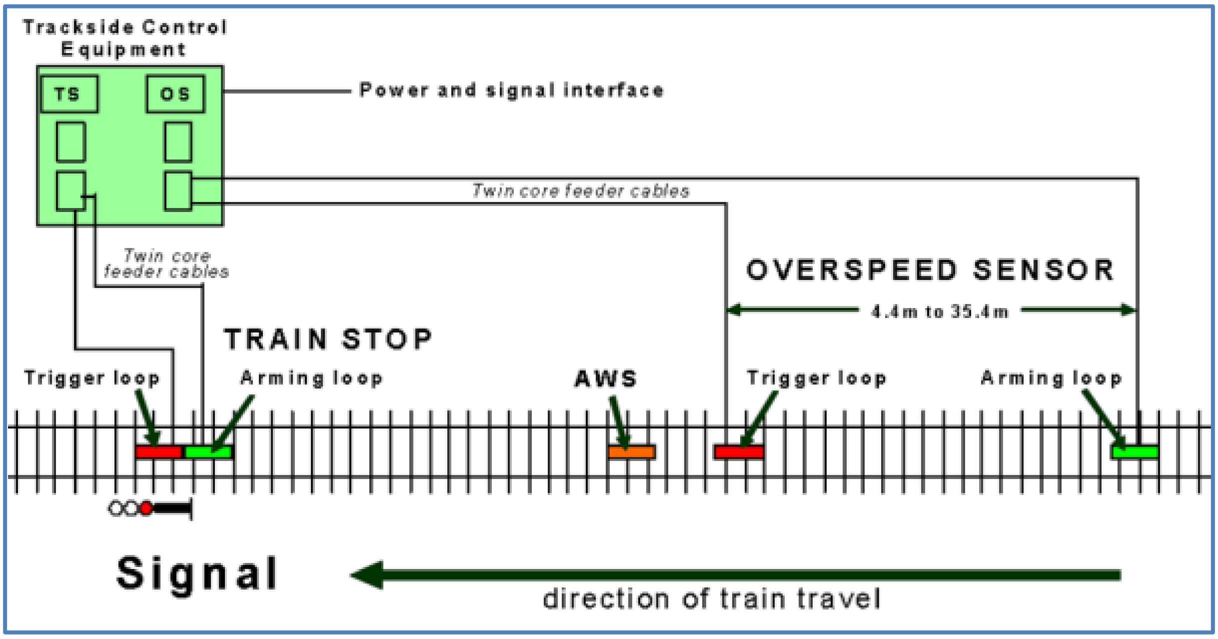


Figure 6

A Train Stop System (**TSS**) function is created by placing the Arming Loop immediately before the Trigger Loop placed (generally) at a stop signal. TSS loops emit frequencies when the signal is displaying a stop aspect. Should a train pass over the TSS loops, a full emergency brake application occurs until the train is brought to a standstill. TPWS is generally applied only to those signals that protect junctions, so is not provided at every signal.

An Overspeed Sensor System (**OSS**) function is created by placing the Arming Loop a calculated distance before the Trigger Loop; this loop separation determines the set speed of the OSS loops. OSS loops are provided on the approach to buffer-stops, some permanent speed restrictions (PSR) and most signals fitted with TSS.

When a train detects the Trigger frequency within a critical time period following detection of the Arming frequency, the result is a full emergency brake application until the train is brought to a standstill. Hence an OSS acts as a speed check, applying the brakes should a train be approaching a buffer stop, PSR or signal at danger at an excessive speed.

The on-board timer of freight trains is set at a longer value than for passenger trains; this reflects lower braking performance necessitating a more cautious approach to the signal at danger. Thus OSS loops check freight trains at lower speeds than passenger trains.

TPWS is a system with limited functionality; it was chosen for national implementation for the following reasons:

- TPWS is a capable and cost effective means of addressing the majority of the risk associated with SPADs.
- TPWS is capable of speedy introduction avoiding protracted development and extended safety approval timescale.
- TPWS can provide immediate safety benefits after installation; the rolling stock could be modified and each signal fitment commissioned independently.

TPWS only requires an active train and an installed loop to work for a given signal; there is no requirement for an extensive network. TPWS is a very effective train stop system but has some limitations as a speed supervision system. This is especially apparent when there is a mix of rolling stock characteristics and TPWS is attempting to act as a speed trap on the approach to a speed restriction or at a great distance from a signal.

3.4.1.1 Enhanced TPWS

TPWS is an expandable system; additional loops are able to be provided on the approach to a signal. With an increased number of loops the system becomes more continuous, and closer to the functionality offered by GW-ATP.

Enhanced TPWS will add TSS loops at signals currently not fitted with TPWS, and OSS loops designed to stop a train short of a conflict, generally this will be within the overlap for the signal. Additional OSS loops will also be provided on approach to buffer stop and some speed restrictions to afford an increased level of speed monitoring at these locations. Details of this proposal are contained in ‘*ETCS “Plan B” Study, Enhanced TPWS – Paddington to Airport Junction 2017, Train Protection Effectiveness Calculation Summary Report, 122271-ISD-REP-000001, Issue 2, 18 July 2015’* (Reference 1).

Enhanced TPWS will be designed to optimise the protection for Crossrail trains, affording maximum protection available from TPWS for Crossrail services. All other trains operating over Enhanced TPWS will have a significant benefit from the increased TPWS provision, particularly at sites currently not fitted with TPWS at all.

3.4.2 GW-ATP - what is it?

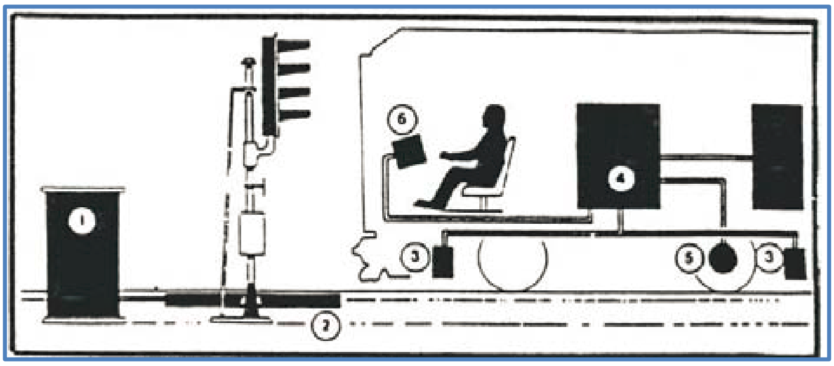
UK trials of ATP took place in Britain following the Clapham accident. British Rail and then Railtrack carried out extensive analysis and consultation into whether ATP should retrospectively be fitted to the UK rail network. The conclusion of the trials was that the costs and risks of retrofitting ATP nationally were prohibitive when compared to the safety benefits that would be realised.

The Great Western ATP (GW-ATP) system trialled was based on a Belgian system and installed on the Main Lines between London Paddington and Bristol. The system incorporates comprehensive speed and position measurement technology and links into the lineside signals so the system knows the status of the line ahead. This information is transmitted to the train via a series of beacons and transmitter loops. A similar system is in place on the Chiltern Line. These are the only ATP installations on the UK main line network.

GW-ATP Beacon

GW-ATP Infill Loop

GW-ATP on-board equipment continuously monitors the speed of the train against permitted line speed, which can be intermittently updated. An on-board computer determines whether the train is going too fast, and automatically applies the brake where necessary. GW-ATP removes the risk of drivers ignoring or cancelling warnings.



1 Trackside equipment location
2 Transmitting beacon at signal
3 Receiving aerial
4 Computer and train interface
5 Odometry (speed / distance)
6 Driver's display

The general principle of the system is that the driver is still required to observe lineside signals but is given an indication of the target speed using LEDs associated with the speedometer.

An audible warning is given if the speed limit is infringed. If the driver fails to reduce speed the system will apply the brakes. Once the train speed has reduced below the maximum permitted (target) speed, the system allows the driver to take control of the train. ATP constantly polices observation of the speed limit and the braking distance required; it is constantly recalculating the

HST Speedometer

correct speed at which the train should be travelling.

3.4.3 ERTMS/ETCS - what is it?

The European Rail Traffic Management System (ERTMS), of which the European Train Control System (ETCS) is part, is the European Union mandated train control system intended to achieve railway interoperability and compatibility throughout the European rail network. ERTMS will offer many benefits to the railway through the application of its cab signalling and train protection component.

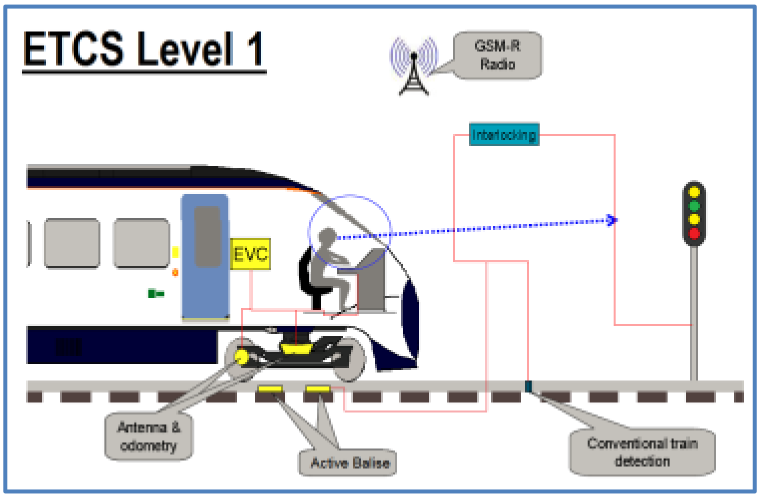
ERTMS is composed of four component parts;

- European Train Control System (ETCS) - The train control element which provides ATP. ETCS is not in itself a signalling system, but is a component part of the signalling system.
- Global System for Mobile communications – Railways (GSM-R) - This is the telecommunications element of ERTMS for data and voice communications.
- European Traffic Management Layer - The command element which is used to optimise operations through improved management of train running to maximise utilisation and reduce scheduling conflicts.
- European Operational Rules (EOR) – A single rule set designed to standardise certain aspects of rail operation across Europe.

ETCS is not the same as ERTMS. The terms are often confused and used interchangeably. This document primarily concerns/refers to ETCS and the GSM-R element where necessary.

Different levels of ETCS functionality may be implemented: Level National Train Control (NTC), Level 0, Level 1 (L1), L2, and L3. A description of the levels is given in the table below:

ETCS Levels	Level Description
Level NTC	Enables ETCS fitted trains to operate on infrastructure not fitted with ETCS. Safe movement of the train is controlled by the underlying national control systems; in case of UK this will be TPWS and AWS.
Level 0	ETCS fitted trains operating on lines with no ETCS or any other train protection or warning system.
Level 1	Movement authority (e.g. from a conventional line-side signal) is passed to the train via active ‘balises’ on the track. Generally repeating the indication from the lineside signalling system.
Level 2	Movement authority is passed to train via radio network (GSM-R) from a Radio Block Centre (RBC). Conventional train detection systems are utilised in conjunction with interlocking system to enforce safe train separation.
Level 3	Builds on Level 2, but enforces safe train separation using safety critical data from the train, rather than conventional train detection systems. Level 3 is yet to be fully defined by the European Rail Authority (ERA).

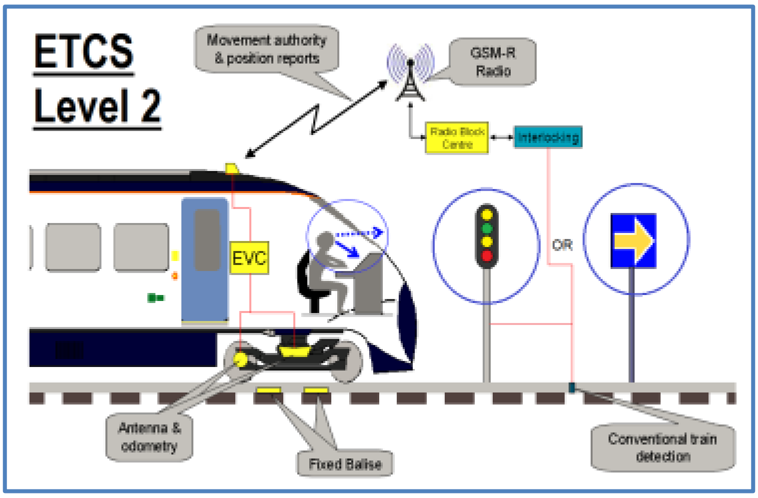


The system is available from a number of suppliers and is also used on railways outside the European Union.

Continuous ATP is an inherent part of ETCS functionality for Level 2 and above, with Level 1 providing balise based intermittent ATP.

Network Rail has an implementation plan for national deployment of ETCS L2. A pilot project has been installed and is in operation on the Cambrian Route in Wales. ECTS L2 is also being installed on the Thameslink Route in the core section; this will be an ETCS L2 system with lineside signals, with a programme to add Automatic Train Operation (ATO) at a later time.

ETCS L2 will ultimately mean that lineside signals (and with future development of ETCS L3, lineside train detection) may be removed.



Under all levels of ETCS train drivers are provided with a target speed and the movement authority distance on a screen in the cab (see Figure 7). The train identifies where it is through a combination of trackside equipment (balises) and on-board sensors (odometry), while instructions from the control centre are conveyed to the driver through GSM-R.

Figure 7

3.4.4 CBTC – what is it?

CBTC is a generic term for a train control system widely used on intensively operated metro-type railways and in use on sections of the London Underground. These systems may use radio or inductive loops for data transmission. Train position is continuously and dynamically reported through a trackside processor which facilitates moving block operation rather than fixed block as provided by traditional signalling systems (including ECTS L2). Moving block systems provide optimum route utilisation and close train operation, but to realise the full benefits of these systems they are best applied where all the rolling stock is identical, or has very similar performance characteristics, e.g. a typical metro railway.

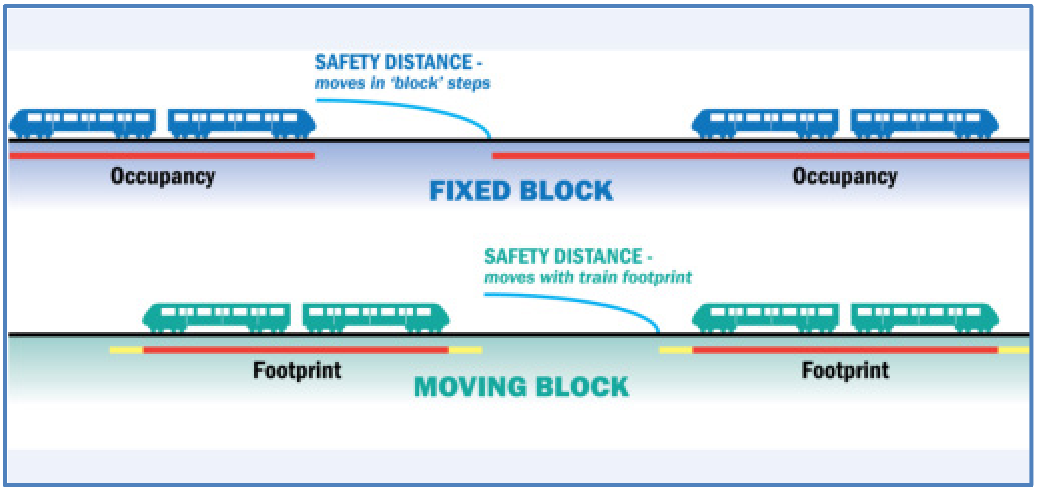


Figure 8

CBTC systems can pinpoint the actual position of a train more accurately than fixed block signalling systems. This produces a better overall traffic management solution, particularly on high density infrastructure such as that through Central London (figure 8, above).

CBTC moving block systems may be implemented with mixed rolling stock, but in such cases the system performance benefits would be more limited. Main Line operations involving different types of train are less suited to CBTC.

CBTC may include on-board and trackside processors capable of implementing Automatic Train Protection functions, as well as optional Automatic Train Operation (**ATO**) and Automatic Train Supervision (**ATS**) functions, as defined in the IEEE 1474 standard.

CBTC architecture will vary between suppliers, but the following components are generally part of a CBTC system:

On-board ATP system: This continuously controls the train speed according to the safety profile, applying the brake if it is necessary. It communicates with the trackside ATP subsystem in order to exchange information for safe operation, for example movement authority, speed and 'distance to go' (braking distance).

On-board ATO system: The component responsible for automatic control of the train within the limits established by the ATP subsystem, or even to operate the train in a fully automatic mode while maintaining traffic regulation targets and passenger comfort. It also allows the selection of different automatic driving strategies to adapt to runtime and minimise energy consumption.

Trackside ATP system: This subsystem manages all communications with the other trains in the area. It calculates the limits of safe movement authority trains must respect while operating in the area to maintain safety.

Trackside ATO system: In charge of controlling the destination and regulation targets of every train. The trackside ATO functionality provides all trains in the system with essential data relating to the current journey. Additionally, the Trackside ATO may perform auxiliary tasks, including alarm/event communication and management, or handling skip/hold station commands.

ATS system: Acts as the interface between the operator (signaller) and the system, managing the traffic according to the specific regulation criteria. Other tasks may include the event and alarm management and acting as the interface with external systems.

Interlocking system: When needed as an independent subsystem (for instance as a fall-back system), the interlocks provide vital control of trackside objects such as points or signals, as well as other related functionality. For simple systems, the functionality of the interlocking may be integrated into the trackside ATP system.

3.5 Train types & Services

All services that currently operate to Heathrow Airport from London Paddington use GW-ATP.

HSTs are the main train type in the area and generally operate on the Main Lines. HSTs are fitted with GW-ATP and TPWS and must operate with GW-ATP where available on the Western route as this provides the greatest level of train protection. Trains fitted with both GW-ATP and TPWS are able to run on infrastructure outside Western route where GW-ATP is not available, allowing use of diversionary routes where needed.

HSTs are due to be largely replaced as part of the Intercity Express Programme (**IEP**). IEP trains will be fitted with GW-ATP, TPWS and ETCS. It should be noted that the provision of GW-ATP on the IEP trains is a stand-alone facility and not integrated with ETCS. Switching between GW-ATP and ETCS is a manual process carried out before a train enters service at the start of a journey. As such IEP trains will initially operate with GW-ATP until ETCS is provided on a larger area of the Western route.

Heathrow Express services started in 1997 and operate predominantly on the Main Lines with Class 332 trains and are only fitted with GW-ATP. Heathrow Connect services started in 2005 on the Relief Lines, operating with Class 360 trains that are fitted with GW-ATP and TPWS. As these trains only operate in areas fully fitted with GW-ATP this protection is always available.

The Crossrail service will replace Heathrow Connect services, but will not be fitted with GW-ATP. Crossrail trains (Class 345) will have ETCS, TPWS and CBTC train protection systems. Provision of GW-ATP would provide limited benefit as the lines on which the services will primarily operate will ultimately have ETCS available.

Trains for local services (mainly Class 165/166) have TPWS only, and there is a plan to replace them with Electric Multiple Units (EMU) prior to Crossrail service introduction. These cascaded trains will only be fitted with TPWS.

The following table shows the protection used on each class of train in regular use on the relevant section:

Paddington to Airport Junction – Trains				Train Protection Fitted		
Class/ Type	**Service**	**Picture**	**Service Frequency May 2018**	**GW - ATP**	**TPWS**	**ETCS**
43 / HST	High Speed routes		3 tph	Y	Y	N

Class/ Type	Service	Picture	Service Frequency May 2018	GW - ATP	TPWS	ETCS
332 / EMU	Heathrow Express		4 tph	Y	N	N
360 / EMU	Heathrow Connect		0 tph (Replaced by Class 345)	Y	Y	N
180 / DMU	High speed routes		0 tph (Replaced by IEP)	Y	Y	N
165-166 / DMU	Local routes		0 tph (Replaced by Class 365 or Class 387)	N	Y	N
345 / EMU	Future Crossrail		4 tph (Increasing to 10 tph)	N	Y	Y
IEP / EMU	Future High Speed Routes		8 tph	Y [1]	Y	Y

[1] GW-ATP on IEP trains is stand-alone system, and not integrated with ETCS. Switching between GW-ATP and ETCS is a manual process carried out before a train enters service.

Class/ Type	Service	Picture	Service Frequency May 2018	GW - ATP	TPWS	ETCS
365	Future Local Routes		6 tph (Relief) 1 tph (Main)	N	Y	N
387	Future Local Routes			N	Y	N
Freight / Loco	Freight		1 or 2 tph	N	Y	N

4 Train Protection Plan B

4.1 Plan B – why is it required?

As detailed in section 3.1.3, the permanent and intended train protection arrangements for Crossrail trains from Paddington to Heathrow will be ETCS. However, in the short term NR and CRL consider potential delays in Plan A delivery could pose a risk to the delivery of initial Crossrail services. For this reason CRL and NR have agreed to develop a fall-back option, Plan B.

Plan B is considered to be required due to perceived risks in delivering ETCS in the area between Paddington and Heathrow Tunnel Portal only. Factors considered to increase the likelihood of delay to delivery include:

- Supplier staff availability
- Limited delivery experience of ETCS in the UK
- Delivery in an area undergoing significant modification
- Existing complexity of rail infrastructure in the area

For the Western route from Paddington, it is intended that ETCS L2 with signals will be implemented by the commencement of Crossrail train operation (Plan A). ETCS L2 is to be rolled out initially from Heathrow Portal to the Heathrow Terminals and then Paddington to Heathrow Portals. The Heathrow Portal to Heathrow Terminals route must be implemented first because at present it only has the GW-ATP system, meaning only trains equipped with GW-ATP may operate to Heathrow.

The Heathrow Airport lines lend themselves to being the first to have ETCS; it is a simple stretch of line, and has limited interfaces with other Crossrail works. Paddington to Heathrow Portals is complex, and being altered to accommodate Crossrail and IEP services. This makes for more challenging implementation, hence the requirement to have a ready Plan B.

There is absolute confidence that ETCS will be delivered in the Heathrow Tunnel area (Heathrow Portal to Heathrow Airport Terminal Stations). As this section of the route is not complex and is not being significantly modified, provision in time for planned Crossrail services is a much lower risk; the area can be modified in full separation from the operational Main Line.

The remit for Plan B was to identify a viable fall-back option should ETCS prove not to be deliverable. A viable Plan B would permit the new Crossrail Class 345 train to operate from Paddington to Heathrow Tunnel Portal and realise the safety, reliability and service requirements for initial Crossrail operation.

4.2 Plan B Option Development and Selection (Process)

4.2.1 Governance of Railway Investment Projects (GRIP)

NR commissioned the Plan B project in line with Network Rail's Governance of Railway Investment Projects (GRIP), as described in Figure 9 below. The Plan B project engaged consultant engineers Vertex to support identification and review of options.

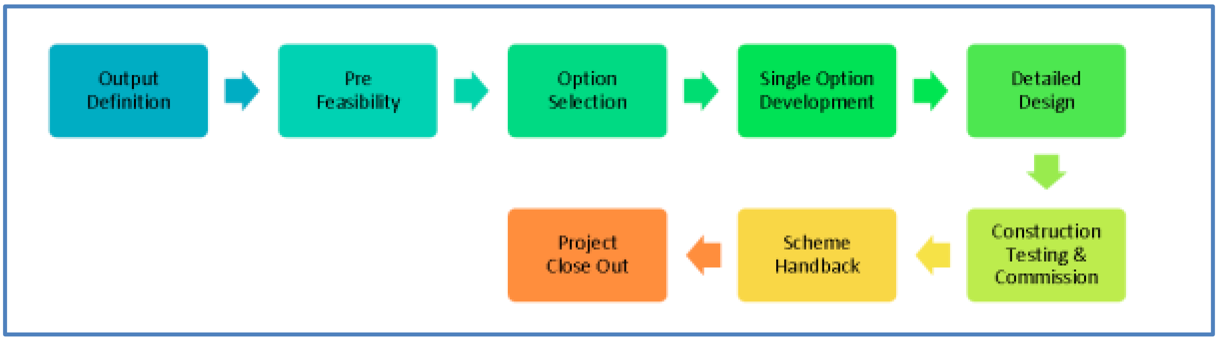


Figure 9

GRIP comprises 8 stages, from definition of required outputs through to handover for operational use and close out of the project.

As Plan B is a fall-back project the team limited development to GRIP 3 (Option Selection), the objectives are shown in table below:

GRIP Stage	Stage Aim	Main Output
3	Develops options for addressing constraints. Assesses and selects the most appropriate option that delivers the stakeholders requirements, together with confirmation that the outputs can be economically delivered	Single option determined and stakeholder approval to option approved through Approval in Principle (AIP)

Criteria were developed against which the viability of possible options were considered for development:

- Cost (including design, construction and future maintenance costs)
- Lifespan
- Achievable in time/outline programme
- Advantages
- Disadvantages
- Safety risk (including safety risk relative to GW-ATP and staff risk)
- Degraded Mode operations
- Signalling System Design Impact
- Compliance with standards
- Approved technology
- Impact to parties
- Requirement for exemption from RSR99

4.2.2 Common Safety Method for Risk evaluation and Assessment (CSM RA)

CSM RA is a framework that describes the common mandatory European risk management process for the rail industry. Further information can be found in ORR document - *Guidance on the application of Commission Regulation (EU) 402/2013 – March 2015*[2]

The Plan B project applied CSM RA methodology to the initial option selection stages and has undertaken to develop a preliminary system definition for each option. This preliminary system definition was used to assist in analysing what risks were being changed by options and the level of impact on safety that could be expected from each option being proposed.

In effect, this analysis of what was being changed and a preliminary risk assessment of that change constituted a preliminary risk assessment of that option.

This process is in line with ORR guidance on the application of CSM RA.

4.2.3 Options Development

The Plan B project was remitted to review viable fall back options. Vertex considered and reviewed options in conjunction with NR and CRL. The main stages of the option development are shown in Figure 10 below.

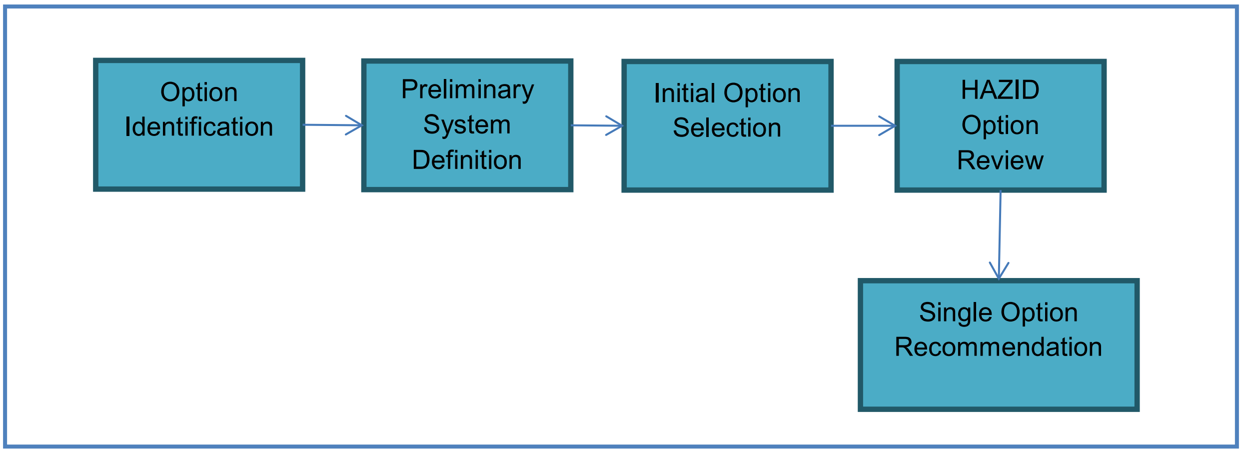


Figure 10

4.2.4 Options to extend CRL CBTC System (CBTC Overlay)

At an early stage of the Crossrail Programme (circa 2012) during the development of the CRL Client requirements the option to overlay CBTC for an extended area on the mainline network to Ealing Broadway was considered. Due to the way each system would be required to operate, the complexity of the area being overlaid and potential degraded modes of operation, the proposal to overlay CBTC was discounted. The transition area from CBTC to NR signalling and control systems was moved from Ealing Broadway to Westbourne Park.

Initial discussion between CRL and NR concluded that assumptions made in 2012 as to the risk and complexities of this proposal were still valid. In many respects the challenges that

[2] Guidance on the application of Commission Regulation (EU) 402/2013 – March 2015

had led to the need for a fall-back option for ETCS would be the same for the CTBC option, and would have caused further complication when ETCS was then provided in the area.

It was agreed between NR and CRL not to take the CTBC overlay solution any further and this was discounted from the Plan B option selection process, and not considered in the Vertex assessment.

4.2.5 GW-ATP/ETCS/TPWS system comparison

A NR peer review meeting compared GW-ATP and TPWS functionality to understand and quantify the differences. The aim was to consider whether enhancing TPWS could produce a comparable level of functional protection to GW ATP for the Class 345 trains. The peer review concluded that certain features of GW-ATP could not be duplicated, but enhancing TPWS would lead to comparable performance levels. A summary of the comparison of systems is contained in the table below:

Function	GW-ATP	ETCS L2	'Standard' TPWS	'Enhanced' TPWS
Supervision	***Continuous -*** Supervision of driver using "distance to go" calculations, intermittent contact with lineside infrastructure	***Continuous -*** Supervision of driver using "distance to go" calculations. Contact with interlocking via radio	***Intermittent -*** Supervision and contact with lineside infrastructure	***Intermittent -*** Supervision and contact with lineside infrastructure
Transmission failure monitored. (Beacon or radio or loop)	***Yes –*** If an expected transmission is missed. System changes to partial supervision mode and makes an immediate (but recoverable) brake application	***Yes –*** If an expected radio transmission is missed. System changes to partial supervision mode and makes an immediate (but recoverable) brake application	***Yes –*** Loop failure indicated to signaller. For most TPWS failures, signal on approach is held at red	***Yes –*** Loop failure indicated to signaller. For most TPWS failures, signal on approach is held at red
Display to driver	***Yes –*** Provides assistance to driver with cab display and audible warnings	***Yes –*** Provides assistance to driver with cab display and audible warnings	***Yes –*** Notifies driver of brake demand and TPWS isolation/failure only	***Yes –*** Notifies driver of brake demand and TPWS isolation/failure only
Monitors changes in permanent speed restrictions (PSR)	***Yes –*** Changes are displayed to driver. with speed calculated based on braking performance	***Yes –*** Changes are displayed to driver. with speed calculated based on braking performance	***Some PSRs –*** Speed checked on approach to the PSR and only Regulated PSRs	***Some PSRs –*** Speed checked on approach to the PSR and only Regulated PSRs

Function	GW-ATP	ETCS L2	'Standard' TPWS	'Enhanced' TPWS
Monitors adherence to maximum permitted line-speed	***Yes***	***Yes***	***No***	***Partial -*** Speed checked at the start a restriction for Regulated PSRs. Speed check set 10% greater than speed restriction
Monitors diverging speed at junctions	***Yes***	***Yes***	***Partial -*** Regulated PSRs when no restricting junction signal controls are provided. Only at MAF-SD controlled junctions	***Partial -*** Regulated PSRs when any junction signal controls provided. Add to MAR, MAY-FA and MAF-SD controlled junctions. MAR controls will check the speed of train has been checked before aspect released
Monitors temporary speed restrictions (TSR)	***Yes***	***Yes***	***Partial -*** Considered on Regulated TSRs if in place more than 12 months or, less than 12 months on >100mph lines with >200 trains per day	***Partial -*** Considered on Regulated TSRs if in place more than 12 months or, less than 12 months on >100mph lines with >200 trains per day
Stop train if it passes signal at danger	***Yes -*** Within overlap, with release speed calculated based on braking performance and overlap length except where in-fill loop provided	***Yes -*** Within overlap, full details still to be confirmed	***Some signals -*** Generally only for signals that provide protection at junctions	***Yes -*** Fit all main signals with TPWS TSS
Prevent train approaching signal faster than braking performance permits	***Yes –*** Using distance to go calculations based on train braking performance	***Yes –*** Using distance to go calculations based on train braking performance	***Some signals -*** If TPWS OSS as fitted. Most signals fitted with TPWS use one or more OSS, designed to stop most trains in SOD	***Yes -*** TPWS OSS as fitted. Signals fitted with one or more OSS, designed to stop Class 345 trains with 12% braking in OL

Function	GW-ATP	ETCS L2	'Standard' TPWS	'Enhanced' TPWS
Monitors approach to buffer stops	***Yes -*** Controls train speed to maximum of 6mph	***Yes -*** Full details still to be confirmed	***Yes, -*** Single OSS on approach to buffers. Generally speed checked to be less than 12.5mph	***Yes, -*** Additional OSS approach to buffers. Generally speed checked to be less than 12.5mph
Monitor position light moves at reduce speed (e.g. call-on)	***Yes***	Details still to be confirmed	***No***	***No***
Monitors train rolling away	***Yes –*** Monitors correspondence between direction of movement and controller position	***TBC -*** May be part of Class 345 trains requirements	***No -*** Part of Class 345 trains requirements	***No –*** Part of Class 345 trains requirements

4.2.6 Developed Options

Working together Vertex, NR and CRL developed a number of options for review against the agreed criteria. Options developed were not limited to technical solutions for train protection; also considered were operational/procedural and programme options. TPWS options were developed using system comparison information as described in section 4.2.4. Some of the other options considered would have required exemption from RSR99.

Options considered are shown in the table below:

Option	Description	RSR99 Exemption Required
0	Do Nothing – Run Crossrail Class 345 service in Level NTC, with no further infrastructure changes	Yes
1	Standard TPWS Implementation on Heathrow Airport lines. TPWS integrated into control system with fault reporting	Yes
2	(Option 1) plus enhancing on existing TPWS fitted signal to current minimum requirements (integrated into control system with fault reporting)	Yes
3	(Option 2) plus the addition of TPWS on all plain line signals. (Integrated into control system with fault reporting)	Yes
4	Enhanced TPWS: TPWS on all signals designed to stop Class 345 train in the overlap (Integrated into control system for fault reporting)	Yes
5	(Option 4) with extra TPWS on PSRs, junctions signal to reduce risk of train speeding. (Integrated into control system with fault reporting)	Yes
6	(Option 5) but no fault reporting/integration into control system for additional TPWS that are not being provided by Crossrail scheme ("bolt-on" TPWS)	Yes
7	Fit GW-ATP to Crossrail Class 345 Rolling Stock	No

Option	Description	RSR99 Exemption Required
8	Fit ETCS Level 1	No
9	Alter track layout such that Crossrail Operations are physically Isolated from GWML	Yes
10	Utilise existing GW-ATP fitted rolling stock (e.g. HEX/Heathrow Connect) for additional Crossrail Operation until ETCS Level 2 provided	No
11	Separate Class 345 Trains by Time (absolute block equivalent)	Yes
12	Second Driver on the Footplate of Class 345	Yes
13	Utilise IEP GW-ATP fitted rolling stock	No
14	Delay Running additional Crossrail Service with Class 345 until ETCS Level 2 is provided	No
15	(Option 0) but with Minimum Transition Infrastructure to ETCS L2 at Heathrow Tunnel Portal to enable transition to ETCS L2	Yes

4.2.7 Initial Options Selection

Vertex prepared the system definition and reviewed each option against this, presenting their results for use by the project. For each of the options their outputs included:

- A clear statement on what was being changed and the scope of the change;
- The system objective, e.g. intended purpose;
- System functions and elements, where relevant (including e.g. human, technical and operational elements);
- System boundary including other interacting systems; and
- Physical and functional interfaces.

A Network Rail initial option review panel undertook a peer review of these outputs to determine/recommend options considered viable for a more detailed Hazard Identification Review (HAZID).

Vertex report *Crossrail ETCS GRIP 1-3 Options Analysis* (Reference 3) records the full option selection process and for each option records:

- preliminary system definition
- review of option against the selection criteria
- outcome of the quorate panel review
- recommendation on options for further detailed review

4.2.8 Options Discounted at Initial Options Selection

Many options were discounted as part of the initial option selection. A summary of the main justifications for not progressing options is given in the table below:

Option	Description	Summary of why Option Discounted
0	Do Nothing	Option 1 or 15 would need to be done as minimum to allow operation to Heathrow
1	Minimum TPWS Implementation on Airport lines.	Below the minimum level of train protection that would be considered acceptable when current services have ATP. Not acceptable to just retain existing train protection system.
2	(Option 1) plus enhancing on existing TPWS.	Below the minimum level of Train Protection that would be considered acceptable when current services have ATP. Not acceptable to just retain existing train protection system.
7	Fit GW-ATP to Crossrail Rolling Stock	Unable to fit the GW-ATP driver console equipment in designed cab. GW-ATP equipment on the driver console is a considerable constraint in optimising the console layout. Unable to fit the GW-ATP equipment cabinet in the driving cab due to insufficient space. Significant Rolling Stock Delivery delay risk arising from level of redesign required thus risks in delivery of Plan A. Reputational damage to NR and CRL would be significant if service delivery is delayed. There is no existing design for a module to interface GW-ATP to the ETCS backbone on the Crossrail train Development of a successful operational transition from CBTC to GW-ATP at Westbourne Park also requires an entirely new interface between two systems not previously attempted
8	Fit ETCS Level 1	ETCS Level 1 is an immature technology in the UK and has no planned deployment for UK. The first significant usage therefore carries considerable implementation risk from unknowns similar to ETCS Level 2 (Plan A). As such, not really a viable fall back(Plan B) for Plan A.
9	Alter layout so Crossrail physically Isolated GWML.	Not Credible - Operationally impractical to physically isolate two lines out of Paddington to Heathrow Portals. May be utilised as a potential HAZID control measure along with other options.
11	Separate Class 345 Trains by Time	Not credible - would cause extensive operational issues since non-Crossrail traffic would be barred from Paddington to Heathrow portals
12	Second Driver.	Not credible – a procedural hazard control is non-preferred in the risk-control hierarchy. Additional operational expense in terms of requiring extra drivers to be recruited and trained prior to Crossrail Operation, and retain until ETCS then no longer required. Could be utilised as a potential HAZID control measure - for use in degraded modes.
13	Utilise IEP rolling stock.	Not credible – Would require train compatibility and route clearance issues. Increase driver training demand and re-training for Class 345 when ETCS provided. Deemed as not achieving Plan B requirements to allow use of Class 345 to enter service.
14	Delay Running Crossrail Service	Deemed as not achieving Plan B requirements to allow Crossrail Operation. Noted as an outcome and not an option for Plan B. Defers the significant safety and capacity benefits that come with the new Crossrail rolling stock and final services.
15	(Option 0) but with Minimum Transition to ETCS	Not Credible - Linked to Option 0 - It is below the minimum requirement. ORR is not likely to accept this.

A selection of TPWS options were considered acceptable to progress based on the following key assumptions and factors:

- SPAD risk level would be comparable to GW-ATP and acceptable for a short transition period;

- No technical system development risks (known technology);
- Integration with rolling stock would be understood minimising development issues; and
- Lowest overall risk delivery made most appropriate as a Plan B option.

These options were taken forward for further risk analysis, to determine which was most appropriate for Plan B development.

5 Option Risk Assessment (Overrun/ Safety Justification)

The various functions of TPWS, ETCS and GW-ATP enable them to mitigate SPAD, buffer stop commission and over-speeding risks to varying levels. ETCS has a number of other functions that may permit management of additional risks, but those are still in development as part of the National ERTMS Programme.

5.1 Levels of Safety

The Safety Risk Model (**SRM**) has been developed and published by RSSB to support members' own studies. The primary objectives of the SRM are:

- To provide an estimate of the extent of the current risk on the railway; and
- To provide risk information and risk profiles relating to the railway.

This information is used for risk assessments, appraisals, and to inform decision making throughout the railway industry.

The SRM models hazards that collectively define an overall level of risk on the UK railway. It estimates the total UK network risk and indicates the current level of residual risk (i.e. the level of risk remaining with the current mitigations in place).

The SRM is a key tool used to help support taking safe decisions by:

- Monitoring: are operations safe or might changes be required?;
- Analysing and selecting options: what (if anything) should I change and can it be done safely; and
- Making a change: how do I make sure a change is safe?

Data from the SRM was employed in the Plan B HAZID exercise to inform the decisions of the review group (see section 5.4 Further Options Selection (HAZID-Hazard Identification)).

Train protection systems mitigate against four main hazardous areas that cause train accidents:

- SPADs, leading to collisions and derailment
- Over-speeding, leading to derailments
- Permissive movements, leading to collision
- Buffer stop/rollback collisions, leading to derailment

The table below is from the document *The Strategy for the Train Protection and Warning System (TPWS) – Issue 2 (Draft) – February 2015* (Reference 13) and gives an overview of the level of residual risk from the SRM that could be further mitigated with TPWS. These figures assume that the current TPWS and ATP systems are in place.

Type of Collision or Derailment Event	Risk (FWI/yr)
Passenger train SPAD leading to collisions between trains	0.26

Type of Collision or Derailment Event	Risk (FWI/yr)
Non-Passenger train SPAD leading to collisions between trains	0.18
Passenger Train SPAD at Level crossing	0.012
Non-Passenger Train SPAD at Level crossing	0.0016
Passenger train derailment due to SPAD at S&C	0.062
Non-passenger train derailment due to SPAD at S&C	0.028
Passenger train derailment due to overspeeding	0.017
Non-passenger train derailment due to overspeeding	0.0035
Buffer stop collisions	0.10
Total risk	0.6641

It can be seen that based on SRM data, collision and derailment due to SPADs currently represents a larger share of residual risk than other derailments or buffer stop collision.

Total residual risk of events that could be mitigated by TPWS: -

- SPAD risk - 0.5463 FWI/year
- Over-speeding 0.0205 FWI/year
- Buffer stop collision - 0.10 FWI/year

SRM figures are based on TPWS or ATP currently operating on the network. It is estimated that without train protection figures would increase by a significant amount. Estimated figures are SPAD risk increasing to 1.15 FWI/year and over-speeding risk increasing to 0.05 FWI/year.

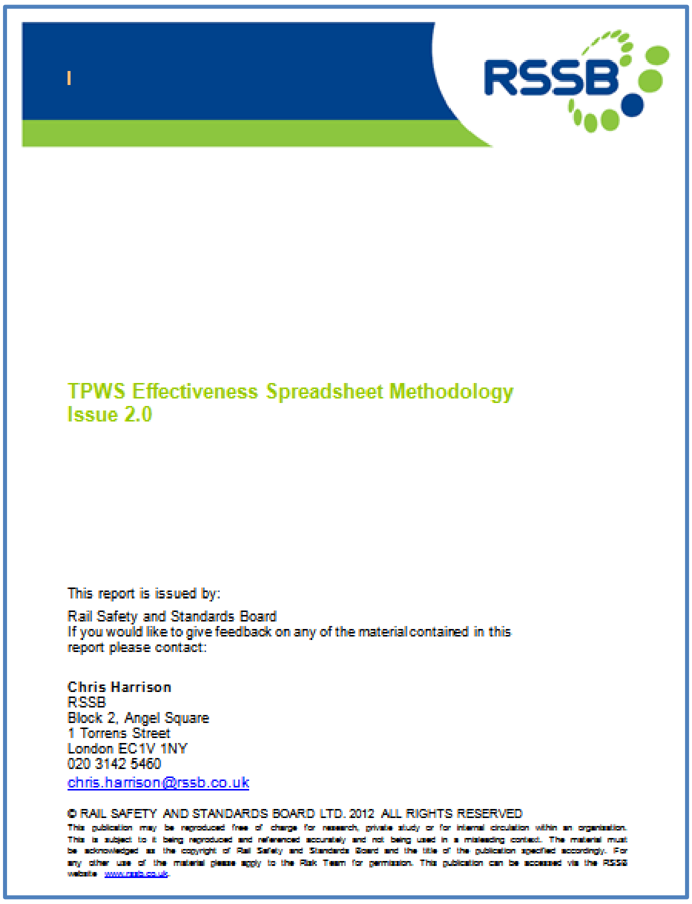
Based on the SRM data it can be seen that should a train protection system be changed as in case of the proposed by Plan B, SPAD risk is the area that warrants the greatest consideration; this would potentially pose the most significant change in risk.

As such, the project team has analysed the likely change in SPAD risk that can be expected using the tools currently available (see section 5.3, Overrun Risk Assessment (Train Protection Effectiveness)).

Risks of permissive operation (the movement of a train at an already occupied platform) will be limited due to the length of the Class 345 Crossrail train, at over 200m. This is significantly longer than the Heathrow Connect Class 360 at just over 100m. As Class 345 trains are so long it will not be possible for Crossrail to carry out any planned permissive operations at Paddington or Heathrow. Permissive operation will only be authorised in times of degraded operations or during times of severe disruption.

5.2 TPWS Effectiveness Tool

TPWS effectiveness values are a measure of the effectiveness of a given signal that take into account all trains that use that signal and the likelihood that a train would be stopped before a given collision point. This likelihood is expressed in terms of a percentage and the TPWS effectiveness is defined as the expected number of trains that will stop before the first conflict point in the event of a TPWS trip.


TPWS Effectiveness Spreadsheet Methodology
Issue 2.0

This report is issued by:
Rail Safety and Standards Board
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RSSB developed the Methodology for TPWS Effectiveness in 2012. This methodology was validated, and is contained within an Excel spreadsheet tool.

The methodology was originally developed for use when assessing SPAD risk using the Signals Assessment Tool (SAT), and Detailed Assessment (DA) process. These have recently been replaced with the SORAT process (see section 6.1 Further Overrun Risk Assessment Proposed) and the methodology has been included within the SORAT software.

The methodology employs historical data to determine the probable speed of a train on approach to a signal at danger and thus the effectiveness of the TSS and OSS loops provided.

Analysis of data from OSS and TSS trips that resulted in SPADs was used to determine an expected speed distribution and proposition of expected brake activations at TSS and OSS loops.

Each class of train expected to use a particular signal under assessment is added to the tool and the overall effectiveness is determined based on the speed distributions calculated, location and number of TSS and OSS loops. Overall effectiveness at a signal is affected by the mix of trains with differing braking performance and/or quantity and position of TPWS loops.

Maximum effectiveness achievable has been limited to 95% for TPWS and 99% for ATP. 100% effectiveness is not a realistic goal; not all risk from overrun can be mitigated with a train protection system, no matter how good.

5.3 Overrun Risk Assessment (Train Protection Effectiveness)

How much SPAD risk train protection systems are addressing and how effective those systems are at mitigating risk, is addressed in the following section. It should be noted that TPWS is a simpler system than ATP, and does not mitigate as much of the risk on a like for like basis. But as TPWS is more widely used, it has the potential to offer protection to more trains per unit installed.

The Enhanced TPWS concept provides an interim solution that could be fitted more quickly than ATP or ETCS, and would provide a substantial proportion of (but not all) the risk reduction benefits of ETCS.

Work has been carried out using the TPWS Effectiveness Tool (see section 5.2, TPWS Effectiveness Tool) as part of the Plan B development process. An estimate of the level of effectiveness Enhanced TPWS would provide at each signal when compared to GW-ATP and ETCS has been carried out. As the overall effectiveness of the system will also depend on the number and type of rolling stock in operation, a best-estimate of the May 2018 timetable has been used in these calculations (see section 3.5, Train Types and Services).

It should be noted that the effectiveness percentage is the combined effectiveness for all the timetabled trains expected to pass that signal and stop within the overlap for that signal (see figure 11, below).

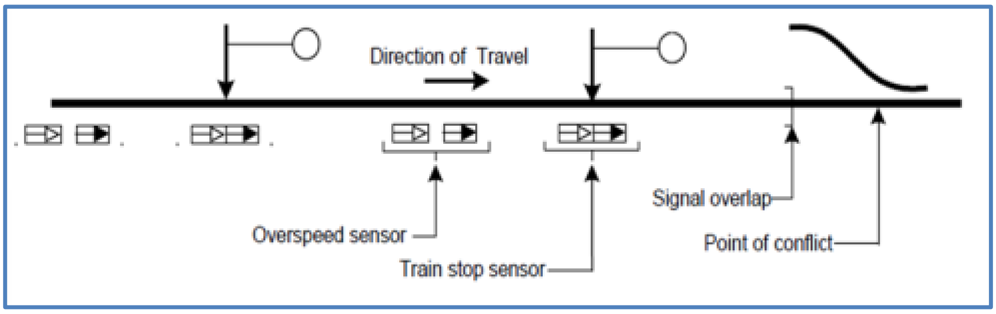

Figure 11

Note: TPWS is normally designed to stop 12%g trains before the point of conflict. The Enhanced TPWS installation assessed has been designed to stop the Crossrail rolling stock within the overlap. This makes it comparable to GW-ATP in that it checks a train's speed of approach to prevent the train exceeding the overlap.

5.3.1 Train Protection Effectiveness (Relief Lines)

Generally, there is a small reduction in calculated train protection effectiveness at most signals when the Heathrow Connect trains (Class 360) are replaced by Crossrail trains (Class 345) without GW-ATP. This is mainly driven by the reduction in maximum effectiveness achievable from 99% for GW-ATP to 95% for TPWS.

Signals currently fitted with only GW-ATP fall to 0.0% effectiveness (e.g.SN209) as no GW-ATP trains are planned to operate on Relief Lines. Predictably, a substantial increase in effectiveness is achieved when Enhanced TPWS is provided as it benefits all trains passing that signal. If only ETCS is provided the overall effectiveness is slightly greater than that currently achieved with GW-ATP and Heathrow Connect services. This is due to the increased frequency of service from 2 tph to 4 tph, increasing the proportion of trains with

99% effectiveness. But the effectiveness of signals with only ETCS projection is significantly lower than with the Enhanced TPWS option as shown in the table below, where arrows are used to show the relative effectiveness between the existing arrangements and that with enhanced TPWS.

Signal Number	Down Relief - Overall TPWS+ATP % Effectiveness			
	Pre-May 2018	Post-May 2018		
	With GW-ATP & Class 360 services	Existing TPWS & Class 345 services	Enhanced TPWS & Class 345 services	With ETCS & Class 345 services
SN111	96.0%	95.0%	95.0% ▼	96.6%
SN123	94.6%	93.1%	95.0% ▲	95.4%
SN127	94.9%	93.9%	94.6% ▼	95.7%
SN137	91.8%	89.8%	94.6% ▲	93.2%
SN153	91.1%	88.8%	94.5% ▲	92.6%
SN163	91.7%	89.2%	95.0% ▲	93.1%
SN175	96.0%	95.0%	95.0% ▼	96.6%
SN187	92.9%	90.8%	95.0% ▲	94.1%
SN199	95.9%	94.9%	95.0% ▼	96.5%
SN203	94.3%	93.8%	93.8% ▼	95.1%
SN209	20.8%	0.0%	92.4% ▲	34.4%
SN211	92.4%	91.8%	92.9% ▲	93.5%
SN215	88.3%	87.0%	92.5% ▲	90.2%
SN225	91.0%	90.3%	92.5% ▲	92.4%
SN233	90.1%	89.2%	92.5% ▲	91.6%
SN239	88.6%	87.3%	92.5% ▲	90.4%
SN243	94.1%	93.3%	94.6% ▲	94.9%
SN253	20.8%	0.0%	93.1% ▲	34.4%
SN265	91.8%	91.2%	92.4% ▲	93.0%
SN273	20.8%	0.0%	93.1% ▲	34.4%
SN283	93.7%	93.2%	93.2% ▼	94.6%
SN287	90.7%	90.1%	92.4% ▲	92.1%
SN303	87.7%	86.3%	92.3% ▲	89.7%

Signal Number	Up Relief - Overall TPWS+ATP % Effectiveness			
	Pre-May 2018	Post-May 2018		
	With GW-ATP & Class 360 services	Existing TPWS & Class 345 services	Enhanced TPWS & Class 345 services	With ETCS & Class 345 services
SN284	94.5%	93.9%	93.9% ▼	95.3%
SN276	93.2%	92.8%	92.8% ▼	94.2%
SN266	21.4%	0.0%	92.4% ▲	35.2%
SN258	93.3%	92.3%	94.0% ▲	94.3%
SN248	95.0%	94.2%	95.0% ►	95.7%
SN244	21.4%	0.0%	92.4% ▲	35.2%
SN238	93.5%	93.1%	93.1% ▼	94.5%
SN232	93.7%	93.0%	93.4% ▼	94.7%
SN224	92.1%	91.6%	92.4% ▲	93.4%
SN214	21.4%	0.0%	92.5% ▲	35.2%
SN210	88.8%	87.6%	92.4% ▲	90.6%
SN206	75.2%	69.4%	92.6% ▲	79.4%
SN202	94.7%	94.0%	94.0% ▼	95.4%
SN192	96.0%	95.0%	95.0% ▼	96.6%
SN186	95.5%	94.3%	95.0% ▼	96.2%
SN174	96.0%	95.0%	95.0% ▼	96.6%
SN164	92.4%	90.2%	95.0% ▲	93.7%
SN156	94.7%	93.3%	95.0% ▲	95.6%
SN144	75.8%	68.1%	95.0% ▲	80.4%
SN134	96.0%	95.0%	95.0% ▼	96.6%
SN114	96.0%	95.0%	95.0% ▼	96.6%
SN112	96.0%	95.0%	95.0% ▼	96.6%

5.3.2 Train Protection Effectiveness (Main Lines)

Main Line services will not be affected by the introduction of Crossrail train operations in times of normal operation. As such, there is no planned change to rolling stock types or service frequency during normal working. The proposed Enhanced TPWS will be more effective on those occasions when Crossrail services are diverted to the Main Lines, generally at night or on weekends.

There is a general increase in train protection effectiveness at signals not currently fitted with TPWS. When Enhanced TPWS fitments are provided, protection is increased as EMU services planned in the post-electrification timetable will use the Main Lines and are not fitted with GW-ATP. See table below.

Signal Number	Down Main - Overall TPWS+ATP % Effectiveness	
	GW-ATP and Existing TPWS	GW-ATP and Enhanced TPWS
SN107	98.8%	98.8% ►
SN125 (1)	98.1%	98.1% ►
SN125 (2)	98.8%	98.8% ►
SN135	98.3%	98.7% ▲
SN151	91.3%	98.7% ▲
SN159	91.3%	98.7% ▲
SN173	91.3%	98.7% ▲
SN179	91.3%	98.7% ▲
SN191	91.3%	98.7% ▲
SN201	98.7%	98.7% ►
SN207	91.3%	98.7% ▲
SN213	91.3%	98.7% ▲
SN231	91.3%	98.7% ▲
SN237	91.3%	98.7% ▲
SN249	98.7%	98.7% ►
SN255	98.7%	98.7% ►
SN271	98.6%	98.7% ▲
SN285	98.7%	98.7% ►

Signal Number	Up Main - Overall TPWS+ATP % Effectiveness	
	GW-ATP and Existing TPWS	GW-ATP and Enhanced TPWS
SN280	98.5%	98.7% ▲
SN270	98.5%	98.7% ▲
SN254	98.7%	98.7% ►
SN246	91.3%	98.7% ▲
SN234	91.3%	98.7% ▲
SN222	91.3%	98.7% ▲
SN212	91.3%	98.7% ▲
SN204	98.7%	98.7% ►
SN194	91.3%	98.7% ▲
SN178	91.3%	98.7% ▲
SN160	91.3%	98.7% ▲
SN146	91.3%	98.7% ▲
SN120	98.7%	98.7% ►
SN106	98.8%	98.8% ►

5.3.3 Train Protection Effectiveness (Airport Lines)

The Airport Lines signals are currently only used by trains fitted with GW-ATP. Consequently, when no GW-ATP trains operate TPWS falls to 0.0% effectiveness for those signals only used by Heathrow Connect Services and 56.6% for those also used by Heathrow Express (e.g.SN316). Predictably, a substantial increase in effectiveness is achieved when Enhanced TPWS is provided as it is benefiting all trains that pass the signal, as seen in the table below:

Signal Number	Airport Lines - Overall TPWS+ATP % Effectiveness			
	Pre-May 2018	Post-May 2018		
	With GW-ATP & Class 360 services	Existing TPWS & Class 345 services	With Enhanced TPWS & Class 345 services	With ETCS & Class 345 services
SN292	99.0%	86.5%	95.0% ▼	99.0%
SN300	99.0%	99.0%	99.0% ►	99.0%
SN316	99.0%	56.6%	97.3% ▼	99.0%
SN319	99.0%	99.0%	99.0% ►	99.0%
SN321	99.0%	99.0%	99.0% ►	99.0%
SN323	99.0%	0.0%	95.0% ▼	99.0%

5.4 Further Options Selection (HAZID-Hazard Identification)

Following the initial option selection review, a number of options remained that required further detailed assessment, as they could not be separated using the initial option selection criteria. It was determined that a Hazard Identification (HAZID) review should be undertaken in respect of the remaining options to determine the differences in risk between them.

Options were assessed against a set of agreed criteria to determine a single option to be carried forward as the most viable Plan B.

Vertex facilitated the exercise to develop the initial set of criteria; each of the options was then reviewed against these:

- Safety
  - SPAD risk
  - Over-speed/Derailment risk
    - PSRs/TSRs
    - junction considerations
  - Risk to workers
  - Operational risk (safety – degraded mode operations.)
- Operational performance risk (delay – degraded mode operations.)
- Maintenance impacts
  - Access
  - Workload
- Option costs
- Legislative conformance (RSR99)
- Deliverability
- Operability of signalling transition(s)

5.4.1 Options Summary at HAZID

Based on failure data of TPWS loops in the Plan B area, a failure rate was calculated to be 25.47 months with a time to repair of 30 minutes, for a two man team.

Routine maintenance of TPWS is limited to one visit per year and will be carried out at the same time as ATP equipment maintenance thus minimising worker exposure, but an additional 20.4 minutes per TPWS loop would be required.

Based on the figures above it is estimated that each additional TPWS loop fitted will lead to an approximate 50 minutes of on track work per year.

Estimation of each options increase in track work is given in the following table:

Option	Estimated Additional Track Work
3	50 man hours per year
4	77 man hours per year
5	107 man hours per year

Risk to workers due to the additional TPWS equipment proposed was compared in qualitative manner with expected level of overrun risk of each option for each signal.

A summary of the main findings of the HAZID exercise is given in the following table:

Option	Description	Summary of HAZID
3	Enhanced TPWS: TPWS on ALL signals. Existing TPWS enhanced to current standards	Addresses similar level of risk as ATP, and meets the minimum baseline requirement
4	Enhanced TPWS: TPWS on all signals to stop Class 345 train in the overlap	Addresses similar level of risk as ATP, and meets the minimum baseline requirement More risk imposed when installing and maintaining than Option 3
5	(Option 4) with extra TPWS at PSRs, Buffer Stops and junction PSRs	Addresses similar level of risk as ATP, and meets the minimum baseline requirement. More risk imposed when installing and maintaining than Option 3
6	(Option 3 to 5), but no separate fault reporting	Not a standalone option. More risk imposed when installing by linking into the interlocking data. No appreciable benefit for short duration. Discounted
10	Utilise GW-ATP fitted rolling stock for additional Crossrail service until ETCS provided	Does not meet requirements of Plan B to allow use of Class 345 for service. Retained as open CRL and NR may take forward if TPWS option not credible. Initial investigation would suggest GW-ATP rolling stock would not be available to deliver Crossrail service

5.5 Plan B final selected option

Extensive review, evaluation and quantification of the levels of safety offered by each option have been performed. Enhanced TPWS has been found to offer a similar level of signal overrun protection to the current GW-ATP/TPWS arrangements and in some cases it has been found to exceed the benefit predicted from the ETCS Plan A proposal.

TPWS is used nationally and is already in place on a majority of the area of Crossrail operation. Within the area concerned, TPWS will be upgraded from the standard level of fitment to Enhanced TPWS, providing a level of protection that as far as reasonably practicable replicates the protection levels of GW-ATP. Enhanced TPWS proposals are demonstrably safe, fit for purpose and represent the best option as a fall-back if ETCS delivery is delayed.

Enhanced TPWS operation offers the best fall-back option for Crossrail services between Paddington and Heathrow Tunnel Junction. The lines from Airport Junction to Heathrow Airport will remain fitted with GW-ATP (for the Heathrow Express Services) and additionally be equipped with ETCS (see figure 12 below).

Crossrail trains will be equipped with ETCS for operation in the areas that have ETCS operational (Heathrow Tunnel Junction to Heathrow).They will use Enhanced TPWS on other parts of the route.

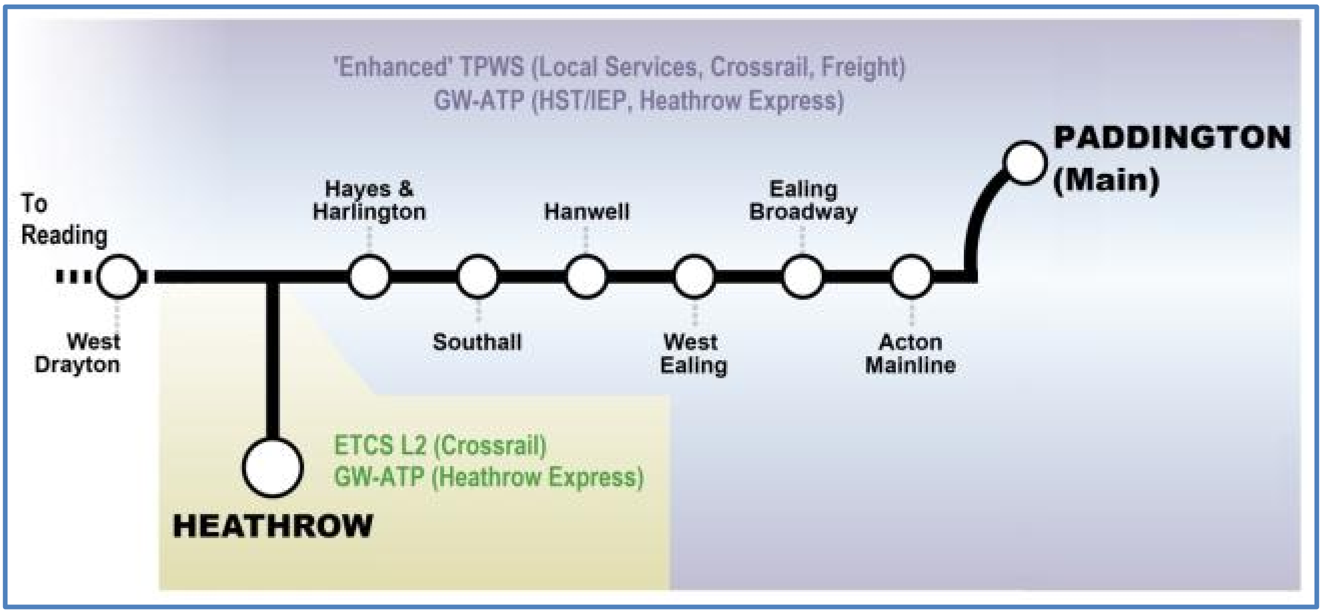

Figure 12

It is recommended from the HAZID exercise, in order to minimise risk to work force, that the minimum level of TPWS fitment is provided that manages the maximum SPAD risk. As such, Option 3 is considered the preferred option.

As the detailed design is developed during GRIP 4, a signal by signal overrun risk evaluation will be performed (See section 6.1 Further Overrun Risk Assessment Proposed), both option 4 and option 3 will be considered. Option 3 will be selected if option 4 shows no significant reduction in risk. If the overrun risk for any signal is significantly worsened, that signal will be provided with an enhanced level of TPWS protection as per option 4.

Additional TPWS for PSR junctions can be discounted and should not be progressed. The risks associated with over-speeding are small and no additional mitigation can be justified for the expected limited duration of Plan B.

6 Network Rail Safety Assurance Process

Network Rail's Health and Safety Management System (H&SMS) describes the framework and arrangements in place to deliver the company's health and safety objectives. To achieve these objectives for the Crossrail Works, the Network Rail Programme has a System Safety Strategy and Plan.

The Crossrail System Safety Strategy and Plan sets out the proposed mechanism to achieve safety assessment/verification for the works and compliance with relevant legislation and Railway Standards in accordance with governance principles set out by the Network Rail Acceptance Panel (NRAP).

Safety Assurance will be achieved by application of the CSM-RA, a common mandatory European risk management process for the rail industry, and production of a Safety Assessment Report by an independent assessment body. Further information can be found in ORR document - *Guidance on the application of Commission Regulation (EU) 402/2013* – March 2015.[3]

The Plan B Project safety assurance process has started, with initial options selection following a process in line with CSM-RA (see section 4.2.3, Options Development).

In line with accepted Network Rail processes, as the design is developed further the project will go through all of the detail to ensure the outcomes meet, or exceed expectations. A final Safety Justification report will then be produced. The final Safety Justification report will be reviewed and accepted (as appropriate) by a NR System Review Panel (SRP). This process will provide final assurance of achievement of the objectives.

Before acceptance by a SRP the Safety Justification will be reviewed by an Independent Safety Assessor (ISA), whose review shall cover the following topics:

a) Scope;

b) Hazards identified;

c) Assessment of risks;

d) Control measures during the change period and afterwards;

e) Residual risks; and

f) Arrangements for monitoring and review.

[3] Guidance on the application of Commission Regulation (EU) 402/2013 – March 2015

6.1 Management of safety activities: Further Overrun Risk Assessment Proposed

Assessments carried out to date have given an indicative effectiveness for Enhanced TPWS at mitigating signal overrun risk. These results have shown that when further risk assessment is carried out, signal overrun risk for an Enhanced TPWS solution would be similar to, and in some cases greater than, that offered by GW-ATP or ETCS alone.

Should further Plan B development of the scheme be required Network Rail would be required to carry out a more detailed Signal Overrun Risk Assessment Process in line with CSM RA, Railway Industry Standards and its own company standards.

Signal overrun risk assessment processes have been established over many years and developed from the requirements of now withdrawn Railway Group Standard, *GI/RT7006 - Prevention and Mitigation of Overruns – Risk Assessment.*

Network Rail's company standards now cover the process in more detail, and the basis of this process has recently been published by RSSB as a Railway Industry Standard, *RIS-0386-CCS, Rail Industry Standard on Signal Overrun Risk Evaluation and Assessment.*[4]

To support the Signal Overrun Assessment process, Network Rail has developed the Signal Overrun Assessment Tool (**SORAT**). SORAT is a software tool that calculates signal overrun risk, on a signal by signal basis, and stores the results on a national database. Calculations are based on complex algorithms and historical data on the likelihood and consequences of a signal being passed at danger.

[4] RIS-0386-CCS, Rail Industry Standard on Signal Overrun Risk Evaluation and Assessment

SORAT requires detailed information about the local layout, trains used and timetable associated with each signal. This information is used to determine a Risk Score per signal using the Fatality Weighted Index (**FWI**) as shown in Figure 13 below.

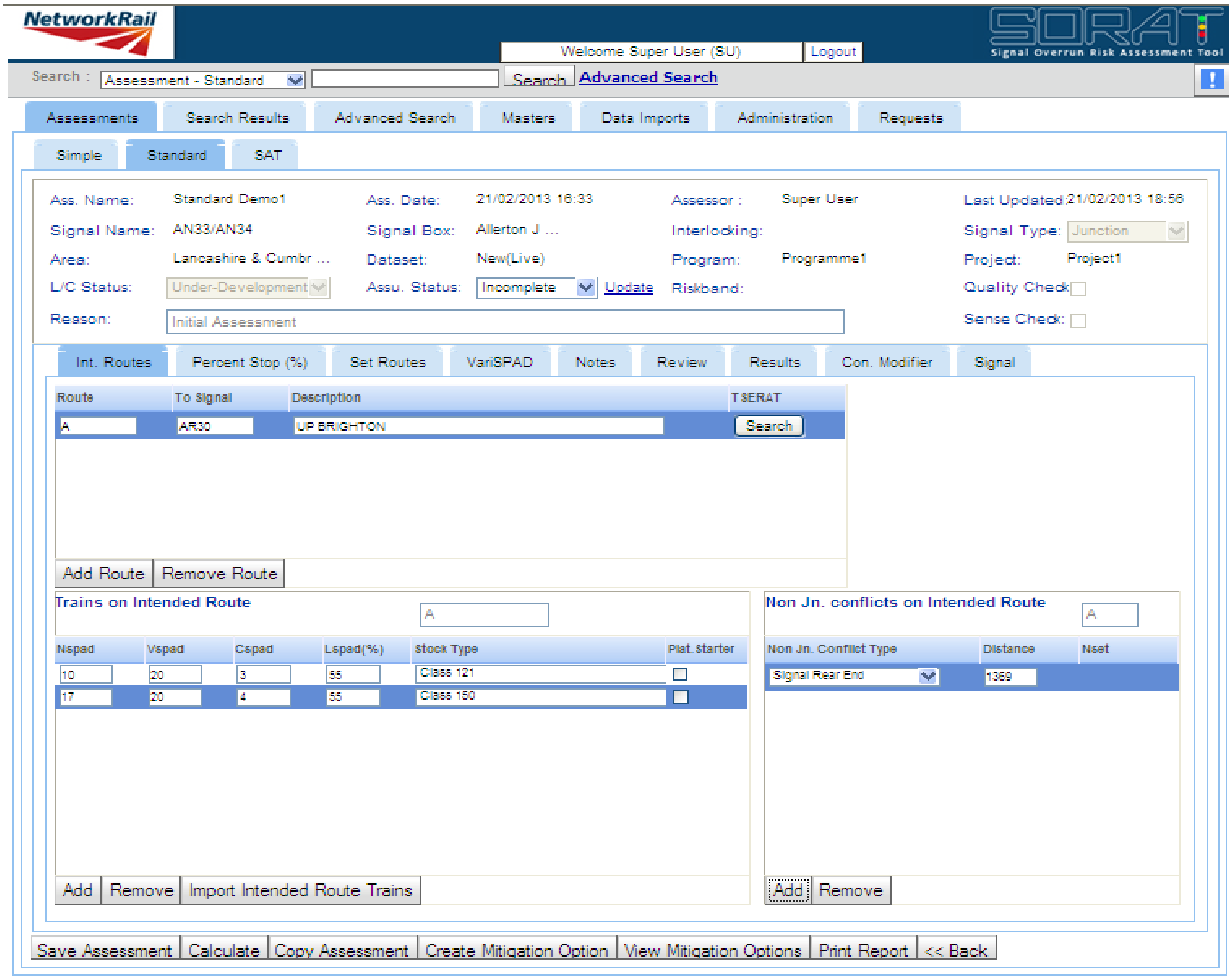

Figure 13

This enables Network Rail to rank each signal based on risk score. SORAT is then used for a more detailed assessment, in consultation with the train operators, for those signals that present the highest risk. It can then be determined whether the proposed mitigations against overrun risk at that signal are suitable and sufficient. This review (known as a “VariSPAD”) considers the level of train protection provided on each signal and other risk factors that may increase or decrease SPAD risk (Figure 14).

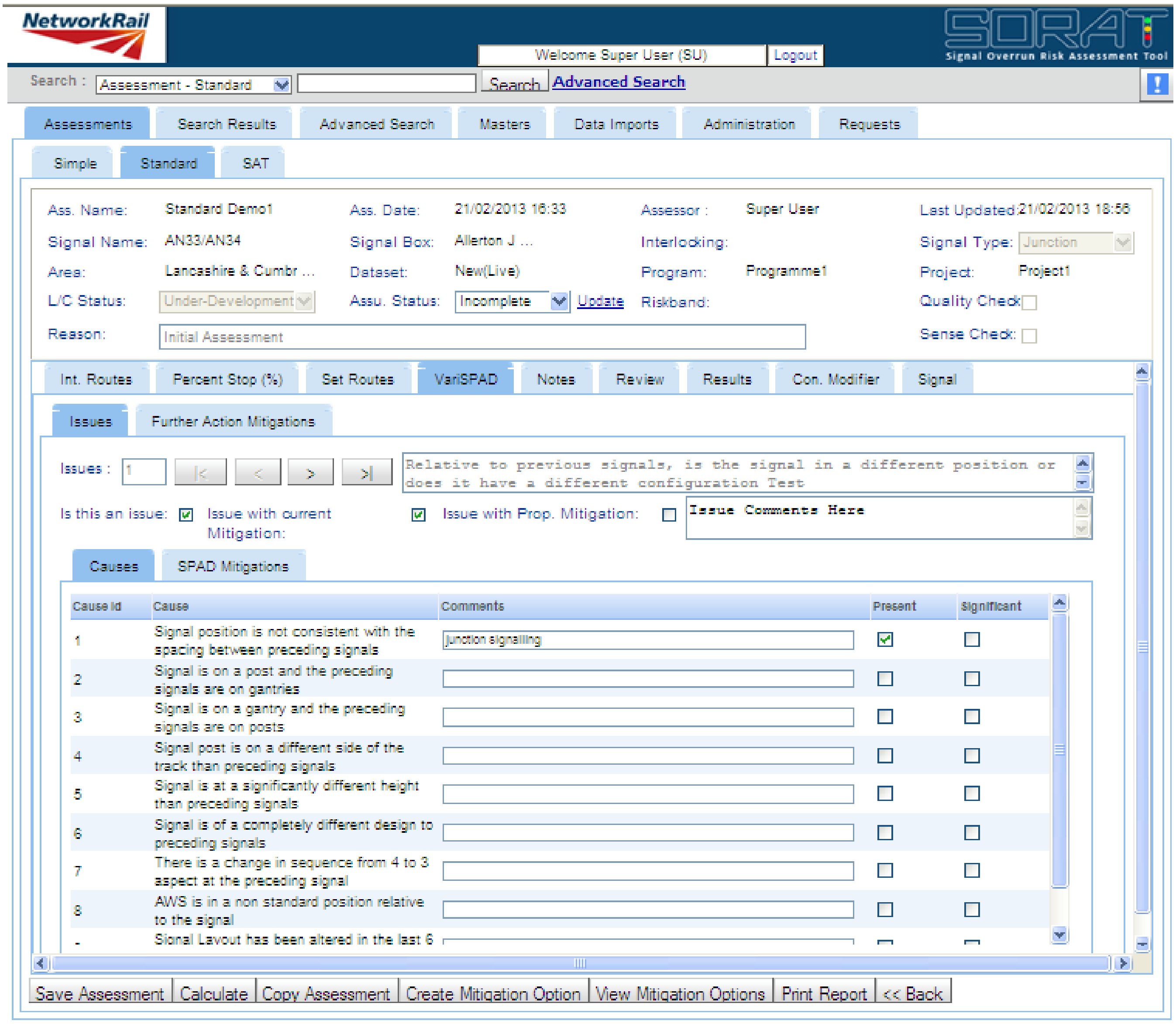

Figure 14

SORAT has built in risk algorithms similar to those used to estimate the train protection effectiveness as part of the GRIP 3 option selection process (see section 5.2 TPWS Effectiveness Tool). In this instance however the algorithm has the benefit of the final agreed train quantities and TPWS/GW-ATP arrangements.

Results are produced, and SORAT then stores all commissioned signals' records. These records can then be reviewed and updated if changes occur to the signal or its use, for example layout change, train type change or timetable variations (Figure 15).

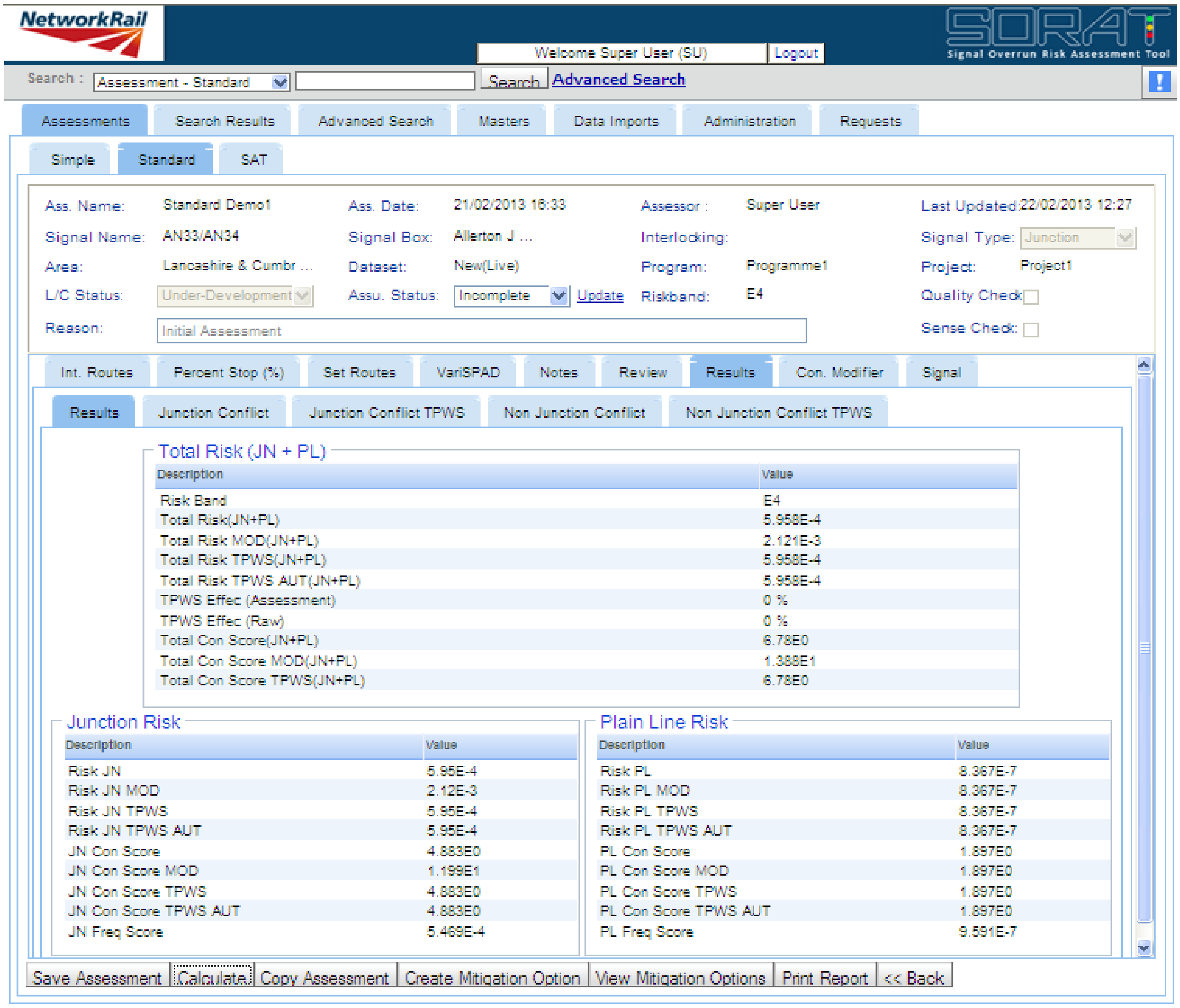

Figure 15

Should the Plan B Project be required to be progressed, each signal will be taken through the SORAT process, and only if the levels of risk are determined to be As Low As Reasonably Practicable (ALARP) by Network Rail and TOC/FOC users will the signal and its train protection be entered into service.

7 Conclusion

The strategy of using TPWS for train protection has been supported for several years and has been a key element of rail industry safety policy.

Following extensive review, evaluation and quantification of the levels of safety offered by Enhanced TPWS it has been found to offer a similar protection level to the current GW-ATP/TPWS for the proposed mix of services and rolling stock.

We conclude that:

- The safety benefits from using TPWS to mitigate Signal Passed at Danger risks are substantial, and are already being delivered but will be improved;
- TPWS is, within its design limitations, an effective system for mitigating SPAD risk;
- The provision and maintenance of additional TPWS equipment will not expose the workforce to significant additional risks;
- TPWS is not considered a train protection system under RSR99 where it is reasonably practicable to install an Automatic Train Protection system, such as that intended for Plan A implementation. On this basis, it is necessary for us to obtain an exemption from this requirement in order to use Enhanced TPWS as our fall-back train protection solution; and
- The planned Crossrail service with new Class345 trains will offer significant passenger benefits outside of those considered within RSR99.

Should ETCS prove un-deliverable in time for the start of Crossrail operation, TPWS will be enhanced from the standard level of coverage, and as such will give comparable levels of train protection, and allow additional safety benefits to be realised from the introduction of Crossrail services.

Enhanced TPWS proposals are demonstrably safe, fit for purpose and represent the best option as a fall-back if ETCS delivery is delayed.

8 Stakeholder engagement/consultation

Stakeholders have been engaged /consulted. A summary record of this process is provided below and where applicable the letters of support are available. For further detail see *Stakeholder Engagement Plan – Status updated* (Reference 8)

Stakeholder	Stakeholder contact	NR/CRL Lead contact	Primary forum and status of response
First Great Western Board & operations	Mark Hopwood	Robbie Burns	Presentation given on proposal. Support deferred to project team.
First Great Western project team.	Mike Hog & Ian Brightmore	Matthew Steel	GWML ETCS Steering Group and Direct contact Letter in support 19 Dec '14. (Reference 12)
Heathrow Express Board & Operations	Keith Harding	Matthew Steele	Meeting held 28 Jan '15. Supportive.
Heathrow Express project team	Pat Lyons	Peter Martell	GWML ETCS Steering Group. Group keen to work with NR to make ETCS work, but understand the need for a Plan B and what it entails.
FOCs	The various – members of ETCS Steering group	James Waight	GWML ETCS Steering Group No objections
ATOC	Phil Barrat	Matthew Steele	Presentation given on proposal. In discussion PB understood the proposals and did not have any substantive concerns
Crossrail Ltd	Matthew White	Matthew Steele	Presentation given on proposal Letter of support from CRL sent to the ORR on 17 Nov.'14 (Reference 9)
RfL	Howard Smith	Matthew White	Presentation given on proposal Letter of support from CRL sent to the ORR on 17 Nov.'14 (Reference 9)
CTOC/MTR	Steve Murphy (MD)	Dave Milburn	Presentation used at briefing/discussion, DM, AS and PR met with SM and OB. Letter in support 16 Dec '14. (Reference 11)
MTR Operations	Oliver Bratton	Paul Richardson	Presentation used at briefing/discussion, DM, AS and PR met with SM and OB. Letter in support 16 Dec '14. (Reference 11)
W&W Route Director	Patrick Hallgate	Matthew Steele	Direct Contact Implicitly involve and are supportive
W&W Route ETCS Client and Sponsors	Mike Gallop/ Peter Martell/ Simon Maple	Matthew Steele	Direct Contact Implicitly involve and are supportive.
RSSB	Tom Lee	Dave Milburn	DM presented to Train Protection Strategy Group (TPSG) 03 Dec '14. TPSG had no objections this is recorded in the TPSG minutes.

Stakeholder	Stakeholder contact	NR/CRL Lead contact	Primary forum and status of response
ORR (Exec level)	Alan Price, Richard Price	Matthew White	
ORR (Case level)	John Gillespie, Ian Maxwell,	Andrew Simmons/ Dave Milburn	Andrew Simmons / John Gillespie discussions.
DfT	Claire Moriatty	Matthew Steele	Presentation used at briefing/discussion. Also through the via the Sponsor brief.
Paddington Survivors Groups	Pam Warren and Jonathan Duckworth	Robbie Burns	Presentation used at briefing/discussion given by Robbie Burns & Matt Steele. Engaged and pleased to be given the opportunity to understand the proposal. No significant follow up questions or comments.
Network Rail Head of Signalling	Jeremy Morling	Dave Milburn	Presentation at briefing/discussion Supportive.
Chiltern Railway coordination of ORR submissions and message	Simon Jarrett	David Milburn	Presentation at briefing/discussion Letter of support (Reference 10)

9 References

Reference	Title
1	ETCS "Plan B" Study, Enhanced TPWS – Paddington to Airport Junction 2017, Train Protection Effectiveness Calculation Summary Report, 122271-ISD-REP-000001, Issue 2, 18 July 2015.
2.	Vertex Systems Engineering, Final Option Selection Version 1.4, 24 March 2015.
3.	Vertex Systems Engineering, GRIP 1-3 Options Analysis Version 3.5, 2 April 2015.
4.	Enhanced TPWS - HAZID workshop with FGW Addendum and Appendix A and B, Version 1.0, 10th February 2015
5.	Crossrail Stage Two Opening, Paddington to Heathrow, May 2018, Safety Impacts arising in the case of a delay to Implementation of Crossrail Stage 2. CRL1-XRL-K-RST-CR001-50001, Version 1. 12 November 2014.
6.	Crossrail Stage Two Opening, Paddington to Heathrow, May 2018. Provision of GW-ATP on Crossrail Class 345 trains, CRL1-XRL-K-RST-CR001-50002, Version 1. 12 November 2014.
7.	RSSB, SPAD and TPWS activity report, quarter 3 – 2013/14
8.	Stakeholder Engagement Plan – Status updated
9.	Letter of support from CRL to ORR, Andrew Wolstenholme, CEO CRL and Howard Smith, Operations Director CRL, dated 17 November 2014.
10.	Letter of support from Chiltern Railways, Simon Jarrett, Head of Technical Services, dated 3 December 2014.
11.	Letter of support MTR, Steve Murphy, Managing Director – MTR Crossrail, dated 16 December 2014.
12.	Letter of support FGW, Mike Hogg, Projects Planning Director FGW, dated 19 December 2014.
13	The Strategy for the Train Protection and Warning System (TPWS) – Issue 2 (Draft) – February 2015