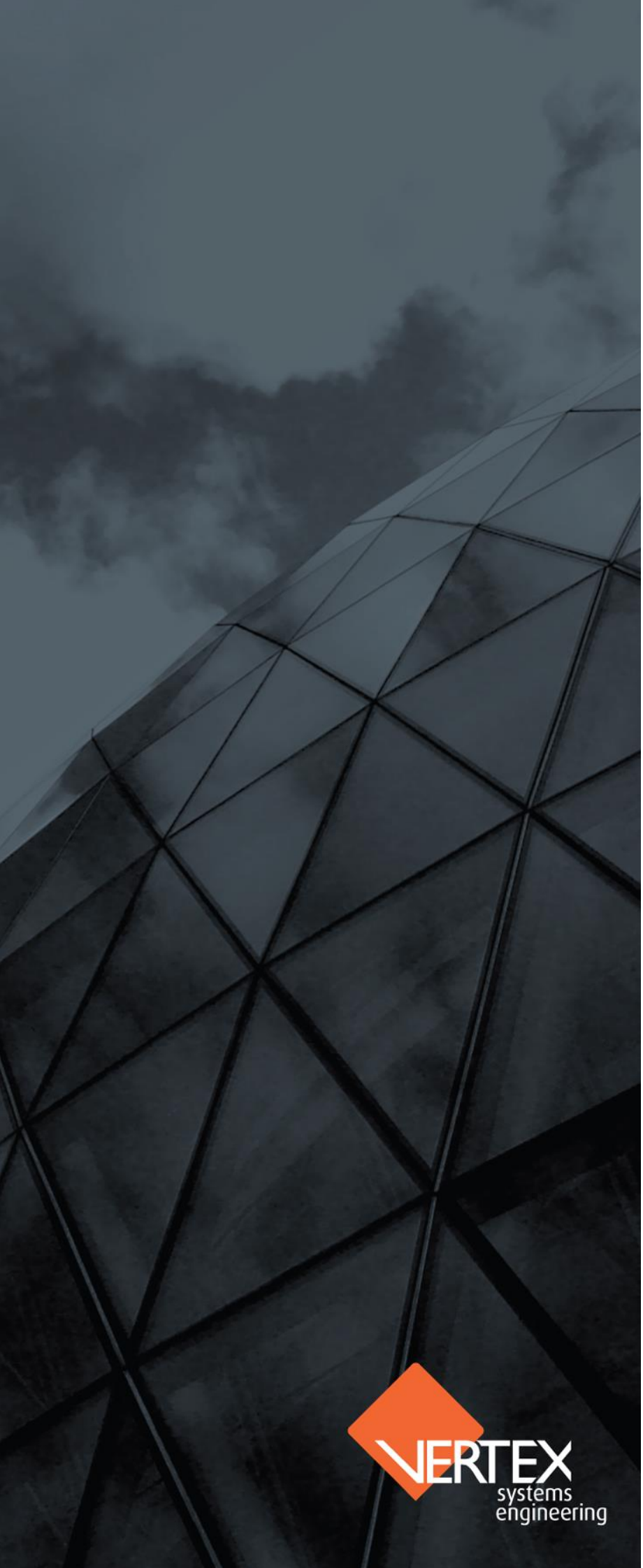

A Report for
Network Rail
from
Vertex Systems Engineering

Version 3.5
2nd April 2015

Crossrail ETCS
GRIP 1-3 Options Analysis

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AMENDMENT HISTORY		
Version	Sections	Amendment Details
1.0	All	First Issue to Network Rail for page turn review
2.0	All	Updated to Client Comments following Page Turn exercise
2.1	All	Updated following review by Client
3.1	Appendix E	Minor update to summary table
3.2	Section 6.1	Updated to reflect identification and consideration of Option 16: Provide over-speed functionality for Crossrail trains using simplified ETCS plus selected TPWS option for SPAD risk
3.3	Section 1.5	Updated to reflect FGW TURBO 165 Rolling Stock Class is not currently fitted with the GW-ATP Train Protection System
3.4	Section 1.5, Options 10 and 14	Future rolling stock highlighted in bold in Section 1.5. Updated Options 10 and 14 disadvantages sections following review by Client.
3.5	Section 3.11, 3.15	Disadvantages amended to show potential for delays to wider Crossrail programme should Class 345 operations be delayed

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1 Introduction

1.1 Purpose

The purpose of this report is to analyse the options available to Network Rail if ETCS L2 is not available for Class 345 Crossrail passenger service on the GWML from 0m (existing Paddington Station) to Signals SN321, SN323, SN325 on the Airport Lines in April 2018.

Date	Anticipated Status
Prior to April 2017	Crossrail signalling works on the GWML (as per Scheme Plans Ref 5) complete.
April 2017	ETCS L2 provided for non-passenger service. To be used for integration testing of Class 345.
April 2018	ETCS L2 Passenger Operation with Class 345 Paddington to Heathrow Airport (4 tph).
December 2018	Latest fall-back date for provision of ETCS L2 from 0m to 12m30ch for Class 345 passenger service.

Table 1 Signalling Delivery Programme

A scheme plan extract found in Figure 1 shows the area, including SN321, SN323, SN325.

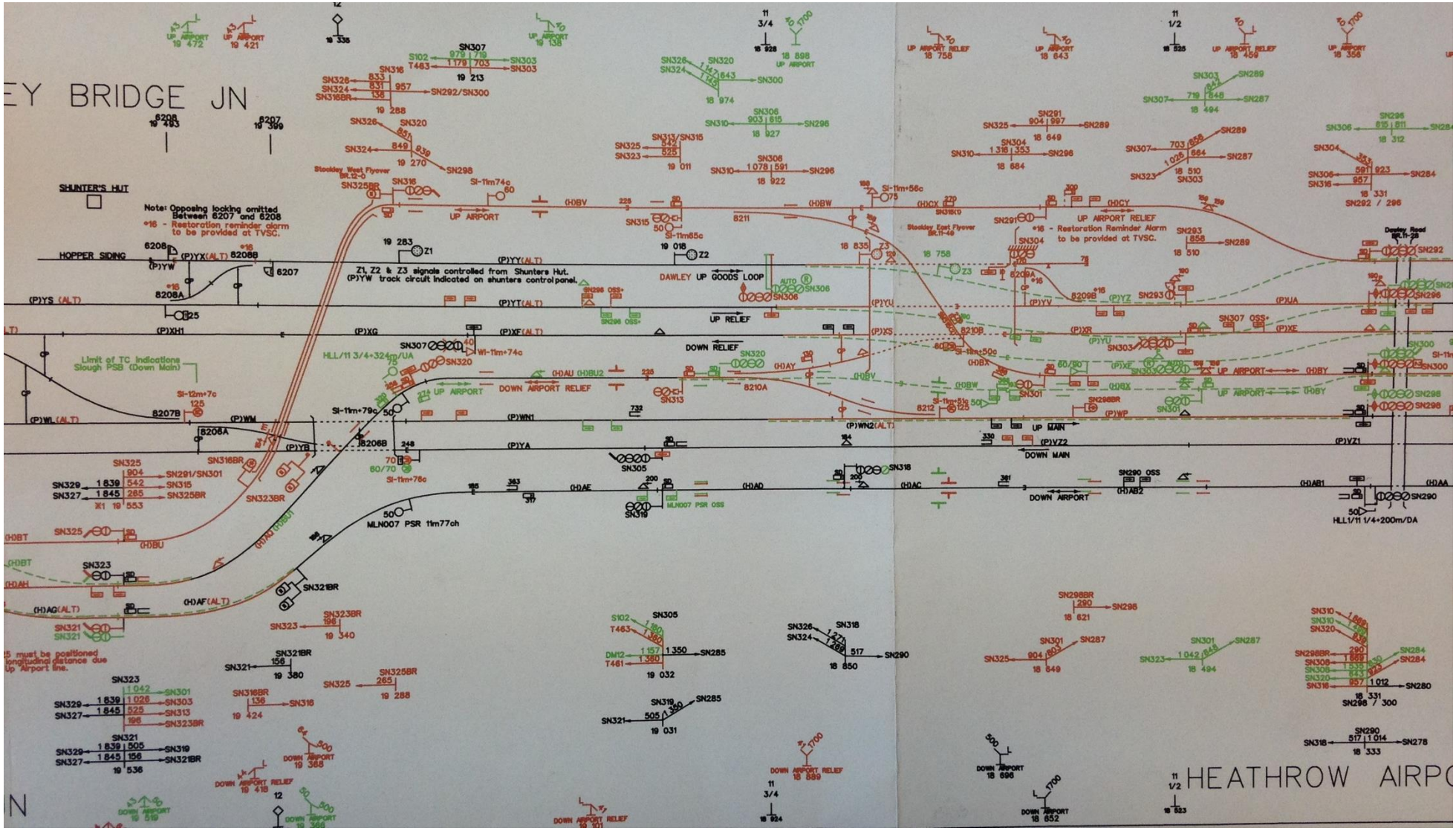


Figure 1: Scheme Plan Extract (Ref 5) of Airport Lines following Crossrail enabling works

1.2 Brief Description of Project and Background

The Railway Safety Regulations of 1999 prohibit the operation of a train on a railway unless a train protection system is in service. Crossrail is currently programmed to be running Class 345 trains (4 tph) from the existing Paddington Station to Heathrow Airport from April 2018.

The train protection system for Crossrail trains in the area in question was anticipated to be ETCS Level 2 from April 2018, but this may be unavailable on the portion of route from 0m to Signals SN321, SN323, SN325 on the Airport Lines until December 2018. ETCS Level 2 Operations on the portion of line from SN321, SN323, SN325 (HEX infrastructure) to Heathrow Airport are being provided by a separate project and will be available for passenger service operations by April 2018.

Should ETCS not be available for Crossrail passenger services, Crossrail Class 345 trains will be reliant on the “legacy” national systems in place, as detailed in Section 1.3. Crossrail trains have not been procured with GW-ATP functionality and therefore will have reduced safety relative to the existing GW-ATP stock.

According to the ORR (Ref 1), any exemption from the Regulations has to include a case study backed up by sufficient evidence.

A “train protection system” as defined by the letter from ORR has two meanings:

Firstly, “where it is reasonably practicable to install it, 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 the journey”.

Secondly, “where it is not reasonably practicable to install such equipment, it means equipment installed at specific locations which causes the brakes of the train to apply automatically in specified circumstances”.

1.3 Current Signalling System

There is currently a mixture of train protection mechanisms along this route, with a central control point at Thames Valley Signalling Centre at Didcot; see Table 2 for an overview of this mix.

Area	Lines	Current Control System	Current Interlocking	Current TP Systems
Paddington to Stockley Bridge Junction	All	IECC Scaleable	Smartlock	AWS/TPWS & GW-ATP
Stockley Bridge Junction to Heathrow Airport	Airport Lines Only	IECC Scaleable	Smartlock	AWS & GW-ATP

Table 2: Current Signalling Systems

1.4 Future Signalling System

Table 3 shows the planned status of the GWML and HEX infrastructure in April 2018.

Area	Lines	Future Control System	Future Interlocking	Future Infrastructure TP Systems
Paddington to Stockley Bridge Junction	All	IECC Scaleable	Smartlock	AWS/TPWS, GW-ATP & ETCS L2
Stockley Bridge Junction to SN321, SN323, SN325	Airport Lines Only	IECC Scaleable	Smartlock	GW-ATP, AWS & ETCS L2 (ETCS provided as part of Western ETCS project)
SN321, SN323, SN325 to Heathrow Airport	Airport Lines Only	IECC Scaleable	Smartlock	GW-ATP, AWS & ETCS L2 (ETCS provided by other projects)

Table 3: Future Signalling Systems

1.5 Rolling Stock Types (0m to 12m 30ch)

Table 4 shows the mix of rolling stock using the GWML.

Rolling Stock Class	TOC / FOC	Train Protection System Aboard
345	**Crossrail**	**CBTC, ETCS & AWS/TPWS**
360	Heathrow Connect	GW-ATP & AWS/TPWS
TURBO 166	FGW	AWS/TPWS
43 (HST)	FGW	GW-ATP & AWS/TPWS
180	FGW	GW-ATP & AWS/TPWS
TURBO 165	FGW	AWS/TPWS
332	Heathrow Express	GW-ATP & AWS
800/801	**IEP ToC**	**GW-ATP (As per tender requirements), ETCS & AWS/TPWS**

Rolling Stock Class	TOC / FOC	Train Protection System Aboard
Multiple	Multiple	TPWS/AWS

Table 4: Rolling Stock Types. NOTE: Bold text means the stock is not yet in service, but is on order.

2 Methodology

The following sections describe the analysis rationale.

2.1 GSN

Goal Structuring Notation (GSN) is a graphical notation for presenting the structure of engineering arguments. It can be used to present any situation where one wishes to make a claim and where the support for that claim will be based upon evidence and argument.

The GSN diagram assists with the demonstration or clarification of how a set of evidence items may be combined together and argued to demonstrate the top claim.

Before the application of the GSN process on this Report, an internal assessment was conducted by the Vertex team and the following outputs were realised:

- Determining the Assignment Goal
- The options available; Justifications and contents
- Detailed options analysis using established criteria
- Analysing arguments raised for and against
- Analysing evidences for and against
- Solution

In Appendix A, a single option is demonstrated (Enhanced TPWS with Fault Reporting). The criteria are generic to all options.

The diagram shows the logical link from questions (criteria) on safety issues, cost, reliability and evidences analysed, incorporating the criteria supplied in the original remit.

2.2 Criteria for High Level Option Analysis

The assessment took each of the options in turn and considered them with respect to the following criteria:

- Costs
  - Design and Construction Cost
  - Future maintenance costs
- Lifespan

- Achievable in Time/ outline programme
- Advantages
- Disadvantages
- Safety Risk
- Introduces Safety Risk (relative to GW-ATP)
- Staff risk e.g. from line-side working
- Degraded Mode Operations
- Signalling System Design Impact
- Compliant with Standards
- Approved Technology
- Impact to Parties
- Requires ORR Exemption to Rail Safety Regs 1999

2.3 System Definition Applied

With request from the client to address this issue by adopting the CSM principles, this report has been put together following these principles as stipulated by the ORR on "the guidance on the application of common safety method on risk evaluation and assessment".

According to this regulation, a preliminary system definition is in effect "an analysis of what is being changed and a preliminary risk assessment of that change".

This report shall attempt to undertake this preliminary assessment by addressing the following issues to the extent necessary to enable the client to be able to make an informed decision on the proposed options.

1) Give a clear statement on what is being changed and the scope of the change.
2) The system objective, e.g. intended purpose.
3) System functions and elements, where relevant (including e.g. human, technical and operational elements).
4) System boundary including other interacting systems.
5) Physical and functional interfaces.

2.4 Options Identification

An initial set of options (1-4 in Table 7) was identified by the NR client team. A further internal assessment was conducted by the Vertex team to identify other potential options based on physical changes to the railway infrastructure, operations and rolling stock.

Following the conclusion of the options selection workshop the chosen option(s) will be subject to further development including a detailed systems definition. To support the optional analysis an initial comparative analysis of GW-ATP, TPWS and TPWS enhancement is provided in Appendix B.

2.5 Programme Timeline

Stage	Details	Date
1)	Draft Report submitted to NR	15/08/2014
2)	Page Turn-Over Exercise	20/08/2014
3)	Report Updated and Re-issued to NR	26/08/2014
4)	NR Stage Gate Review	28/08/2014
5)	Comments Received on Report from NR Panel	08/09/2014
6)	Option Selection Workshop	15/09/2014
7)	Production of Hazard Log	25/09/2014

Table 5 Programme Timeline

2.6 Assumptions

The following has been assumed:

No	Assumption	Options Affected
1)	Crossrail Class 345 trains will have TPWS and AWS functionality via ETCS Level NTC.	0,1,2,3,4,5,6,9,11,12,15
2)	Crossrail drivers are competent in the use of TPWS/AWS “legacy” systems from April 2018.	0,1,2,3,4,5,6,9,11,12,15
3)	Crossrail drivers will have adequate route-knowledge of the GWML, in excess of that required for the currently proposed cab-signalled ETCS operations (e.g. speed limits).	0,1,2,3,4,5,6,9,11,12,15
4)	GSM-R voice communications will be available from April 2018	All, where rolling stock Class uses GSM-R voice communications

No	Assumption	Options Affected
5)	GWML ETCS shall be provided by December 2018 and that Crossrail operations are required from April 2018 (4 tph Paddington to Heathrow).	All
6)	No operations (other than 4 tph Class 345 Crossrail between Paddington and Heathrow airport) with non-GW-ATP stock are planned prior to the introduction of ETCS in December 2018.	All
7)	IEP Class 800 rolling stock has infrastructure compatibility for entire current HEX route.	13
8)	IEP Class 800 rolling stock can transition from GW-ATP to ETCS L2 signalling	13
9)	Provision of ETCS on HEX infrastructure will not result in the removal of existing GW-ATP/AWS infrastructure.	10, 13
10)	Class 345 rolling stock can transition from ETCS Level NTC (or Level 1) to Level 2 operations and vice-versa.	0,1,2,3,4,5,6,9,10,11,12,15
11)	Transitional balises, signage etc. will be required at the Transition point between Level NTC and Level 2 (and vice-versa). These transitional arrangements would need to be removed prior to commencement of ETCS Level 2 operations.	0,1,2,3,4,5,6,9,11,12,13,15
12)	Use of Level NTC operations by Crossrail would be discontinued in favour of Level 2 as soon as functionality is available.	0,1,2,3,4,5,6,9,11,12,13,15
13)	Class 345 cab is suitable for double-crewing.	12

Table 6 Assumptions

3 Outputs: Summary of Options

The following sections details, for each option, an analysis against the criteria contained in Section 2.2 together with an initial system definition.

The table below summarises the options identified following the initial assessments by the Vertex team.

Option No	Option Description	Section In Report
0)	Option 0 - Do Nothing - Run Crossrail Operations in Level NTC, with no further infrastructure changes other than those currently planned	3.1
1)	Option 1 - Standard TPWS Implementation from 0m to 12m30ch (including fly-over). TPWS integrated into control system with fault reporting	3.2
2)	Option 2: As Option 1 plus compliance to TI022 (integrated into control system with fault reporting)	3.3
3)	Option 3: As Option 2 plus the addition of TPWS on all auto signals (integrated into control system with fault reporting)	3.4
4)	Option 4: Enhanced TPWS as per SDG report for all signals (integrated into control system with fault reporting)	3.5
5)	Option 5: As Option 4 with enhanced TPWS on PSRs, MAR, MAY (integrated into control system with fault reporting)	3.6
6)	Option 6: As Option 5 but no fault reporting/integration into control system for additional TPWS that are not being provided by Crossrail scheme ("bolt-on" TPWS)	3.7
7)	Option 7: Fit GW-ATP to Crossrail Class 345 Rolling Stock	3.8
8)	Option 8: Fit ETCS Level 1	3.9
9)	Option 9: Alter track layout such that Crossrail Operations are Physically Isolated from GWML	3.10
10)	Option 10: Utilise existing GW-ATP stock (e.g. HEX/Heathrow Connect) for additional Paddington to Heathrow shuttle until ETCS Level 2 provided	3.11
11)	Option 11: Separate Class 345 Trains by Time	3.12
12)	Option 12: Second Driver on the Footplate of Class 345	3.13
13)	Option 13: Utilise Available IEP Rolling Stock.	3.14
14)	Option 14: Delay Running 4 tph Crossrail Service until ETCS Level 2 is in Operational Use	3.15
15)	Option 15 - As Per Option 0 but with Minimum Transition Infrastructure to ETCS L2 at SN321/SN323/SN325 to enable ETCS L2 Operations	3.16

Table 7 Options Summary

3.1 Option 0 - Do Nothing - Run Crossrail Operations in Level NTC, with no further infrastructure changes other than those currently planned

3.1.1 System Definition

Infrastructure to be altered only as currently planned by Crossrail, as per Scheme Plans (Ref. 5). This provides 'classic' TPWS functionality, but not on all signals, in line with current TPWS design standards i.e. TPWS protecting junctions/convergences only (Ref 4) (Ref 9).

Crossrail Scheme works do not include the full fitment of TPWS on the Airport Lines in line with Standards (see Table 9 for details on which signals are not fitted).

Rolling stock to be 4 tph Crossrail Class 345 with 2 tph Heathrow Connect withdrawn. No alterations to FGW or freight operations.

Class 345 rolling stock would use TPWS/AWS in ETCS Level NTC from Paddington Station throughout whole journey to Heathrow Airport and back.

Should ETCS Level 2 Operation be desired on HEX infrastructure from SN321, SN323, SN325 to Heathrow Airport then infrastructure to enable the ETCS Level transition e.g. signage, balises etc. is required: see Option 15.

Heathrow Connect GW-ATP services (2 tph) to be withdrawn.

3.1.2 Analysis

1) Costs

- **Design and Construction Cost**

There are no additional costs over and above those already accounted for by the proposed Crossrail works, since no additional infrastructure is required.

- **Future maintenance costs**

There are no additional maintenance costs over and above those already anticipated as a result of Crossrail works.

2) Lifespan

This Option does not have a lifespan, as such, since no additional equipment is being employed. Transition to ETCS L2 across whole Paddington to Heathrow running would occur prior to December 2018, as soon as functionality is provided on the GWML.

3) Achievable in Time/ outline programme

No alterations to the existing Crossrail programme are required, since no infrastructure changes are being proposed. This option is the default position and therefore carries no more programme risk that the existing schedule of works being carried out by Crossrail.

4) Advantages

This option incurs no additional expense in terms of rolling stock or infrastructure design or installation, provided that a derogation is sought against fitment of TPWS on the Heathrow Branch west of Stockley Bridge Junction. There is also no impact to on-going maintenance costs.

There is no additional exposure of staff to the risks of lineside working in order to install or maintain equipment.

The programme of Crossrail works on the GWML is already well understood and planned by that Project and therefore this Option represents the path of least resistance i.e. carry on with what is already planned with no changes.

No contractual (ToC) negotiations are needed, since Class 345 trains are available to Crossrail ToC and the Heathrow Connect stock is released for use elsewhere as anticipated should ETCS functionality be delivered on the GWML from April 2018.

Any delay to the delivery of ETCS on HEX would have no impact to Class 345 operations.

5) Disadvantages

Class 345 operations were planned to be ETCS-based (cab signalling) from Paddington to Heathrow from the outset in April 2018.

Use of TPWS/AWS as proposed by this option may require alterations to driver training, since route knowledge becomes more critical when line-side signalling is utilised compared to cab signalling.

The withdrawal of 2 tph GW-ATP (Heathrow Connect) and their replacement with 4 tph non-GW-ATP (Class 345) introduces a safety risk to the route due to the increased risk of SPADs.

Class 345 stock must be configured and certified to run in Level NTC to be able to utilise the legacy national systems (AWS/TPWS) as proposed in this option. This adds a constraint onto Crossrail, since Level NTC operations would not otherwise have been required this early in Crossrail operations.

A derogation would be required for non-fitment of TPWS at the signals listed in Table 9, along with additional signals protecting junctions/convergences on the Heathrow branch (T5/T4 junction, Ref. 12).

6) Safety Risk

The replacement of Heathrow Connect (2 tph) GW-ATP stock for 4 tph non-GW-ATP Class 345 Crossrail stock introduces a safety risk to operations from Paddington. Current standards as applied by Crossrail do not require TPWS to be fitted at every signal, and therefore there is an increased risk of SPAD at signals that are not fitted with TPWS compared to GW-ATP operations. A list of signals together with the calculated TPWS effectiveness for the installations detailed in Crossrail scheme plans (Ref 5) for Class 345 stock is found in Appendix D and is summarised in Table 8. The calculations are based on Class 345 characteristics of max. speed 90 mph and 12% g braking performance performed using the SAT TPWS Effectiveness Calculator tool (Ref 7).

An analysis of the overall TPWS effectiveness for all traffic on the route with existing TPWS equipment has been conducted in Ref. 2).

Class 345 TPWS Effectiveness	No. of Signals (total= 168[1])
100%	94
>98% but <100%	12
>0% but <98%	6
0%	56

Table 8 TPWS Effectiveness (pre enhancement)

[1] Total of 168 signals is from 0mp to SN321, SN323, SN325 and does not include signals on the Heathrow Branch

Due to the nature of TPWS deployment, the majority of SPAD risk is concentrated onto rear-end collisions, with the exception of the signals listed in Table 9, where a risk of collision at a junction exists.

HEX infrastructure would require TPWS installation on signals as required by GE/RT8075 (Ref 4). Currently, HEX infrastructure does not utilise TPWS resulting in an existing derogation for TPWS usage (Ref. 79) on HEX, see also Section 6.3.4 of Ref. 9). HEX infrastructure has standard AWS deployment (Ref. 12). The signals requiring TPWS fitment on HEX infrastructure are in addition to those contained within Table 8.

The risk of SPAD is influenced by many factors. Since Crossrail ToC is a new organisation, no information will be available as to the effectiveness of their driver training and therefore how their operations will compare with other ToC's SPAD rates.

Crossrail drivers are currently expecting to be using ETCS cab-based signalling and therefore Crossrail driver training may not currently incorporate sufficient route-knowledge to enable operations by line-side signal control.

In addition to SPAD risk, substitution of non-GW-ATP operations also marginally increases derailment risks on approach to MAY-FA signals should the lower speed route be set. This is because GW-ATP stock receives in-cab speed information about MAY-FA junction approach speeds which is absent in stock using TPWS/AWS.

GW-ATP provides indication and speed supervision to the driver on PSRs/TSRs and so there is an increase in risk in this Option in terms of exceeding these restrictions when in Level NTC.

There is no additional risk to staff in terms of line-side working for this option, since no additional installations or maintenance are required (subject to derogation against TPWS fitment standards) over that which is currently planned by Crossrail.

7) Degraded Mode Operations

No changes would be required to existing processes for dealing with failed signalling equipment, either on-board trains (failed TPWS receiver) or on track (failed TPWS unit). TPWS lineside equipment installed as per the Interface Requirements (Ref. 8) has fault reporting functionality and also will hold the preceding signal at red should a failure be detected.

8) Signalling System Design Impact

None - no alterations proposed to the current Scheme Plans.

9) Compliant with Standards

The implementation of TPWS is from 0mp to Stockley Bridge Junction (on Airport lines) is in-line with current Standards (although compliance to TI022 will need to be confirmed with Crossrail designers). The additional TPWS units required to meet standards on the Airport Lines up to SN321, 323, 325 are described in Table 9 and without these this Option is not compliant with TPWS standards.

AWS is present throughout the route, including signals on HEX infrastructure.

10) Approved Technology

No additional equipment is proposed in this option.

11) Impact to Parties

No impact to infrastructure design, installation or on-going maintenance unless additional TPWS units are installed to meet Standards i.e. no derogation sought.

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling arrangement (i.e. no longer ETCS cab-based signalling).

The increased risk of SPAD of Crossrail trains relative to GW-ATP trains will have an impact on passenger safety, both on Crossrail trains and also to other Operators who may be in collision with a Crossrail train should it SPAD.

12) Requires ORR Exemption to Rail Safety Regs 1999

This Option would be likely to require an exemption, based upon the interpretation of the letter sent by ORR to Network Rail. The reason for this is that ORR appear to view either the use of ETCS or GW-ATP as being 'reasonably practicable', especially given that GW-ATP infrastructure is already installed across the whole Paddington to Heathrow route and that funding has been provided to enable ETCS operation.

13) Justification for Discontinuation of Analysis

This Option has been analysed, however it is unlikely to be acceptable to ORR since it introduces Safety Risk from non-GW-ATP operations. Any infrastructure which is not compliant with standard TPWS design rules will also need to be remedied or a derogation sought and therefore extra costs will be incurred.

3.2 Option 1 - Standard TPWS Implementation from 0m to 12m30ch (including fly-over). TPWS integrated into control system with fault reporting

3.2.1 System Definition

Rolling stock to be 4 x Crossrail Class 345 per hour with 2 tph Heathrow Connect withdrawn. No alterations to FGW or freight operations.

Class 345 to use ETCS Level NTC from Paddington to SN321, 323, 325 and then to transition to ETCS L2 to Heathrow Airport (and vice-versa).

Infrastructure to be TPWS implementation in line with existing design standards prior to the ETCS transition point. This would require the following TPWS installations (Ref. 10) over and above the works being carried out by Crossrail:

Type	Signals
TPWS TSS	SN316, SN325, SN326, SN323, SN324, SN321
TPWS OSS	SN316, SN325, SN326, SN323, SN324, SN321

Table 9 Option 1 Additional TPWS Requirements

3.2.2 Analysis

1) Costs

- **Design and Construction Cost**

The design/construction costs for this Option have been estimated as £2,572,378.00 (ref. 10) for the TPWS components.

Additional costs would be incurred for the Level NTC to Level 2 (and vice-versa) transitional equipment- balises and signage. This additional equipment does not represent a significant increase on the £2.6M sum above.

- **Future Maintenance Costs**

The introduction of additional line-side infrastructure will incur an on-going maintenance cost. However, since TPWS grills, ETCS balises and signage do not require extensive maintenance, adjustment or servicing, this cost is not substantial given the limited numbers being deployed.

The maintenance costs for the TPWS elements would continue, even once ETCS Level 2 running is commenced on the GWML. Level NTC to Level 2 transitional equipment could be

removed upon ETCS Level 2 running across the entire Paddington to Heathrow route prior to December 2018 and therefore are a maintenance cost only for the maximum period of April-December 2018.

2) Lifespan

The Lifespan of this option is the design life of the alterations made for Crossrail, which are likely to be in the region of 25 years minimum. Transition to ETCS L2 running across the whole Paddington to Heathrow route would occur prior to December 2018, as soon as functionality is provided.

3) Achievable in Time/ outline programme

This Option would require integration of the proposed signalling changes into the Crossrail programme of works. Given the limited number of alterations required, this could be easily achieved in the timescales available, provided the required changes (especially to control system data) are agreed to by Crossrail prior to their procurement.

4) Advantages

The use of ETCS from SN321, SN323, SN325 on the Airport Lines onwards allows that technology to be utilised for the non-GWML portion of the journey to Heathrow.

No contractual (ToC) negotiations are needed, since Class 345 trains are available to Crossrail ToC and the Heathrow Connect stock is released for use elsewhere as anticipated should ETCS functionality be delivered on the GWML from April 2018.

5) Disadvantages

The requirement for additional TPWS units to meet Standards creates a substantial cost. These units would only add value to Class 345 operations until the migration to whole-route ETCS Level 2 running prior to December 2018, when they would become defunct. Removing the units would be cost prohibitive since they are integrated into the interlocking/control system and therefore maintenance costs would remain long after the end of Level NTC running.

Any alterations to the current Crossrail scheme will require liaison and agreement with the Crossrail team and brings an element of programme risk.

Not all of the safety risk from non-GW-ATP/ETCS operation is mitigated, since in this option TPWS is not fitted to all signals.

The Level NTC to Level 2 (and vice-versa) transitional equipment will need to be removed when the entire route becomes ETCS Level 2 prior to December 2018.

6) Safety Risk

The replacement of Heathrow Connect (2 tph) GW-ATP stock for 4 tph non-GW-ATP Class 345 Crossrail stock introduces a safety risk to operations from Paddington. Current standards as applied by Crossrail do not require TPWS to be fitted at every signal.

This option removes SPAD risk from junction collisions, but does not eliminate risk from rear-end collisions since not all signals are required to be fitted with TPWS.

The risk of SPAD is influenced by many factors. Since Crossrail ToC is a new organisation, no information will be available as to the effectiveness of their driver training and therefore how their operations will compare with other ToC's SPAD rates.

Crossrail drivers are currently expecting to be using ETCS cab-based signalling and therefore Crossrail driver training may not currently incorporate sufficient route-knowledge to enable operations by line-side signal control.

In addition to SPAD risk, substitution of non-GW-ATP operations also marginally increases derailment risks on approach to MAY-FA signals should the lower speed route be set. This is because GW-ATP stock receives in-cab speed information about MAY-FA junction approach speeds which is absent in stock using TPWS/AWS.

GW-ATP provides indication and speed supervision to the driver on PSRs/TSRs and so there is an increase in risk in this Option in terms of exceeding these restrictions when in Level NTC.

There additional risk to staff in terms of line-side working for this option, since additional installations and maintenance are required over that which is currently planned by Crossrail. This includes both additional TPWS units and the transitional equipment at the newly created ETCS Level NTC to ETCS Level 2 boundary.

7) Degraded Mode Operations

No changes would be required to existing processes (up to transition onto ETCS L2 at SN321, 323, 325) for dealing with failed signalling equipment, either on-board trains (failed TPWS receiver) or on track (failed TPWS unit). TPWS lineside equipment installed as per the Interface

Requirements (Ref. 8) has fault reporting functionality and also will hold the preceding signal at red should a failure be detected.

From SN321, 323, 325 to Heathrow Airport, the rolling stock would be in ETCS Level 2 and would therefore follow ETCS degraded mode operations should a fault occur.

8) Signalling System Design Impact

This Option requires additional TPWS installations in order to meet current TPWS design Standards (Ref. 4) (Ref. 9). The additional infrastructure is not currently planned for delivery by Crossrail due to the existing derogation for HEX and therefore would require the signalling scheme plans to be re-worked in light of the proposed changes.

The addition of TPWS units will require inputs/outputs into the interlocking and also alterations to the control system. The capacity of the interlocking to accept the required number of inputs/outputs is a potential constraint on any addition of TPWS.

9) Compliant with Standards

Yes- the proposed TPWS deployment in this option is compliant with Standards (Ref. 4) (Ref.9), excepting any existing TPWS design carried out by Crossrail that does not meet TI022. A previous study has identified 5 signals that do not meet TI022 requirements (Ref. 2) and the design of these would need to be amended to meet Standards- see Option 2.

Fully integrating the additional TPWS into the signalling system and control system (i.e. fault reporting supplied to signallers and signal at rear replaced to red should a fault occur) is compliant with the TPWS Interface Design Requirements (Ref. 8).

10) Approved Technology

Yes- no non-standard technology is proposed. ETCS balises have been approved as part of the Cambrian ETCS deployment.

11) Impact to Parties

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling arrangement (i.e. no longer wholly ETCS cab-based signalling) and requirements for a transition from Level NTC to Level 2 ETCS (and vice-versa).

The increased risk of SPAD of Crossrail trains relative to GW-ATP trains will have an impact on passenger safety, both on Crossrail trains and also to other Operators who may be in collision with a Crossrail train should it SPAD. In this Option, SPADs by Class 345 would lead to read-end collisions only.

The amendment to infrastructure will require liaison with Crossrail to amend their signalling design to the new requirements.

12) Requires ORR Exemption to Rail Safety Regs 1999

This Option is compliant with existing Standards for train protection. However, the level of protection supplied it still less than GW-ATP operations. ORR may reject this Option as being compliant to the Regulations since ORR appear to view either the use of ETCS or GW-ATP as being 'reasonably practicable', especially given that GW-ATP infrastructure is already installed across the whole Paddington to Heathrow route and that funding has been provided to enable ETCS operation (Ref. 1).

13) Justification for Discontinuation of Analysis

N/A

3.3 Option 2: As Option 1 plus compliance to TI022 (integrated into control system with fault reporting)

3.3.1 System Definition

As per Option 1, but with compliance to TI022 for 110mph trains with 12%g braking for all TPWS fitted signals. This involves the following additional works (Ref. 10) to those already listed for Option 1:

Type	Signals
TPWS OSS (new)	SN280, SN270, SN204,
TPWS OSS (move existing)	SN284, SN280, SN270 (2x), SN204 (2x), SN280, SN270 (2x)

Table 10 Option 2 additional TPWS requirements

3.3.2 Analysis

1) Costs

- **Design and Construction Cost**

The design/construction costs for this Option have been estimated as £3,422,458.00 (Ref. 10).

Additional costs would be incurred for the Level NTC to Level 2 (and vice-versa) transitional equipment- balises and signage. This additional equipment does not represent a significant increase on the £3.4M sum above.

- **Future maintenance costs**

The introduction of additional line-side infrastructure will incur an on-going maintenance cost. However, since TPWS grills, ETCS balises and signage do not require extensive maintenance, adjustment or servicing, this cost is not substantial given the limited numbers being deployed.

The maintenance costs for the TPWS elements would continue, even once ETCS Level 2 running is commenced on the GWML. Level NTC to Level 2 transitional equipment could be removed upon ETCS Level 2 running across the entire Paddington to Heathrow route prior to December 2018 and therefore are a maintenance cost only for the maximum period of April-December 2018.

2) Lifespan

The Lifespan of this option is the design life of TPWS equipment/interlocking/control system, which are likely to be in the region of 25 years minimum. Transition to ETCS L2 running across whole Paddington to Heathrow route would occur prior to December 2018, as soon as functionality is provided.

3) Achievable in Time/ outline programme

This Option would require integration of the proposed signalling changes into the Crossrail programme of works. Given the limited number of alterations required, this could be easily achieved in the timescales available, provided the required changes (especially to control system data) are agreed to by Crossrail prior to their procurement.

4) Advantages

Compliance to TI022 may bring safety improvement for all non-GW-ATP rolling stock using TPWS as their train protection system. This includes stock other than the Class 345.

5) Disadvantages

The requirement for additional TPWS units to meet design standards creates a substantial cost. These units would only add value to Class 345 operations until the migration to whole-route ETCS Level 2 running prior to December 2018, when they would become defunct due to the usage of ETCS Level 2. Removing units after December 2018 would be cost prohibitive since they are integrated into the interlocking/control system and therefore maintenance costs would remain long after the end of Level NTC running.

Any alterations to the current Crossrail scheme will require liaison and agreement with the Crossrail team and brings an element of programme risk.

Not all of the safety risk from non-GW-ATP/ETCS operation is mitigated, since in this option TPWS is not fitted to all signals.

The Level NTC to Level 2 (and vice-versa) transitional equipment will need to be removed when the entire route becomes ETCS Level 2 prior to December 2018.

6) Safety Risk

The replacement of Heathrow Connect (2 tph) GW-ATP stock for 4 tph non-GW-ATP Class 345 Crossrail stock introduces a safety risk to operations from Paddington. Current standards as applied by Crossrail do not require TPWS to be fitted at every signal.

This option removes SPAD risk from junction collisions, since TI022 loop positioning renders TPWS fully effective for Class 345 (12% g braking) but does not eliminate risk from rear-end collisions since not all signals are required to be fitted with TPWS.

The risk of SPAD is influenced by many factors. Since Crossrail ToC is a new organisation, no information will be available as to the effectiveness of their driver training and therefore how their operations will compare with other ToC's SPAD rates.

Crossrail drivers are currently expecting to be using ETCS cab-based signalling and therefore Crossrail driver training may not currently incorporate sufficient route-knowledge to enable operations by line-side signal control.

In addition to SPAD risk, substitution of non-GW-ATP operations also marginally increases derailment risks on approach to MAY-FA signals should the lower speed route be set. This is because GW-ATP stock receives in-cab speed information about MAY-FA junction approach speeds which is absent in stock using TPWS/AWS.

GW-ATP provides indication and speed supervision to the driver on PSRs/TSRs and so there is an increase in risk in this Option in terms of exceeding these restrictions when in Level NTC.

There additional risk to staff in terms of line-side working for this option, since additional installations and maintenance are required over that which is currently planned by Crossrail. This includes both additional TPWS units and the transitional equipment at the newly created ETCS Level NTC to ETCS Level 2 boundary.

7) Degraded Mode Operation

No changes would be required to existing processes (up to transition to ETCS L2 at SN321, 323, 325) for dealing with failed signalling equipment, either on-board trains (failed TPWS receiver) or on track (failed TPWS unit). TPWS lineside equipment installed as per the Interface Requirements (Ref. 8) requires fault reporting functionality and also will hold the preceding signal at red should a failure be detected.

From SN321, 323, 325 to Heathrow Airport, the rolling stock would be in ETCS Level 2 and would therefore follow ETCS degraded mode operations should a fault occur.

8) Signalling System Design Impact

This Option requires additional TPWS installations in order to meet current TPWS design Standards (Ref. 4) (Ref. 9). The additional infrastructure is not currently planned for delivery by Crossrail due to the existing derogation for HEX and Crossrail design being completed prior to the latest issue of TI022. This option requires the signalling scheme plans to be re-worked in light of the proposed changes.

The addition of TPWS units will require inputs/outputs into the interlocking and also alterations to the control system. The capacity of the interlocking to accept the required number of inputs/outputs is a potential constraint on any addition of TPWS.

9) Compliant with Standards

Yes- this Option is compliant with TPWS standards (Ref. 9) (Ref. 8) (Ref. 4).

10) Approved Technology

Yes- no non-standard technology is proposed. ETCS balises have been approved as part of the Cambrian ETCS deployment.

11) Impact to Parties

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling arrangement (i.e. no longer wholly ETCS cab-based signalling) and requirements for a transition from Level NTC to Level 2 ETCS (and vice-versa).

The increased risk of SPAD of Crossrail trains relative to GW-ATP trains will have an impact on passenger safety, both on Crossrail trains and also to other Operators who may be in collision with a Crossrail train should it SPAD. In this Option, SPADs by Class 345 would lead to rear-end collisions only.

The amendment to infrastructure will require liaison with Crossrail to amend their signalling design to the new requirements.

12) Requires ORR Exemption to Rail Safety Regs 1999

This Option is compliant with existing Standards for train protection. However, the level of protection supplied is still less than GW-ATP operations. ORR may reject this Option as being compliant to the Regulations since ORR appear to view either the use of ETCS or GW-ATP as being 'reasonably practicable', especially given that GW-ATP infrastructure is already installed across the whole Paddington to Heathrow route and that funding has been provided to enable ETCS operation (Ref. 1).

13) Justification for Discontinuation of Analysis

N/A

3.4 Option 3: As Option 2 plus the addition of TPWS on all auto signals (integrated into control system with fault reporting)

3.4.1 System Definition

As per Option 2, but with the addition of TPWS to all auto signals prior to the ETCS Level transition point at SN321, SN323, SN325. This would require the following TPWS installations:

Type	Signals
TPWS TSS	SN316, 325, 326, 323, 324, 321, 127, 174, 173, 178, 179, 164, 163, 160, 159, 153, 137, 134, 135, 144, 146, 151, 191, 192, 203, 209, 210, 211, 212, 222, 231, 234, 237, 244, 246, 253, 258
TPWS OSS	SN316, 325, 326, 323, 324, 321, 280, 270, 204, 280, 270, 127, 174, 173, 178, 179, 164, 163, 160, 159, 153, 137, 134, 135, 144, 146, 151, 191, 192, 203, 209, 210, 211, 212, 222, 231, 234, 237, 244, 246, 253, 258

Table 11 Option 3 Additional TPWS Equipment Requirement

3.4.2 Analysis

1) Costs

- **Design and Construction Cost**

The design/construction costs for the TPWS elements of this Option have been estimated as £8,319,273.00 (Ref. 10).

Additional costs would be incurred for the Level NTC to Level 2 (and vice-versa) transitional equipment- balises and signage. This additional equipment does not represent a significant increase on the £8.3M sum above.

- **Future maintenance costs**

The number of additional TPWS installations represents a considerable additional expense in terms of on-going maintenance, as well as introducing additional access requirements. This is especially true since upon ETCS running from Paddington to Heathrow prior to December 2018 the additional TPWS equipment could not be easily removed due to its integration into the control system. Therefore approx. 25 years of ongoing maintenance costs for the additional TPWS units are implicit in this option.

ETCS balises and signage for the Level NTC to Level 2 transition do not require extensive maintenance, adjustment or servicing, this cost is not substantial given the limited numbers

being deployed and that they can be removed when full-route ETCS operations commence prior to December 2018.

2) Lifespan

The equipment installed in this Option has a life span in excess of 25 years.

3) Achievable in Time/ outline programme

The number of additional TPWS units required by this Option (approx. 80 no.) represents a considerable additional package of works to those already in planning by Crossrail. These additional works would require considerable reworking of the Crossrail signalling delivery programme and would require additional installation/testing resources.

Given the 2+ year lead time (i.e. alterations not required prior to enter into service prior to April 2018) the Option could be implemented in time. The critical constraining factor is that any required control system data changes are advised to and agreed to by Crossrail prior to their procurement.

4) Advantages

This application of TPWS removes the risk of rear-end collisions resulting from Class 345 SPADs, in addition to removing the risk at junctions/convergences.

Installation of TPWS on all signals may bring a safety improvement for all non-GW-ATP rolling stock using TPWS as their train protection system. This includes stock other than the Class 345 (e.g. FGW Class 166).

The use of ETCS from Heathrow Tunnel onwards allows that technology to be utilised for the non-GWML portion of the journey to Heathrow.

No contractual (ToC) negotiations are needed, since Class 345 trains are available to Crossrail ToC and the Heathrow Connect stock is released for use elsewhere as anticipated should ETCS functionality be delivered on the GWML from April 2018.

5) Disadvantages

The addition of so many TPWS units (~80 number) represents a substantial capital cost to address a situation that is expected to only exist from April 2018 - (latest) December 2018. The

additional units will attract on-going maintenance costs until they can be removed, which may be decades from installation (due to integration into control system).

This Option requires TPWS units to be installed on signals where Standards do not require them to be installed. This could lead to knock-on effects of tripping out trains which are being driven via ATP, should TPWS OSS sensors not tolerate ATP speed profiles.

The number of alterations represents a significant change to the proposed Crossrail works on the GWML and therefore represents a programme risk.

6) Safety Risk

This option removes SPAD risk from junction collisions and rear-end collisions since all signals are required to be fitted with TPWS which will bring Class 345 to a halt before any conflict point (i.e. within the Safe Overrun Distance) with 100% effectiveness.

In addition to SPAD risk, substitution of non-GW-ATP operations also marginally increases derailment risks on approach to MAY-FA signals should the lower speed route be set. This is because GW-ATP stock receives in-cab speed information about MAY-FA junction approach speeds which is absent in stock using TPWS/AWS.

GW-ATP provides indication and speed supervision to the driver on PSRs/TSRs and so there is an increase in risk in this Option in terms of exceeding these restrictions when in Level NTC.

Crossrail drivers are currently expecting to be using ETCS cab-based signalling and therefore Crossrail driver training may not currently incorporate sufficient route-knowledge to enable operations by line-side signal control, which increases risks of derailment due to overspeed.

There additional risk to staff in terms of line-side working for this option, since additional installations and maintenance are required over that which is currently planned by Crossrail. This includes both additional TPWS units and the transitional equipment at the newly created ETCS Level NTC to ETCS Level 2 boundary.

7) Degraded Mode Operation

No changes would be required to existing processes (up to transition onto ETCS L2 at SN321, 323, 325) for dealing with failed signalling equipment, either on-board trains (failed TPWS receiver) or on track (failed TPWS unit). TPWS lineside equipment installed as per the Interface

Requirements (Ref. 8) requires fault reporting functionality and also will hold the preceding signal at red should a failure be detected.

From SN321, 323, 325 to Heathrow Airport, the rolling stock would be in ETCS Level 2 and would therefore follow ETCS degraded mode operations should a fault occur.

8) Signalling System Design Impact

This Option requires additional TPWS installations that exceed the current TPWS design Standards (Ref. 4) (Ref. 9). The additional infrastructure is not currently planned for delivery by Crossrail due to:

- Non-standards mandated TPWS fitments proposed
- The existing derogation against TPWS fitment for HEX
- Crossrail design being completed prior to the latest issue of TI022.

This option requires the signalling scheme plans to be re-worked in light of the proposed changes.

The addition of TPWS units will require inputs/outputs into the interlocking and also alterations to the control system. The capacity of the interlocking to accept the required number of inputs/outputs is a potential constraint on any addition of TPWS.

9) Compliant with Standards

Yes- this Option exceeds the minimum required fitments specified in TPWS standards (Ref. 9) (Ref. 8) (Ref. 4).

10) Approved Technology

Yes- no non-standard technology is proposed. ETCS balises have been approved as part of the Cambrian ETCS deployment.

11) Impact to Parties

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling arrangement (i.e. no longer wholly ETCS cab-based signalling) and requirements for a transition from Level NTC to Level 2 ETCS (and vice-versa).

The increased risk of SPAD of Crossrail trains relative to GW-ATP trains will have an impact on

The amendment to infrastructure will require liaison with Crossrail to amend their signalling design to the new requirements.

Adding TPWS to auto signals may create a risk of tripping rolling stock which is being driven in a manner which is inconsistent with the OSS deployments but which would not have SPADed e.g. ATP stock.

12) Requires ORR Exemption to Rail Safety Regs 1999

This Option provides functionality in excess of TPWS standards and also in compliance with the Regulations since a train protection system is provided on all signals. No exemption would be required from the ORR.

13) Justification for Discontinuation of Analysis

N/A

3.5 Option 4: Enhanced TPWS as per SDG report for all signals (integrated into control system with fault reporting)

3.5.1 System Definition

As per Option 3, but with the TPWS installations designed to stop 12% g 90 mph trains within the overlap rather than Safe Overrun Distance. This replicates part of GW-ATP functionality, in terms of preventing trains from SPADing beyond the relevant signalling section.

The 6-track section of route from Paddington to Ladbroke Grove already has already been designed with this functionality as part of Crossrail and IEP scheme specifications (Ref. 2). Additional equipment on the rest of the line of route to the Level NTC/Level 2 ETCS transition point at SN321, SN323, SN325 is as follows:

Type	Number
New TPWS OSS	73
Move existing TPWS OSS	48

Table 12 Option 4 TPWS Infrastructure Requirements

3.5.2 Analysis

1) Costs

- **Design and Construction Cost**

The design/construction costs for this Option have been estimated as £9,758,210.000 (ref. 10) for the TPWS components.

Additional costs would be incurred for the Level NTC to Level 2 (and vice-versa) transitional equipment- balises and signage. This additional equipment does not represent a significant increase on the £9.8M sum above.

- **Future maintenance costs**

The number of additional TPWS installations represents a considerable additional expense in terms of on-going maintenance, as well as introducing additional access requirements. This is especially true since upon ETCS running from Paddington to Heathrow prior to December 2018 the additional TPWS equipment could not be easily removed. Therefore approx. 25 years of maintenance costs are implicit in this option.

ETCS balises and signage for the Level NTC to Level 2 transition do not require extensive maintenance, adjustment or servicing, this cost is not substantial given the limited numbers being deployed and that they can be removed when full-route ETCS operations commence prior to December 2018.

2) Lifespan

The equipment installed in this Option has a lifespan in excess of 25 years.

3) Achievable in Time/ outline programme

The number of additional TPWS units required by this Option and the movements to existing OSS represents a considerable additional package of works to those already in planning by Crossrail. These additional works would require considerable reworking of the Crossrail signalling delivery programme and would require additional installation/testing resources.

Given the 2+ year lead time (i.e. alterations not required prior to enter into service prior to April 2018) the Option could be implemented in time. The critical constraining factor is that any required control system data changes are advised to and agreed to by Crossrail prior to their procurement.

4) Advantages

The application of TPWS on all signals removes the risk of collisions resulting from SPADs. The enhancement to stop trains in the overlap rather than SOD has minor operational benefits in terms of impact should a SPAD occur.

Installation of TPWS on all signals may bring a safety improvement for all non-GW-ATP rolling stock using TPWS as their train protection system. This includes stock other than the Class 345 (e.g. FGW Class 166).

The use of ETCS from Heathrow Tunnel onwards allows that technology to be utilised for the non-GWML portion of the journey to Heathrow.

No contractual (ToC) negotiations are needed, since Class 345 trains are available to Crossrail ToC and the Heathrow Connect stock is released for use elsewhere as anticipated should ETCS functionality be delivered on the GWML from April 2018.

5) Disadvantages

The additional TPWS units installed creates a substantial cost. These units would only add value to Class 345 operations until the migration to whole-route ETCS Level 2 running prior to December 2018, when they would become defunct due to the usage of ETCS Level 2. Removing TPWS units after December 2018 would be cost prohibitive since they are integrated into the interlocking/control system and therefore maintenance costs would remain long after the end of Level NTC running.

Any alterations to the current Crossrail scheme will require liaison and agreement with the Crossrail team and brings an element of programme risk.

The Level NTC to Level 2 (and vice-versa) transitional equipment will need to be removed when the entire route becomes ETCS Level 2 prior to December 2018.

Adding TPWS to all signals may create a risk of tripping rolling stock which is being driven in a manner which is inconsistent with the OSS deployments but which would not have SPADed e.g. ATP stock.

6) Safety Risk

This Option has the same Safety Risk for Class 345s as Option 3. For Option 3 the TPWS arrangements are such that the Class 345 can be brought to a stop within the SOD as the worst case. For Option 4, the maximum over-run distance is limited to within the overlap.

The enhanced OSS position may have positive safety effects on other non-ATP stock with inferior braking characteristics or higher speeds than the Class 345.

GW-ATP provides indication and speed supervision to the driver on PSRs/TSRs and so there is an increase in risk in this Option in terms of exceeding these restrictions when in Level NTC.

The Option also has Safety Risk to staff required to work lineside in order to install and maintain the proposed equipment.

7) Degraded Mode Operation

No changes would be required to existing processes (up to transition onto ETCS L2 at SN321, 323, 325) for dealing with failed signalling equipment, either on-board trains (failed TPWS receiver) or on track (failed TPWS unit). TPWS lineside equipment installed as per the Interface

Requirements (Ref. 8) requires fault reporting functionality and also will hold the preceding signal at red should a failure be detected.

From SN321, 323, 325 to Heathrow Airport, the rolling stock would be in ETCS Level 2 and would therefore follow ETCS degraded mode operations should a fault occur.

8) Signalling System Design Impact

This Option requires additional TPWS installations that exceed the current TPWS design Standards (Ref. 4) (Ref. 9). The additional infrastructure is not currently planned for delivery by Crossrail due to:

- Non-standards mandated TPWS fitments proposed
- The existing derogation against TPWS fitment for HEX
- Crossrail design being completed prior to the latest issue of TI022.

This option requires the signalling scheme plans to be re-worked in light of the proposed changes.

The addition of TPWS units will require inputs/outputs into the interlocking and also alterations to the control system. The capacity of the interlocking to accept the required number of inputs/outputs is a potential constraint on any addition of TPWS.

9) Compliant with Standards

Yes- this Option exceeds the minimum required fitments specified in TPWS standards (Ref. 9) (Ref. 8) (Ref. 4).

10) Approved Technology

Yes- no non-standard technology is proposed. ETCS balises have been approved as part of the Cambrian ETCS deployment.

11) Impact to Parties

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling arrangement (i.e. no longer wholly ETCS cab-based signalling) and requirements for a transition from Level NTC to Level 2 ETCS (and vice-versa).

The amendment to infrastructure will require liaison with Crossrail to amend their signalling design to the new requirements.

Adding TPWS to auto signals may create a risk of tripping rolling stock which is being driven in a manner which is inconsistent with the OSS deployments but which would not have SPADed e.g. ATP stock.

12) Requires ORR Exemption to Rail Safety Regs 1999

This Option provides functionality in excess of TPWS standards and also in compliance with the Regulations since a train protection system is provided on all signals. No exemption would be required from the ORR.

13) Justification for Discontinuation of Analysis

N/A

3.6 Option 5: As Option 4 with enhanced TPWS on PSRs, MAR, MAY (integrated into control system with fault reporting)

3.6.1 System Definition

As Per Option 4 but with additional OSS units to cover the following speed restriction types:

- Approach to 3 number PSRs as identified in Ref. 2)
- Approach to 7 number MAY-FA signals as identified in Ref. 2)
- Approach to 4 number MAR signals as identified in Ref. 2)

3.6.2 Analysis

1) Costs

- **Design and Construction Cost**

The design/construction costs for this Option have been estimated as £12,370,435.00.

Additional costs would be incurred for the Level NTC to Level 2 (and vice-versa) transitional equipment- balises and signage. This additional equipment does not represent a significant increase on the £12.4M sum above.

- **Future Maintenance Costs**

The number of additional TPWS installations represents a considerable additional expense in terms of on-going maintenance, as well as introducing additional access requirements. This is especially true since upon ETCS running from Paddington to Heathrow prior to December 2018 the additional TPWS equipment could not be easily removed. Therefore approx. 25 years of maintenance costs are implicit in this option.

ETCS balises and signage for the Level NTC to Level 2 transition do not require extensive maintenance, adjustment or servicing, this cost is not substantial given the limited numbers being deployed and that they can be removed when full-route ETCS operations commence prior to December 2018.

2) Lifespan

The equipment installed in this Option has a life span in excess of 25 years.

3) Achievable in Time/ outline programme

The number of additional TPWS units required by this Option and the movements to existing OSS represents a considerable additional package of works to those already in planning by Crossrail. These additional works would require considerable reworking of the Crossrail signalling delivery programme and would require additional installation/testing resources.

Given the 2+ year lead time (i.e. alterations not required prior to enter into service prior to April 2018) the Option could be implemented in time. The critical constraining factor is that any required control system data changes are advised to and agreed to by Crossrail prior to their procurement.

4) Advantages

This Option increases Safety beyond Option 4 levels due to removing risks of overspeed derailments at the speed restriction covered.

The application of TPWS on all signals removes the risk of collisions resulting from SPADs. The enhancement to stop trains in the overlap rather than SOD has minor operational benefits in terms of impact should a SPAD occur.

Installation of TPWS on all signals may bring a safety improvement for all non-GW-ATP rolling stock using TPWS as their train protection system. This includes stock other than the Class 345 (e.g. FGW Class 166).

The use of ETCS from Heathrow Tunnel onwards allows that technology to be utilised for the non-GWML portion of the journey to Heathrow.

No contractual (ToC) negotiations are needed, since Class 345 trains are available to Crossrail ToC and the Heathrow Connect stock is released for use elsewhere as anticipated should ETCS functionality be delivered on the GWML from April 2018.

5) Disadvantages

This Option has a high costs.

Additional OSS proposed for MAY-FA junctions could trip out vehicles travelling on the higher speed route.

Adding TPWS to auto signals may create a risk of tripping rolling stock which is being driven in a manner which is inconsistent with the OSS deployments but which would not have SPADed e.g. ATP stock.

6) Safety Risk

The risk of Class 345 SPADs leading to a conflict are reduced to zero, as per Option 4. This Option also removes the risk of overspeed derailments on approach to MAY-FA/MAR junctions and at permanent speed restrictions. The safety benefit in enforcing such speed restrictions is considered to be marginal. Drivers would be operating in Level NTC and therefore would have to have sufficient route knowledge in order to use line-side signalling. The restricted number of routes anticipated (Paddington to Heathrow only) for Class 345 stock may also lessen the risk of overspeed derailment.

An analysis of the overall TPWS effectiveness at all signals for all traffic on the route with enhanced TPWS equipment has been conducted in Ref. 2).

The Option also has Safety Risk to staff required to work lineside in order to install and maintain the proposed equipment.

7) Degraded Mode Operations

As per Option 4.

8) Signalling System Design Impact

This Option requires additional TPWS installations that exceed the current TPWS design Standards (Ref. 4) (Ref. 9). The additional infrastructure is not currently planned for delivery by Crossrail due to:

- Non-standards mandated TPWS fitments proposed
- The existing derogation against TPWS fitment for HEX
- Crossrail design being completed prior to the latest issue of TI022

This option requires the signalling scheme plans to be re-worked in light of the proposed changes.

The addition of TPWS units will require inputs/outputs into the interlocking and also alterations to the control system. The capacity of the interlocking to accept the required number of inputs/outputs is a potential constraint on any addition of TPWS.

9) Compliant with Standards

Yes- this Option exceeds the minimum required fitments specified in TPWS standards (Ref. 9) (Ref. 8) (Ref. 4).

10) Approved Technology

Yes- no non-standard technology is proposed. ETCS balises have been approved as part of the Cambrian ETCS deployment.

11) Impact to Parties

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling arrangement (i.e. no longer wholly ETCS cab-based signalling) and requirements for a transition from Level NTC to Level 2 ETCS (and vice-versa).

The amendment to infrastructure will require liaison with Crossrail to amend their signalling design to the new requirements.

Adding TPWS to signals in excess of 'normal' fitment patterns and to MAY-FA junctions may create a risk of tripping rolling stock which is being driven in a manner which is inconsistent with the OSS deployments but which would not have SPADed/exceeded the speed restriction e.g. ATP stock.

12) Requires ORR Exemption to Rail Safety Regs 1999

This Option provides functionality in excess of TPWS standards and also in compliance with the Regulations since a train protection system is provided on all signals. No exemption would be required from the ORR.

13) Justification for Discontinuation of Analysis

N/A

3.7 Option 6: As Option 5 but no fault reporting/integration into control system for additional TPWS that are not being provided by Crossrail scheme ("bolt-on" TPWS)

3.7.1 System definition

3.7.2 Analysis

1) Costs

- **Design and Construction Cost**

The costs of this implementation would be the same costs as for Option 5, less an estimated £800,000 for data changes to the control system. This gives a total of in the region of £11,500,000.

- **Future maintenance costs**

As per Option 5, but with the possibility of reversing the changes should a temporary solution be feasible, since no changes to the control system data will be made.

2) Lifespan

As per Option 5, but with the possibility of removing the additional units when ETCS Level 2 operation begins on the GWML.

3) Achievable in Time/ outline programme

As per Option 5, but with no constraint on finalising design prior to data changes to be made by Crossrail.

4) Advantages

This Option delivers the Safety benefits of Option 5, but at slightly lower cost.

It may be feasible to remove the TPWS units once ETCS Level 2 operations commence on the GWML.

5) Disadvantages

The amount of equipment required to be installed represents a substantial cost.

Maintenance costs would be on-going for the duration of the TPWS equipment life (25+ years), unless removal is feasible upon ETCS Level 2 operations.

Fault reporting is not available to the signaller and therefore they would not be notified of TPWS failures.

6) Safety Risk

The Safety Risk is almost exactly the same as per Option 5. However, fault reporting is not available to the signaller and therefore they would not be notified of TPWS failures. This would result in small potential for SPADs of a signal where the TPWS was defective. Such a situation would require both a SPAD and a TPWS failure and is not considered credible in the circa 7 months of operation prior to the introduction of whole route ETCS Level 2.

7) Degraded Mode Operations

Due to lack of fault reporting in this Option, it would not be known if the additional TPWS units had failed and therefore 'hidden failures' could occur. Should failed TPWS equipment be identified, the current procedures for failed signalling equipment would be followed.

8) Signalling System Design Impact

The additional TPWS units would need to be interfaced to the interlocking, but not into the control system.

9) Compliant with Standards

This Option is not-compliant to the TPWS Design Interface standard (Ref. 8), since integration into the control system is absent. There would therefore be no fault reporting to the signallers in the event of TPWS failure. A derogation would need to be sought.

10) Approved Technology

Yes- no non-standard technology is proposed. ETCS balises have been approved as part of the Cambrian ETCS deployment.

11) Impact to Parties

As per Option 5.

12) Requires ORR Exemption to Rail Safety Regs 1999

Class 345 operations would be fully protected by TPWS and therefore no exemption would be required since a train protection system is in place.

13) Justification for Discontinuation of Analysis

N/A

3.8 Option 7: Fit GW-ATP to Crossrail Class 345 Rolling Stock

3.8.1 System Definition

Rolling Stock to be 4tph Paddington to Heathrow Airport Class 345 fitted with GW-ATP.

No additional infrastructure works other than those currently planned by Crossrail (Ref. 5).

2 tph Heathrow Connect to be withdrawn.

3.8.2 Analysis

1) Costs

- **Design and Construction Cost**

This Option has no infrastructure costs, but requires the rolling stock design of Class 345 to be modified such that it has GW-ATP functionality. The cost of adding this functionality this late in the design is expected to be considerable.

- **Future Maintenance Costs**

No additional infrastructure maintenance is required.

Maintenance costs would be increased for the ToC, since additional equipment is being added to the Class 345.

2) Lifespan

The changes would have a lifespan of the service-life of the Class 345s fitted out i.e. in excess of 25 years.

3) Achievable in Time/ outline programme

It is not known if the rolling stock design could be amended to incorporate GW-ATP functionality in the time available.

4) Advantages

No infrastructure amendments required at all.

Any delay to the delivery of ETCS on HEX would have no impact to Class 345 operations.

No contractual (ToC) negotiations are needed, since Class 345 trains are available to Crossrail ToC and the Heathrow Connect stock is released for use elsewhere as anticipated should ETCS functionality be delivered on the GWML from April 2018.

This Option completely removes any constraints on ETCS provision, either on HEX or GWML infrastructure. ETCS signalling on HEX or GWML infrastructure could be delayed until full Crossrail service to Heathrow commences.

5) Disadvantages

Rolling Stock design would have to be amended, which may be a considerable hurdle.

Driver training amendments would be required by Crossrail ToC, since the expected ETCS L2 signalling system would be being replaced with GW-ATP.

6) Safety Risk

There is no safety risk, since Class 345 operations would now be protected by GW-ATP.

7) Degraded Mode Operations

Degraded Mode Operations would use the existing processes for any failures in GW-ATP trackside or train borne infrastructure.

8) Signalling System Design Impact

None- there is no impact on the signalling system as it already has GW-ATP functionality.

9) Compliant with Standards

Operations will be as per current HEX operations and the existing derogation on not-fitment of TPWS (Ref. 6) could be extended to Class 345 if necessary.

10) Approved Technology

No non-approved technology is required for infrastructure. The approvals for GW-ATP on the rolling stock would be the responsibility of Crossrail ToC.

11) Impact to Parties

There is no impact to Crossrail infrastructure works. However, there is a major impact to Crossrail fleet-side works, since Class 345 would have to have its design amended to

incorporate GW-ATP functionality. This change could be limited to those trains required to operate on the Paddington-Heathrow shuttle, but the design costs would be the same irrespective of the number fitted.

Driver training for Crossrail ToC would have to be amended to take into account the new signalling system.

12) Requires ORR Exemption to Rail Safety Regs 1999

Class 345 operations would be fully protected by ATP and therefore no exemption would be required since a train protection system is in place.

13) Justification for Discontinuation of Analysis

N/A

3.9 Option 8: Fit ETCS Level 1

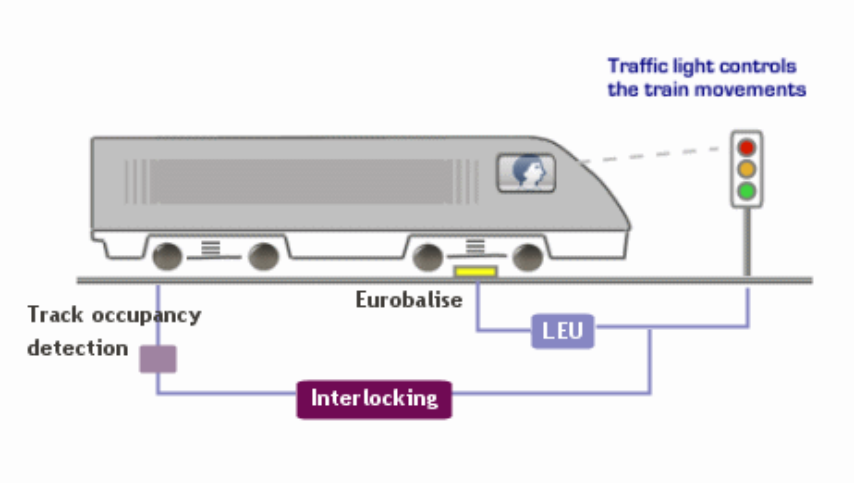


Figure 2: ETCS Level one

3.9.1 System definition

In the basic application of ETCS L1, ETCS is overlaid on existing traditional signalling equipment, through the provision of a trackside spot-based update of signalling information to the ETCS on-board equipment.

On the approach to each signal, a balise group is placed. This Balise can be electrically connected to the signal or via a data link, which is also equally connected via a local lineside Electronics Unit (LEU). Thus, the information transmitted by the balise group to the train is determined by the signal aspect currently being displayed. Trains can receive different Movement Authority (MA) data according to the signal aspect; a short MA prevents a train from passing red aspects. The tracks speed and gradient information is also transmitted, allowing the ETCS on-board equipment to supervise the train's speed.

Rolling Stock equipment remains unchanged on the Class 345.

3.9.2 Analysis

1) Costs

- **Design and Construction Cost**

Requires the purchase and installation of Lineside Electronic Units and balise groups at all relevant signals, and associated testing. Transitional equipment (balises and signage) for the Level 1 to Level 2 (and vice-versa) is also required.

Vertex are not aware of any examples of ETCS L1 being employed in the UK which can be used as a basis for cost comparison. Product Acceptance costs for LEUs could be high, unless defrayed by the manufacturer.

It is anticipated that this Option would be higher cost than any TPWS based option.

- **Future maintenance costs**

Maintenance costs are dependent upon the selected LEUs and balises.

The introduction of ETCS L1 would introduce new equipment on top of the existing conventional infrastructure which therefore would increase maintenance costs.

Modern electronic lineside equipment is typically 'fit and forget' and therefore maintenance costs would be expected to be low and to represent little additional effort on top of the existing regime.

2) Lifespan

Dependent on selected LEUs/balises. Lifespan of hardware anticipated to be 30 years.

3) Achievable in Time/ outline programme

No ETCS L1 implementation has been undertaken in the UK and therefore any programme would be a risk, since it is an untested technology.

It is likely that Product Acceptance would be required for LEUs, which would add additional time before any installation could commence.

4) Advantages

This option does not require changes to interlockings. LEUs also exist that are solar powered, so interaction with the signalling power supply is also not necessary.

The balises will only affect trains using ETCS and therefore any unintended consequences on other rolling stock (e.g. accidental TPWS tripping) would be avoided.

Use of ETCS Level 1 would be a chance for the industry to investigate this technology and get the relevant products approved for use elsewhere.

No changes to rolling stock (Class 345) design required, since the train is already configured to be able to use ETCS Level 1

Compatible with other ETCS rolling stock e.g. IEP.

5) Disadvantages

ETCS Level 1 is an immature technology in the UK and has not been deployed before. The first usage therefore carries considerable implementation risk from unknowns.

The cost and time of approving the necessary equipment (LEUs) is also a disadvantage.

L1 ETCS will only interact with trains equipped with ETCS-based signalling.

There may be a ETCS baseline issue with compatibility between Baseline 2 and Baseline 3 trains and ETCS L1 requiring adaptations to the on-board software.

6) Safety Risk

There is no safety risk relative to GW-ATP, since ETCS L1 has similar functionality. There is no impact on other, not-ETCS fitted, rolling stock types e.g. those using AWS/TPWS.

7) **Degraded Mode Operations**

Degraded mode Operations as per ETCS requirements would be used. It is not clear if Level 1 ETCS has a well-developed set of operational procedures, since it has not been used before as an overlay system in the UK.

8) Signalling System Design Impact

No impact on existing signalling system. LEUs can be driven directly from signals and do not require direct interaction with the interlocking.

9) Compliant with Standards

ETCS must be compliant with TSIs and ETCS baseline. NR Company Standards and Railway Group Standards may not be mature for this application.

10) Approved Technology

Vertex is not aware of any LEUs with UK approval.

ETCS balises have been approved as part of the Cambrian ETCS deployment.

11) Impact to Parties

No impact on Crossrail, other than minor amendments to driver training required due to use of ETCS Level 1 and transition from ETCS Level 1 to ETCS Level 2 (and vice-versa) at Signals.

Impact to maintainer- new asset types added which will require training.

No impact on other train operators e.g. FGW/HEX.

12) Requires ORR Exemption to Rail Safety Regs 1999

Not required- ETCS L1 is a train protection system that provides full speed supervision on approach to signals.

13) Justification for Discontinuation of Analysis

N/A

3.10 Option 9: Alter track layout such that Crossrail Operations are Physically Isolated from GWML

3.10.1 System Definition

In this Option, the track layout would be amended such that there are lines from Paddington to Heathrow which are used exclusively by Class 345 services (4 tph) with no other services running on them (i.e. physically isolate proposed Class 345 service from all over moves).

This could be achieved by both permanently removing switches and crossings, building entire new lines, or by clipping points out of service such that conflicting routes cannot be set.

3.10.2 Analysis

1) Justification for Discontinuation of Analysis

It is operationally impractical to physically isolate 2 lines out of Paddington due to the consequential capacity issues for TOCs. The cost and timescale to build two new lines to avoid such operational issues is prohibitive and not achievable in timescales.

3.11 Option 10: Utilise existing GW-ATP stock (e.g. HEX/Heathrow Connect) for additional Paddington to Heathrow shuttle until ETCS Level 2 provided

3.11.1 System Definition

Crossrail services are conducted by rolling stock other than Class 345 which already has GW-ATP functionality i.e. 4 tph GW-ATP services Paddington to Heathrow.

3.11.2 Analysis

1) Costs

- **Design and Construction Cost**

None- there is no design or construction involved in this Option.

- **Future maintenance costs**

There is no infrastructure maintenance required over and above what is already planned.

Any rolling stock substituted for the Class 345 would have to be maintained by the relevant ToC.

2) Lifespan

This Option has no defined lifespan, but the lifespan could be considered to be the lease length/ ToC franchise length for the GW-ATP rolling stock.

3) Achievable in Time/ outline programme

Yes- no infrastructure works are required. The 'works' to achieve this Option would be purely of a contractual basis between ToCs and the RoSCos.

4) Advantages

No infrastructure works required and no risk to the existing programme of Crossrail infrastructure works.

No risk to staff from lineside working as no additional installations or maintenance required.

Operations would be completely independent of ETCS delivery.

5) Disadvantages

It may be contractually difficult and potentially challenging (e.g. in terms of driver training and leasing of stock) for Crossrail ToC have non-Class 345 operating under the Crossrail banner or to 'delay' the running of Class 345 and by extension Crossrail operations.

Assumes sufficient stock is available - current Heathrow Connect service is 2 trains per hour.

This Option would delay the introduction of Class 345 trains and may have knock-on implications for their testing. Any delay to Class 345 testing could have consequential effects to the introduction of the rolling stock on the full Crossrail route. Delay to Crossrail defers the significant safety and other benefits the project offers e.g. reduction of overcrowding and reduction of road journeys.

Contractual negotiations would be required between ToCs and RoSCos. This option would impact other ToCs who may be expecting to use the ATP stock on other routes.

6) Safety Risk

None- all proposed services would be protected by GW-ATP, which is installed across the whole route.

7) Degraded Mode Operations

Degraded Mode Operations would use the existing processes for any failures in GW-ATP trackside or train borne infrastructure.

8) Signalling System Design Impact

None- no alterations to the existing system are proposed.

9) Compliant with Standards

Yes- Operations would be conducted as currently under GW-ATP. The derogation for not-fitment of TPWS on HEX infrastructure/rolling stock (Ref. 6) may have to be extended to the selected rolling stock Class.

10) Approved Technology

No technology is being proposed for this Option. Existing stock would be used.

11) Impact to Parties

Driver training for Crossrail ToC would have to be amended to take into account the new signalling system i.e. GW-ATP rather than ETCS Level 2.

No impact on Crossrail infrastructure works or future infrastructure maintenance costs.

Crossrail ToC would require contractual negotiations to acquire GW-ATP stock for the duration on non-ETCS Level 2 provision. Alternatively, Crossrail ToC franchise could be delayed and another ToC run the 4 tph.

12) Requires ORR Exemption to Rail Safety Regs 1999

Operations would be fully protected by ATP and therefore no exemption would be required since a train protection system is in place.

13) Justification for Discontinuation of Analysis

N/A

3.12 Option 11: Separate Class 345 Trains by Time (absolute block equivalent)

3.12.1 System Definition

4 tph Class 345 Paddington to Heathrow using Level NTC, transitioning to ETCS Level 2 at SN321, 323, 325.

2 tph Heathrow Connect withdrawn.

Creation of a form of absolute block working, whereby all other traffic is barred from the GWML on all or a subset of lines whilst Crossrail trains are routed to/from Paddington after having left HEX infrastructure. This Option is not considered feasible and has not been expanded further.

3.12.2 Analysis

1) **Justification for Discontinuation of Analysis**

This Option has not been analysed as it would cause extensive operational issues to the GWML, since non-Crossrail traffic would be barred from Stockley Bridge Junction to Paddington all the while Crossrail trains were on the GWML.

3.13 Option 12: Second Driver on the Footplate of Class 345

3.13.1 System definition

This Option takes a procedural approach. The Option is to man each Class 345 with two trained drivers rather than one. Level NTC Operations to be undertaken throughout entire Paddington - Heathrow route.

NOTE: This Option could also generate an additional Option of transitioning from Level NTC to Level 2, but this would require additional infrastructure at the Level transition boundary.

3.13.2 Analysis

1) Costs

- **Design and Construction Cost**

None - no infrastructure or rolling stock design/construction needed. The only costs in this Option are the additional staff costs for Crossrail ToC.

- **Future maintenance costs**

None - no additional infrastructure or rolling stock elements.

2) Lifespan

This Option can be employed for any time period, subject to staffing availability and has no lifespan as such.

3) Achievable in Time/ outline programme

Yes- no infrastructure or rolling stock changes required. The only additional effort would be the requirement to recruit and train a sufficient quantity of drivers. Given the small number of trains involved (4 tph shuttle) this would represent few individuals.

4) Advantages

No amendments to infrastructure or rolling stock required.

Completely independent of infrastructure and rolling stock programme.

Low cost, which potentially could be further reduced by leveraging the use of a second driver as part of Crossrail ToC driver training programme for the Class 345.

5) Disadvantages

The use of procedural hazard control mechanisms is non-preferred in the risk-control hierarchy. Designing out risks or applying physical control mechanisms should take precedence.

6) Safety Risk

Due to the nature of TPWS deployment, the majority of SPAD risk is concentrated onto rear-end collisions, with the exception of the signals listed in Table 9, where a risk of collision at a junction exists.

HEX infrastructure would require TPWS installation on signals as required by GE/RT8075 (Ref 4). Currently, HEX infrastructure does not utilise TPWS resulting in an existing derogation for TPWS usage (Ref. 79) on HEX, see also Section 6.3.4 of Ref. 9). HEX infrastructure has standard AWS deployment.

The risk of SPAD is influenced by many factors. Since Crossrail ToC is a new organisation, no information will be available as to the effectiveness of their driver training and therefore how their operations will compare with other ToC's SPAD rates. The employment of an additional driver in the Class 345 would substantially reduce the risk of SPAD.

Crossrail drivers are currently expecting to be using ETCS cab-based signalling and therefore Crossrail driver training may not currently incorporate sufficient route-knowledge to enable operations by line-side signal control.

In addition to SPAD risk, substitution of non-GW-ATP operations also marginally increases derailment risks on approach to MAY-FA signals should the lower speed route be set. This is because GW-ATP stock receives in-cab speed information about MAY-FA junction approach speeds which is absent in stock using TPWS/AWS. The employment of an additional driver in the Class 345 would substantially reduce this risk.

GW-ATP does not provide information to the driver on PSRs/TSRs and so there is no change in risk for these speed restrictions. The employment of an additional driver in the Class 345 would substantially reduce this risk.

There is no additional risk to staff in terms of line-side working for this option, since no additional installations or maintenance are required (subject to derogation against TPWS fitment standards) over that which is currently planned by Crossrail.

7) Degraded Mode Operations

This option does not have a degraded mode. Should second drivers not be available, the Class 345 services would not be able to run.

8) Signalling System Design Impact

None - there is no amendment to signalling design.

9) Compliant with Standards

No. The implementation of TPWS from 0mp to Stockley Bridge Junction (on Airport lines) is in-line with current Standards (although compliance to TI022 will need to be confirmed with Crossrail designers). The additional TPWS units required to meet standards on the Airport Lines up to SN321, SN323, SN325 are described in Table 9.

Additional TPWS installations would also be required on HEX since the existing Derogation (Ref. 6) from TPWS fitment would no longer be valid should Level NTC be used through to Heathrow Airport. HEX is not currently fitted with TPWS (Ref. 12).

AWS is present throughout the route, including signals on HEX infrastructure.

10) Approved Technology

No technology is required. This is a procedural based Option.

11) Impact to Parties

No impact to infrastructure projects.

Crossrail ToC would incur additional expense in terms of requiring extra drivers to be recruited and trained prior to April 2018.

12) Requires ORR Exemption to Rail Safety Regs 1999

It is highly likely that this Option would require an exemption to the Regulations from the ORR. This is a procedural option which does not utilise a technological Train Protection System.

ORR appear to view either the use of ETCS or GW-ATP as being 'reasonably practicable', especially given that GW-ATP infrastructure is already installed across the whole Paddington to Heathrow route and that funding has been provided to enable ETCS operation.

There is a possibility that given suitable risk assessment that ORR would accept this solution for a fixed period of time prior to full ETCS Level 2 implementation.

13) Justification for Discontinuation of Analysis

This Option has been analysed, but is unlikely to be feasible due to the potential requirement for an ORR exemption and also non-compliance to TPWS standards across the Paddington to Heathrow Airport route.

3.14 Option 13: Utilise Available IEP Rolling Stock.

3.14.1 System Definition

This Option requires the rolling stock to be used for the 4 tph service from Paddington to Heathrow to be switched from Class 345 to Class 800 IEP. 2 tph Heathrow Connect to be withdrawn.

The Class 700 would use GW-ATP to Signals SN321, SN323, SN325 where a transition to ETCS Level 2 would then be made. Should it be wished to avoid these costs, GW-ATP could be employed for the entire route to Heathrow Airport (as per Option 10 in Section 3.11).

3.14.2 Analysis

1) Costs

- **Design and Construction Cost**

The only design and construction costs are the installation of the transition equipment to commence ETCS Level 2 running at SN321, SN323, SN325. These costs are not considered to be substantial.

- **Future maintenance costs**

No additional maintenance costs over and above those already anticipated as a result of Crossrail works, excepting for the transitional equipment. These costs are minimal due to the nature of balises and signage.

2) Lifespan

This Option has no lifespan - it could be used for as long as there is GW-ATP or ETCS Level 2 signalling on the route. The lifespan would likely be constrained by the availability of the Class 800 trains, which are not currently planned to be used on Crossrail and therefore would be needed elsewhere.

3) Achievable in Time/ outline programme

Yes- provided that Class 700 vehicles are available by April 2018 and the relevant contractual negotiations can be completed.

4) Advantages

No additional infrastructure amendments needed other than for transitional arrangements at SN321, SN323, SN325.

No rolling stock design alterations needed- Class 800 already designed to be fitted with ETCS and GW-ATP.

Existing Heathrow Connect stock released for use elsewhere as currently planned.

5) Disadvantages

Contractual negotiations would be required in order for Crossrail ToC to use Class 800.

Class 800 in use on Crossrail would not be available for use elsewhere.

Crossrail ToC driver training would have to be for Class 800 rolling stock and would therefore be non-applicable to future use of Class 345.

Dependent on the programme of Class 800 stock, which is currently independent of Crossrail.

6) Safety Risk

There is no safety risk, since Class 800 can use GW-ATP and ETCS Level 2.

7) Signalling System Design Impact

None- the only additional infrastructure is the transitional equipment at SN321, SN323, SN325 which does not interface to the signalling system.

8) Compliant with Standards

Yes- Operations would be under existing GW-ATP standards or ETCS L2.

9) Approved Technology

Yes- no non-standard technology is proposed. ETCS balises have been approved as part of the Cambrian ETCS deployment. Approval of Class 800 trains would be the responsibility of the ToC.

10) Impact to Parties

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling arrangement (i.e. no longer wholly ETCS cab-based signalling) and requirements for a transition from Level NTC to Level 2 ETCS (and vice-versa) and new Class of train.

Contractual negotiations would be required between Crossrail ToC and the IEP in order to enable usage of Class 800.

11) Requires ORR Exemption to Rail Safety Regs 1999

Not required- Operations would be protected by GW-ATP or ETCS Level 2.

12) Justification for Discontinuation of Analysis

N/A

3.15 Option 14: Delay Running 4 tph Crossrail Service until ETCS Level 2 is in Operational Use

3.15.1 System Definition

Delay introduction of Class 345 until ETCS is available across whole route from Paddington to Heathrow.

Heathrow Connect services could be withdrawn or extended until Class 345 Operations begin.

3.15.2 Analysis

1) Costs

- **Design and Construction Cost**

None- no design or construction in addition to that already proposed by Crossrail.

- **Future maintenance costs**

None- no additional infrastructure or rolling stock changes to maintain.

2) Lifespan

NA- This Option can be 'used' for as long as required until full ETCS Level 2 is available from Paddington to Heathrow.

3) Achievable in Time/ outline programme

Yes- this option is completely independent of all other constraints as no infrastructure changes or rolling stock is required.

4) Advantages

This Option is the easiest to implement, since it requires no changes.

5) Disadvantages

It may be contractually difficult to delay Crossrail services to Heathrow. The service to Heathrow (and intermediate stations served by Heathrow Connect) may be reduced since Heathrow Connect is scheduled to be withdrawn and in this situation would not be replaced with Crossrail services until ETCS is available.

This Option would delay the introduction of Class 345 trains and may have knock-on implications for their testing. Any delay to Class 345 testing could have consequential effects to the introduction of the rolling stock on the full Crossrail route. Delay to Crossrail defers the significant safety and other benefits the project offers e.g. reduction of overcrowding and reduction of road journeys.

6) Safety Risk

None.

7) Degraded Mode Operation

N/A- No operations proposed.

8) Signalling System Design Impact

None.

9) Compliant with Standards

Yes- no Operations proposed.

10) Approved Technology

N/A- no infrastructure or rolling stock design changes proposed.

11) Impact to Parties

Impact to Crossrail ToC in that their Operations are delayed until the commencement of ETCS L2 running prior to December 2018.

Crossrail ToC would also gain extra time prior to the usage of Class 345.

No impact on other operators, unless Heathrow Connect services are extended to run until Class 345 enters service.

Should Heathrow Connect services be withdrawn and not immediately replaced with Class 345 services, there will be a capability reduction for those stations previously served by Heathrow Connect.

12) Requires ORR Exemption to Rail Safety Regs 1999

N/A

13) Justification for Discontinuation of Analysis

N/A

3.16 Option 15 - As Per Option 0 but with Minimum Transition Infrastructure to ETCS L2 at SN321/SN323/SN325 to enable ETCS L2 Operations

3.16.1 System Definition

TPWS infrastructure to be altered only as currently planned by Crossrail, as per Scheme Plans (Ref. 5). This provides 'classic' TPWS functionality, but not on all signals, partially in line with current TPWS design standards i.e. TPWS protecting junctions/convergences only. Crossrail Scheme TPWS works do not fully cover the Airport Lines infrastructure to existing Standards requirements.

Rolling stock to be 4 x Class 345 per hour, with no GW-ATP functionality. Rolling stock routed to Heathrow Airport would use TPWS/AWS in ETCS Level NTC from Paddington Station up to Signals SN321, SN323, SN325 where a transition to ETCS Level 2 would then be made.

ETCS Level 2 Operation on HEX infrastructure past SN321, SN323, SN325 requires transitional infrastructure e.g. signage, balises etc. (see NEPT/ERTMS/REQ/0007 Issue 2.0) to enable the Class 345 to transition from ETCS Level NTC to Level 2 and vice-versa. Transitional equipment will be required in both directions.

2 tph Heathrow Connect GW-ATP services to be withdrawn.

3.16.2 Analysis

1) Costs

- **Design and Construction Cost**

No additional TPWS costs over and above those already accounted for by the proposed Crossrail works. Transitional (Level NTC to Level 2 and vice versa) balises and signage are required.

- **Future maintenance costs**

No additional maintenance costs over and above those already anticipated as a result of Crossrail works, excepting for the transitional equipment. These costs are minimal due to the nature of balises and signage

2) Lifespan

The Lifespan of this option is the design life of the alterations made for Crossrail, which are likely to be in the region of 25 years minimum.

When ETCS Level 2 through running (Paddington to Heathrow) is required, the transitional equipment would need to be removed at the extant NTC:L2 level boundary.

3) Achievable in Time/ outline programme

Minor alterations to the existing Crossrail programme are required, since the only infrastructure change required is the installation of transitional equipment/signage.

4) Advantages

This option incurs no additional expense in terms of rolling stock.

Only minor infrastructure changes are required and therefore there is extremely limited impact to on-going maintenance. Level NTC to Level 2 (and vice-versa) equipment needs to be removed once full-route ETCS Level 2 running commences, so maintenance costs are limited only for the duration of the delay to ETCS Level 2 provision on the GWML.

The programme of Crossrail works on the GWML is already well understood the minor changes this Option requires do not pose a risk to programme.

The use of ETCS from Signals SN321, SN323, SN325 onwards allows that technology to be utilised for the non-GWML portion of the journey to Heathrow.

No contractual (ToC) negotiations are needed, since Class 345 trains are available to Crossrail ToC and the Heathrow Connect stock is released for use elsewhere as anticipated should ETCS functionality for in service usage be delivered on the GWML from April 2018.

5) Disadvantages

Class 345 operations were planned to be ETCS-based (cab signalling) from Paddington to Heathrow from the outset in April 2018.

The withdrawal of 2 tph GW-ATP (Heathrow Connect) and their replacement with 4 tph non-GW-ATP (Class 345) introduces a safety risk to the route from 0MP to Signals SN321, SN323, SN325.

Use of Level NTC up to Signals SN321, SN323, SN325 as proposed by this option may require alterations to driver training, since route knowledge becomes more critical when line-side signalling is utilised.

Class 345 stock must be configured and certified to run in Level NTC to be able to utilise the legacy national systems (AWS/TPWS) as proposed in this option. This adds a constraint onto Crossrail, since Level NTC operations would not have been required this early in Crossrail operations.

6) Safety Risk

There is additional risk to staff in terms of line-side working for this option, since additional equipment installations/removals and maintenance are required over that which is currently planned by Crossrail.

The replacement of Heathrow Connect (2 tph) GW-ATP stock for 4 tph non-GW-ATP Class 345 Crossrail stock introduces a safety risk to operations from Paddington. The current Crossrail infrastructure designs do not require TPWS to be fitted at every signal, and therefore there is an increased risk of SPAD at signals that are not fitted with TPWS compared to current GW-ATP operations.

The risk of SPAD is influenced by many factors. Since Crossrail ToC is a new organisation, no information will be available as to the effectiveness of their driver training and therefore how their operations will compare with other ToC's SPAD rates.

Crossrail drivers are currently expecting to be using ETCS cab-based signalling on the GWML and therefore Crossrail driver training may not currently incorporate sufficient route-knowledge to enable operations by line-side signal control.

In addition to SPAD risk, substitution of non-GW-ATP operations also marginally increases derailment risks on approach to MAY-FA signals should the lower speed route be set. This is because GW-ATP stock receives in-cab speed information about MAY-FA junction approach speeds which is absent in stock using TPWS/AWS.

GW-ATP does not provide information to the driver on PSRs/TSRs and so there is no change in risk for these speed restrictions.

7) Degraded Mode Operations

No changes would be required to existing processes for dealing with failed signalling equipment, either on-board trains (failed TPWS receiver) or on track (failed TPWS unit). ETCS degraded mode processes would be used past the transition point to ETCS Level 2.

8) Signalling System Design Impact

None - no alterations proposed to the current Scheme Plans other than the requirement for Transitional equipment (signage and balises) to enable transition from Level NTC to Level 2 ETCS (and vice-versa).

9) Compliant with Standards

The implementation of TPWS by Crossrail is not in-line with current Standards on the Airport Lines, since they would not be required should ETCS L2 be available on GWML. The additional units required to meet Standards on the Airport Lines are described in Option 1.

AWS is present throughout the route, including signals on HEX infrastructure.

10) Approved Technology

Yes- no non-standard technology is proposed. Balises have been approved as part of the Cambrian deployment of ETCS.

11) Impact to Parties

Minor impact to infrastructure design, installation and on-going maintenance due to the transitional equipment at the Level NTC to Level 2 ETCS boundary.

Impact to Crossrail ToC- driver training will need to be amended to take into account altered signalling (i.e. no longer ETCS) and transitional arrangements at the conventional:ETCS boundary at Signals SN321, SN323, SN325.

The increased risk of SPAD of Crossrail trains whilst in Level NTC will have an impact on passenger safety, both on Crossrail trains and also to other Operators who may be in collision with a Crossrail train should it SPAD.

12) Requires ORR Exemption to Rail Safety Regs 1999

This Option would be likely to require an exemption, based upon the interpretation of the letter sent by ORR to Network Rail (Ref. 1). The reason for this is that ORR appear to view either the use of ETCS or GW-ATP as being 'reasonably practicable' on the GWML, especially given that GW-ATP infrastructure is already installed across the whole Paddington to Heathrow route and that funding has been provided for ETCS.

13) Justification for Discontinuation of Analysis

Not applicable- this Option has been analysed.

However, it is unlikely this Option would be acceptable to ORR since it introduces Safety Risk from non-GW-ATP operations. Any infrastructure which is not compliant with standard TPWS design rules will also need to be remedied or a derogation sought.

4 Historical Safety Issues on the Line of Route

4.1 Historical Incidents

4.1.1 Southall, 1997:

Collision between passenger train and freight train at a junction caused by the passenger train SPADing. The passenger train's AWS system was faulty and its ATP system had been switched off.

Relevance to this report: Any solution that does not provide train protection at junctions could result in a similar outcome due to SPAD. The standard implementation of TPWS already mandated by Standards controls this risk.

4.1.2 Ladbroke Grove, 1999:

SPAD of non-ATP fitted Turbo train causing head-on collision with ATP-fitted HST.

Relevance to this report: Any solution that does not provide train protection at junctions could result in a similar outcome due to SPAD. The standard implementation of TPWS already mandated by Standards controls this risk.

4.1.3 Commentary

The historic incidents of non-ATP stock causing major rail disasters on the GWML are illustrative of why significant risk assessment should be carried out prior to any non-ATP solution being recommended.

A further incident of collision caused by SPADing in the same area would cause massive reputational damage to Network Rail, above and beyond the potential for injury or loss of life.

4.2 Current SPAD Status

Vertex was provided with current SPAD data by the client for the Paddington to Heathrow Airport route. There is no evidence of major SPAD issues, although given the small proportion of non-ATP traffic on the line (due to the above mentioned incidents) this does not provide evidence that SPADs would not occur if ATP supervision was removed.

5 Conclusion Of Options Analysis report

This report analyses the options available to Network Rail if ETCS L2 is not available on the Western Mainline from 0m to signals SN321, SN323, SN325 on the Airport Lines, before it is required for Crossrail passenger service in April 2018.

Criteria for assessment have been developed and a total of 15 options were identified for assessment. For each option a preliminary system definition (as required for CSM analysis) and a summary advantages/disadvantages for safety, standards and cost analysis have been prepared.

This document acts as the pre-workshop paper for the Options Selection Workshop. Based on the decision by the SRP panel, the selected Options will be developed further such that a HAZID workshop can be held. All findings will form part of Network's Rails wider submission to ORR. Figure 3 shows the current status.

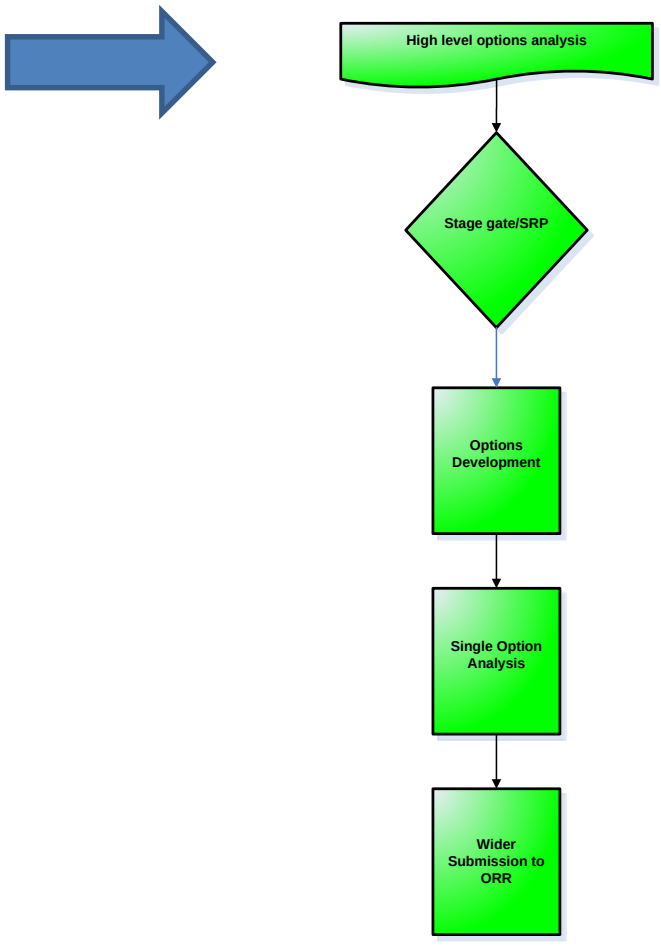


Figure 3 Project Flow

6 Summary of Options Selection Workshop

The following sections provide a summary of the Options Selection workshop held on the 10th of September 2014.

The Pre-Workshop note Ref 13) describes the process for assessing and ranking the options to enable final option selection. The process, based on the NRIP VM2 Option Selection procedure, consisted of two stages of

Stage 1 - Participants determine the credible options for ranking and selection.

Stage 2 - Participants to conduct a detailed assessment, ranking and final selection from the credible options determined in Stage 1.

The quorate panel subsequently determined that performing options selection by detailed review of the option summary table utilised for Stage 1 was an acceptable methodology for Stage 2.

6.1 Findings

6.1.1 Options Selection Workshop Findings 1 - Credible Options Selected

An Option Selection was held on September 10th 2014. The quorate panel determined:

- The credible options selected for further development and HAZID analysis are options 3, 4 and 5. All are to be considered without incorporating fault reporting in the base option.
- Option 10 is to be retained as "open for further analysis" and the client will advise the action owning party.

6.1.2 Options Selection Workshop Findings 2 - Identification of Additional Credible Option

Based on the detailed review the quorate panel identified a further Option;

- Option 16: Provide over-speed functionality for Crossrail trains using simplified ETCS plus selected TPWS option for SPAD risk.

Option 16 utilises the ETCS TSR functionality to supervise the line speed profile. It consists of Application Level 1 with or without infill transmission and trains equipped with ETCS operating

on a line equipped with Eurobalises. This functionality is available in a number of modes and is available in Unfitted Mode but it is not available in Level NTC (Ref 14) .

The client subsequently issued a request to Crossrail to consider working with their supplier (Bombardier) to adapt the system to provide this functionality in Level NTC.

Post Meeting Note - Crossrail have determined that this would import unacceptable system development and schedule risk and would require incorporation into National Notifiable Technical Rules (NNTR). Therefore this Option has been discontinued for further consideration and analysis.

6.1.3 Options Selection Workshop Findings 3 - Design Options and Control Measures

During the workshop, it was further determined that the following non-credible options could be used to support the application of the credible options in the following ways:

- Design Options

  Option 6 (No fault - reporting) is retained as a potential cost / complexity - saving measure for all TPWS option implementations depending on the infrastructure and risk profile.

- Control Measures

  Options 9 and 11 (use a dedicated line). This is envisaged as line 6 only (currently classified as freight only), this will become the Crossrail WB line.

  Option 12- second driver for use in degraded mode.

Appendix E summaries the detailed Options selection results including the SRP quorate panel decision and justification by stage and option.

7 References

1) Office of Rail Regulator Letter; Train Protection Paddington to Heathrow, 20141624/1; 24th June 2014.
2) ETCS "Plan B" Study 122271ISD-ASS-ESG-0000001. Version: 1.0; 27th June 2014
3) GE/GN8605, ETCS System Description, Railway Group Guidance Note. 2010
4) GE/RT8075 Issue 1 AWS and TPWS Interface Requirements
5) Crossrail Resignalling Works Scheme Plans 10-GW-033-01 through 10-GW-033-06
6) Derogation 01/109/DGN, 25/02/2008. Non-fitment of TPWS to Heathrow Express rolling stock and infrastructure, derogation against GE/RT8030 (now superseded by GE/RT8075)
7) SAT TPWS Effectiveness Calculator. See, for example, 122271-ISD-CAL-ESG-000002 and TI095
8) NR/SP/SIG/10133 Issue 3, Train Protection and Warning System (TPWS) Signalling Interface Design Requirements (formerly RT/E/S/10133)
9) NR/SP/SIG/10137 Issue 3, Train Protection and Warning System (TPWS) Selection of New Signals And Other Locations For Provision of TPWS (formerly RT/E/S/10137)
10) TPWS Options Costs (GRIP 0 Estimation), E. Schwartz, Network Rail
11) NEPT/ERTMS/REQ/007, ETCS On-board System - Baseline 3 - National On-board Subsystem Requirements Specification, Issue 2.0
12) Heathrow Airport Branch Lines Scheme Plan, S39/2/105, Version MB
13) Crossrail ETCSGRIP 3 SRP Option Selection Workshop Pre-Meeting Note GRIP 1-3 Options AnalysisV1.0
14) ERTMS/ETCS - Baseline 3, Systems Requirements Specification Chapters 3 &4 Issue 3.0

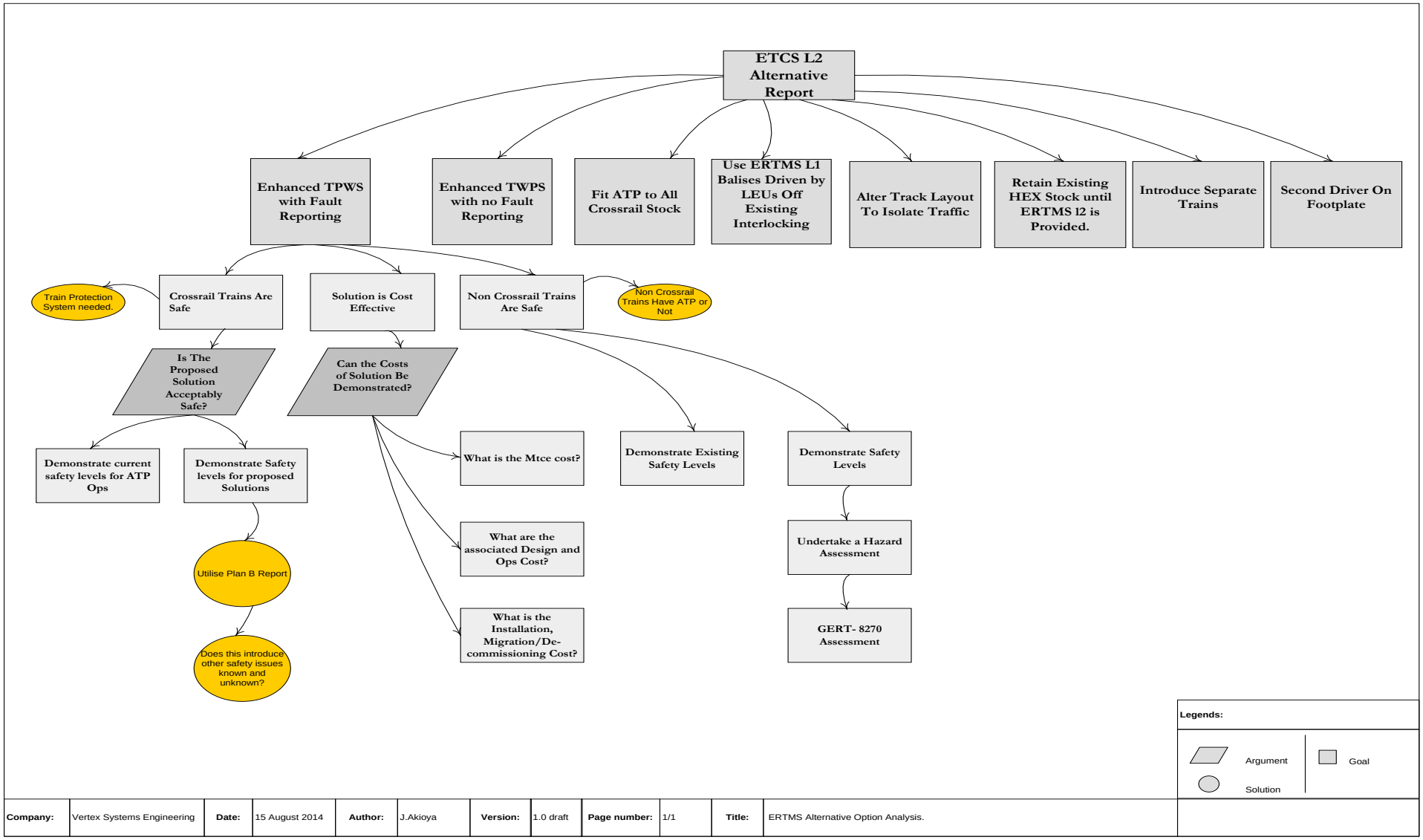
8 Abbreviations

Abbreviation	Definition
ATP	Automatic Train Protection
CBTC	Communications Based Train Control
CSM	Common Safety Method (for risk assessment)
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EVC	European Vital Computer
FGW	First Great Western
GSN	Goal Structuring Notation
GSM-R	Global System for Mobile Communications – Railway
GW-ATP	Great Western Automatic Train Protection
GWML	Great Western Mainline
HAZID	Hazard Identification
HEX	Heathrow Express
IECC	Integrated Electronic Control Centre
IEP	Intercity Express Programme
LEU	Lineside Electronic Unit
MAR	Main route approach controlled from red
MAY-FA	Main route approach controlled from yellow with flashing aspects in rear
NR	Network Rail
NTC	National Train Control (system)
ORR	Office of Rail Regulation
OSS	Over-Speed Sensor
PSR	Permanent Speed Restriction
SOD	Safe Overrun Distance
SPAD	Signal Passed At Danger
SRAC	Safety Related Application Condition
SRP	System Review Panel
SSI	Solid State Interlocking
STM	Specific Transmission Module
TP	Train Protection (System)
tph	Trains per hour
TPWS	Train Protection and Warning System

Abbreviation	Definition
TSR	Temporary Speed Restriction
TSS	Train Stop Sensor

Table 13 Abbreviations

Appendix A GSN



Appendix B Comparison of GW-ATP, TPWS and Enhanced TPWS

Features	GW-ATP	"10137" TPWS	TPWS Enhancement
Supervision	Continuous supervision of driver using "distance to go" calculations, intermittent contact with lineside infrastructure	Intermittent supervision and contact with lineside infrastructure	Intermittent Supervision and contact with lineside infrastructure
Beacon failure	If an expected signal beacon is missing, the system changes to partial supervision mode and makes an immediate (but recoverable) brake application	TPWS failure indicated to signaller. For some TPWS failures, signal on approach is held at red.	Depends on options selected; ie. Option 3 (this has fault reporting) or 4 (No fault reporting)
Display to driver	Provides assistance to driver with cab display and audible warnings	Notifies driver of brake demand and TPWS isolation/failure only	Notifies driver of brake demand and TPWS isolation/failure entry.
Monitors changes in permanent speed restrictions (PSR)	Yes	"Regulated PSR" only	Enhance protection at "Regulated PSR" by providing additional OSS for PSR+10% at commencement of PSR.
Monitors adherence to maximum permitted linespeed	Yes	No	No. TOC consultation to ask about extent if any of over-speeding.
Monitors diverging speed at junctions	Yes	Only for MAF and MAF-SD junction signalling on 60mph+ lines where reduction is greater than 1/3.	Extend standard fitment to include MAY-FA junction signalling on 60mph+ lines where reduction is greater than 1/3. For MAR, check the sighting point against the first OSS encountered to ensure train is under control before the aspect release point.

Features	GW-ATP	"10137" TPWS	TPWS Enhancement
Monitors temporary speed restrictions (TSR)	Yes	Considered on 60mph+ lines where reduction is greater than 1/3 where TSR in place more than 12 months or for less than 12 months on >100mph lines with >200 trains per day.	Excluded from study for this project, but expected to need TOC consultation.
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 for signals not excluded in 10137 Appendix A, applying TI-022 to stop 12%g train within safe overrun distance (SOD)	Fit TPWS to all signals fitted with GW-ATP lineside equipment on Main, Relief and Airport lines (up to NR boundary at SN321, 323 & 325). Design TPWS to stop 12%g Class 345 train (90mph) within the overlap rather than SOD
Prevent train approaching signal faster than braking performance permits	Yes, using distance to go calculations based on braking performance, odometry and gradients.	Yes if TPWS is fitted, using one or more OSS "speed traps" on approach if TSS insufficient to stop within SOD	Design TPWS to stop 12%g Class 345 train within the overlap rather than TPWS SOD
Monitors approach to buffer stops	Yes	No	No, because Class 345 is too long to join or share in Paddington platforms so are unlikely to use this facility.
Monitors for train rolling away	Yes, and monitors correspondence between direction of movement and controller position.	No	No

Table 14 Comparative Analysis of GW-ATP, TPWS and Enhanced TPWS

Appendix C TPWS Requirements from GE/RT8075

Provision of TPWS track equipment
3.1.3.1 TPWS track sub-system equipment shall be provided on all passenger lines at the locations specified in 3.1.3.2 to 3.1.3.8, except where exemptions are permitted by 3.1.4.
3.1.3.2 TPWS shall be provided on passenger lines at all main stop signals and stop boards that protect crossing or converging movements with any running line or siding.
3.1.3.3 TPWS shall be provided at any main stop signal on a non-passenger line that protects a crossing of, or convergence with, a passenger line.
3.1.3.4 TPWS shall be provided at a stop signal where conflicting movements could take place in the overlap of the next stop signal ahead.
3.1.3.5 On non-track circuit block lines with a semaphore equivalent aspect sequence, TPWS shall be provided at the first home signal at the end of a block section where conflicting movements could take place within station limits ahead.
3.1.3.6 It is permissible to provide TPWS at other signals where required for mitigation of SPAD risk, as set out in GK/RT0045.
3.1.3.7 TPWS shall be provided on the approach to the buffer stop at the end of a passenger platform.
3.1.3.8 TPWS shall be provided on the approach to speed restrictions where the permitted speed on the approach is 60 mph or more and the speed restriction reduces the speed by at least one-third, except for:
a) Temporary speed restrictions in place for three months or less.
And
b) Temporary speed restrictions in place for between three months and twelve months, subject to risk assessment, as set out in 3.1.4.2

Appendix D Pre-Enhancement TPWS Effectiveness (Class 345)

Signal No.	TPWS Class 345 Effectiveness Prior to Enhancement
SN111 (1)	100.0%
SN123	98.3%
SN127	99.6%
SN137	100.0%
SN153	100.0%
SN163	100.0%
SN175	100.0%
SN187	95.6%
SN199	100.0%
SN203	100.0%
SN209	0.0%
SN211	100.0%
SN215	100.0%
SN225	100.0%
SN233	100.0%
SN239	100.0%
SN243	100.0%
SN253	0.0%
SN265	100.0%
SN273	0.0%
SN283	100.0%
SN287	100.0%
SN303	100.0%
SN323	0.0%
SN316	0.0%
SN292	91.0%
SN284	100.0%
SN276	100.0%
SN266	0.0%
SN258	100.0%
SN248	100.0%
SN244	0.0%
SN238	100.0%
SN232	99.5%
SN224	100.0%

Signal No.	TPWS Class 345 Effectiveness Prior to Enhancement
SN214	0.0%
SN210	100.0%
SN206	74.5%
SN202	100.0%
SN192	100.0%
SN186	100.0%
SN174	100.0%
SN164	100.0%
SN156	100.0%
SN144	100.0%
SN134	100.0%
SN114	100.0%
SN112	100.0%
SN107	100.0%
SN125 (1)	100.0%
SN125 (2)	100.0%
SN135	99.7%
SN151	0.0%
SN159	0.0%
SN173	0.0%
SN179	0.0%
SN191	0.0%
SN201	99.2%
SN207	0.0%
SN213	0.0%
SN231	0.0%
SN237	0.0%
SN249	100.0%
SN255	100.0%
SN271	100.0%
SN285	100.0%
SN319	0.0%
SN321	0.0%
SN316	0.0%
SN300	100.0%
SN280	100.0%
SN270	100.0%
SN254	100.0%
SN246	0.0%
SN234	0.0%
SN222	0.0%

Signal No.	TPWS Class 345 Effectiveness Prior to Enhancement
SN212	0.0%
SN204	99.7%
SN194	0.0%
SN178	0.0%
SN160	0.0%
SN146	0.0%
SN120	100.0%
SN106 (2)	100.0%
SN316	0.0%
SN292	91.0%
SN284	100.0%
SN276	100.0%
SN266	0.0%
SN258	100.0%
SN248	100.0%
SN244	0.0%
SN238	100.0%
SN232	99.5%
SN224	100.0%
SN214	0.0%
SN210	100.0%
SN206	74.5%
SN202	100.0%
SN192	100.0%
SN186	100.0%
SN174	100.0%
SN164	100.0%
SN156	100.0%
SN144	100.0%
SN134	100.0%
SN114	100.0%
SN112	100.0%
SN316	0.0%
SN300	100.0%
SN280	100.0%
SN270	100.0%
SN254	100.0%
SN246	0.0%
SN234	0.0%
SN222	0.0%
SN212	0.0%

Signal No.	TPWS Class 345 Effectiveness Prior to Enhancement
SN204	99.7%
SN194	0.0%
SN178	0.0%
SN160	0.0%
SN146	0.0%
SN120	100.0%
SN106 (2)	100.0%
SN111 (1)	100.0%
SN123	98.3%
SN127	99.6%
SN137	100.0%
SN153	100.0%
SN163	100.0%
SN175	100.0%
SN187	95.6%
SN199	100.0%
SN203	100.0%
SN209	0.0%
SN211	100.0%
SN215	100.0%
SN225	100.0%
SN233	100.0%
SN239	100.0%
SN243	100.0%
SN253	0.0%
SN265	100.0%
SN273	0.0%
SN283	100.0%
SN287	100.0%
SN303	100.0%
SN323	0.0%
SN107	100.0%
SN125 (1)	100.0%
SN125 (2)	100.0%
SN135	99.7%
SN151	0.0%
SN159	0.0%
SN173	0.0%
SN179	0.0%
SN191	0.0%
SN201	99.2%

Signal No.	TPWS Class 345 Effectiveness Prior to Enhancement
SN207	0.0%
SN213	0.0%
SN231	0.0%
SN237	0.0%
SN249	100.0%
SN255	100.0%
SN271	100.0%
SN285	100.0%
SN319	0.0%
SN321	0.0%

Table 15 TPWS Effectiveness for Class 345 as delivered by Crossrail Scheme (Ref. 5) (Ref. 2)(no enhancement)

Appendix E Options Selection Table

Pre-Workshop		Post-Workshop		Decision and Justification	Comment	Section
Option No	**Option**	**Option No**	**Option**			
0	Do Nothing - Run Crossrail Operations in Level NTC, with no further infrastructure changes other than those currently planned.	0	Do Nothing - Run Crossrail Operations in Level NTC, with no further infrastructure changes other than those currently planned.	Not Credible - Option 15 incorporates Option 0	Option 15 retained after Stage 1 analysis.	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.1
1	Standard TPWS Implementation from 0m to 12m30ch (including fly-over). TPWS integrated into control system with fault reporting	1	Standard TPWS Implementation from 0m to 12m30ch (including fly-over). TPWS integrated into control system with fault reporting	At Stage 2 deemed not credible - Below the minimum option for protection. Not acceptable to retain existing train protection system.	Stage 1 - Passed	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.2
2	(Option 1) plus compliance to TI022 (integrated into control system with fault reporting).	2	(Option 1) plus compliance to TI022 (integrated into control system with fault reporting).	At Stage 2 deemed not credible - Below the minimum option for protection.	Stage 1 - Passed	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.3
3	(Option 2) plus the addition of TPWS on all auto signals (integrated into control system with fault reporting).	3	(Option 2) plus the addition of TPWS on all auto signals (integrated into control system with fault reporting).	Credible - meets the minimum baseline requirement	Goes forward for HAZID analysis	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.4

Pre-Workshop		Post-Workshop		Decision and Justification	Comment	Section
Option No	**Option**	**Option No**	**Option**			
4	Enhanced TPWS: as per SDG report for all signals (integrated into control system for fault reporting)	4	Enhanced TPWS: as per SDG report for all signals (integrated into control system for fault reporting)	Credible - meets the minimum baseline requirement	Goes forward for HAZID analysis	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.5
5	(Option 4) with enhanced TPWS on PSRs, MAR, MAY (integrated into control system with fault reporting).	5	(Option 4) with enhanced TPWS on PSRs, MAR, MAY (integrated into control system with fault reporting).	Credible - meets the minimum baseline requirement	Goes forward for HAZID analysis	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.6
6	(Option 5) but no fault reporting/integration into control system for additional TPWS that are not being provided by Crossrail scheme ("bolt-on" TPWS).	6	(Option 5) but no fault reporting/integration into control system for additional TPWS that are not being provided by Crossrail scheme ("bolt-on" TPWS).	At Stage 2 deemed not credible but retained as a bolt on option depending on the infrastructure.	N/A	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.7
7	Fit GW-ATP to Crossrail Class 345 Rolling Stock	7	Fit GW-ATP to Crossrail Class 345 Rolling Stock	At Stage 2 deemed not credible - Cannot risk the delay in delivery and there is quite an impact on cost due to rolling stock. The reputational damage to NR is also large.	N/A	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.8
8	Fit ETCS Level 1	8	Fit ETCS Level 1	At Stage 1 deemed not credible - As per the report disadvantages analysis.	N/A	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.9

Pre-Workshop		Post-Workshop		Decision and Justification	Comment	Section
Option No	**Option**	**Option No**	**Option**			
9	Alter track layout such that Crossrail Operations are physically Isolated from GWML.	9	Alter track layout such that Crossrail Operations are physically Isolated from GWML.	At Stage 1 deemed Not Credible - As per the report analysis Operationally impractical to physically isolate 2 lines out of Paddington.	To be utilised as a potential HAZID control measure along with Option 11 for credible options 3, 4, and 5. - Uses a dedicated line which is envisaged as line 6 only (freight only) which will become the Crossrail WB line.	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.10
10	Utilise existing GW-ATP stock (e.g. HEX/Heathrow Connect) for additional Paddington to Heathrow shuttle until ETCS Level 2 provided.	10	Utilise existing GW-ATP stock (e.g. HEX/Heathrow Connect) for additional Paddington to Heathrow shuttle until ETCS Level 2 provided.	At Stage 2 Retained	To be retained as open, the client will advise the action owning party to undertake for further analysis.	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.11
11	Separate Class 345 Trains by Time (absolute block equivalent).	11	Separate Class 345 Trains by Time (absolute block equivalent).	At Stage 1 deemed not credible - As per the report analysis. Causes extensive operational issues.	To be utilised as a potential HAZID control measure along with Option 11 for credible options 3, 4, and 5. - Uses a dedicated line which is envisaged as line 6 only (freight only) which will become the Crossrail WB line.	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.12

Pre-Workshop		Post-Workshop		Decision and Justification	Comment	Section
Option No	Option	Option No	Option			
12	Second Driver on the Footplate of Class 345.	12	Second Driver on the Footplate of Class 345.	At stage 1 deemed not credible - As per the report analysis.	To be utilised as a potential HAZID control measure - Second driver for use in degraded mode.	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.13
13	Utilise Available IEP Rolling Stock.	13	Utilise Available IEP Rolling Stock.	At Stage 1 deemed Not credible - due to extended train compatibility issues such as route clearance issues and crash worthiness.	N/A	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.14
14	Delay Running 4 tph Crossrail Service until ETCS Level 2 is in operational use.	14	Delay Running 4 tph Crossrail Service until ETCS Level 2 is in operational use.	Noted as an outcome and not an option. Furthermore it is also deemed unacceptable to delay Crossrail.	N/A	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.15
15	(Option 0) but with Minimum Transition Infrastructure to ETCS L2 at SN321/SN323/SN325 to enable ETCS L2 Operations.	15	(Option 0) but with Minimum Transition Infrastructure to ETCS L2 at SN321/SN323/SN325 to enable ETCS L2 Operations.	Not Credible - Linked to Option 0 - It is below the minimum requirement. ORR are not likely to accept this.	N/A	Crossrail ETCS GRIP 1-3 Options Analysis Section 3.16

Discontinued
In Discussion
Retained

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