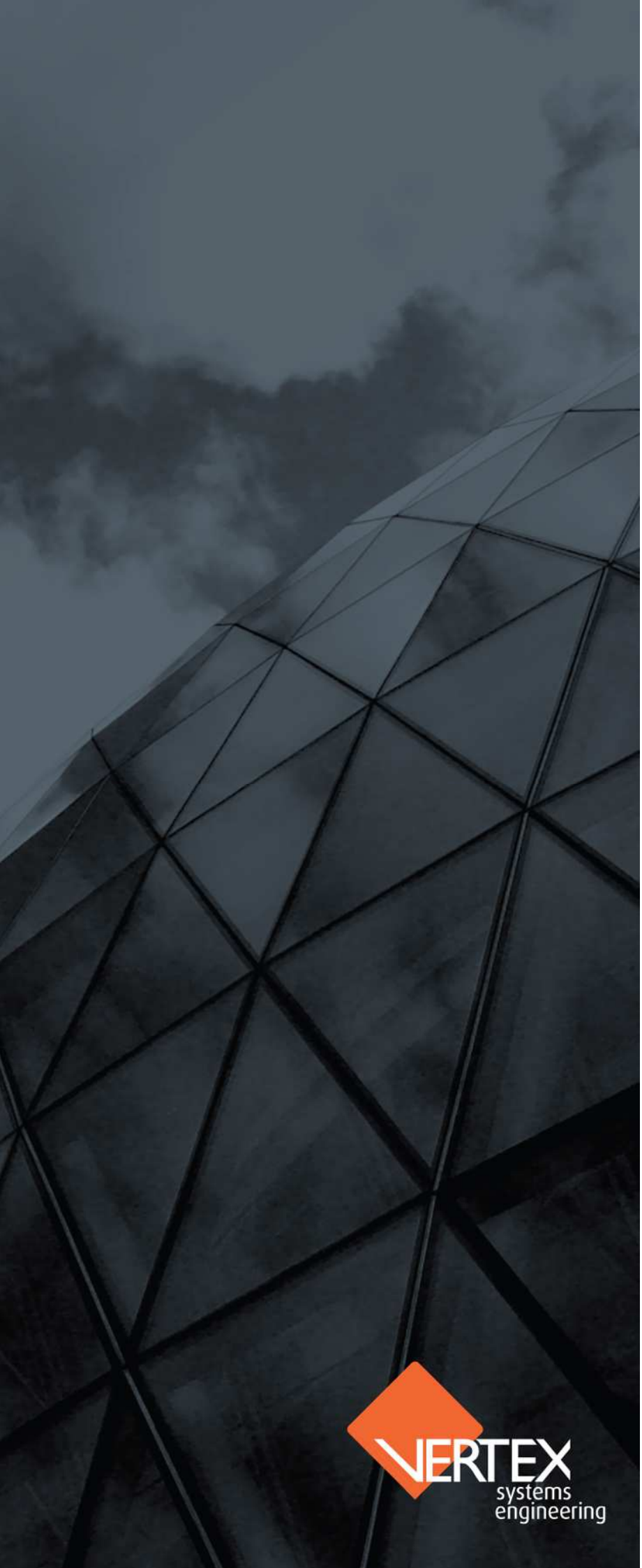

A Report for
Network Rail
from
Vertex Systems Engineering

Version 1.4
24th March 2015

Crossrail ETCS
Final Option Selection

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AMENDMENT HISTORY		
Version	Sections	Amendment Details
1.0	All	First Issue for progress update session
1.1	5.1. and 5.3	Updated to reflect Client comments
1.2	6	Section added to consider impact of increasing ETCS delay to 20 months
1.3	8	Updated to reflect up version to reference item Crossrail ETCS GRIP 1-3 Options Analysis, v3.3 10th February 2015
1.4	1	Typo corrected in Section 1.

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Table of Contents

1 Introduction and Purpose

This paper is an addendum to the previously issued Options Analysis Report (Ref. 1), which investigates Options that could be deployed should ETCS be delayed on the Great Western Main Line until after the introduction of Crossrail Class 345 services.

The paper provides a summary of a Workshop held on the 25th of September 2014 and subsequent hazard analysis of the final selected option.

The Workshop considered the three credible options carried forward from a previous Option Selection Workshop (see Section 6 and Ref 1). These are:

- Option No 3: Standard TPWS Implementation to TI022 from 0m to 12m30ch plus the addition of TPWS on all auto signals
- Option No 4: Enhanced TPWS as per SDG report (Ref. 4) for all signals
- Option No 5: As Option 4 with enhanced TPWS on PSRs, MAR, MAY

These Options were refined at this Workshop to give more detail as to their implementation. They were then assessed against a set of criteria to determine a single Option to be carried forward. This process is detailed further in section 4.

The final selected Option was analysed via a HAZID, findings from which are provided in Appendix D.

2 Methodology

2.1 Options Refinement of the Three Carried Forward Options

Given the system definition variations possible within each Option, the panel conducted a refinement of the 3 Options to generate a more detailed system description. The group determined the approach be based on:

1) If the design is within standards
2) Method 1 or 3 integration into interlocking to be used
3) Fault reporting to signaller is “Blue Square” or “Lamp out”
4) Lines to be fitted
5) Estimated Option Cost (see Appendix B) and Practicability based upon refined System Definition

During this phase, the group identified criteria for Option Evaluation and Hazard Identification (see section 2.2). These were captured in a spread-sheet which was later used to evaluate the refined Options whilst being displayed to the group via a projector.

2.2 Evaluation Criteria for Single Option Selection

The group identified the following areas for analysis:

1) Safety
    a. SPAD risk
    b. Overspeed/Derailment risk
        i. PSRs/TSRs
        ii. MAY-FA/MAR considerations
    c. Risk to Workers
    d. Operational Risk (Safety – degraded mode Ops)
2) Operational risk (delay – degraded mode Ops)
3) Maintenance Impacts
    a. Access
    b. Workload
4) Option Costs

5) ORR Acceptability (Railway Regs 1999)
6) Deliverability
7) Operability of Signalling Transition(s)

2.3 HAZID of Final Selected Option

A HAZID analysis was done on the final selected Option in-line with the Briefing Note (ref. 2). This HAZID was formally created in the appropriate spreadsheet template following the Workshop by Vertex. However, the Hazards were principally identified during the Workshop as part of the Options selection process.

3 Options Refinement Findings

3.1 Scope of Fitment - Compliance with Design Standards

The group assessed all Options to be compliant, as all mandate TPWS fitments in excess of signalling design standards.

3.2 TPWS Interlocking Integration Method and Fault Reporting Indications

The group rejected Method 1 on basis of impracticability/cost. The benefits of Method 1 would be lost to signallers in the majority of cases since the current control system uses 'Lamp Out' failure reporting for TPWS and mixed indications are not permitted by Standards i.e. even if Method 1 was utilised, signallers would not receive the benefit in terms of indications.

Use of Method 3 was considered the most practicable approach, since data changes can be avoided. Method 3 was considered compliant with standards since the Options are retro-fitments to existing signalling rather than a new scheme.

3.3 Lines to be Fitted (Mains v Reliefs)

The Crossrail Class 345 services are scheduled to only use Relief lines excepting in perturbed running. The Group therefore considered whether Options should be deployed on Relief lines only or Mains and Reliefs.

It was noted that perturbed running occurs nightly and every weekend at Paddington due to scheduled maintenance possessions. The Group therefore concluded that both Mains and Reliefs should be fitted for all Options.

3.4 Comparative Options Cost Calculation

The Options have been estimated as having the following costs (OPEX and CAPEX) over their lifecycle:

Option 3	Option 4	Option 5
£7.5M	£11.2M	£13.9M

For details of how these figures were reached, see Appendix B.

3.5 Conclusion of Options Refinement

The Conclusion of this phase of works was that fitment should be carried out on both Mains and Reliefs using Method 3 integration into the interlocking. All Options would then be viable and compliant with Standards.

4 Options Evaluation

4.1 Safety

4.1.1 SPAD Risk

Option 3	Option 4	Option 5
Meeting TI-022 requirements means there is minimal SPAD risk from fitted signals. Class 345 stops in Safe Overrun Distance (SOD): fully effective for 12%g braking.	The maximum over-run distance is limited to within the overlap. This eliminates residual risk of SPAD compared to Option 3. Given low rates of collisions caused by SPAD across the Network and the minor differences in TPWS effectiveness, the additional expense of enhancing TPWS OSS to stop Class 345 trains in the signal overlap was not considered justified by the Group. Post-meeting note - analysis of the TPWS effectiveness of 'standard' vs 'enhanced' TPWS positioning, has illustrated that there are only minor benefits to implementing Option 4 as opposed to Option 3 in terms of preventing collisions following a SPAD. This conforms with the conclusion of the Group during the meeting.	Option 5 offers minimal advantages over Option 4 in terms of SPAD. Option 5 can only contribute to SPAD reduction due to control of speed on approach to signals. However, this would only impact traffic with inferior braking characteristics than Class 345, since TPWS is 100% effective for 12%g braking stock.

4.1.2 Overspeed/Derailment Risk

Option 3	Option 4	Option 5
This option does not provide protection for speed limits, since speed is controlled only at signal approaches and regulated speed restrictions in line with existing requirements for TPWS deployment. TPWS cannot provide continuous speed supervision and is inherently inferior to ATP in this regards The substitution of non-GW-ATP operations also marginally increases derailment risks on approach to MAY-FA junctions should the lower speed route be set. 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 over speed. On approach to MAR- OSS would be armed when signal at red. Effect would be dependent on whether train has passed OSS when signal steps up. The Group considered that the partial replication of ATP functionality in terms of enforcing non-Regulated speed restrictions via TPWS OSS was not justified. The reasons for this decision were: The UK uses a route-knowledge based system of driver training and in all non-ATP areas this is considered sufficient TPWS can only provide spot, not continuous supervision The number of incidences of derailment caused by over-speed throughout the network (the vast majority of which is not ATP-fitted) are relatively low	Same as Option 3 - Option 4 only affects the stopping position of SPADing stock.	Option 5 produces some benefits since OSS would be deployed at PSRs and TSRs and on approach to diverging speed junctions. However, these OSS would only be 'spot' supervision and drivers could accelerate after having encountered them.

4.1.3 Risk to Workers

Option 3	Option 4	Option 5
Installing and maintaining equipment exposes workers to the risks of lineside working. For maintenance workers this extends to the lifespan of the equipment. To minimise this risk, the Option with the lowest amount of additional lineside equipment is therefore desirable.	Option 4 has more OSS than Option 3 (41 vs 73) and therefore greater risk to workers both from installation and on-going maintenance works.	Option 5 has more OSS than Option 3 or Option 4 (41 vs 73 vs 108) and therefore greater risk to workers both from installation and on-going maintenance works.

4.1.4 Operational Risk

Option 3	Option 4	Option 5
Method 3 integration is not helpful to maintainers or signallers in terms of identifying TPWS failures. More equipment on the track means more failures. These will be right-side failures and will cause the signal in rear to be replaced to red. This will trigger degraded mode working for the signaller whilst the issue is diagnosed and repaired. Degraded mode working is inherently less safe than normal mode operation. 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. TPWS tripping is more binary than ATP due to no 'caution' warning - emergency braking of TPWS trains more likely. Emergency braking can lead to minor on-board injuries to passengers due to falling.	Issues are the same as Option 3, but will occur with more frequency due to the larger amount of equipment required by Option 4.	As per Option 4 for degraded mode impact: Additional units for Option 5 would not be cut into interlocking if used as stand-alone units for PSRs/TSRs. Option 5 would increase risk of tripping ATP trains relative to Option 3 and 4 since there is more equipment regulating speed limits.

4.2 Operational Risk (Delays)

Option 3	Option 4	Option 5
Method 3 integration is not helpful to maintainers or signallers in terms of identifying TPWS failures. More equipment on the track means more failures. These will be right-side failures and will cause the signal in rear to be replaced to red. This will trigger degraded mode working for the signaller whilst the issue is diagnosed and repaired. This will lead to service delays. 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. Tripping of TPWS will lead to delays whilst the system is reset. Should the TPWS equipment not be removed prior to deployment of ETCS, would mean another 25 years of operational difficulties.	Issues are the same as Option 3, but will occur with more frequency due to the larger amount of equipment required by Option 4.	As per Option 4 for degraded mode impact: Additional units for Option 5 would not be cut into interlocking. Option 5 would increase risk of tripping ATP trains relative to Option 3 and 4 since there is more equipment regulating speed limits.

4.3 Maintenance Impacts

4.3.1 Access

Option 3	Option 4	Option 5
Increased installations of TPWS, increases the number of failures expected. Additional failures lead to diversion of maintenance workers from routine/scheduled maintenance to fault response works. Additionally, during signalling failures, the increased workload on signallers has a direct impact on access between 0m – 4m and 4m – 12m, since signallers will not accept possessions etc. during degraded mode operations. Currently access between 0m – 4m and 4m – 12m is restricted to no more than 2 x Line Blockages - 4 in total More equipment means more scheduled maintenance required: increases demand on access and possession shifts. Access to Paddington area is already extremely limited.	Issues are the same as Option 3, but will occur with more frequency due to the larger amount of equipment required by Option 4.	Issues are the same as Option 3, but will occur with more frequency due to the larger amount of equipment required by Option 5.

4.3.2 Workload/Resources

Option 3	Option 4	Option 5
The number of additional TPWS installations represents a considerable additional expense in terms of on-going maintenance. Therefore approx. 25 years of ongoing maintenance costs for the additional TPWS units are implicit in this option. More line side equipment may be required, i.e.; cable protections, UTXs, etc. More equipment means more scheduled maintenance required: increases loading on existing resources or leads to requirement for more staff.	Issues are the same as Option 3, but will occur with more frequency due to the larger amount of equipment required by Option 4.	Issues are the same as Option 3/4, but will occur with more frequency due to the larger amount of equipment required by Option 5.

4.3.3 Options Costs

Option 3	Option 4	Option 5
CAPEX: £7.3m Approximately OPEX: £207k (over 25 yrs)	CAPEX: £10.8m Approximately OPEX: £318k (over 25 yrs)	CAPEX: £13.5m Approximately OPEX: £439k (over 25 yrs)

4.3.4 ORR Acceptability

Option 3	Option 4	Option 5
Since ATP infrastructure is present, the Option is potentially unsatisfactory due to non-continuous speed supervision. The provision of TPWS on all signals may satisfy the requirement for Train Protection to prevent SPAD.	Since ATP infrastructure is present, the Option is potentially unsatisfactory due to non-continuous speed supervision. The provision of TPWS on all signals may satisfy the requirement for Train Protection to prevent SPAD.	Since ATP infrastructure is present, the Option is potentially unsatisfactory due to non-continuous speed supervision. However, Option 5 gives 'spot' speed supervision and is therefore an improvement in this regard compared to Options 3 & 4. The provision of TPWS on all signals may satisfy the requirement for Train Protection to prevent SPAD.

4.3.5 Deliverability

Option 3	Option 4	Option 5
The additional package of works to those already in planning by Crossrail would require considerable reworking of the Crossrail signalling delivery programme.	As per Option 3 but more acute due to increased number changes to existing signal plans required (moving OSS to enhanced positions as well as fitting signals that currently don't have TPWS).	As per Option 4 but more acute due to the need for additional OSS at non-signal locations.

4.3.6 Signalling Transition(s)

Option 3	Option 4	Option 5
New fringe NTC:L2 created. This will create a driver training requirement and additional infrastructure to be placed on the lineside (balises, signage).	Same for all Options.	Same for all Options.

5 Conclusion and Next Steps

5.1 Option Refinement

The three brought-forward Options were initially refined to provide a more detailed System Definition for each Option. The conclusion of this Phase of the process was that:

- All Options exceed Standards in terms of what signals should be TPWS fitted
- All new TPWS can be installed using SSI Interface Method 3 to avoid impacting on Plan A; Method 1 would provide little benefit over Method 3 without providing a new IECC screen to display a TPWS fault. It was considered reasonable for a signaller to assume that a “lamp out” is a TPWS fault because as all signals are LED (high availability).
- All Options should be fitted on both Mains and Reliefs

5.2 Options Evaluation

The Options Evaluation process considered each Option against a variety of Criteria. The most important of these are Safety-related. The conclusions are as follows:

5.2.1 SPAD Risk

The Group considered that there was only minor benefit to be achieved in fitting signals with enhanced TPWS to 12% G braking trains to be stopped in the overlap as opposed to the SOD.

It was proposed to use TPWS Calculators to determine the TPWS Effectiveness for Option 3 and 4 in order to quantify the difference between the two Options (see Appendix C). These calculations show that there is no increase in effectiveness for Option 4 v Option 3 on the Up and Down Mains. On the Reliefs, the vast majority of signals do not benefit from Option 4 enhancement and those which show benefit are typically less than 0.5% more effective with Option 4 than Option 3. The maximum loss of effectiveness is 1.6% for SN123.

The difference in effectiveness was not considered significant enough to warrant the enhancement of TPWS as mandated by Options 4 and 5, due to the increased cost of fitments and the increase in risk to workers who must install and maintain the additional equipment. Option 3 has the lowest amount of equipment fitted and therefore is the preferred Option on this measure.

For context, the RSSB Safety Risk Model calculates there to be 0.24 incidents a year of SPADs by passenger trains leading to collisions (HET-01 and HET-02P) across the entire network (0.5 FWI risk).

It should be noted that meeting TI-022 requirements results in 100% effectiveness of TPWS for Class 345 trains.

5.2.2 Overspeed/Derailment Risk

The Group noted that ATP currently protects trains from overspeed, as it is fitted to PSRs and TSRs and enforces speed limits. The Group also noted that, other than Regulated Speed Restrictions, the enforcement of speed restrictions via TPWS is not required in non-ATP areas which make up the vast majority of the Network.

The Group did not feel that, given the UK's philosophy of route-based driver training, that speed enforcement (other than mandated in Standards for Regulated Speed Restrictions) is required. Non-fitment of additional OSS for enforcement of speed limits also reduces exposure to line-side working, thus reducing risks for installation and maintenance staff.

For context, the RSSB Safety Risk Model does not discriminate between derailments caused by Overspeed trains or for other reasons, but gives a figure of 5.7 incidences (HET-12) for passenger trains a year across the whole Network (1.62 FWI total risk for all incidents).

5.2.3 Risk to Workers

Any infrastructure amendments requiring trackside working for either installation or on-going maintenance would increase risks to staff. Therefore, the Group concluded that Options with the lowest additional equipment burden would be preferable to those requiring more equipment to be fitted/maintained.

For context, the RSSB Safety Risk Model gives the 4.3 incidences a year of infrastructure workers struck by trains (HEM19) with a total risk of 1.6 FWI per year across the Network.

5.2.4 Operations Risk (Safety)

The addition of TPWS required by all Options increases the number of signalling failures that will be expected on the route. The effect of a TPWS failure is to hold the signal in rear at red, leading to delays. Whilst the fault is being investigated/repaired, signallers will be utilising degraded mode operations which increases the likelihood of an error being made since full interlocking protection will not be in place should e.g. trains be talked past red signals.

5.3 Final Option Selection

The Group selected Option 3: Installation of TI022 compliant TPWS to all signals (including auto signals) on both the Mains & Reliefs (excluding further fitments for over-speed and junctions etc.).

Additional TPWS enhancement to limit SPAD to the overlap and additional fitments to mitigate over-speed at speed restrictions and junctions was rejected. This was due to the increased costs and safety risks associated with maintenance (staff exposure) of these additional units for relatively minimal additional safety benefit from over-speed incidents.

5.4 HAZID of Option 3

The selected Option, Option 3, was subjected to a HAZID as described in the Briefing Note (Ref. 2). The HAZID was recorded by VSE and took account of the Hazards identified as part of this Workshop and also independent review of the Option by Vertex.

The HAZID has resulted in the production of a Hazard Log, in Excel format, which will be used to identify and control Hazards associated with Option 3.

A summary of the identified Hazards can be found in Appendix D. The full Hazard Log will be issued for review by the Panel.

Hazard Classification	No. of Hazards prior to Mitigation	No. of Hazards Following Mitigation
Negligible	3	0
Tolerable	11	14
Intolerable	1	1

The Hazard Log contains details of the mitigations applied. These mitigations would form part of the conditions of any Safety Case developed for the project. The Hazard Log has been handed over to Network Rail for its continued development.

6 Further Update- Delay in ERTMS Up to December 2019

6.1 Introduction

Supporting Network Rail's wider submission to ORR, NR requested Vertex to consider a lengthening of the period ERTMS L2 is unavailable for up to 20 months until December 2019. This to be considered specifically in relation to the three carried forward Options 3, 4 and 5. This will:

- Be over and above the existing consideration of an 8 month time bound exemption period.
- Cover all rolling stock that currently uses the section of track between 0mp and 12m30ch (Heathrow Tunnel) i.e.: Not limited to non-ATP Crossrail rolling stock.

6.2 Methodology

The following process was followed

1) Assess the Options Analysis report (Ref 1) to determine assumptions affected by the request.
2) Determine new and or updated assumptions.
3) Assesses the three carried forward Options 3, 4 and 5 for a period of up to 20 months, specifically the changes in analysis findings relative to the original analysis (and 13 criteria items) for 20 months vs 8 months.
4) Assess the changes to the HAZID of Option 3 for a period of up to 20 months, specifically the changes in analysis findings relative to the original analysis for an exemption period of 8 months including new hazards, change in existing hazards, frequency or consequence.

6.3 Findings

The findings are detailed in the followed sections.

6.3.1 Assumptions Check

The following table details the assumptions associated with Options 3, 4 and 5 and whether they remain Valid or Not-Valid by the change in timespan.

Two additional Assumptions (15 and 16) have been added.

No	Assumption	Options 3, 4 and 5 Affected	0 to 8 months	8 to 20 months
1)	Crossrail Class 345 trains will have TPWS and AWS functionality via ETCS Level NTC.	Yes	Valid	Valid
2)	Crossrail drivers are competent in the use of TPWS/AWS “legacy” systems from April 2018.	Yes	Valid	Valid
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).	Yes	Valid	Valid
4)	GSM-R voice communications will be available from April 2018	Yes , where rolling stock Class uses GSM-R voice communications	Valid	Valid
5)	GWML ETCS shall be provided by December 2018 and that Crossrail operations are required from April 2018 (4 tph Paddington to Heathrow).	Yes	Valid	Not Valid
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.	Yes	Valid	Not Valid
7)	IEP Class 800 rolling stock has infrastructure compatibility for entire current HEX route.	No	Valid	Valid
8)	IEP Class 800 rolling stock can transition from GW-ATP to ETCS L2 signalling	No	Valid	Valid
9)	Provision of ETCS on HEX infrastructure will not result in the removal of existing GW-ATP/AWS infrastructure.	No	Valid	Valid
10)	Class 345 rolling stock can transition from ETCS Level NTC (or Level 1) to Level 2 operations and vice-versa.	Yes	Valid	Valid

No	Assumption	Options 3, 4 and 5 Affected	0 to 8 months	8 to 20 months
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.	Yes	Valid	Valid
12)	Use of Level NTC operations by Crossrail would be discontinued in favour of Level 2 as soon as functionality is available.	Yes	Valid	Valid
13)	Class 345 cab is suitable for double-crewing.	No	Valid	Valid
14)	Timetable will not change to that which is currently found in the TPWS spreadsheets	Yes	Not Valid	Valid
15)	**IEP running will not commence prior to ETCS L2 Operation**	**Yes**	**Not Valid**	**Valid**
16)	**2017 Crossrail stageworks are as presented in the scheme plans supplied to Vertex**	**Yes**	**Not Valid**	**Valid**

6.3.2 Options Analysis for 20 months ETCS Delay

The Options Analysis was considered with the new context of a 20 month ETCS delay, as opposed to 8 months. This concluded that there were no significant changes to the 13 assessment criteria, provided the new assumptions (15 and 16) are valid.

Option No	Findings
3	No Significant Changes
4	No Significant Changes
5	No Significant Changes

6.3.3 HAZID of Option 3

The assessment of changes to the HAZID of Option 3 relative to the original analysis identified no significant changes to either the Frequency or Consequence associated with the potentially increased time period of non-ETCS running.

7 Conclusion

A period of 20 months delay to ETCS specifically in relation to the three carried forward Options shows no significant changes relative to the previously completed:

- Options Analysis - Option 3 is still the preferred Option
- HAZID of Option 3

This is due to:

- The new timeframe resulting in no major changes to technology, construction, operation and timetable detailed for the 0 to 8 month exemption.
- The originally allocated Hazid frequencies considered are of sufficient robustness to be applicable to an extended time period of non-ETCS running.
- The lifespan of the installed equipment being greater than 20 months

The above conclusions are contingent on the revised assumptions table.

8 References

1) Vertex Systems Engineering, Crossrail ETCS GRIP 1-3 Options Analysis, v3.3 10th February 2015
2) Vertex Systems Engineering, Crossrail ETCS GRIP 3 Hazid Workshop Pre-Meeting Note
3) TPWS Effectiveness Calculations, 12227-ISD-CAL-ESG-000014 to 000017
4) ETCS "Plan B" Study 122271ISD-ASS-ESG-0000001. Version: 1.0; 27th June 2014
5) RSSB Safety Risk Model v8.1, 1st July 2014, Table A1

Appendix A Workshop Attendance Register

MEETING ATTENDANCE RECORD

Meeting Title	Crossrail ETCS GRIP 3 Hazid Workshop
Date	25/09/14
Location	Hardwick House

NAME	√ / ∝	Signature
Siraj Ali, Consultant VSE		
STEVE HEBBES, " "		
SIAN HARDAKER " "		
JOLLY AHUJA " "		
SIV SIVAPALAN		
PETE ELSTON		
DANIEL SMART		
STEVEN WOOD		
LOUIS [illegible]		
Christopher Wells		
IAN WATSON		
DAVID [illegible]		
RICHARD EVANS		

Appendix B Option Costings

B.1 CAPEX

Option	New TSS	New OSS	Total Capital Cost
3	19	41	£7.3M
4	19	73	£10.9M
5	19	108	£13.5M

B.2 OPEX

Routine Maintenance Costs

Estimates are based on 1 visit a year of duration 20.4 minutes for both TSS and OSS. 20.4 mins is a combined 'A' (10.2) and 'B' (10.2) service. Cost per minute for a 2-man maintenance team has been estimated at £4.

Option	Additional Grills	Cost Per Year	Cost over 25 years
3	60	£6,364.80	£122,400
4	92	£7,507.20	£187,680
5	127	£10,363.20	£259,080

Estimated Faulting Costs

Estimation of MTBF provided by Eddy Schwartz:

No of Assets Padd to Stockley Jcn	179
No of Failures on Asset Padd to Stockley Jcn	253
No of Months	36
MTBF = No of Assets x Months / No of Failures	
MTBF =	25.47 Months (2.12 years)

Time to fix a TPWS failure has been estimated at 30 minutes, with a £4 per minute cost of a 2-man maintenance team.

Option	Additional Grills	Expected Failures/ Year	Cost/ 25 year lifespan
3	60	36.74912	£84,806
4	92	43.34511	£130,035
5	127	59.8351	£179,505

The faulting costs do not take into account the cost of delay minutes.

Appendix C Comparative TPWS Effectiveness

		Overall TPWS+ATP % Effectiveness	Overall TPWS+ATP % Effectiveness		Overall TPWS+ATP % Effectiveness	
Line	Signal Number	With TI-022 + Auto Signals & Class 345 services (=Option 3)	With GW-ATP & Connect services	Change	With Plan B & Class 345 services (=Option 4)	Change
Up Relief	SN316	96.7%	98.0%	-1.3%	96.7%	0.0%
Up Relief	SN292	95.0%	98.0%	-3.0%	95.0%	0.0%
Up Relief	SN284	93.9%	94.3%	-0.4%	93.9%	0.0%
Up Relief	SN276	94.4%	94.9%	-0.5%	94.2%	0.2%
Up Relief	SN266	92.4%	21.2%	71.2%	92.4%	0.0%
Up Relief	SN258	94.9%	95.5%	-0.6%	95.0%	0.0%
Up Relief	SN248	95.0%	95.6%	-0.6%	95.0%	0.0%
Up Relief	SN244	92.4%	21.2%	71.2%	92.4%	0.0%
Up Relief	SN238	93.1%	93.3%	-0.2%	93.1%	0.0%
Up Relief	SN232	93.4%	94.0%	-0.5%	93.6%	-0.1%
Up Relief	SN224	95.0%	95.6%	-0.6%	94.9%	0.1%
Up Relief	SN214	92.5%	21.2%	71.3%	92.5%	0.0%
Up Relief	SN210	93.8%	94.2%	-0.4%	94.3%	-0.5%
Up Relief	SN206	92.6%	75.0%	17.6%	92.6%	0.0%
Up Relief	SN202	92.2%	92.7%	-0.4%	92.5%	-0.3%
Up Relief	SN192	95.0%	95.7%	-0.8%	95.0%	0.0%
Up Relief	SN186	95.0%	95.8%	-0.8%	95.0%	0.0%
Up Relief	SN174	95.0%	95.8%	-0.8%	95.0%	0.0%
Up Relief	SN164	95.0%	95.8%	-0.8%	95.0%	0.0%
Up Relief	SN156	95.0%	95.8%	-0.8%	95.0%	0.0%
Up Relief	SN144	95.0%	95.8%	-0.8%	95.0%	0.0%
Up Relief	SN134	95.0%	95.8%	-0.8%	95.0%	0.0%
Up Relief	SN114	95.0%	95.8%	-0.8%	95.0%	0.0%
Up Relief	SN112	95.0%	95.8%	-0.8%	95.0%	0.0%
Down Relief	SN111 (1)	95.0%	95.8%	-0.8%	95.0%	0.0%

		Overall TPWS+ATP % Effectiveness	Overall TPWS+ATP % Effectiveness		Overall TPWS+ATP % Effectiveness	
Line	Signal Number	With TI-022 + Auto Signals & Class 345 services (=Option 3)	With GW-ATP & Connect services	Change	With Plan B & Class 345 services (=Option 4)	Change
Down Relief	SN123	93.4%	94.5%	-1.1%	95.0%	-1.6%
Down Relief	SN127	94.4%	95.1%	-0.7%	94.4%	0.0%
Down Relief	SN137	95.0%	95.7%	-0.7%	95.0%	0.0%
Down Relief	SN153	95.0%	95.7%	-0.7%	95.0%	0.0%
Down Relief	SN163	95.0%	95.8%	-0.8%	95.0%	0.0%
Down Relief	SN175	95.0%	95.8%	-0.8%	95.0%	0.0%
Down Relief	SN187	95.0%	92.6%	2.4%	95.0%	0.0%
Down Relief	SN199	95.0%	95.8%	-0.8%	95.0%	0.0%
Down Relief	SN203	93.8%	94.2%	-0.4%	93.8%	0.0%
Down Relief	SN209	92.4%	20.6%	71.8%	92.4%	0.0%
Down Relief	SN211	95.0%	95.6%	-0.6%	94.9%	0.1%
Down Relief	SN215	95.0%	95.6%	-0.6%	95.0%	0.0%
Down Relief	SN225	94.5%	95.0%	-0.5%	94.8%	-0.3%
Down Relief	SN233	95.0%	95.6%	-0.6%	95.0%	0.0%
Down Relief	SN239	95.0%	95.6%	-0.6%	95.0%	0.0%
Down Relief	SN243	95.0%	95.6%	-0.6%	95.0%	0.0%
Down Relief	SN253	93.1%	20.6%	72.5%	93.1%	0.0%
Down Relief	SN265	95.0%	95.6%	-0.6%	94.8%	0.2%
Down Relief	SN273	93.1%	20.6%	72.4%	93.1%	0.0%
Down Relief	SN283	93.7%	94.1%	-0.4%	93.5%	0.2%
Down Relief	SN287	95.0%	95.6%	-0.6%	95.0%	0.0%
Down Relief	SN303	95.0%	95.6%	-0.6%	95.0%	0.0%
Down Relief	SN323	95.0%	98.0%	-3.0%	95.0%	0.0%
Up main	SN316	96.7%	98.0%	-1.3%	96.7%	0.0%
Up main	SN300	98.0%	98.0%	0.0%	98.0%	0.0%
Up main	SN280	97.8%	97.8%	0.0%	97.8%	0.0%
Up main	SN270	97.8%	97.8%	0.0%	97.8%	0.0%
Up main	SN254	97.8%	97.8%	0.0%	97.8%	0.0%
Up main	SN246	97.8%	90.4%	7.3%	97.8%	0.0%
Up main	SN234	97.8%	90.4%	7.3%	97.8%	0.0%

		Overall TPWS+ATP % Effectiveness	Overall TPWS+ATP % Effectiveness		Overall TPWS+ATP % Effectiveness	
Line	Signal Number	With TI-022 + Auto Signals & Class 345 services (=Option 3)	With GW-ATP & Connect services	Change	With Plan B & Class 345 services (=Option 4)	Change
Up main	SN222	97.8%	90.4%	7.3%	97.8%	0.0%
Up main	SN212	97.8%	90.4%	7.3%	97.8%	0.0%
Up main	SN204	97.8%	97.7%	0.0%	97.8%	0.0%
Up main	SN194	97.8%	90.4%	7.3%	97.8%	0.0%
Up main	SN178	97.8%	90.4%	7.3%	97.8%	0.0%
Up main	SN160	97.8%	90.4%	7.3%	97.8%	0.0%
Up main	SN146	97.8%	90.4%	7.3%	97.8%	0.0%
Up main	SN120	97.8%	97.8%	0.0%	97.8%	0.0%
Up main	SN106 (2)	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN107	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN125 (1)	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN125 (2)	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN135	97.8%	97.7%	0.0%	97.8%	0.0%
Down Main	SN151	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN159	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN173	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN179	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN191	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN201	97.8%	97.7%	0.1%	97.8%	0.0%
Down Main	SN207	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN213	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN231	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN237	97.8%	90.4%	7.3%	97.8%	0.0%
Down Main	SN249	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN255	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN271	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN285	97.8%	97.8%	0.0%	97.8%	0.0%
Down Main	SN319	98.0%	98.0%	0.0%	98.0%	0.0%
Down Main	SN321	98.0%	98.0%	0.0%	98.0%	0.0%

Appendix D Excerpt of Hazard Log

Hazard ID	Location	Source	Discipline	Hazard Description	Hazard Consequences
01	Generic - across all of the line (0m - 12m30)	VSE Review	Signalling	TPWS not as effective at preventing SPAD as GW-ATP: TPWS OSS are 'spot' rather than continuous supervision and therefore driver could accelerate to a red signal.	Risk of SPAD leading to collision (rear-end). Multiple fatalities possible, especially given derailment could occur onto adjacent lines.
02	Generic - across all of the line (0m - 12m30)	VSE Review	Track	Workers must be line-side to install TPWS equipment. Risk of being struck by train.	Fatality to worker struck.
03	Generic - across all of the line (0m - 12m30)	VSE Review	Track	Additional TPWS equipment installed on track, leads to increased risk of trips/falls to staff working track-side	Minor injury to worker

Hazard ID	Location	Source	Discipline	Hazard Description	Hazard Consequences
04	Generic - across all of the line (0m - 12m30)	VSE Review	Lineside E&P	Additional TPWS equipment must be maintained- increased exposure to line-side working and associated risk of workers being struck by vehicles	Fatality to worker struck.
05	Part of the line where ATP is present	VSE Review	Driver	Additional TPWS equipment trips ATP trains due to ATP drivers style of driving not compatible with new OSS positions	Minor injuries to passengers due to falling- especially given approach to Paddington when people are standing to exit/ moving through carriages to find seats.
06	Generic - across all of the line (0m - 12m30)	VSE Review	Signalling	TPWS installed with no definitive indication of failure to signaller (i.e. lamp-out provided, not 'blue square' indication) or maintainer, leading to confusion over state of railway should TPWS fail.	A worker would have to investigate putting them in danger. Worst case: worker struck by train leading to fatality.

Hazard ID	Location	Source	Discipline	Hazard Description	Hazard Consequences
07	Level NTC: L2 ETCS fringe (Heathrow Tunnel)	VSE Review	Driver	New fringe created from AWS/TPWS to ETCS L2 at entrance to Heathrow tunnel. Driver becomes confused/ improperly trained and does not carry out transition properly.	Risk of not having a correct protection system active on board. Increasing the SPAD risk and derailment. Worst case: collision, multiple fatalities.
08	Generic - across all of the line (0m - 12m30)	VSE Review	Signalling	Operational issues caused by TPWS failures leading to signal in rear held at red. Method 3 integration means signaller unaware of cause of failure. Would lead to degraded mode operations if signal approached at danger until cause could be established.	Risk of train collision due to trains being talked past red signals (caused by TPWS failure) and therefore full interlocking protection is lost. Any collision would lead to multiple fatalities.
09	Junctions with approach release/ divergent routes with varying speed limits	VSE Review	Signalling	Approach speed controlled junctions fitted with GW-ATP not speed restricted when approached by non-ATP train. Leads to risk of over-speed.	Potential for derailment - multiple fatalities especially if adjacent line obstructed.

Hazard ID	Location	Source	Discipline	Hazard Description	Hazard Consequences
10	Generic - across all of the line (0m - 12m30)	VSE Review	Driver	Drivers unfamiliar with use of Level NTC and associated route knowledge due to expecting to use cab signalling via ETCS. Risk of over-speed and SPAD.	Potential for derailment or SPAD leading to collision.
11	PSR/TSR locations	VSE Review	Driver	Driver does not obey TSRs/PSRs which are no longer enforced by GW-ATP.	Potential for derailment or SPAD caused by over-speed.
12	Future signalling fringe	VSE Review	Driver	Should Level NTC running be required following introduction of Crossrail service through-running from Stratford, a new fringe will be created at CBTC: NTC boundary	SPAD/overspeed leading to collision should signalling transitions not be handled correctly

Hazard ID	Location	Source	Discipline	Hazard Description	Hazard Consequences
13	Amended signalling fringe	VSE Review	Driver	Should Level NTC running be required following introduction of Crossrail depot mainline route. An amended fringe will be created at the Crossrail depot signalling system: NTC boundary	SPAD/overspeed leading to collision should signalling transitions not be handled correctly
14	Signal with complex approach	VSE Review	Signalling	TPWS failure may affect multiple routes at complex junctions, leading to increased operational impact of any TPWS failure at that signal. Increased degraded mode moves required	Risk of train collision due to trains being talked past red signals (caused by TPWS failure) and therefore full interlocking protection is lost. Any collision would lead to multiple fatalities.
15	Generic - across all of the line (0m - 12m30)	VSE Review	Train	TPWS reset procedure in Level NTC not well understood: rate of 'reset and continue' type errors not known.	Erroneous reset and continue could lead to collision and multiple fatalities.

Hazard ID	Location	Source	Discipline	Hazard Description	Hazard Consequences
16	Generic - across all of the line (0m - 12m30)	VSE Review	Train	Level NTC degraded mode procedures not well understood. Operational Procedures between driver and signaller may need to be looked at in event of Level NTC on-board failure. If GW-ATP fails, train is still protected by TPWS (as typically they are dual-fitted e.g. Heathrow Connect). This is not the case for TPWS only train as no secondary train protection system is present.	Increased risk of SPAD in degraded mode leading to collision potential.
17	Trains - Transition Points L2 to NTC	VSE Review	Signalling	EMI issues which compromise ATP function at the transition point	Increased risk of SPAD leading to collision and or derailment

END OF DOCUMENT