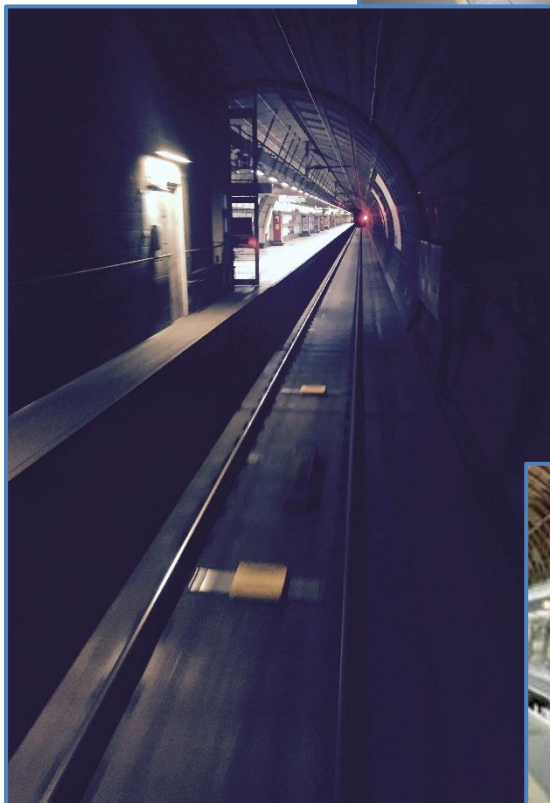


Western Route Train Protection 0 to 12mp - Railway Safety Regulations 1999 Exemption Application Report



1 Executive Summary

- 1.1.1 This report explains the reasoning and justification supporting Network Rail Infrastructure Limited (NR) application in association with Great Western Railway Limited (GWR), Crossrail Limited (CRL), Heathrow Express Operating Company Limited (HEX) and MTR Corporation (Crossrail) Limited (MTR) for a new 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).
- 1.1.2 An exemption is currently in place for Class 345 trains operating Crossrail services on the Great Western Mainline (GWML) 0 – 12mp, but this ends on 31st Dec 2019. A new exemption is required due to the delay in implementing the European Train Control System (ETCS) and the planned Class 387 train introduction on services currently using Great Western Automatic Train Protection (GW-ATP).
- 1.1.3 This new exemption application applies between Paddington and Airport Junction on the Western Mainline where it is proposed the train protection system will be provided by Enhanced Train Protection Warning System (TPWS) that has been delivered to provide a comparable level of protection to existing GW-ATP for the Class 345 Crossrail trains until ETCS is operational.
- 1.1.4 The exemption application applies only in relation to Crossrail and Heathrow Express services and will only be utilised until ETCS is installed and available for the passenger operations between London Paddington and Heathrow Airport.
- 1.1.5 The planned Crossrail services with Class 345 trains will offer significant passenger benefits outside of those considered within the Regulations making delivery of the Crossrail service still a priority.
- 1.1.6 New Class 387 trains are proposed to operate on the Heathrow Express (HEX) service replacing the Class 332. This is due to changes caused by High Speed 2 (HS2) that also offer significant passenger benefits outside of those considered within the Regulations making the change of trains a priority.
- 1.1.7 Delivery of ETCS, that will be fully compliant with the Railway Safety Regulations (1999) for the passenger operation of Crossrail and Heathrow Express services remains a primary objective of NR, GWR, MTR, HEX and CRL.
- 1.1.8 Several issues have arisen and materialised in delivering ETCS in the area between Paddington and Heathrow Tunnel Portal. Issues have included (but not limited to):
- Supplier /staff availability;
 - Train delivery and testing;
 - Limited delivery experience of ETCS in the UK;
 - Delivery in an area undergoing significant modification;
 - Integration of other work in the area; and

- Existing complexity of rail infrastructure in the area.

1.1.9 For the reasons above a revised delivery option has been developed in line with NRs Governance of Railway Investment Projects (GRIP) and the Common Safety Method for Risk Evaluation and Assessment (CSM-RA) framework (the statutory risk management process for the mainline railway).

1.1.10 In the development of this delivery option a number of delivery scenarios and outline system definitions were developed in line with ORR guidance. To inform industry members reviewing and selecting options we have:

- Developed a range of initial options for appraisal (including options that would not require an exemption);
- Analysed each option against a number of safety, feasibility, performance and cost criteria; and
- Undertaken extensive stakeholder engagement.

1.1.11 From the range of options available, it was concluded that Enhanced TPWS remained an appropriate interim Train Protection System solution for GWML 0 – 12mp operation until Dec 2023 as it would (but are not limited to):

- Achieve similar levels of overrun protection to ATP;
- use a known and proven technology;
- allow for a level of contingency for ETCS delivery risks; and
- allow axle counter delivery to achieve a more resilient railway with improved safety for maintenance staff.

1.1.12 Following detailed analysis of Enhanced TPWS it was found to offer a similar level of signal overrun protection to the current GW-ATP/TPWS arrangements.

1.1.13 Enhanced TPWS still provides a robust fall-back train protection option for the area between Paddington and Heathrow Tunnel Portal until ETCS is able to be delivered for the Crossrail and HEX services.

1.1.14 Due to the relatively small difference in risk levels between ETCS and Enhanced TPWS delaying the introduction of axle counters was not considered as required. Delaying of axle counter provision would continue the greater risk to staff and prevent the reduction in delays to train services in the area.

1.1.15 NR, CRL, HEX, MTR and GWR are keen to progress this application for exemption with the ORR, and will fully participate in any public consultation that the ORR considers appropriate to ensure the best outcome for users of, and stakeholders in, the rail network.

1.1.16 NR, CRL, HEX, MTR and GWR remain totally committed to delivering ETCS operations for GWML 0 – 12mp. The ORR 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 Regulation 3 of those

Regulations. This exemption would be required to permit operation of Crossrail Class 345 by MTR and Heathrow Express Class 387 by GWR from 1st October 2019 to 31st December 2023 on the area of Western Route detailed below until ETCS is installed and available for passenger operation:

- Paddington Station to Heathrow Airport Junction (0m to 11m 52ch); and
- Heathrow Airport Junction to Heathrow Tunnel Junction (11m 13ch to 12m 27ch).

Network Rail

June 2019

Contents

1	Executive Summary	2
2	Introduction	7
2.1	Purpose	7
2.2	Scope	7
2.3	Timescale	8
2.4	Abbreviations and Definitions.....	8
3	Background.....	11
3.1	The Crossrail Route (overview).....	11
3.2	Exemption area (Overview).....	15
3.3	Regulations.....	18
4	Train Protection Systems	20
4.1	Introduction	20
4.2	TPWS – what is it?.....	22
4.3	GW-ATP - what is it?	24
4.4	ERTMS/ETCS - what is it?	25
4.5	CBTC – what is it?	28
4.6	GW-ATP/ETCS/TPWS system comparison	29
4.7	Train types & Services	31
4.8	Train Detection Systems.....	34
5	Train Protection Exemption	35
5.1	Why is an exemption required?.....	35
5.2	Option Development and Selection (Process).....	36
6	Option Risk Assessment (Overrun/ Safety Justification).....	43
6.1	Introduction	43
6.2	Levels of Safety	43
6.3	TPWS Effectiveness Tool	45
6.4	Risk Assessment	46
6.5	Service Levels and Trains.....	46
6.6	Detailed Options Selection and Hazard Identification (HAZID).....	49
6.7	Summary of Risk Assessment	49
6.8	Final selected option.....	53

7	Network Rail Safety Assurance Process	56
7.1	Introduction	56
7.2	Management of safety activities: Further Overrun Risk Assessment Proposed	57
8	Conclusion	61
9	Stakeholder engagement/consultation	62
10	References	64

2 Introduction

2.1 Purpose

- 2.1.1 This report summarises Network Rail Infrastructure Limited's (NR) application under Regulation 6 of the Railway Safety Regulations 1999 (RSR99) in association with Crossrail Limited (CRL), First Greater Western Limited trading as Great Western Railways (GWR), Heathrow Express (HEX) 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).
- 2.1.2 This exemption application is required to support continued use of train protection arrangements for a limited period on services to be operated in the area between London Paddington and Heathrow Airport on the Great Western Mainline (GWML), part of the Western Route. This proposal will need to be implemented when GWR uses Class 387 trains to replace the current HEX Class 332 trains and Crossrail services using Class 345 trains replace the current Class 360 trains.
- 2.1.3 The exemption will be utilised by NR, GWR and MTR to operate using Enhanced TPWS as the train protection system for all or part of the route from Paddington to Heathrow Tunnel Junction.
- 2.1.4 The exemption, if granted, will also mitigate the impact of any further delays in delivery of ETCS and allow delivery of axle counters to improve the resilience of the GWML.
- 2.1.5 It is felt prudent by NR, HEX, GWR, MTR and CRL that we should secure such an option, to ensure adequate train protection is in place for the opening of Crossrail and the introduction of the new trains on HEX services.
- 2.1.6 The Paddington to Heathrow corridor is a challenging environment in which to complete an ETCS installation owing to the existing complex layout, improvements delivered for Crossrail, Intercity Express Program (IEP) and High Speed 2 (HS2) and high capacity utilisation.

2.2 Scope

- 2.2.1 This exemption application applies to both Crossrail and HEX passenger services operating Class 345 and Class 387 trains in the following area of GWML:
- Paddington Station to Heathrow Airport Junction (0m to 11m 52ch); and
 - Heathrow Airport Junction to Heathrow Tunnel Junction (11m 13ch to 12m 27ch).
- 2.2.2 Exemption is not being applied for, or required in respect of, testing or driver training operations of Class 345 or 387 trains that will be required prior to passenger service introduction of the ETCS system.

2.3 Timescale

- 2.3.1 This exemption is required for the changes to HEX service operation on the GWML planned for December 2019 until ETCS is in operation. Therefore, exemption is applied for the period from 1st October 2019 up to and including to 31st December 2023.
- 2.3.2 Application is made from 1st October 2019 ahead of planned passenger service operation to allow early introduction to facilitate occasional operation for driver training or familiarisation ahead of timetable change.
- 2.3.3 Application is made until 31st December 2023 beyond planned ETCS commissioning in December 2022 to allow contingency for ETCS passenger operation given the potential risks with deployment in the complex area.

2.4 Abbreviations and Definitions

- 2.4.1 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:

AsBo - Assessment Body

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

CBTC - Communications Based Train Control

Ch - Chain

CRL - Crossrail Limited (Company registration number: 04212657)

CSM-RA - Common Safety Method on Risk evaluation and Assessment

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

FWI - Fatality Weighted Injuries

GRIP - Governance of Railway Investment Projects

GW-ATP - Great Western Automatic Train Protection

GWML - Great West Main Line

GWR – First Greater Western Limited trading as Great Western Railway
(Company registration Number: 05113733)

HAZID – A Hazard Identification process

HEX– Heathrow Express Operating Company Limited (Company registration number: 3145133)

HS2 - High Speed 2

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

MP - Mile Post

MTBSAF - Mean Time Between Service Affecting Failures

MTR – MTR Corporation (Crossrail) Limited (Company registration number: 08754715)

NR - Network Rail Infrastructure Limited (Company registration number: 02904587)

OL – Overlap. Safety zone beyond each stop signal

ORR – Office of Rail and Road

OSS – Over Speed System

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

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

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

SOD - Safe Overrun Distance

SORAT - Signal Overrun Assessment Tool

SPAD – Signal Passed at Danger

Standard TPWS - TPWS fitted in line with current standards

TfL - Transport for London

Tph - Trains Per Hour

TPWS - Train Protection Warning System

TSI CCS - Technical Specification for Interoperability for Command, Control & Signalling

TSS – Train Stop System

3 Background

3.1 The Crossrail Route (overview)

- 3.1.1 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).

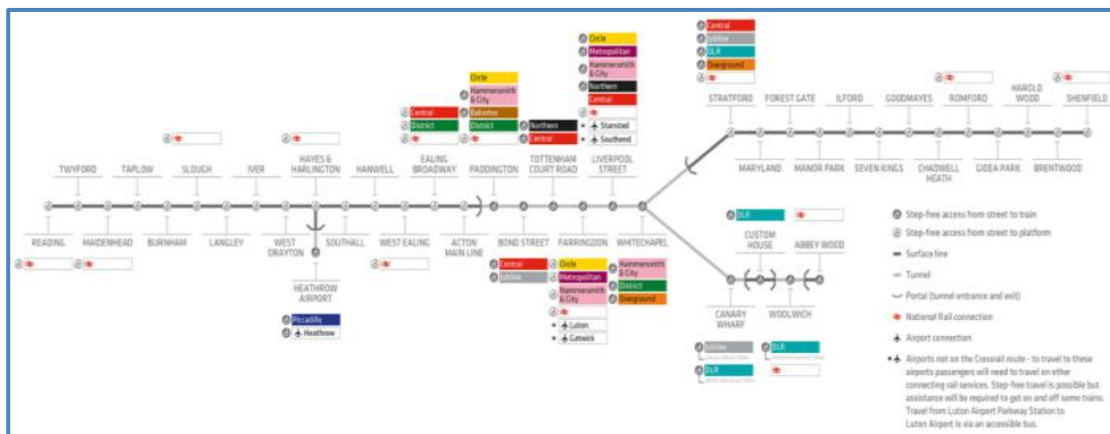


Figure 1

- 3.1.2 Introduction of Crossrail trains operating a 4 trains per hour (tph) service between Paddington and Heathrow will provide a significant increase in capacity, alleviating existing overcrowding on that section of route.

Crossrail Route Train Protection

- 3.1.3 The Western (Paddington to Reading) and Eastern (Stratford to Shenfield) 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 2023.
- 3.1.4 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.

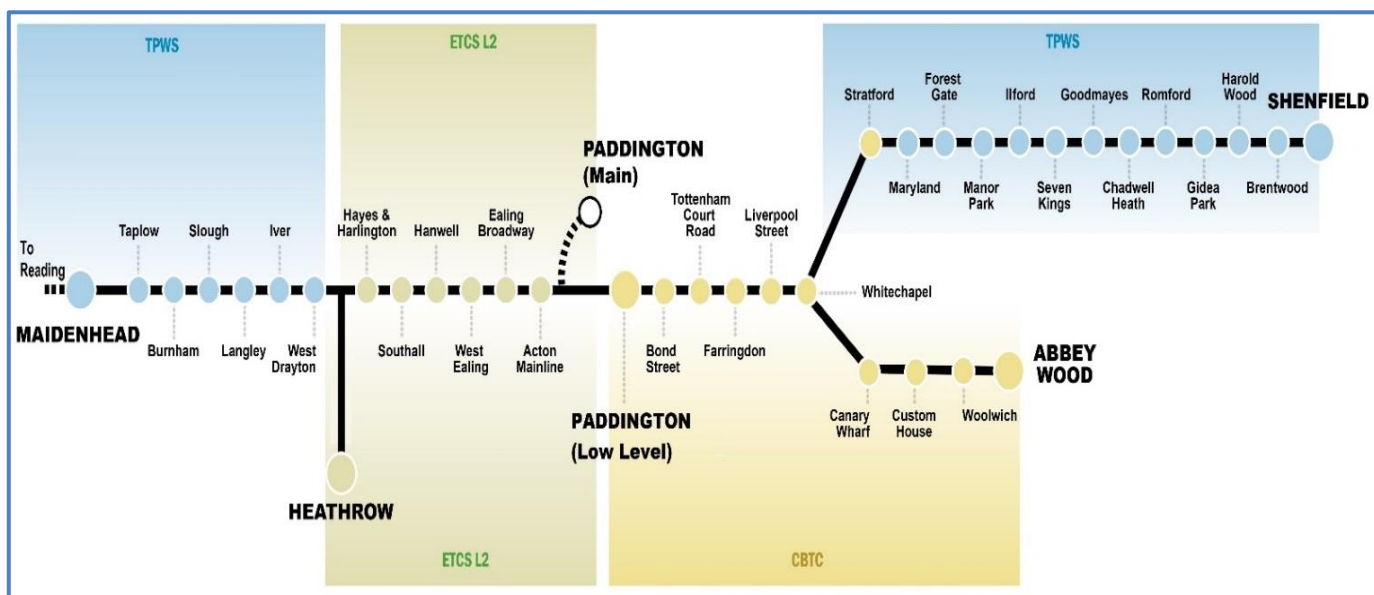


Figure 2

3.1.5 The planned train protection system to be used from Paddington to Heathrow is European Train Control System (ETCS) Level 2. This new system was planned to be delivered by December 2019, but this is no longer achievable due to the following key issues:

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

3.1.6 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 and requires exemption from Railways (Interoperability) Regulations 2011. CBTC will provide Automatic Train Operation (ATO) which by default includes Automatic Train Protection (ATP).

3.1.7 As Crossrail is a new mainline railway, it is subject to the Railways (Interoperability) Regulations 2011 and as such European Rail Traffic Management System (ERTMS) is mandated by the Technical Specification for Interoperability for Command, Control & Signalling (TSI CCS) for the Central section.

3.1.8 As ERTMS is not presently capable of providing Automatic Train Operation (ATO) and moving block signalling to the required level of performance,

Crossrail sought non-application of the TSI CCS for the Central section because application would compromise the economic viability of the project.

- 3.1.9 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 with ATO to operate in future.

Crossrail Trains

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

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



- 3.1.12 The contract between TfL and Bombardier covered the supply, delivery and maintenance of 70 Class 345 trains and a depot at Old Oak Common.
- 3.1.13 The new trains have been manufactured and assembled at Bombardier's UK plant at Derby and have been introduced to surface sections of the Crossrail route before services start through Crossrail's Central underground section.
- 3.1.14 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.
- 3.1.15 The train does 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 physical space to provide for a further interfacing train protection system module on the train.

Heathrow Express New Trains

3.1.16 GWR have entered into a contract with Heathrow Express (HEX). HEX require GWR to provide Class 387 trains, train crew and certain management services in relation to the HEX Services.

3.1.17 As part of the GWR provision of Class 387 trains they will be modified for use on HEX Services in substitution for the Class 332 trains.

3.1.18 The HEX class 387 “Electrostar” units manufactured by Bombardier are to an existing design and will be fitted with ETCS at build and can operate with a maximum speed of 110mph.

3.1.19 The replacement of Class 332 trains is due to be completed during 2020 to allow Siemen’s HEX Old Oak Common maintenance facility for Class 332 to be closed and enable work on HS2 to commence.



3.2 Exemption area (Overview)

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

- Paddington Station to Heathrow Airport Junction (0m to 11m 52ch); and
- Heathrow Airport Junction to Heathrow Tunnel Junction (11m 13ch to 12m 27ch).

3.2.2 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).

3.2.3 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 13 of Paddington's platforms.

3.2.4 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 Heathrow Express/Connect trains and Crossrail trains are situated at Old Oak Common approximately three miles from Paddington to the north of the Relief Lines. A Hitachi depot for IEP trains is provided at North Pole, also at approximately three miles from Paddington to the south of the Main Lines.

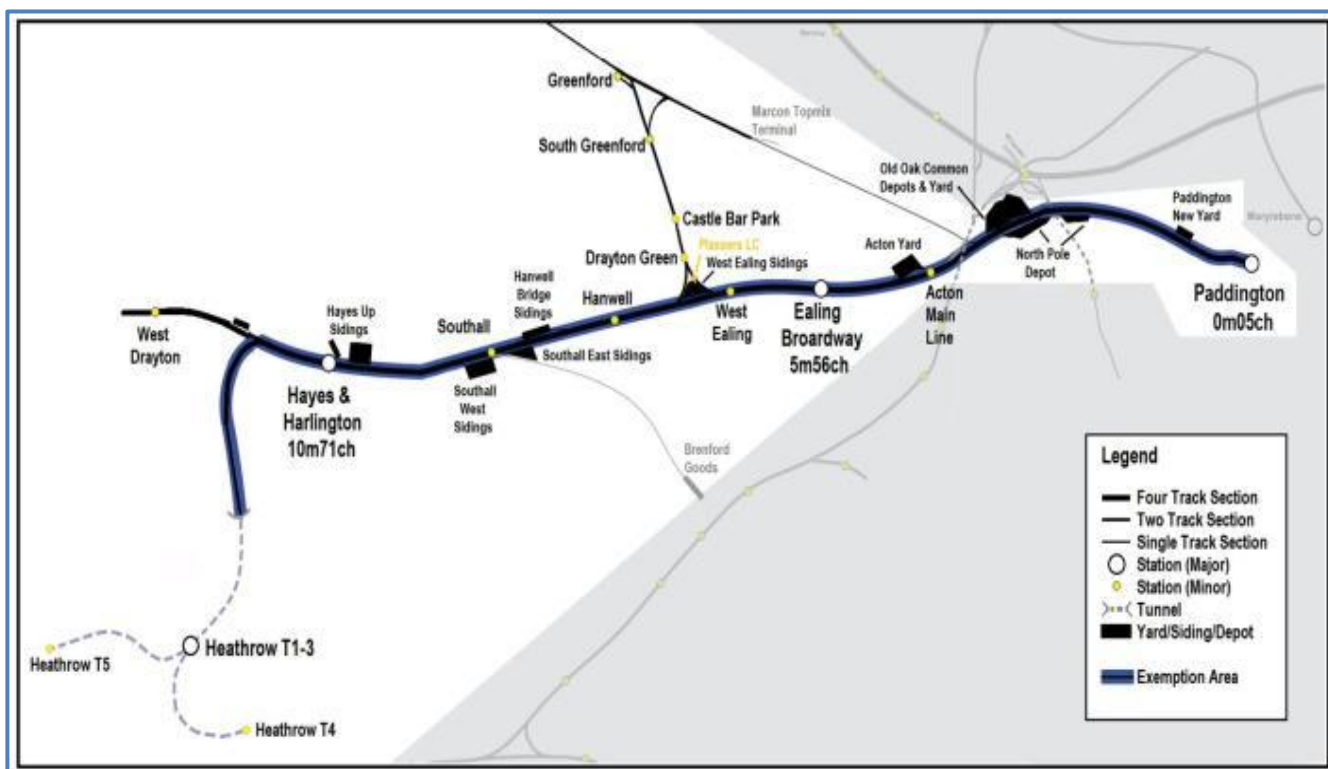


Figure 3

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

- 3.2.6 Trains that operate on the routes and are equipped with GW-ATP may run at speeds above 110mph. 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 110mph.
- 3.2.7 During perturbed operation and scheduled maintenance periods, all services may use either Main or Relief lines into Paddington.
- 3.2.8 Future developments are also planned with a new Old Oak Common station expected to open in 2027 and connect with HS2. It will connect new HS2 services to the Midlands, Scotland and the North and access to the west, central London and Heathrow via Crossrail.

Paddington to Heathrow - Train Protection

- 3.2.9 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, Regulation 2 and 3, meaning all trains on the route were now covered by some form of train protection system.
- 3.2.10 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.
- 3.2.11 In 2014/5 TPWS was further enhanced above those required to meet the RSR99 as part of the justification for current exemption for Class 345 operation.

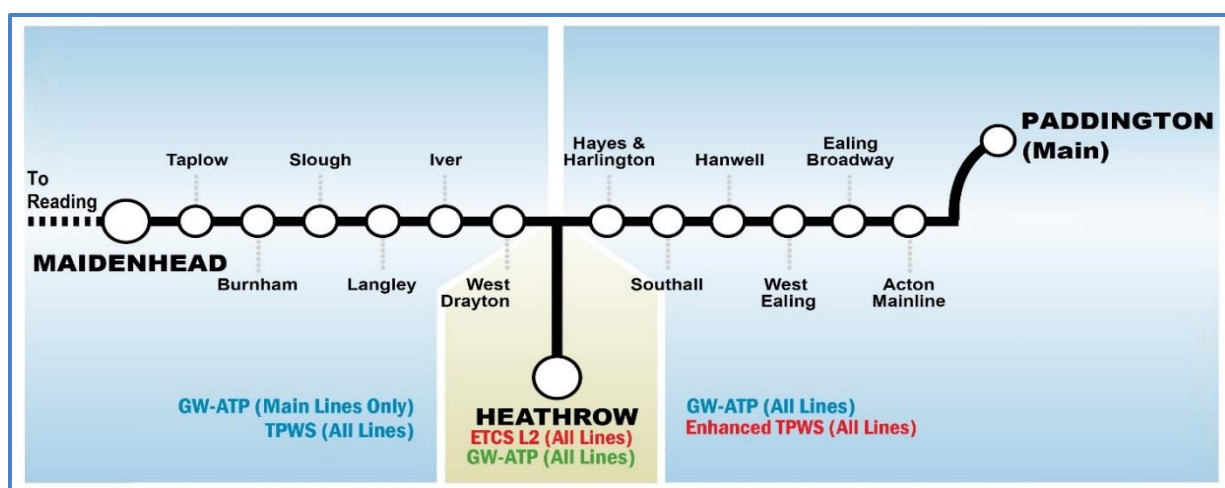


Figure 4

- 3.2.12 The lines from Airport Junction to Heathrow Tunnel are equipped with GW-ATP and ETCS; but currently only trains fitted with GW-ATP run over this section of the route.

- 3.2.13 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 4.7, Train Types and Services). Figure 4 above shows the areas of availability for each system.

3.3 Regulations

History

- 3.3.1 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).
- 3.3.2 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 could have been prevented by ATP.
- 3.3.3 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.
- 3.3.4 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. It was decided by Railtrack, accepted by the Government, that ATP would not be implemented nationally. Both ATP pilot systems remained in place but were not mandated as essential parts of the signalling system.
- 3.3.5 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).
- 3.3.6 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.
- 3.3.7 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.
- 3.3.8 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.

Relevant Regulations

3.3.9 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 principal 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.

3.3.10 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.

Regulation 3

“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.

Regulation 2 (extract)

3.3.11 In broad terms (a) and (b) define the functions offered by TPWS. 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 compliant train protection system if it is not reasonably practicable to install ATP.

4 Train Protection Systems

4.1 Introduction

- 4.1.1 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.
- 4.1.2 Train protection systems supervision can provide 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, GW-ATP and ETCS L1 are intermittent systems, but-GW-ATP and ETCS L1 do continuously monitor speeds.
 - 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.
- 4.1.3 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.

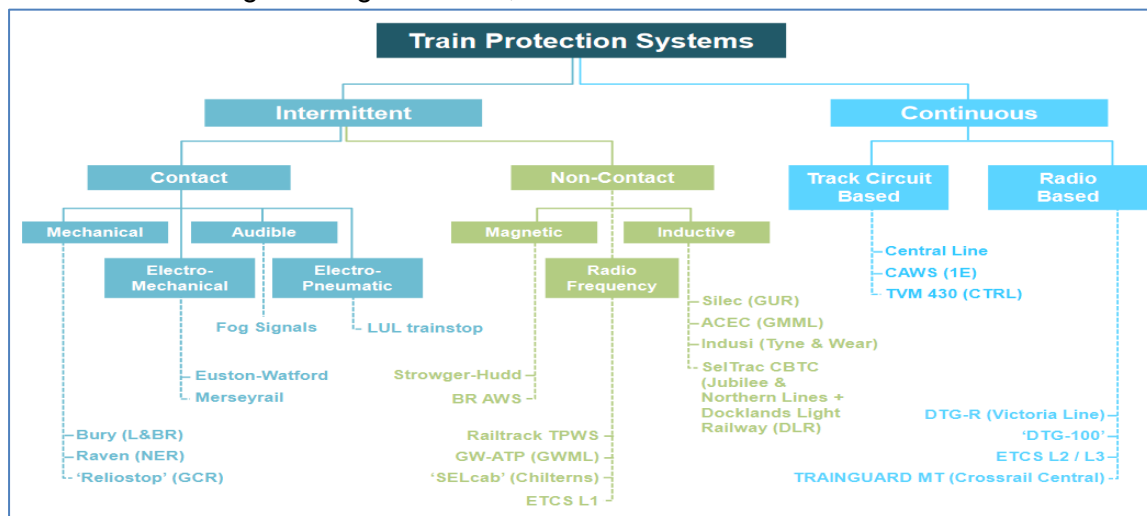


Figure 5

- 4.1.4 **Error! Reference source not found.** shows various types of train protection systems in broad categories.
- 4.1.5 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.
- 4.1.6 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 RSR99.
- 4.1.7 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. E.g. Mersey Rail, Euston DC Lines. When the Trainstop on the track makes contact with the train's Trip Cock the brakes are automatically applied.
- 4.1.8 TPWS is an intermittent loop based system used on most of the UK rail network and is described in section 4.2 of this document.
- 4.1.9 GW-ATP is a beacon based system, which is further described in section 4.3 of this document.
- 4.1.10 CBTC and ETCS (Level 2 and 3) are continuous forms of ATP, which are also further described in sections 4.4 and 4.5 of this document.

4.2 TPWS – what is it?

- 4.2.1 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.

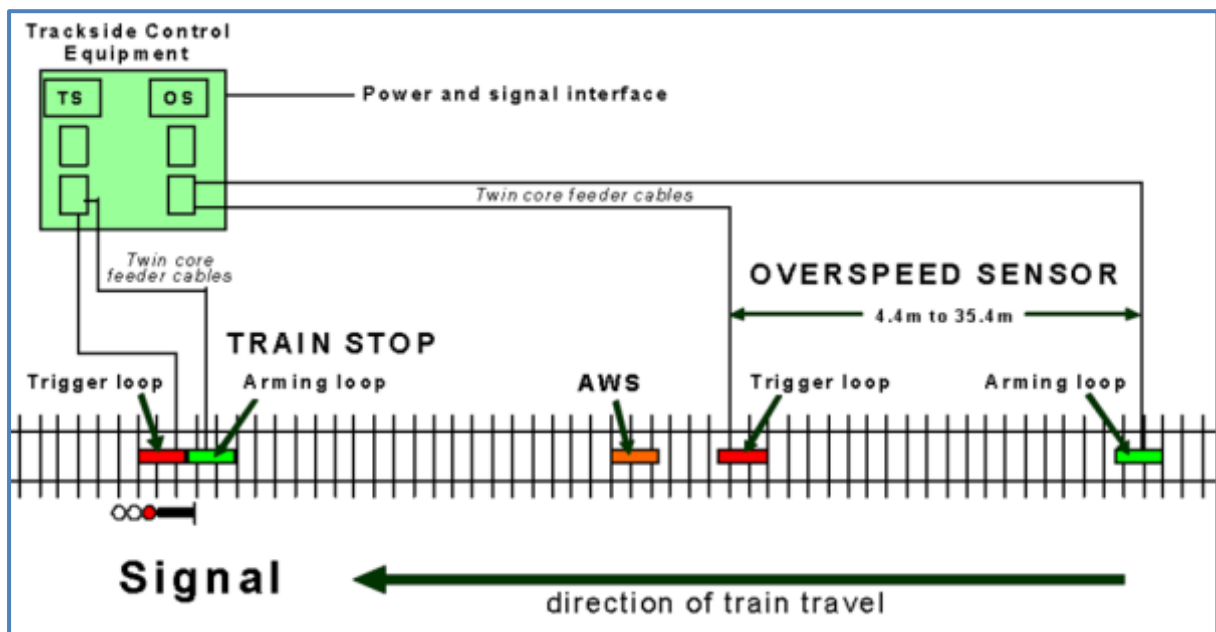


Figure 5

- 4.2.2 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.
- 4.2.3 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.
- 4.2.4 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.

- 4.2.5 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.
- 4.2.6 TPWS 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 was capable of speedy introduction avoiding protracted development and extended safety approval timescale; and
 - TPWS provides immediate safety benefits after installation; the rolling stock could be modified, and each signal fitment commissioned independently.
- 4.2.7 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.

Enhanced TPWS

- 4.2.8 TPWS is an expandable system; additional loops are able to be provided on the approach to a signal, buffer stop or speed restriction there by reducing the intermittency of supervision. With an increased number of loops the system becomes more continuous, and closer to the functionality offered by GW-ATP.
- 4.2.9 Enhanced TPWS added TSS loops at signals not fitted with TPWS, and OSS loops designed to stop a train short of a conflict.
- 4.2.10 Enhanced TPWS was initially designed in support of the existing class 345 exemption affording maximum protection available from TPWS for Crossrail services. This was further optimised during its implementation to provide optimum protection for ALL trains operating over Enhanced TPWS. This gave a significant safety benefit from the increased TPWS provision, particularly at sites currently not fitted with TPWS at all or only had a single OSS loop.

Enhanced TPWS – ‘Plan B’ why was it required?

- 4.2.11 The intended train protection arrangements for Crossrail and Heathrow Express trains from Paddington to Heathrow will be ETCS. However, in the short term NR and CRL considered potential delays to ETCS delivery posed a risk to the delivery of initial Crossrail services. For this reason CRL and NR agreed to develop a fall-back option, ETCS Plan B.
- 4.2.12 Plan B was considered to be required due to risks in delivering ETCS in the area between Paddington and Heathrow Tunnel Portal only. Factors considered to increase the likelihood of delay to deliver ETCS include (but not limited to):

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

4.2.13 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.

4.2.14 Further details of Plan B proposal and exemption application are contained in the 2015 Exemption Application Report (Reference 1).

4.3 GW-ATP - what is it?

4.3.1 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 grossly disproportionate when compared to the safety benefits that would be realised.

4.3.2 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.



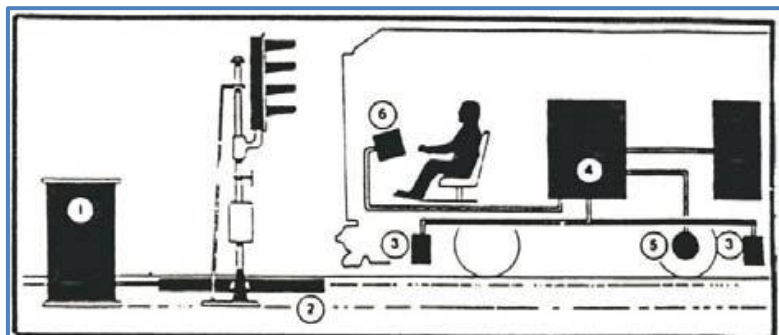
GW-ATP Beacon



GW-ATP Infill Loop

4.3.3 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

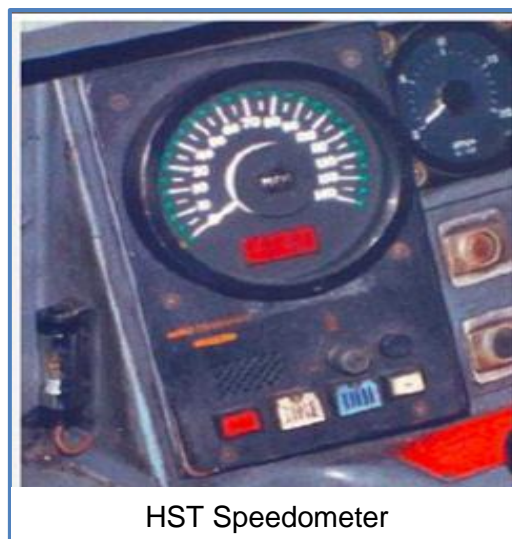
applies the brake where necessary. GW-ATP removes the risk of drivers ignoring or cancelling warnings.



- 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

4.3.4 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.

4.3.5 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 correct speed at which the train should be travelling.



HST Speedometer

4.4 ERTMS/ETCS - what is it?

4.4.1 The European Rail Traffic Management System (ERTMS), of which the European Train Control System (ETCS) is part, is the legally mandated train control and protection 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.

4.4.2 ERTMS is composed of four component parts:

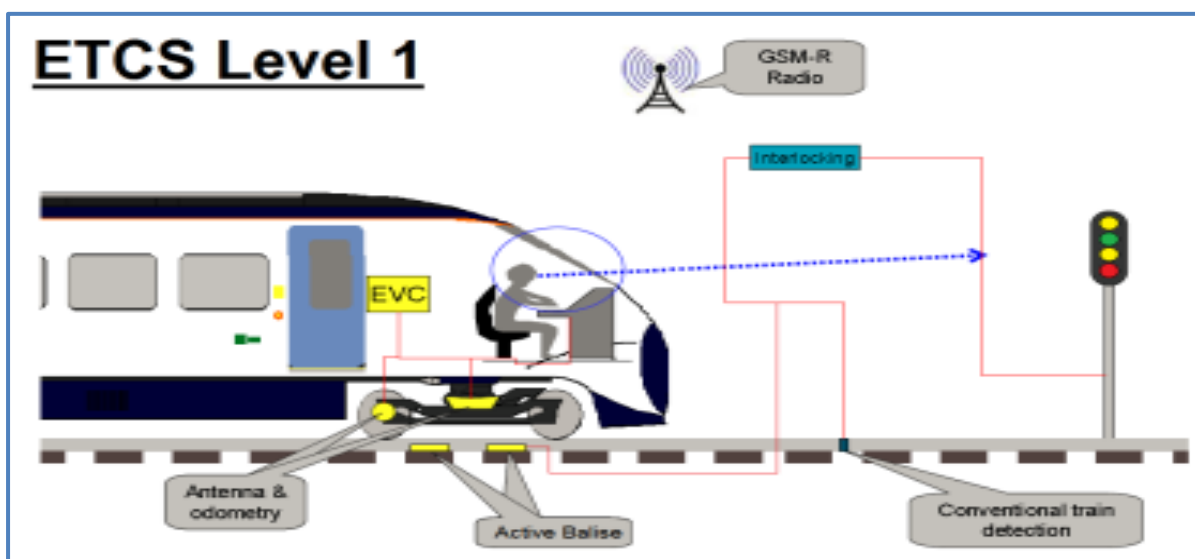
- European Train Control System (ETCS) - The train control element which provides ATP. ETCS is not in itself a signalling system, but is a component part of the signalling system;
- Global System for Mobile communications – Railways (GSM-R) - This is the telecommunications element of ERTMS for data and 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; and
- European Operational Rules (EOR) – A single rule set designed to standardise certain aspects of rail operation across Europe.

4.4.3 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.

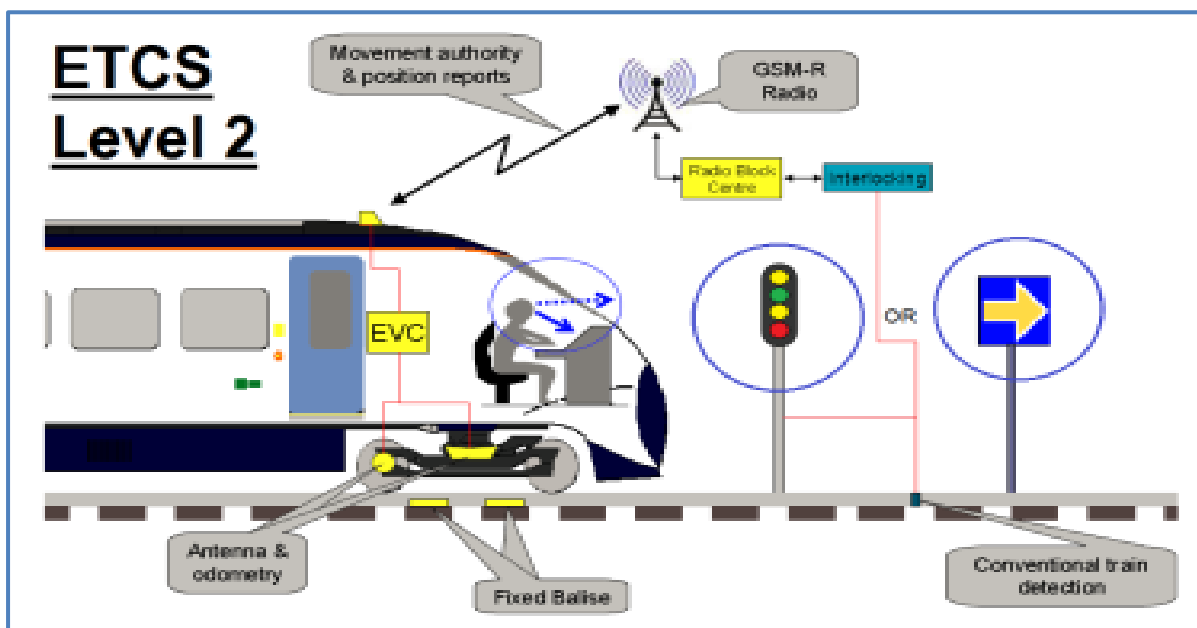
4.4.4 Different levels of ETCS functionality may be implemented: Level National Train Control (NTC), Level 0, Level 1 (L1), L2, and L3. A description of the levels is given in the table below:

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 Union Agency for Railways (ERA).



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

- 4.4.6 Continuous ATP is an inherent part of ETCS functionality for Level 2 and above, with Level 1 providing balise based intermittent ATP similar to GW-ATP.
- 4.4.7 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. ETCS L2 has also been installed on the Thameslink Route in the core section between St Pancras and Blackfriars; this is an ETCS L2 system with lineside signals, and additionally an Automatic Train Operation (ATO) system.

- 4.4.8 ETCS L2 will ultimately mean that lineside signals (and with future development of ETCS L3, lineside train detection) may be removed.
- 4.4.9 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. In addition to the information instructed to the driver ETCS will automatically intervene to control the speed of the train in the event that instructions are not being followed.



Figure 6

4.5 CBTC – what is it?

- 4.5.1 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 ETCS L2). Moving block systems provide optimum route utilisation and close train operation, but

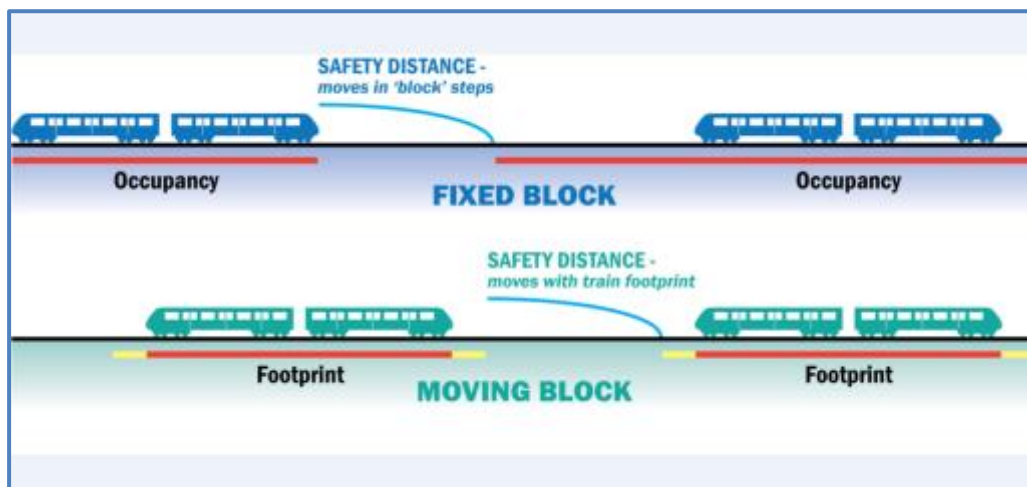


Figure 7

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.

- 4.5.2 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).
- 4.5.3 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 and more suited to ETCS.
- 4.5.4 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 suit of standards.
- 4.5.5 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

Doc Ref:	146152	NWR	REP	MPM	000007
Version No:	A01				
Date:	21 st June 2019				

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; and
- 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.

4.6 GW-ATP/ETCS/TPWS system comparison

- 4.6.1 As part of the previous Plan B work, a NR peer review 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 required trains. The peer review concluded that certain features of GW-ATP could not be duplicated, but enhancing TPWS would lead to comparable performance levels.
- 4.6.2 Further development during the Plan B project identified that not all Enhanced TPWS functions were practical, and overall TPWS effectiveness could be made by considering the conflict point at a signal rather than overlap, and not fitting TPWS to PSRs or Buffer stops.

4.6.3 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 – Balise - failures reported on MSS Radio – Service break after thirty seconds	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
Monitors adherence to maximum permitted line-speed	Yes	Yes	No	No
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 no restricting junction signal controls are provided. Only at MAF-SD controlled junctions







Function	GW-ATP	ETCS L2	'Standard' TPWS	'Enhanced' TPWS
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	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 as many trains as practical before conflicts.
Monitors approach to buffer stops	Yes - Controls train speed to maximum of 6mph	Yes - Controls train speed to maximum of 6mph	Yes, - Single OSS on approach to buffers. Generally speed checked to be less than 12.5mph	Yes, - Single 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	Yes	No	No
Monitors train rolling away	Yes - Monitors correspondence between direction of movement and controller position	Yes - Onboard function	No - Part of Class 345 trains requirements	No - Part of Class 345 trains requirements

4.7 Train types & Services


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

- 4.7.2 HSTs were 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 currently available. 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.
- 4.7.3 HSTs have largely been replaced as part of the Intercity Express Programme (IEP). IEP with Class 80x trains fitted with GW-ATP, TPWS and ETCS. It should be noted that the provision of GW-ATP on the Class 80x 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.
- 4.7.4 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.
- 4.7.5 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.
- 4.7.6 The Heathrow Express service is planned to be operated by Class 387, but will not be fitted with GW-ATP. Heathrow Express trains (Class 387) will have ETCS and TPWS train protection systems.
- 4.7.7 Provision of GW-ATP to Class 345 or Class 387 would provide limited benefit as the lines on which the services will primarily operate will ultimately have ETCS available.
- 4.7.8 Trains for local services (mainly Class 387) have TPWS only.
- 4.7.9 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		2 tph (has recently been replaced by Class 80x)	Y	Y	N

Paddington to Airport Junction – Trains				Train Protection Fitted		
Class/ Type	Service	Picture	Service Frequency May 2018	GW - ATP	TPWS	ETCS
332 / EMU	Heathrow Express		4 tph (Replaced by Class 387)	Y	N	N
360 / EMU	Heathrow Connect		2 tph (Replaced by Class 345)	Y	Y	N
165-166 / DMU	Local routes		4 tph (Replaced by Class 387)	N	Y	N
345 / EMU	Crossrail (inc Heathrow Connect)		2 tph (Increasing to 10 tph)	N	Y	Y
80x/ IEP EMU	High Speed Routes		8 tph	Y ¹	Y	Y
387	Local Routes / Heathrow Express		3 tph (replaced by Class 345 on Local Routes)	N	Y	N (Y for Heathrow Express)

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.

Paddington to Airport Junction – Trains			Train Protection Fitted			
Class/Type	Service	Picture	Service Frequency May 2018	GW - ATP	TPWS	ETCS
Freight / Loco	Freight		1 or 2 tph	N	Y	N

4.8 Train Detection Systems

Why replace track circuits?

- 4.8.1 The area between Paddington and Airport Junction (0 - 12mp) has the largest population of track circuits remaining on the GWML. Some of the train detection equipment in this area is becoming obsolete and has a poor reliability record which is likely to decrease further. Current reliability figures for the area show a Mean Time Between Service Affecting Failures (MTBSAF) of approximately 9 years for train detection with track circuits.
- 4.8.2 Access to track circuit equipment, particularly close to Paddington station is very restricted due to the congested nature of the route in this strategic location. As a result, track circuit failures are both common and difficult to rectify quickly. This can cause significant delay to the timetable and is likely to increase with increase train services planned.
- 4.8.3 A remit was developed to establish the most suitable option for the replacement or renewal of the current track circuits with a view to deliver improved asset reliability with reduced trackside maintenance of train detection infrastructure, in accordance with current NR policy.
- 4.8.4 Western Route selected axle counters as the train detection technology of choice and the performance of commissioned axle counters is expected to give an MTBSAF of approximately 15 years which reinforced this decision.
- 4.8.5 The key purpose of the replacement of track circuits is to:
- remove obsolete signalling infrastructure;
 - improve staff safety;
 - improve asset performance;
 - align with the wider requirements of the Digital Railway vision; and
 - align with current Network Rail policy for train detection.

5 Train Protection Exemption

5.1 Why is an exemption required?

- 5.1.1 For the Western Route from Paddington, it was intended that ETCS L2 with signals would be implemented by the commencement of Crossrail train operation. ETCS L2 has been rolled out initially from Heathrow Portal to the Heathrow Terminals with Paddington to Heathrow Portals to follow. The Heathrow Portal to Heathrow Terminals route was implemented first because it only had GW-ATP system, meaning only trains equipped with GW-ATP may operate to Heathrow.
- 5.1.2 Several issues have arisen and materialised in delivering ETCS in the area between Paddington and Heathrow Tunnel Portal. Issues have included (but not limited to):
- Supplier /staff availability;
 - Train delivery and testing;
 - Limited delivery experience of ETCS in the UK;
 - Delivery in an area undergoing significant modification;
 - Integration of other work in the area; and
 - Existing complexity of rail infrastructure in the area.
- 5.1.3 ETCS has been delivered in the Heathrow Tunnel area (Heathrow Portal to Heathrow Airport Terminal Stations). Heathrow Airport lines lent themselves to being the first to have ETCS; it is a simple stretch of line, and had limited interfaces with other Crossrail works. As this section of the route is not complex and was not being significantly modified, provision as planned was a much lower risk; the area has been modified in full separation from the operational Main Line. Also as detailed in section 3 the provision of new train for the HEX services using Class 387s is now a requirement for exemption as it is replacing an ATP operated service. This change of train is driven by depot closures cause by HS2 developments at Old Oak Common.

5.2 Option Development and Selection (Process)

Governance of Railway Investment Projects (GRIP)

5.2.1 NR commissioned the ETCS project in line with Network Rail's Governance of Railway Investment Projects (GRIP), as described in Figure 9 below.

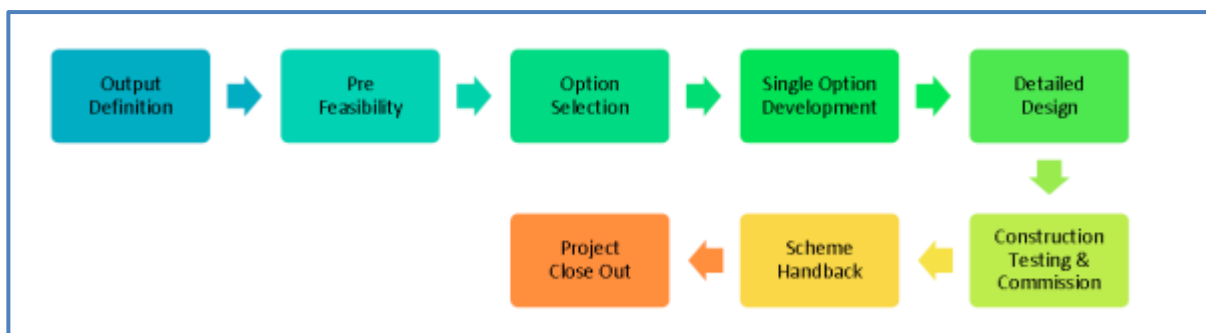


Figure 8

5.2.2 The ETCS Project as part of the wider Paddington to Reading Programme (P2R) engaged consultant engineers Sotera and Vertex to support identification and review of options.

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

5.2.4 Each individual project in the exemption area is following GRIP, but as ETCS, HS2 and Track Circuit Replacement projects overlap a level of joint review and development to GRIP 3 (Option Selection) was carried out.

5.2.5 The objectives of GRIP 3 is 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)

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

- RSR Exemption required and for what duration?
- Quantified Overall Safety Risk
- Non-Quantified Safety Benefits
- Non-Quantified Safety Disbenefits
- Feasible to deliver works required for an exemption prior to Dec 2023

- Technically feasible, irrespective of time frame
- Non-safety benefits
- Non-safety disbenefits
- Further potential mitigations to reduce safety risks
- Costs (capital, maintenance, operational)
- Impact to other parties (e.g. Train Operating Companies, Maintenance, etc)
- Critical assumptions
- Degraded/emergency mode risks

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

- 5.2.7 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* – September 2018²
- 5.2.8 The joint GRIP 3 review of the P2R projects has 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, it has also assisted in identify the significance of the change proposed.
- 5.2.9 Each change has been subject to a significance assessment in line with CSM-RA requirement, and recorded in the table below

Change Description	Significant
Delivery and operation of ETCS, including ETCS train operation.	Yes (NR AsBo)
Change to train detection, delivery and operation of Axle Counters.	Yes (NR AsBo)
Change of trains operating Heathrow Connect services. Proposed Class 345 ETCS operation.	Yes (MTR AsBo)
Change of trains operating Heathrow Express services. Proposed Class 387 ETCS operation.	Yes (GWR AsBo)

- 5.2.10 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 risk assessment was supported by a detailed risk assessment, on risks controlled by train protection.

² [Guidance on the application of Commission Regulation \(EU\) 402/2013 – September 2018](#)

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

Options Development

5.2.12 Working together NR, CRL, MTR, HEX and GWR examined previous Plan B options and workshopped possible alternatives to identify viable options. Vertex and Sotera considered, analysed and reviewed options in conjunction with NR, HEX, MTR, GWR and CRL. The main stages of the option development are shown in Figure 10 below.

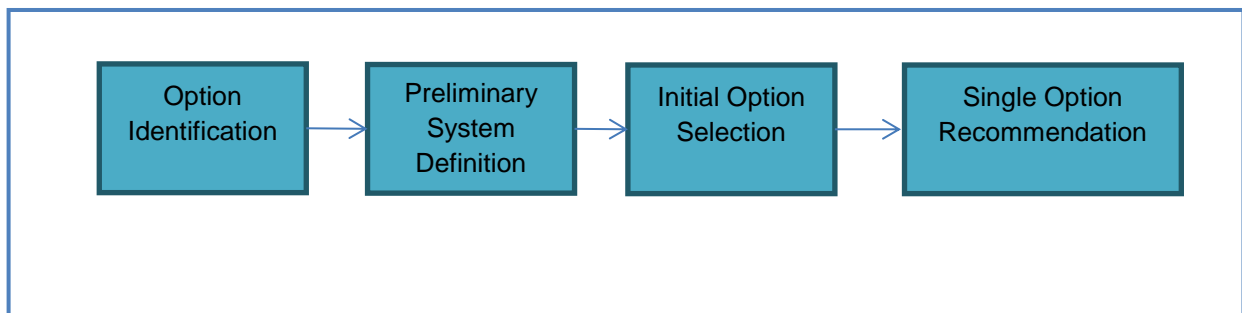


Figure 9

Developed Options

5.2.13 A number of options were agreed 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.

5.2.14 In development of ETCS delivery options three delivery areas had been defined to align with signalling system boundaries that constrained implementation. These areas can be seen in figure 11 below.

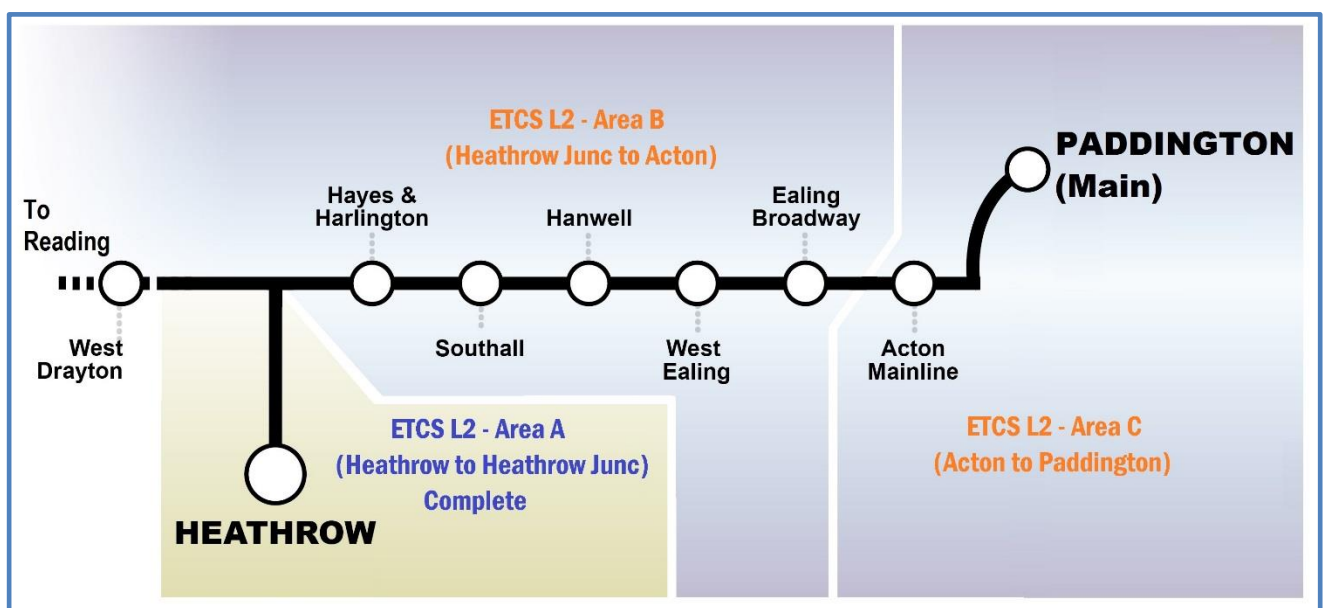


Figure 11

5.2.15 Delivery option developed also included assumptions of the integration with the Track Circuit replacement project that is planned to install axle counters in the area. Delivery dates for ETCS includes a 12month contingency to allow for technical issue resolution, access to be confirmed, and other delivery risks to mitigated.

5.2.16 Options considered are shown in the table below:

Option	Description	RSR99 Exemption Required
Option 1	Do nothing to the existing infrastructure increase service train usage. i.e. continue with enhanced TPWS and run additional Crossrail (CL345) and GWR/HEX(CL387) services as planned with reliance on Level NTC.	Yes
Option 1a	As Per Option 1 but Defer all trackside ETCS fitment in lieu of axle counter upgrade. ETCS Operation - Dec 2022 Axle Counters operating - Dec 2021	Yes - Until Dec 2023
Option 1b	As per Option 1 but Fitment of trackside ETCS as early as possible, defer axle counters ETCS Operation - Dec 2021 Axle Counters operating – Dec 2023	Yes – Until Dec 2021
Option 1c	As per Option 1 Fitment of trackside ETCS (Area B) as early as possible Area B (Heathrow Junction to Acton) ETCS Operation (Area B) - Dec 2020 Axle Counters operating – Dec 2021 ETCS Operation (Area C) – Dec 2022	Yes – Until Dec 2021 (Area B) or Dec 2023 (Area C)
Option 1d	As per Option 1 but install enhanced TPWS on approach to buffer stop and PSRs.	Yes – Until Dec 2021 (Area B) or Dec 2023 (Area C)
Option 2	Fit GW-ATP to Crossrail and HEX service trains (Class 345 & 387).	No
Option 2a	Fit GW-ATP to Crossrail service trains (Class 345 only).	No
Option 2b	Fit GW-ATP to HEX service trains (Class 387 only).	No
Option 3	Utilise existing ATP fitted stock for Crossrail and HEX Services (Class 360, 332, and 80x)	No
Option 3a	Utilise GW-ATP on existing train fleets for Crossrail Services (Class 360, 332, 80x).	No

Option	Description	RSR99 Exemption Required
Option 3b	Utilise GW-ATP on existing train fleets for HEX services (Class 360, 332, 80x).	No
Option 4	Second Driver for Class 345/387	Yes
Option 5	Fitment of ETCS Level 1 Acton (Area C)	Yes – Until Dec 2021 (Area B) or Dec 2023 (Area C)
Option 6	Fitment of ETCS Level 2	No

Initial Options Selection

5.2.17 Initially, Vertex prepared an initial system definition including an initial review of each of the options identified. This information was presented to the project for consideration.

5.2.18 An option review panel peer reviewed these outputs to determine/recommend options it considered viable for a more detailed analysis.

5.2.19 Vertex report 0-12MP RSR Exemption Options Selection Report (Reference 2) 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; and
- recommendation on options for further detailed review.

Options Discounted at Initial Options Selection

5.2.20 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
Option 2	Fit GW ATP to Crossrail and HEX service trains (Class 345 and 387)	Fitment of ATP to existing stock has been considered Both GWR and MTR conclude that retrofitting ATP is highly undesirable, is likely to be unachievable prior to Dec 2019. Fitment carries a substantial cost of several million pounds that alone is grossly disproportionate to the safety risk when compared to Enhanced TPWS operation. This opinion was shared by the stakeholder panel. Retrofitting will also have ergonomic and driver training impacts that are undesirable to Train Operating Companies.

Option	Description	Summary of why Option Discounted
Option 2a	Fit GW ATP to Crossrail service trains (Class 345 only)	As per Option 2
Option 2b	Fit ATP to HEX service trains (Class 387 only).	As per Option 2
Option 3	Utilise existing ATP fitted stock for Crossrail and HEX (Class 360, 332, and 80x)	<p>A relatively small decrease in safety risk by switching stock to ATP-fitted types.</p> <p>Contractual issues surrounding procuring such stock which are likely to be insurmountable in the time available.</p> <p>Driver training issues, since drivers are likely to require retraining on stock that they are not currently familiar with.</p> <p>Knock-on effects to HS2 if Class 332 are retained, since this would prevent the closure of the Class 332 maintenance facility at Old Oak Common. The inability to close this facility would lead to delays in the HS2 programme</p> <p>Knock-on effects to other operators who may be relying on cascade of ATP-stock</p>
Option 3a	Utilise GW-ATP on existing train fleets for Crossrail Services (Class 360, 332, 80x).	As per Option 3
Option 3b	Utilise GW-ATP on existing train fleets for HEX services (Class 360, 332, 80x).	As per Option 3
Option 4	Second Driver on the footplate of Class 345 and 387	<p>This is a procedural control and is subject to human factors and common mode human failures. Safety benefit not quantifiable.</p> <p>Train Operating Companies would be unable to supply a sufficient number of trained 2nd drivers and the cost of doing so would be prohibitive in any case.</p>
Option 5	Fitment of ETCS Level 1 (Area C), ETCS L2 (Area B)	<p>ETCS L1 is not a mature system in the UK. There are no National Deployment Rules developed.</p> <p>Using L1 was predicted to be more difficult than, and would take as long as, deploying L2 and therefore is not a viable option when compared with L2 options.</p>
Option 6	Fitment of ETCS L2 (Area B & C)	<p>This is not deliverable prior to Dec 2019 and is the reason why other options are being sought. Used as a comparison Option in risk analysis.</p>

5.2.21 Continued operation with a 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 delivery risk.

5.2.22 These options were taken forward for further detailed analysis, to determine which was considered most appropriate for delivery.

6 Option Risk Assessment (Overrun/ Safety Justification)

6.1 Introduction

6.1.1 The various functions of TPWS, ETCS and GW-ATP enable them to mitigate SPAD, buffer stop collision 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 ETCS Programme.

6.2 Levels of Safety

6.2.1 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.

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

6.2.3 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).

6.2.4 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?

6.2.5 Data from the SRM was employed in the risk assessment exercise to inform the decisions of the review group (see section 6.4)

6.2.6 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; and
- Buffer stop/rollback collisions, leading to derailment.

6.2.7 The usual measure for harm in the mainline rail industry is 'fatality and weighted injury' (FWI) which is a way of measuring the level of harm or risk in a consistent way, by combining the fatalities, major injuries and minor injuries in one unit of measurement. Each injury type is scored in a way that is

‘statistically equivalent’ to one fatality. The weightings can direct intervention towards those incidents and accidents that lead to the highest levels of risk without ignoring the types of incident that typically have less severe outcomes.

- 6.2.8 The table below is from the SRM (v8.5.0.2) and gives an overview of the level of residual risk from the SRM that could be further mitigated with train protection systems. These national figures assume that the current TPWS and ATP systems are in place.

Type of Collision or Derailment Event	Risk (FWI/yr.)
SPAD leading to collisions between trains	0.58
SPAD at Level crossing leading to collision with road vehicle	0.0145
SPAD leading to train derailment at S&C	0.06
Train derailment due to overspeeding	0.0216
Buffer stop collisions	0.165
Permissive working collision	0.073
Total risk	0.993

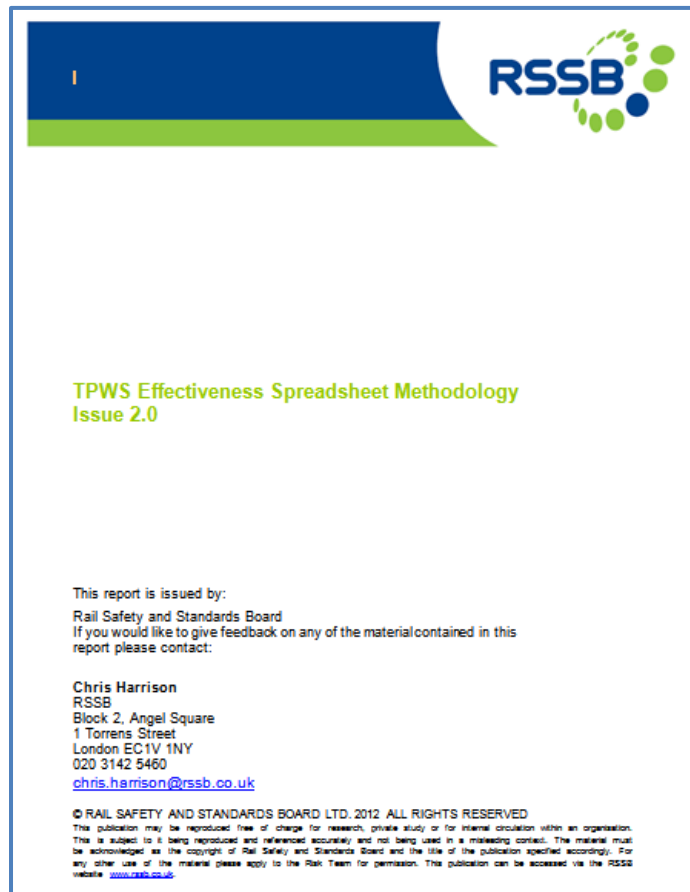
- 6.2.9 It can be seen that based on SRM data, collision and derailment due to SPADs currently represents a larger share of residual risk than other derailments or buffer stop collision.

- 6.2.10 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, and that with ATP fitted nationally Total residual risk would be 0.262 FWI/yr., a 74% reduction.

- 6.2.11 Based on the SRM data it can be seen that should a train protection system be changed SPAD risk is the area that warrants the greatest consideration; this would potentially pose the most significant change in the risk profile.

6.3 TPWS Effectiveness Tool

- 6.3.1 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.
- 6.3.2 RSSB developed the Methodology for TPWS Effectiveness in 2012. This methodology was validated and is contained within an Excel spreadsheet tool.
- 6.3.3 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 7.2 Further Overrun Risk Assessment Proposed) and the methodology has been included within the SORAT software.
- 6.3.4 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.
- 6.3.5 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.
- 6.3.6 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.



6.3.7 The maximum effectiveness of TPWS in reducing the risk from collision and derailment based on this assessment is 95% for Mk1 units. For the Mk3 units the maximum effectiveness is 96.9% and for the Mk4 units the maximum is 98.9%. The values for the Mk3 and Mk4 effectiveness are based upon research conducted for RSSB into reset and continue risk.

6.4 Risk Assessment

6.4.1 How much 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 offer protection to more trains per fitment.

6.4.2 Sotera was commissioned to undertake a detailed, risk assessment of the train protection for the area for each option, with current and future planned service levels. The risk assessment focussed on four key areas of risk: train-train collisions from SPADs, derailments from overspeeding, buffer collisions and the risk to maintainers from servicing additional TPWS trackside units. These were considered to be the hazardous events significantly affected by amending train protection.

6.5 Service Levels and Trains

6.5.1 Current and future service levels have been modelled to give a comparison of level risk for current and expected future timetables.

6.5.2 Current service levels were based upon the working timetable from May to December 2018, as per diagram below.

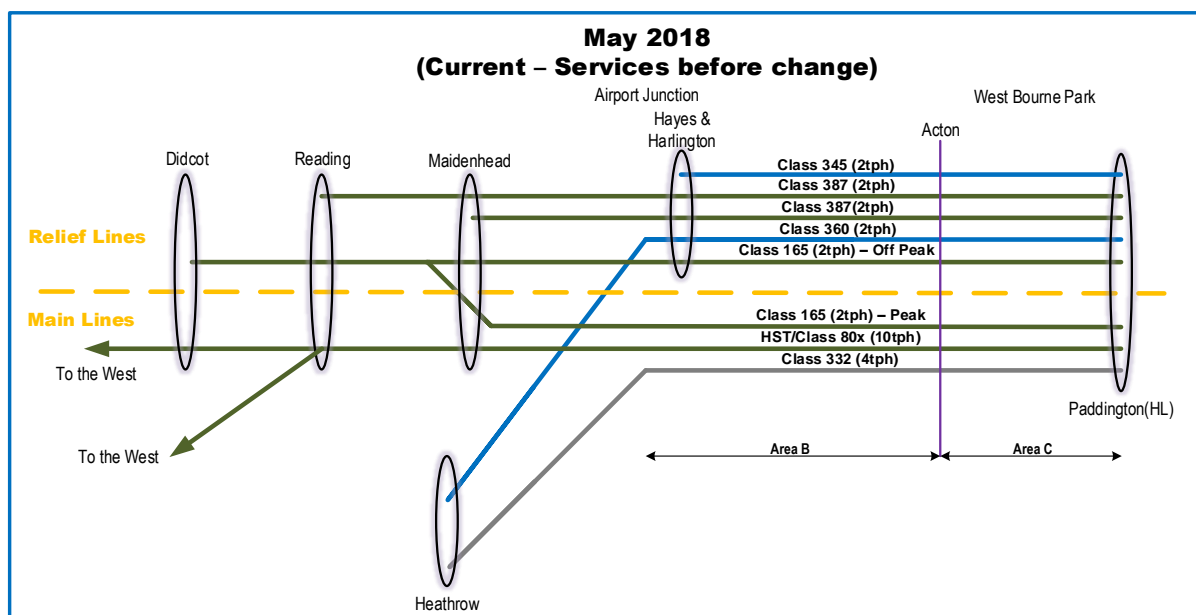


Figure 12

6.5.3 NR, CRL, HEX and GWR together determined three potential future service levels; these are summarised in the diagrams below are termed Timetable 1 to

Timetable 3 (abbreviated to TT1 to TT3). For each of the future timetables' options assessed consideration was given to the alternative stock being operated. These are presented in the diagrams below.

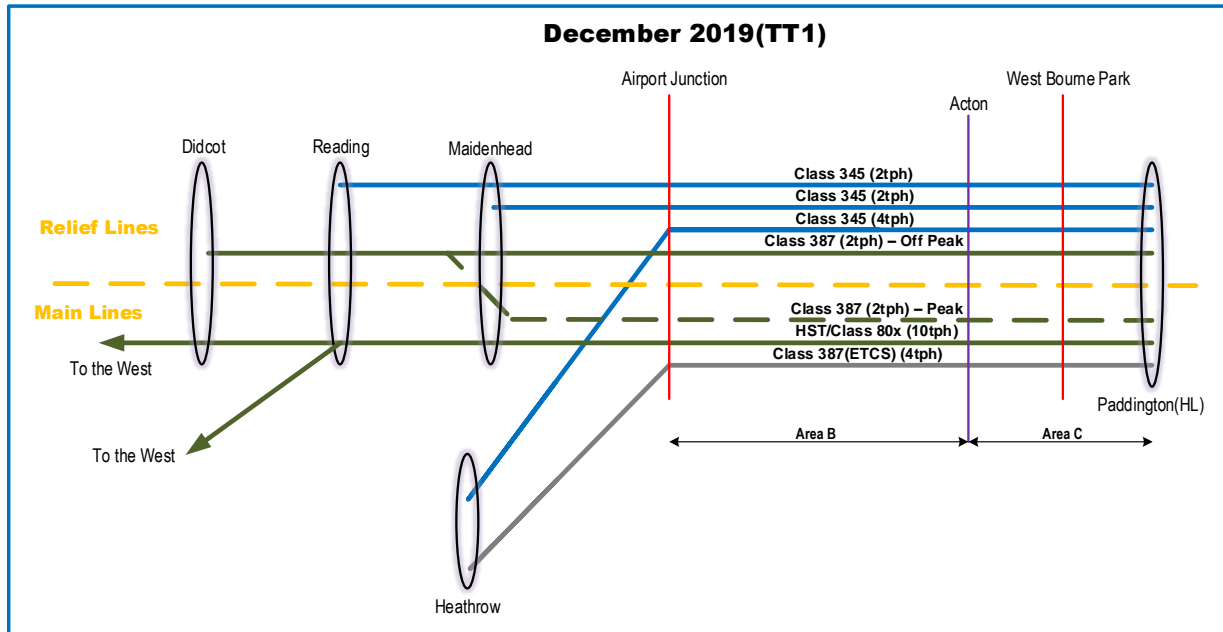


Figure 13

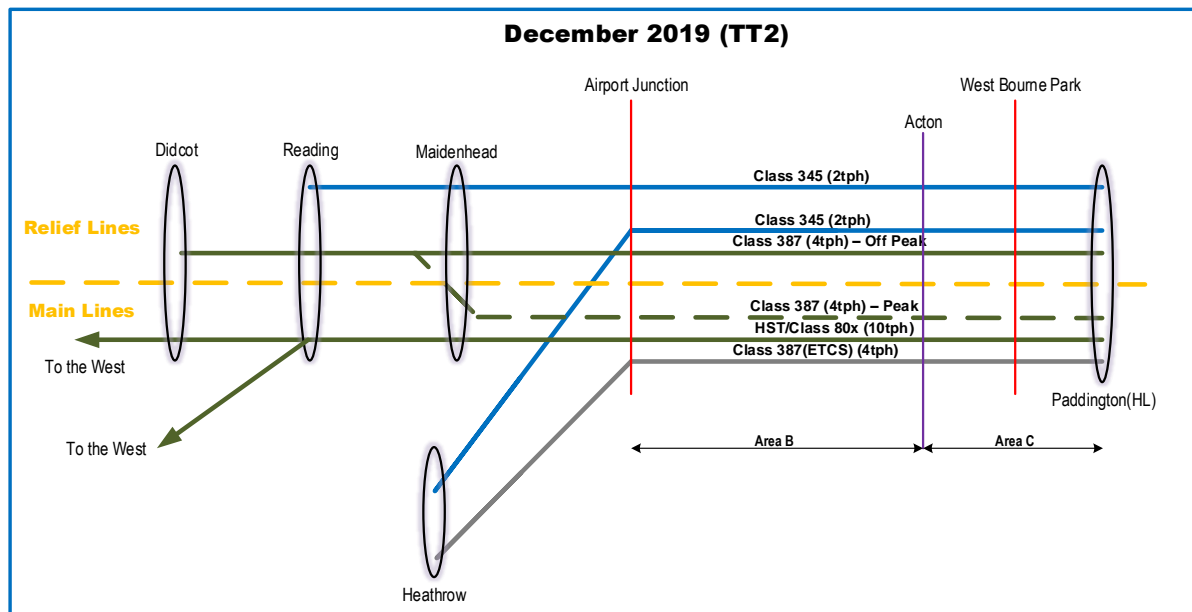


Figure 14

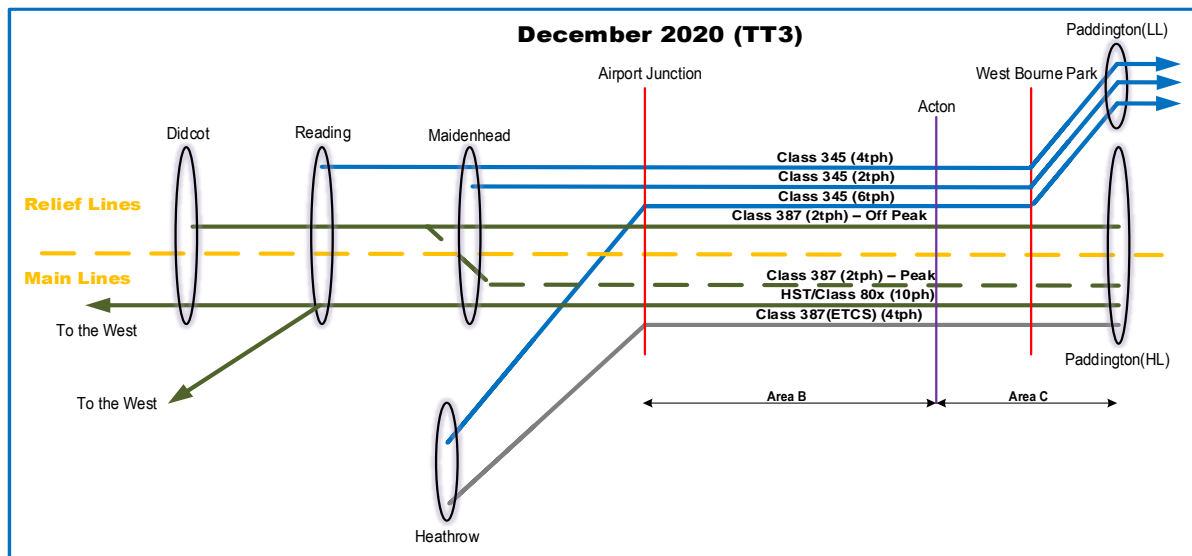


Figure 15

6.6 Detailed Options Selection and Hazard Identification (HAZID)

- 6.6.1 Following the initial option selection review, the options remaining required further detailed assessment to determine the differences in risk between them. This review considered the Risks Assessment work carried out by Sotera and other risks not quantified by the Sotera assessment.
- 6.6.2 Vertex developed the set of criteria that each of the options would be reviewed against and facilitated the workshop.

6.7 Summary of Risk Assessment

Timetable comparison

- 6.7.1 Analyses of the differences in risk managed by train protection between the current timetable and the three potential future timetables (TT1 to TT3) with exiting train protection (Option 1) are shown in table below and illustrated in (figure 16).

Timetable Option	Buffer Collision Risk (FWI/Yr)	Train Collision Risk (FWI/Yr)	Derailment Risk (FWI/Yr)	Maintainer Risk (FWI/Yr)
Exemption Case (May 2018)	0.00388	0.0101	0.000172	0.0000923
TT1 (Dec 2019)	0.00439	0.00704	0.000215	0.0000923
TT2 (Dec2019)	0.0038	0.00633	0.000184	0.0000923
TT3 (Dec2020)	0.00169	0.00796	0.000247	0.0000923

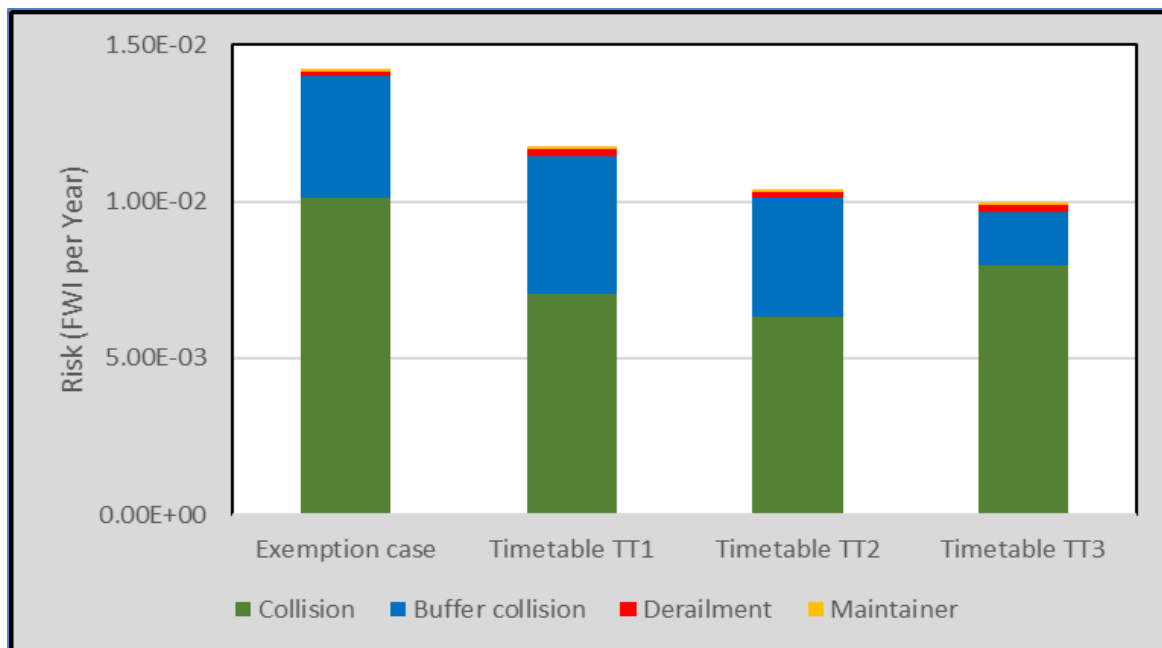


Figure 16

6.7.2 Of all the timetable scenarios, Timetable 3 presents the lowest risk, despite having the highest number of trains operating through the layout.

6.7.3 The individual changes between the timetables are explained as follow:

- Collision risk shows a decrease from current due to removal of use of Class 165/1 trains that have TPWS Mk1. Note that Class 165s have largely already been replaced with Class 387. TT3 shows then a risk increase; this increase is commensurate with the higher number of train services;
- Buffer collision risk shows an increase in risk in TT1 and TT2, due to increase in train approaching Paddington without ATP. Reduction in risk for TT3, this is a direct result from the much lower number of buffer approaches in the layout due to the Crossrail services approaching the central operating section instead; and
- Overspeeding derailment risk shows an increase in risk, this is due to the increase in train services. The increase is commensurate with the increase in train services and the number of PSRs traversed. But as this is significantly smaller than the collision or buffer stop risk it does not impact significantly on the total risk.

6.7.4 Overall, comparing timetables the reduction in collision risk out weights the increase in buffer collision and derailment risk, so it can be seen that future risk that may be controlled by train protection will be reduced due to a planned service and rolling stock changes.

6.7.5 More detail can be found in the Sotera Report - Risk Assessment of the Paddington to Heathrow Airport Junction Train Protection Strategy – Options analysis (Reference 3)

6.7.6 An important assumption underpinning the assessment is that the lower number of train services does not give rise to a higher level of passenger loading on trains, i.e., it is assumed that overall patronage increases and decreases linearly with service levels.

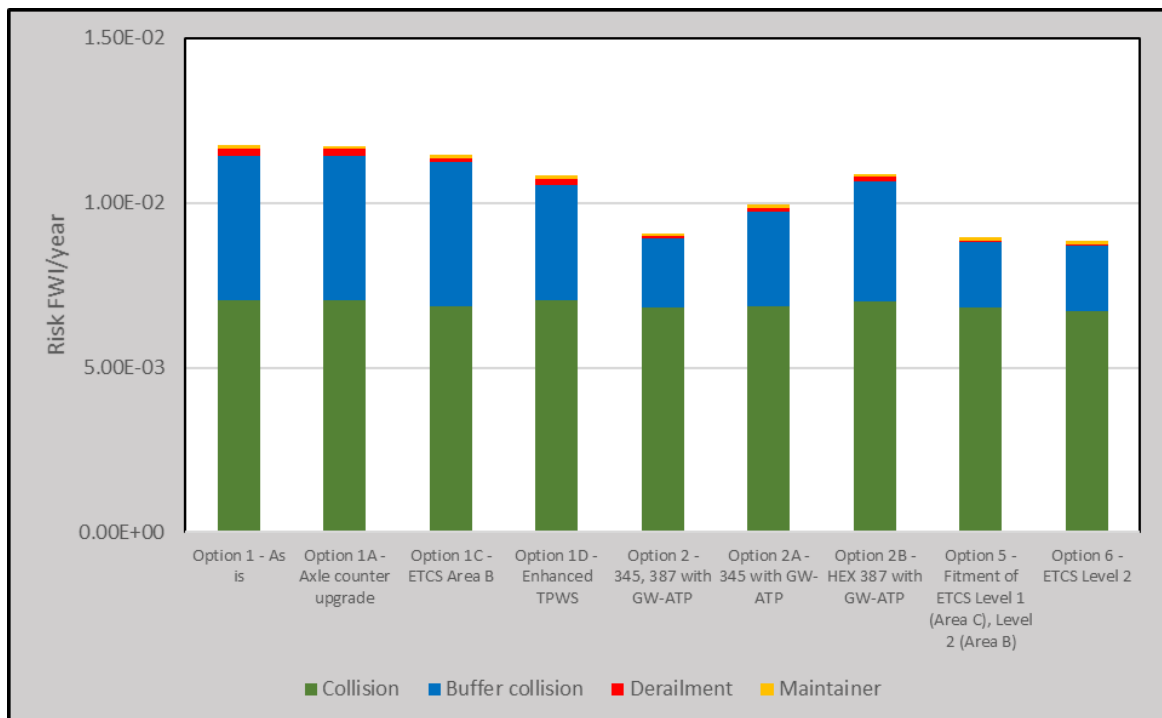
Infrastructure Options comparison

6.7.7 Analyses of the differences between the infrastructure options was carried out for all the current and three potential future timetables (TT1 to TT3) is illustrated below in (figure 17 to 19).

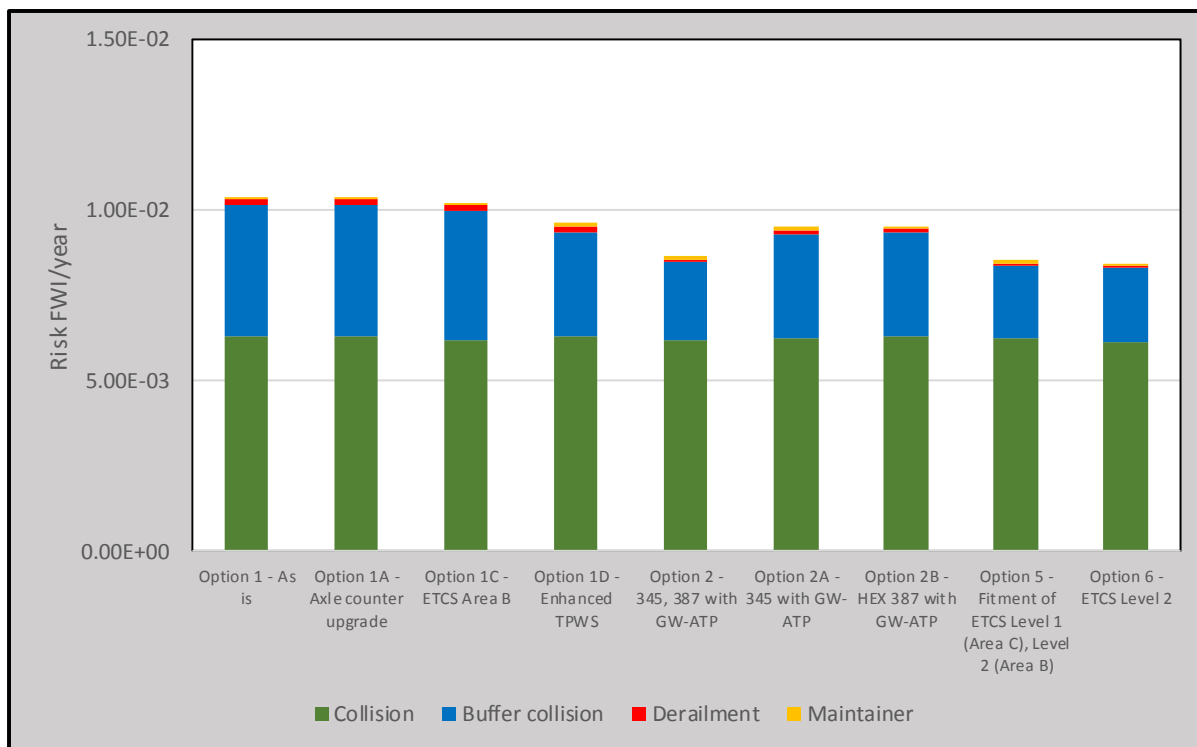
6.7.8 Note that from a risk assessment point of view some options are equivalent so are not separately assessed:

- Option 1 and 1b - the difference between these options being the time when ETCS is completed;
- Options 2a and 3a – the difference being the trains used to provide GW-ATP on Crossrail services; and
- Options 2b and 3b - the difference being the trains used to provide GW-ATP on Heathrow Express services.

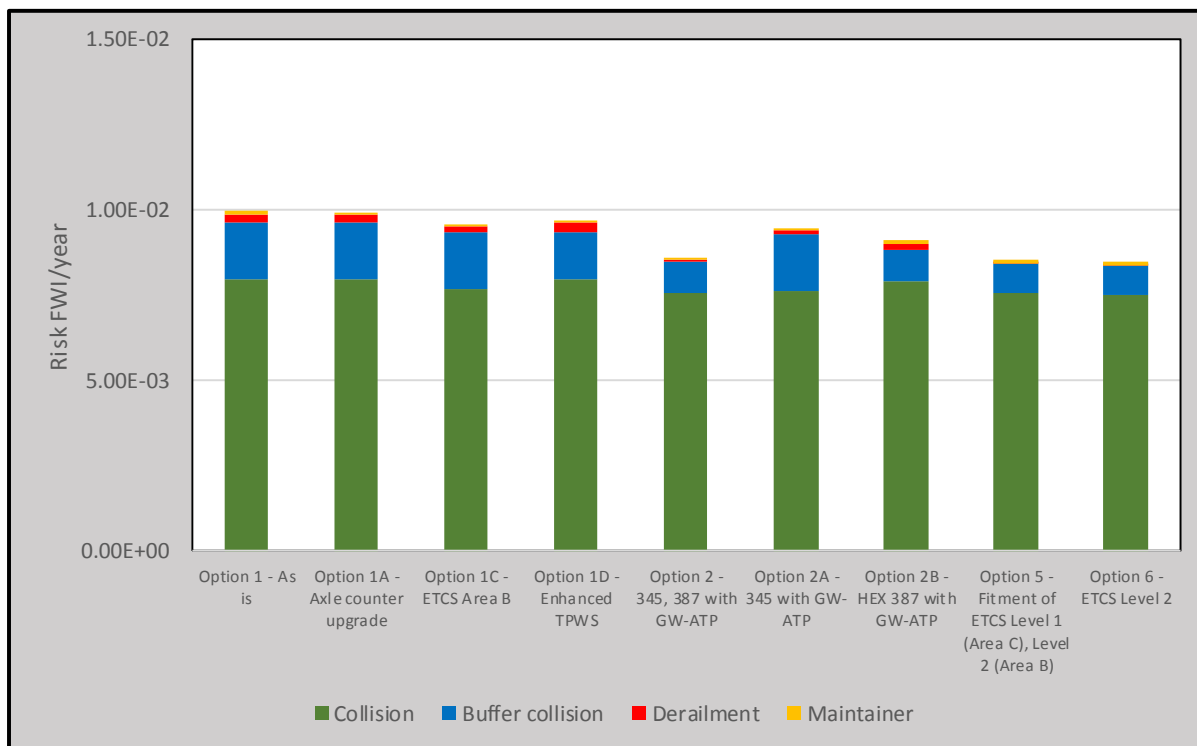
6.7.9 More detail can be found in the Sotera Report - Risk Assessment of the Paddington to Heathrow Airport Junction Train Protection Strategy – Options analysis (Reference 3)



Timetable 1 - Figure 17



Timetable 2 - Figure 18



Timetable 3 - Figure 19

6.7.10 Of all the options, overall, Option 2 (hence Option 3), Option 5 and Option 6 are expected to present the lowest risk, this is as an ATP system in operation on

the HEX and Crossrail services, but as explained in section 5.2.20 these are currently not reasonably practicable to implement.

6.7.11 These options, although not implementable, are not a significant concern as due to service and rolling stock changes proposed, the risk in the area is still reducing overall as shown in figure 16.

6.7.12 Comparison of individual changes between the 1, 1C and 1D options are explained as follows:

- Collision risk shows no significant change, as area already has Enhanced TPWS and so provide similar level of protection to ETCS and ATP;
- Buffer collision risk is reduced significantly when TT3 is implemented. Introduction of Option 1D shows risk is reduction due to the additional protection for trains operating in TPWS, but has increase in Maintainer risk;
- Overspeeding derailment risk shows significant reduction with the ETCS provision, but this is only a small reduction in overall risk; and
- Maintainer risk for Option 1A reduces by 48% with the implementation of axle counters due to less staff required on site for failure and maintenance. However, as maintainer risk is a small contribution to the overall risk profile, the overall level of risk reduces by approximately 0.4%.

6.8 Final selected option

6.8.1 An Option Selection meeting held on the 21st February 2019 to consider options, records of the meeting are contained in Vertex report 0-12MP RSR Exemption Options Selection Report (Reference 2).

6.8.2 After running through the assessment criteria, the preferred option was Option 1c based on the following reasons/ rationale:

- Safety risk is tolerable and expected to be reducing see table below and Figure 20 due to changes in rolling stock type, change in planned services and early delivery of ETCS in area B by Dec 2020;

Option	Buffer Collision Risk (FWI/Yr)	Train Collision Risk (FWI/Yr)	Derailment Risk (FWI/Yr)	Maintainer Risk (FWI/Yr)	Total Risk (FWI/Yr)
Exemption / Current (May 2018)	0.00388	0.0101	0.000172	0.0000923	0.0142443
Dec 2019 Option 1 - Do nothing and Time Table 1	0.00439	0.00704	0.000215	0.0000923	0.0117373
Dec 2020 Option 1c – ETCS Area B and Time Table 3	0.00169	0.00768	0.000134	0.0000923	0.0095963

Option	Buffer Collision Risk (FWI/Yr)	Train Collision Risk (FWI/Yr)	Derailment Risk (FWI/Yr)	Maintainer Risk (FWI/Yr)	Total Risk (FWI/Yr)
Dec 2021 Option 1c– ETCS Area B + Option 1a - Axle Counters and Time Table 3	0.00169	0.00768	0.000134	0.0000479	0.0095519
Dec 2022 Option 6– ETCS Area B & C + Option 1a - Axle Counters and Time Table 3	0.000832	0.00753	0.0000419	0.0000479	0.0084518

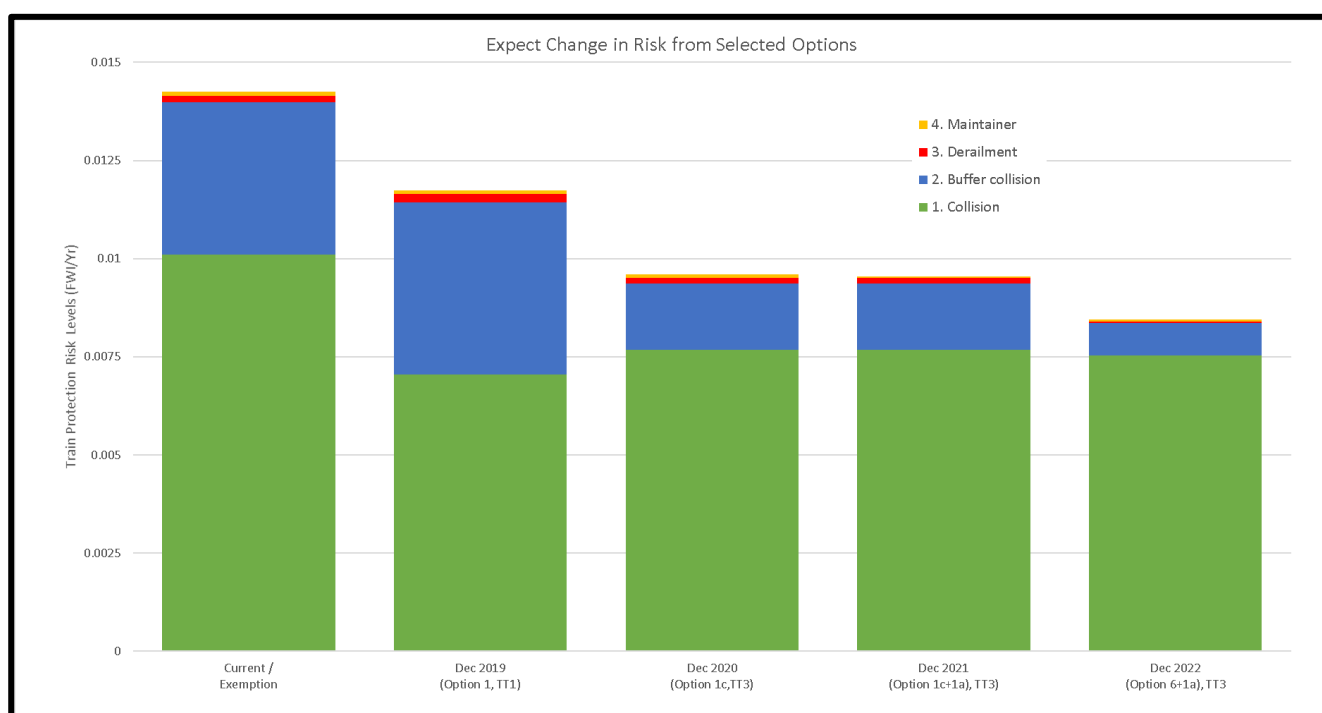


Figure 20

- Resolves ETCS Area A residual issues as quickly as practicable, and based on our model the earliest of all options, by Dec 2020. The 'minimum train length' residual issue was highlighted as having a potential major operational constraint by GWR and HEX;
- Currently anticipated stock types can be run;
- Imposes no delay to the axle counter introduction programme and therefore enables the infrastructure reliance and safety benefits to the maintenance staff of axle counters to be delivered as early as possible; and
- Allows longer time for resolution of ETCS issue should they arise in implementation of Area C and interface to Crossrail.

6.8.3 The main disadvantages associated with Option 1c are:

- Resolution of 'Area A residual issues' does not occur until Dec 2020, which has operational impacts to GWR (no short form 387s can be run) for the period from Class 387 introduction (anticipated to be early December 2019) until Dec 2020; and
- Piecemeal introduction of ETCS creates 'temporary' transitions, which will require drivers to be trained as the landscape evolves to the final layout. This is mitigated by the 2-year period between implementation of ETCS Area B and ETCS Area C.

6.8.4 TPWS is used nationally and is already in place on the majority of the Crossrail and HEX operational area. Within the area concerned, TPWS has been upgraded from the standard level of fitment to Enhanced TPWS, providing a level of protection that, as far as reasonably practicable, replicates a similar protection levels for train collision risk as GW-ATP. Enhanced TPWS proposal is demonstrably safe, fit for purpose and represents what is considered to be the best option as an interim train protection due to delays in ETCS delivery.

6.8.5 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.

6.8.6 Based on these reviews, it is considered that Enhanced TPWS operation offers the best interim option for Crossrail and HEX services between Paddington and Heathrow Tunnel Junction. The lines from Airport Junction to Heathrow Airport will remain fitted with GW-ATP and ETCS.

6.8.7 Due to the relatively small difference in risk levels between ETCS and Enhanced TPWS in Area C it was not considered as required to delay the introduction of axle counters. Delaying of axle counter provision would continue to expose staff to more risk and continue to cause more delays to train services in the area. Crossrail and HEX 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.

6.8.8 It is recommended from the HAZID/driveability exercise, in order to minimise risk at transitions created from delivery of ETCS Area B before ETCS Area C.

6.8.9 Additional TPWS for PSR junctions and Buffer stops can be discounted and should not be progressed. The risk levels associated with over-speeding are considered small and supported by Sotera risk analysis, hence no additional mitigation can be justified for the expected limited duration before ETCS is operational.

7 Network Rail Safety Assurance Process

7.1 Introduction

- 7.1.1 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.
- 7.1.2 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).
- 7.1.3 Safety Assurance will be achieved by application of the CSM-RA, and production of a Safety Assessment Report by an independent assessment body. Further information can be found in ORR document - ORR document - Guidance on the application of Commission Regulation (EU) 402/2013 – September 2018³
- 7.1.4 In line with accepted Network Rail processes, as the design is developed further the projects 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.
- 7.1.5 Before acceptance by SRP the Safety Justification will be reviewed by an Independent Safety Assessor (ISA), whose review shall cover the following topics:
- Scope;
 - Hazards identified;
 - Assessment of risks;
 - Control measures during the change period and afterwards;
 - Residual risks; and
 - Arrangements for monitoring and review.

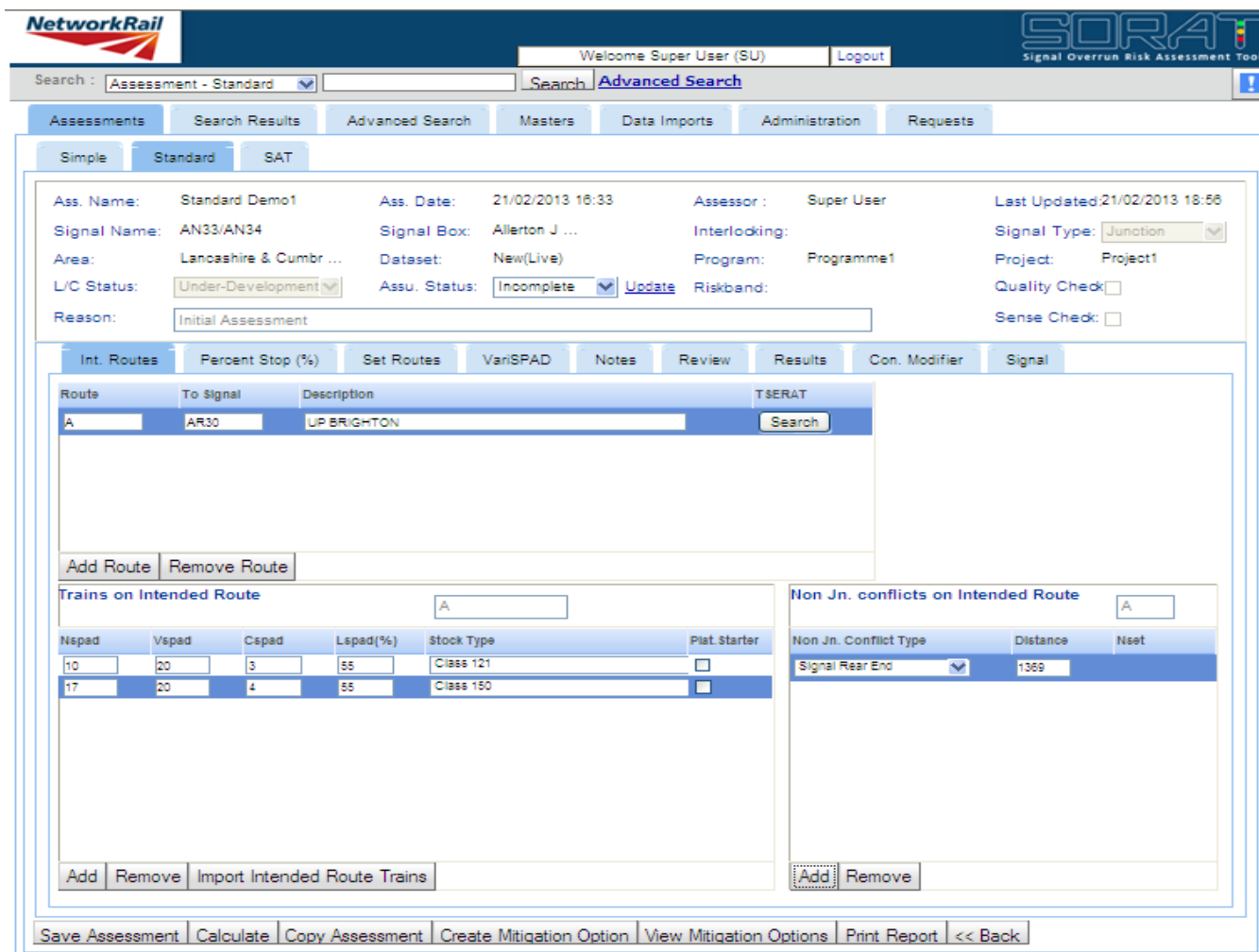
³ [Guidance on the application of Commission Regulation \(EU\) 402/2013 – September 2018](#)

7.2 Management of safety activities: Further Overrun Risk Assessment Proposed

- 7.2.1 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 for some signals greater than, that offered by GW-ATP or ETCS alone.
- 7.2.2 Network Rail will 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 when infrastructure, train service or train types change.
- 7.2.3 Signal overrun risk assessment processes have been established over many years and developed from the requirements of the now withdrawn Railway Group Standard, GI/RT7006 - Prevention and Mitigation of Overruns – Risk Assessment.
- 7.2.4 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 Assessment⁴
- 7.2.5 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 <https://www.rssb.co.uk/rgs/standards/RIS-0386-CCS%20Iss%201.pdf>

7.2.6 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 20 below.



Network Rail

Welcome Super User (SU) Logout

Search: Assessment - Standard Search Advanced Search

Assessments Search Results Advanced Search Masters Data Imports Administration Requests

Simple Standard SAT

Ass. Name: Standard Demo1 Ass. Date: 21/02/2013 18:33 Assessor: Super User Last Updated: 21/02/2013 18:58

Signal Name: AN33/AN34 Signal Box: Allerton J ... Interlocking: Signal Type: Junction

Area: Lancashire & Cumbr ... Dataset: New(Live) Program: Programme1 Project: Project1

L/C Status: Under-Development Assu. Status: Incomplete Update Riskband: Quality Check: ☐

Reason: Initial Assessment Sense Check: ☐

Int. Routes Percent Stop (%) Set Routes VariSPAD Notes Review Results Con. Modifier Signal

Route	To Signal	Description	TSERAT
A	AR30	UP BRIGHTON	Search

Add Route Remove Route

Trains on Intended Route A

Nspad	Vspad	Cspad	Lspad(%)	Stock Type	Plat Starter
10	20	3	55	Class 121	<input type="checkbox"/>
17	20	4	55	Class 150	<input type="checkbox"/>

Add Remove Import Intended Route Trains

Non Jn. conflicts on Intended Route A

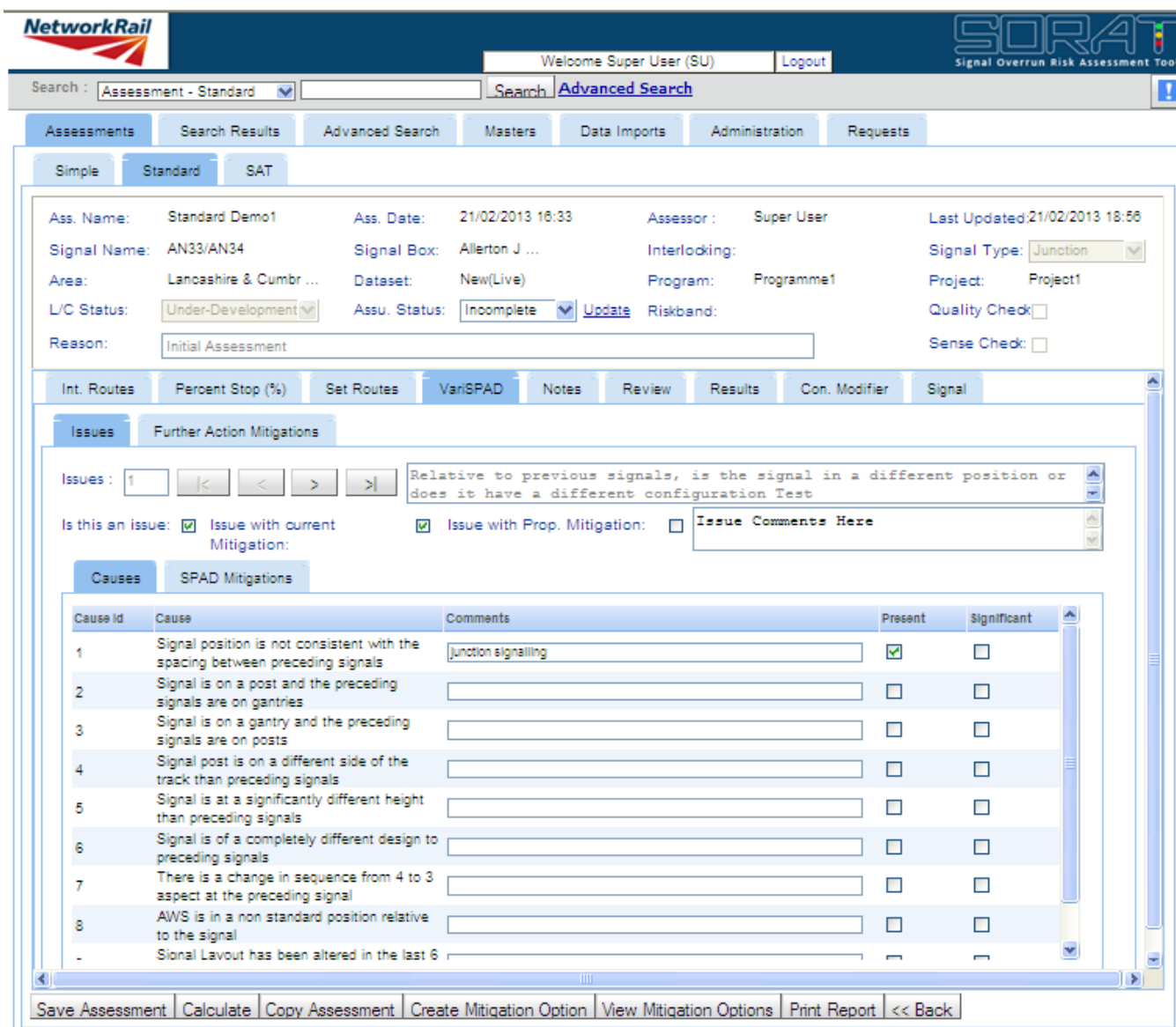
Non Jn. Conflict Type	Distance	Nset
Signal Rear End	1369	

Add Remove

Save Assessment Calculate Copy Assessment Create Mitigation Option View Mitigation Options Print Report << Back

Figure 20

- 7.2.7 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



The screenshot displays the SORAT web application interface. At the top, there's a Network Rail logo and a 'Welcome Super User (SU)' message with a 'Logout' link. Below this is a search bar and navigation tabs: 'Assessments', 'Search Results', 'Advanced Search', 'Masters', 'Data Imports', 'Administration', and 'Requests'. The 'Assessments' tab is active, showing a list of assessments. The 'Standard' assessment type is selected, and the 'Assessment - Standard' search results are displayed. The 'Assessment - Standard' form is shown, with fields for 'Ass. Name', 'Signal Name', 'Area', 'L/C Status', 'Ass. Date', 'Signal Box', 'Dataset', 'Assu. Status', 'Assessor', 'Interlocking', 'Program', 'Project', 'Last Updated', 'Reason', 'Riskband', 'Quality Check', and 'Sense Check'. The 'Assessment - Standard' form is also shown, with tabs for 'Int. Routes', 'Percent Stop (%)', 'Set Routes', 'VariSPAD', 'Notes', 'Review', 'Results', 'Con. Modifier', and 'Signal'. The 'VariSPAD' tab is selected, and the 'Issues' section is active. The 'Issues' section shows a table of causes and their status (Present/Significant). The 'Issues' section also includes a 'Further Action Mitigations' section with a table of causes and their status (Present/Significant).

Cause Id	Cause	Comments	Present	Significant
1	Signal position is not consistent with the spacing between preceding signals	junction signalling	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2	Signal is on a post and the preceding signals are on gantries		<input type="checkbox"/>	<input type="checkbox"/>
3	Signal is on a gantry and the preceding signals are on posts		<input type="checkbox"/>	<input type="checkbox"/>
4	Signal post is on a different side of the track than preceding signals		<input type="checkbox"/>	<input type="checkbox"/>
5	Signal is at a significantly different height than preceding signals		<input type="checkbox"/>	<input type="checkbox"/>
6	Signal is of a completely different design to preceding signals		<input type="checkbox"/>	<input type="checkbox"/>
7	There is a change in sequence from 4 to 3 aspect at the preceding signal		<input type="checkbox"/>	<input type="checkbox"/>
8	AWS is in a non standard position relative to the signal		<input type="checkbox"/>	<input type="checkbox"/>
-	Signal Layout has been altered in the last 6		<input type="checkbox"/>	<input type="checkbox"/>

Figure 21

increase or decrease SPAD risk (Figure 21).

- 7.2.8 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 6.3 TPWS Effectiveness Tool). In this instance, however, the algorithm has the benefit of the final agreed train quantities and TPWS/GW-ATP arrangements.

7.2.9 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 22).

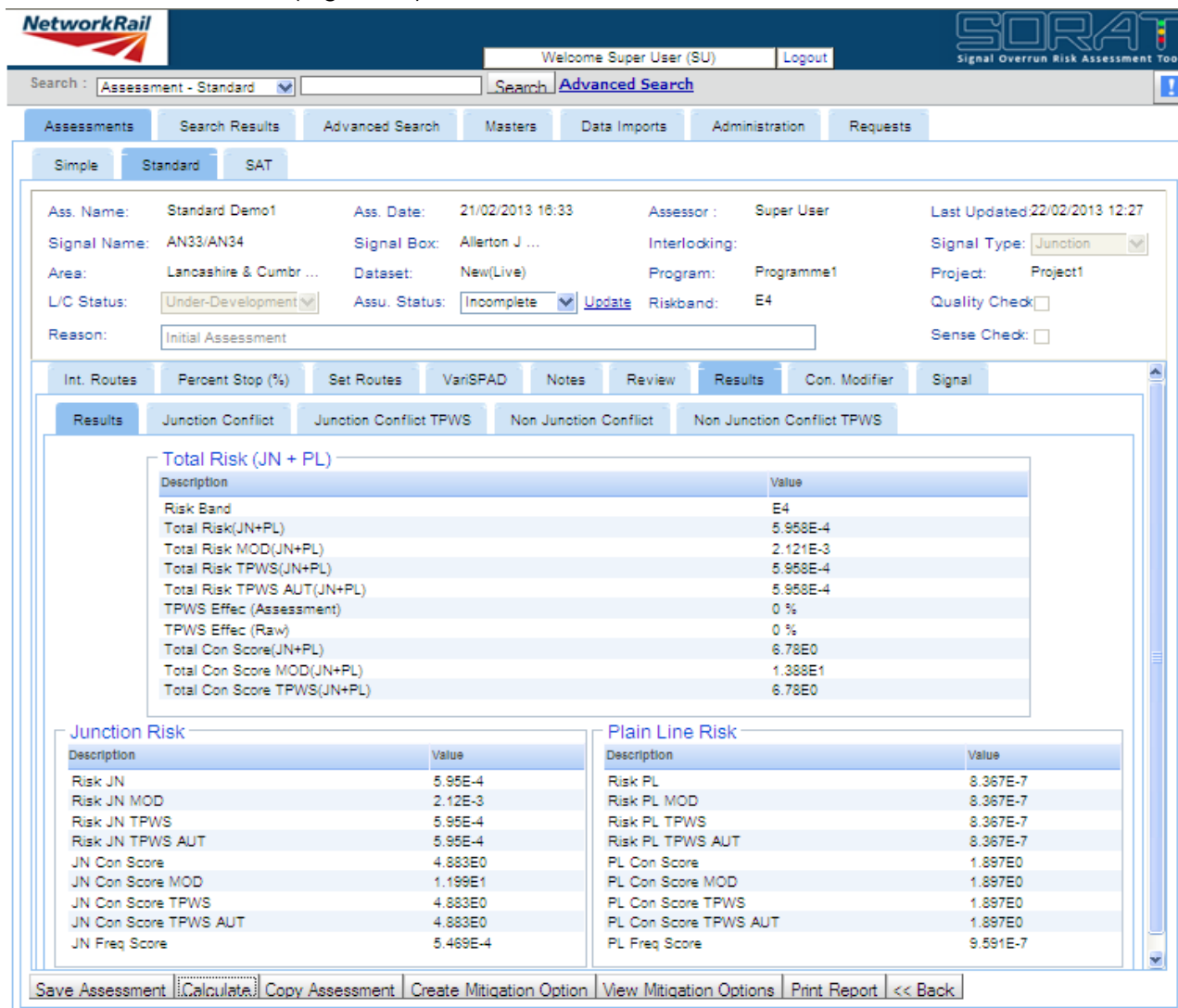


Figure 22

7.2.10 Each signal will need to be taken through the SORAT process, and only if the levels of risk are determined to be (ALARP) by Network Rail and TOC/FOC users will the signal and its train protection be deemed acceptable without additional mitigations.

8 Conclusion

- 8.1.1 The strategy of increasing use of TPWS for train protection has been supported for several years and has been a key element of rail industry safety policy.
- 8.1.2 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.
- 8.1.3 We conclude that:
- The safety benefits from using TPWS to mitigate Signal Passed at Danger risks are substantial;
 - 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 ETCS implementation. On this basis, it is necessary for us to obtain an exemption from this requirement in order to continue use of Enhanced TPWS as our fall-back train protection solution; and
 - The planned Crossrail and HEX service with new Class 345 and Class 387 trains will offer significant passenger benefits outside of those considered within RSR99.
- 8.1.4 Enhanced TPWS proposals are demonstrably safe, fit for purpose and represent what is considered as the best option as a fall-back if ETCS delivery is delayed.

9 Stakeholder engagement/consultation

- 9.1.1 A number of stakeholders have been engaged / consulted, and others will be subsequently informed.
- 9.1.2 The following stakeholders have been a key part of the exemption development and have provided letters in support of the exemption request:
- Great Western Railway;
 - Crossrail Limited;
 - MTR Corporation (Crossrail) Limited; and
 - Heathrow Express Operating Company Limited.
- 9.1.3 Briefing letters have been provided to the following stakeholders asking if further engagement would be required:
- Paddington Survivors Group;
 - Transport Focus;
 - TravelWatch;
 - Borough Councils (Ealing, Hillingdon, Westminster); and
 - Constituency MPs.
- 9.1.4 For further detail of the stakeholder engagement/consultation see the 'Stakeholder Management and Customer Engagement Plan' – See (Reference 4).
- 9.1.5 A summary record of the stakeholder engagement is provided in the table below.

Stakeholder	Stakeholder contact	Primary forum and status of response
Great Western Railway	Stewart Player	Engaged during all stages of the exemption development, attendees at optioneering workshops and attendees alongside NR (and other stakeholders) at ORR exemption progress meetings. Confirms support for the application.
Crossrail Limited	Mark Wild / Howard Smith	Engaged during all stages of the exemption development, attendees at optioneering workshops and attendees alongside NR (and other stakeholders) at ORR exemption progress meetings. Confirms support for the application.
MTR Corporation (Crossrail) Limited	Steve Murphy	Engaged during all stages of the exemption development, attendees at optioneering workshops and attendees alongside NR (and other stakeholders) at ORR exemption progress meetings. Confirms support for the application.
Heathrow Express Operating Company Limited	Stephen Head	Engaged during all stages of the exemption development, attendees at optioneering workshops and attendees alongside NR (and other stakeholders) at ORR exemption progress meetings. Confirms support for application.
Rail Delivery Group	Andy Doherty	Detailed presentation to the industry's Train Protection Strategy Group. Forum noted the exemption request.
Freight Operators	Martin Wadding	Detailed presentation material shared with Freight Operations Sub-Group representative No response received.

10 References

Reference	Title
1	Crossrail Train Protection (Plan B) Railway Safety Regulations 1999 Exemption Application Report, Rev A03, 26 th August 2015
2.	Vertex Systems Engineering, Final Option Selection Version 1.4, 24 th March 2015.
3.	Risk Assessment of the Paddington to Heathrow Airport Junction Train Protection Strategy – Options analysis, Rev 02, 22 nd Jan 2019
4.	Stakeholder Management and Customer Management Plan, V2.0 21 st June 2019
5.	Class 387/1: ETCS ATP Case, Issue 1, 14 th February 2019, Great Western Railway (GWR)
6.	C160 Rolling Stock GW ATP Investigation, C160-MMD-R1-RGN-CR001-50115, Crossrail Limited