Sotera Risk Solutions

Report for Network Rail

Risk Assessment of the Paddington to Heathrow Airport Junction Train Protection Strategy – Options analysis

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REVISIONS

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Rev 00	Peter Dray			Internal version
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1 INTRODUCTION

In 2015, Crossrail had planned for the introduction of train services between Paddington and Heathrow airport in May 2018, with ETCS fitted, Class 345 Crossrail trains replacing Heathrow Connect services. Included in the plan was increasing the peak time number of trains per direction from two trains per hour to four trains per hour. It was also anticipated that the route would be provided with ETCS in time for the commencement of the service, such that when the Heathrow Connect ATP fitted train service was replaced, an equivalent level of protection against SPADs/overruns would be provided by ETCS.

For several reasons, it was found to be impractical to provide the service operating under ETCS on the route by May 2018, and therefore a fall-back plan was developed which ensured an acceptably safe level of safety performance for passengers could be maintained for the interim period. The proposed fall-back arrangements required an application under Regulation 6 of the Railway Regulations 1999 for an exemption in relation to the use of train protection systems (Regulation 3).

Following industry and public consultation and underpinned by risk assessment, an interim arrangement was agreed for which an exemption was agreed with the ORR. The interim arrangement (termed 'Plan B') had the following key features:

- ETCS would not be provided between Paddington and Heathrow Airport Junction by May 2018.
- Enhanced levels of TPWS protection would be provided; signal TPWS would be designed to stop trains with 12%g emergency braking before the conflict point.
- Extra TPWS would not be provided on the approach to buffer stops or for permanent speed restrictions as this was later found to not be practical.
- Crossrail trains would be provided with Mk4 TPWS in-cab units and operate to the May 2018 timetable.

Sotera was commissioned to undertake a detailed, independent, risk assessment of the 'Plan B' train protection strategy. The risk assessment focussed on four key areas of risk: train-train collisions from SPADs, derailments from overspeeding, buffer collisions and the risk to maintainers from servicing additional TPWS trackside units. These were considered to be the hazardous events significantly affected by the proposals.

It is now apparent that a further exemption will be required for an extended period of interim arrangements. A process is being followed to determine the most appropriate protection arrangement to form the basis of the exemption application. This process includes:

a) Establishing a working group to identify possible interim arrangements (termed options) accounting for alternative train protection strategies, timetables, rolling stock deployment and other related industry initiatives.

b) Industry consultation and engagement.

c) Risk assessment of the options.

d) Options analysis to select a preferred option which identifies the option that provides the base balance of safety, cost and operational performance.

This report covers item (c) and presented the results of the risk assessment of the identified options.

Two significant changes from the previous exemption are the planned replacement of the Heathrow Express Cl. 332 stock with ATP with Class Cl. 387s (without ATP) and the progressive introduction of stock with more modern TPWS units which provide better protection again Reset and Continue events following SPADs.

2 SCOPE OF THE ASSESSMENT

The scope of work is described in the following sections.

2.1 Physical boundary of the operation

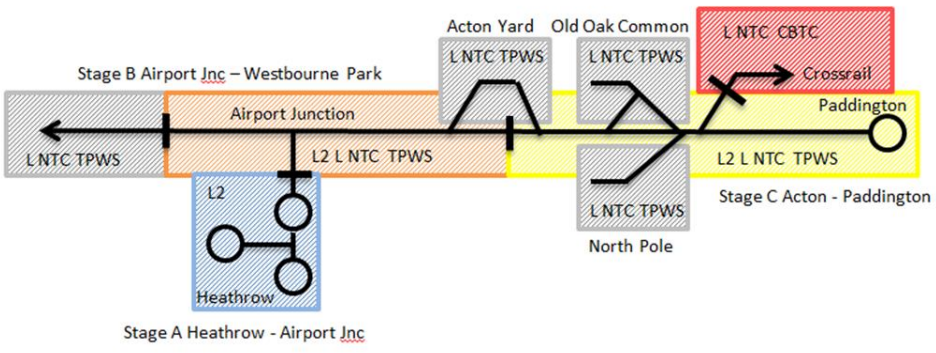
The boundary covers train operation of passenger and freight services over Network Rail infrastructure on the passenger lines between Heathrow Airport Junction and Paddington (0MP to 12MP). This includes:

- Up Main line
- Down Main line
- Up Relief line
- Down Relief line
- Lines to platforms 1 to 14 at Paddington
- The 'Airport Lines' as far as Airport Tunnel Junction.

The layout is as described in the Thames Valley Signalling Centre Western ETCS Overlay Stage B/C Paddington Scheme Plans (1 to 7). The Drawing Numbers for these are 17-GW-017-01 (to-07), Version A.

The analysis refers to three stages of ETCS fitment, Stages A to C. These refer to the areas illustrated in Figure 1. The area shaded blue is Stage A, Orange is Stage B and Yellow is Stage C.

Figure 1 ETCS Fitment stages



2.2 Hazardous Events assessed

The significant 'Train Movement' accidents that may be impacted by the train protection strategy are included, specifically:

- Collision between trains
- Derailments due to overspeeding

- Buffer collisions.

Additionally, risk to maintainers of TPWS equipment is included together with the risk to maintainers responding to track circuit and axle counter failures.

2.3 Service Levels and options

The current timetable, based upon the working timetable[1], has been analysed for the risk assessment, together with three potential future service levels; these are summarised in Table 1. In the table the future cases are termed Timetable 1 to Timetable 3 (abbreviated to TT1 to TT3).

Table 1 Timetable options considered by the assessment

From	To	Timetable Option				Comments
		Current	TT1	TT2	TT3	
Paddington	Heathrow	2 tph	4 tph	2 tph	6 tph	Crossrail services: For TT3, the services enter the Crossrail Central Operating Section via Paddington Low Level Reading/ Maidenhead/ Slough-Paddington services operated by Crossrail.
Paddington	M'head	0.42 tph	2 tph (off-peak) 0 tph (peak)	0 tph	2 tph	
Paddington	Reading	2.71 tph	2 tph (off-peak) 4 tph (peak)	2 tph	4 tph (peak) 2 tph (off-peak)	
Paddington	Hayes and Harlington	2 tph	0 tph	0 tph	0 tph	
Paddington	Didcot	4 tph	2 tph*	4 tph	2 tph**	* Additional 2 tph in one direction during peak. ** Formation, direction and line depends upon time of day. Operated by GWR.
Paddington	Heathrow	4 tph	4 tph	4 tph	4 tph	GWR service replacing Heathrow Express
Great Western Railway High Speed Services Chiltern services Freight services		Assumed as per current timetable				No future changes to service levels covered by the assessment

[1] Working Timetable for Sunday 20 May 2018 to Saturday 08 December 2018, Passenger train services, Section PA01, London Paddington to Greenford and Heathrow Airport.

For each of the future timetables, additional options are assessed to consider the alternative stock being operated. These are presented in Table 2.

Table 2 Future train operating options assessed

From	To	Default			Options
		Exemption	TT1 / TT2	TT3	
Paddington	Heathrow	Cl.345 (CRL)			Fit BR-ATP or operate existing ATP stock
Paddington	Maidenhead	Cl. 387 (no ETCS)	Cl.345 (CRL)		Fit BR-ATP or operate existing ATP stock
Paddington	Reading	Cl. 387 (no ETCS)	Cl.345 (CRL)		Fit BR-ATP or operate existing ATP stock
Paddington	Didcot	Cl. 165	Cl. 387(no ETCS)		-
Paddington	Heathrow	Cl. 332	Cl. 387(inc.ETCS)		Fit BR-ATP or operate Class 332 with BR-ATP

2.4 Infrastructure fitment and options

Prior to the completion of Stage C, with ETCS installed between Heathrow Airport Junction and Heathrow, five alternative infrastructure fitment cases are analysed as part of the risk assessment (some of which have sub-options). Each of these is summarised in Table 3.

Table 3 Infrastructure fitment cases assessed

Reference	Description	Comment
'Exemption Case'	Current fitment case i.e. with existing enhanced TPWS and existing GW-ATP fitment	This case reflects the existing exemption, hence the Crossrail service to Heathrow is set as the Class 345 operating in ETCS Level NTC between Paddington and Heathrow Airport Junction rather than the existing Class 360s with ATP.
Option 1	No infrastructure modification	Equivalent to the base case with the potential future timetables
Option 1a	Defer trackside ETCS fitment in lieu of train detection upgrade. ETCS Operation - Dec 2023	This carries the same train protection preventable risk as option 1, for an extended period prior to the fitment of ETCS. Improved train detection reliability will bring reduced maintainer exposure to on-track hazards.

Reference	Description	Comment
Option 1b	Fitment of trackside ETCS as early as possible ETCS Operation - Dec 2021	The carries the same risk prior to ETCS fitment as option 1, the period prior to the fitment of ETCS is minimised.
Option 1c	Fitment of trackside ETCS (Area B) as early as possible Area B ETCS Operation - June 2020	Area B has ETCS infrastructure fitment between Heathrow Airport Junction and Acton.
Option 1d	Install enhanced TPWS on approach to buffer stops.	This option would further enhance the TPWS fitment. It is assumed that an additional two OSS loops could be provided on the approach to each buffer.
Option 2	Do nothing to the existing infrastructure and fit GW-ATP to Crossrail and HEX service trains.	This option does not require any infrastructure modification. For 2020, this provides a similar level of train protection as ETCS commissioning.
Option 2a	Do Nothing to the existing infrastructure and fit GW-ATP to Crossrail services only.	This option does not require any infrastructure modification.
Option 2b	Do nothing to the existing infrastructure and fit GW-ATP to HEX services only.	This option does not require any infrastructure modification.
Option 3	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for Crossrail and HEX trains (Class 360, 332).	This option does not require any infrastructure modification.
Option 4	Second Driver on the Footplate of Class 345/387	This option does not require any infrastructure modification.
Option 5	Provision of ETCS Level 1 in Area C (Level 2 in area B)	Area B and C cover Heathrow Airport Junction to Paddington
Option 6	Fitment of ETCS Level 2 (Area B and C)	Area B and C cover Heathrow Airport Junction to Paddington

A comprehensive set of options assessed are presented in Table 4, where options are a combination of timetables (Table 1), train services (Table 2) and infrastructure fitment (Table 3).

Table 4 Options assessed by the risk assessment

Option	Option description	Exemption Required	Timetable			
			May-19	Dec-19	Dec-19	Dec-20
			Current levels of service	TT1	TT2	TT3
Baseline	Do nothing to the existing infrastructure or planned train service i.e. continue with existing enhanced TPWS and run current Crossrail (CL345) with reliance on Level NTC.	Yes Until Dec 2021 or Dec 2023	Continue this until ETCS delivery 2022	N/A	N/A	N/A
1	Do nothing to the existing infrastructure, increase train service usage. i.e. continue with existing enhanced TPWS and run additional Crossrail (CL345) and GWR/HEX(CL387) services as planned with reliance on Level NTC.	Yes Until Dec 2021 or Dec 2023 see option 1a) or 1b)	N/A	Y	Y	Y
1a	As Per Option 1 but Defer trackside ETCS fitment in lieu of train detection upgrade. ETCS Operation - Dec 2023 Reduced maintainer exposure to train detection failures	Yes Until Dec 2023	N/A	Covered by Option 1	Covered by Option 1	Covered by Option 1
1b	As per Option 1 Fitment of trackside ETCS as early as possible ETCS Operation - Dec 2021	Yes Until Dec 2021	N/A	Covered by Option 1	Covered by Option 1	Covered by Option 1
1c	As per Option 1 Fitment of trackside ETCS (Area B) as early as possible Area B ETCS Operation - June 2020	Yes - Until Dec 2021 or Dec 2023	N/A	Y (only 6 months of use)	Y (only 6 months of use)	Y
1d	As per Option 1 but install further enhanced TPWS on approach to buffer stop.	Yes - Until Dec 2021 or Dec 2023 see option 1a) or 1b)	N/A	Y	Y	Y

Option	Option description	Exemption Required	Timetable			
			May-19	Dec-19	Dec-19	Dec-20
			Current levels of service	TT1	TT2	TT3
2	Do nothing to the existing infrastructure and fit GW-ATP to Crossrail and HEX service trains.	No	N/A	Y	Y	Y
2a	Do Nothing to the existing infrastructure and fit GW-ATP to Crossrail services only.	No	N/A	Y	Y	Y
2b	Do nothing to the existing infrastructure and fit GW-ATP to HEX services only.	No	N/A	Y	Y	Y
3	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for Crossrail and HEX trains (Class 360, 332).	No	N/A	Y	Y	N/A
3a	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for Crossrail Services (Class 360, 332).	No	N/A	Y	Y	N/A
3b	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for HEX services (Class 360, 332).	No	N/A	Y	Y	Y
4	Second Driver on the Footplate of Class 345/387	Yes	N/A	Covered by Option 1	Covered by Option 1	Covered by Option 1
5	Provision of ETCS Level 1 in Area C (Level 2 in area B)	Yes - Until Dec2021	N/A	Covered by risk Option 1a or 1b	Covered by risk Option 1a or 1b	Covered by risk Option 1a or 1b

Option	Option description	Exemption Required	Timetable			
			May-19	Dec-19	Dec-19	Dec-20
			Current levels of service	TT1	TT2	TT3
6	Fitment of ETCS Level 2 (Area B and C)	Yes - Until Dec2021	N/A	Covered by risk Option 1a or 1b	Covered by risk Option 1a or 1b	Covered by risk Option 1a or 1b

3 APPROACH TO THE RISK ASSESSMENT

3.1 Overall approach

The overall approach to the assessment was to update each element of the risk model completed in 2015 in support of the previous exemption application to provide a new starting point for the assessment. Technical details on the model can be found in the 2015 risk assessment report[2].

The following inputs to the model were updated to develop the new base case:

- The working timetable for May 2018 (the previous model used a predicted May 2018 timetable).
- The potential train paths used by each train through the layout, accounting for whether each service is normally routed via the Fast or Relief lines.
- Current train loading (based upon ORR statistics for entrances, exits and interchanges at Paddington for 2016/17).
- The latest trends in SPADs (For a 10-year period up to the end of August 2018 – data sourced from RSSB's OPSWEB data portal).
- Current fleet operating and train protection fitment (based upon analysis of the timetable and desktop research). Note the Base case reflects the existing exemption, hence the Crossrail service to Heathrow is set as the Class 345 operating in ETCS Level NTC rather than the existing Class 360s with ATP. Class 345 operation may not happen on this service until after December 2019.
- The enhanced TPWS fitment as implemented (based upon signalling scheme plans).
- Reference levels of risk for buffer collisions, overspeeding derailments and personal accidents to workers from the latest version of RSSB's Safety Risk Model (SRM v8.5.0.2).
- Updated assessment of effectiveness of train protection based upon RSSB research and TPWS effectiveness calculator.
- The planned replacement of the Cl. 360 services to Paddington with Crossrail Cl. 345 stock.

Having updated the model, the options presented in Table 4 were assessed by making modification to the model.

[2] Sotera Risk Solutions Limited, Risk Assessment of the Crossrail Train Protection Strategy – Paddington to Heathrow for 2018, Revision 03, December 2015.

In order to undertake the assessment of the options, some minor modifications were made to the scope of the original (2015) model. These include:

- Expanding the model to cover the risk to maintainers while responding to track circuit and axle counter failures.
- Including additional causes of buffer collisions so that the benefits of ETCS where it provides additional protection over ATP can be evaluated, eg, roll back collisions.

The key study assumptions are presented in Section 6. These should be reviewed to ensure reasonableness.

4 RE-BASLINING RESULTS

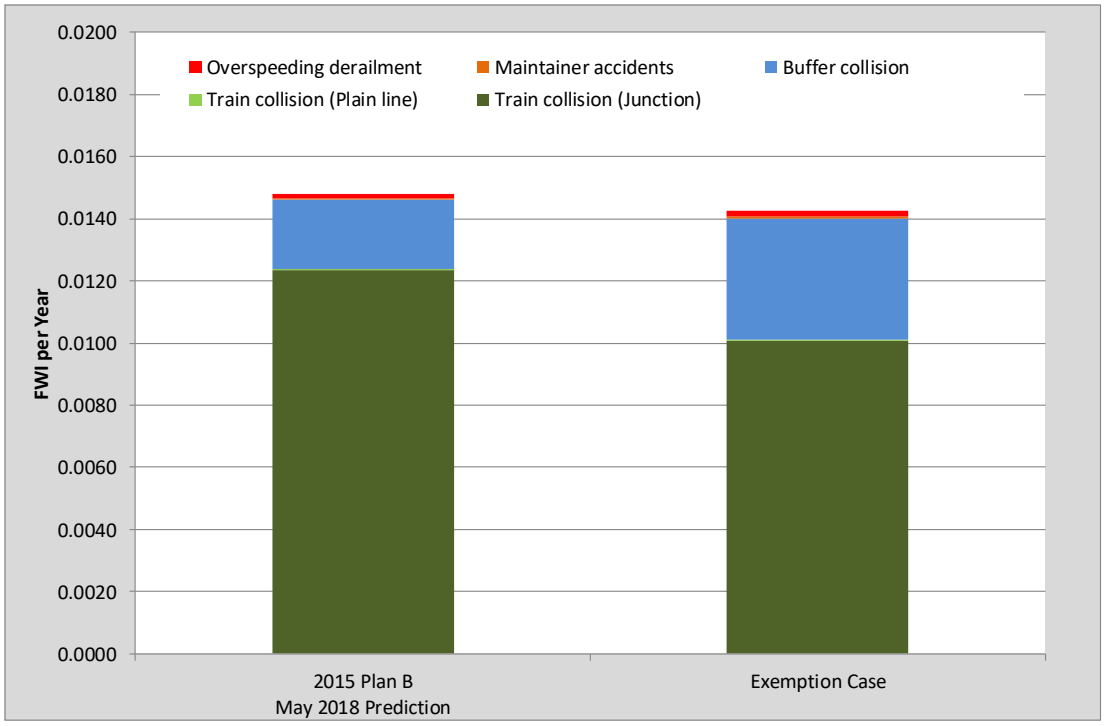
The risk assessment results presented in this section compare the 2015 predictions for 2018 (Plan B) with the current level of risk, accounting for the previous exemption where Cl. 360 services to Heathrow were to be replaced by Cl. 345 operating in Level NTC. The areas where the risk have changed are discussed and explained in the following sections. The updated assessment, accounting for the Cl. 345 operation to Heathrow, is termed the Exemption Case.

The risks from the two cases are presented in Table 5 and Figure 2 below. The maintainer risk shown refers to the maintenance of TPWS loops due to the enhanced level of fitment and to rectify faults with train detection equipment (track circuits), although the latter is not accounted for in the 2015 prediction.

Table 5 Results of the risk assessment

Hazardous Event	2015 Plan B May 2018 Prediction (FWI/yr)	Exemption Case (FWI/yr)	Change
Train-train collision	0.0124	0.0101	-18.3%
Buffer collision	0.0023	0.0039	72.1%
Maintainer accidents	0.000033	0.000092	181.6%
Overspeeding derailment	0.000159	0.000172	8.2%
Total	0.0148	0.0143	-3.8%

Figure 2 Results of the risk assessment



4.1 Overall Results

As can be seen from the overall results, there is a relatively close match between the predictive (Plan B) assessment completed in 2015 and the new 2018 Exemption Case. Overall, there is a 3.8% reduction in risk. The main contributor to the reduction is an 18.3% reduction in collision risk. The changes to the risk for the individual hazardous events are explained in the following sections.

4.2 Train-train collision risk

The overall 18.3% reduction in collision risk is through a combination of factors including:

- A 15.1% increase in the likelihood of a SPAD per signal approached, based upon SPAD data and the number of signals approached.
- A lower number of signal approaches (17.1% lower) due to timetable predictions for the number of trains operating in 2018 being higher than the current timetable.
- An overall improvement in the assessed train protection effectiveness. This is a result of a reduction in the number of train services operating with the older TPWS units (without in-service monitoring and protection against 'reset and continue' SPADs), eg, the Cl. 165/1. Due to the optimised TPWS infrastructure fitment, the limiting factor for the TPWS effectiveness is generally the on-board fitment.

The train loading is very similar between the two assessments.

4.3 Buffer collision risk

Overall the buffer collision risk is 72% higher than previously assessed. The causes of this are:

- Updating to the latest version of RSSBs safety risk model, which shows an 18% increase in risk from the relevant causes of buffer collisions.
- Additional TPWS OSS not being fitted on the approach to buffers (the 2015 modelling assumed that additional TPWS would be fitted).
- An expansion of the scope of the buffer collision model to include causes that would be mitigated through ETCS, eg, roll back collisions.

4.4 Maintainer risk

Maintainer risk is a relatively insignificant contributor to the overall risk profile, comprising 0.6% of the assessed risk. There is a high relative

change to the assessed risk (a 182% increase), however this change is as a result of:

- An increase in risk from the relevant hazardous events from the latest version of RSSBs SRM.
- An expansion to the scope of the model to account for the diagnosis and repair of train detection system failures (Axle counters or track circuits). This is the dominant cause of maintainer risk.

Hence the risk increase is not connected to the operation between Paddington and Heathrow airport junction but due to changes to the reference risk model and the scope of the risk model.

4.5 Overspeeding derailment risk

Overspeeding derailment risk comprises approximately 1% of the overall risk profile for the assessed events. The 8.2% increase in risk from this event is predominantly due to an increase in risk from the relevant causes of the hazardous events from the latest version of RSSB's Safety Risk Model. There is also a slight difference in the distribution between the train journeys completed by stock fitted with ATP and TPWS (ATP provide a higher level of protection through speed monitoring).

4.6 Modelling sensitivity

The most sensitive assumptions in the risk model are the deployment of rolling stock, the train frequency and the train protection system fitted. Hence it is important that the assumptions in Section 6 are reviewed to ensure that they are correct, or reasonable approximations for the current and proposed operation.

5 THE RISK FROM THE IDENTIFIED OPTIONS

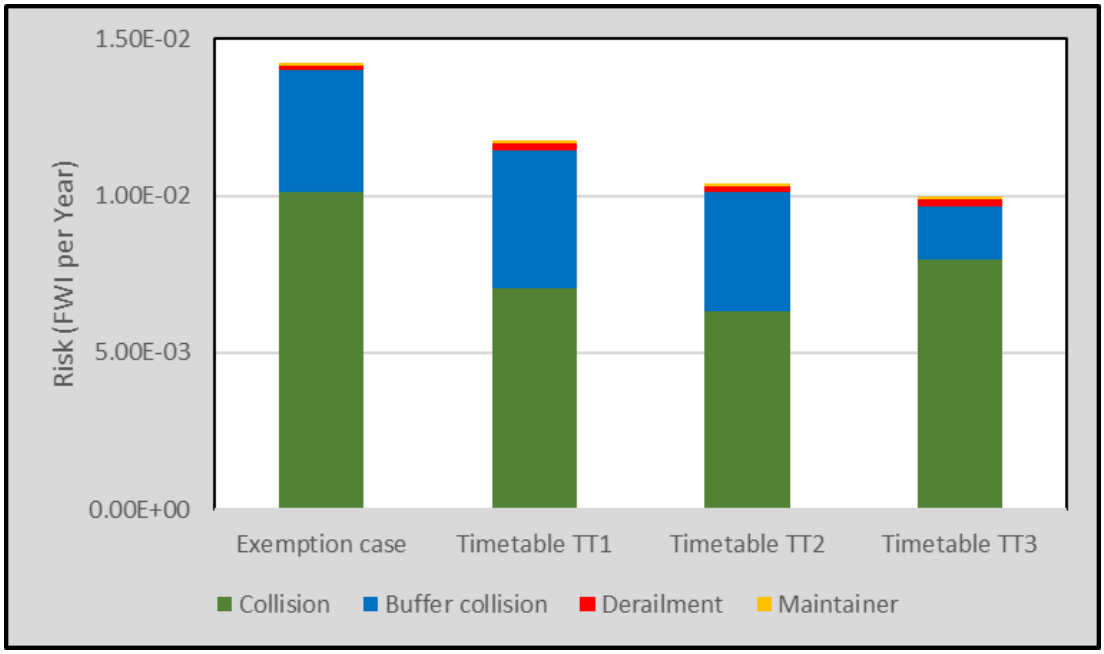
This section of the report presents the risk assessment results for each of the identified options. Section 5.1 analyses the differences between the current timetable and the three potential future timetables (TT1 to TT3). Section 5.2 onwards reviews the effectiveness of each the of potential infrastructure upgrades. The detailed risk results for each option and timetable are listed in Section 8.

5.1 Option 1: Comparison of timetable options

For Option 1, which refers to continuing the existing train protection arrangements trackside, the safety impact of the various timetables has been assessed. The timetables imply certain default rolling stock deployment, which is relevant to the risk from each option. Notably, for the Exemption case, there remains a significant volume of 165/1 stock operated by GWR, which is not present in the future timetable cases.

The results of the assessment are presented in Figure 3.

Figure 3 The impact of different timetable options



Option 1: Comparing the exemption case with Timetable 1

From Figure 3 it can be seen that the Exemption Case presents the highest level of risk. Comparing Timetable 1 (TT1) with the exemption case, the changes to risk are:

- Collision risk shows a significant (30.3%) reduction. This is due to the removal of Cl. 165/1 stock, with Mk1 TPWS[3] that currently operates on the network. Mk1 TPWS presents a significantly lower level of protection due to the potential for reset and continue SPADs. This factor dominates over the small risk increment from the operation of the Class 387 to Heathrow without the protection from ATP as the collision risk is well managed by the enhanced level of TPWS with in service monitoring and protection against reset and continue SPADs (Mk4 TPWS).

- Buffer collision shows a moderate (13.3%) increase in risk. This is due to the high number of approaches by the Cl. 387s, instead of the Cl. 332s; the Cl. 332s have a high level of speed supervision provided by ATP compared to TPWS. Currently, approaching the Paddington platforms there is only one TPWS OSS. Note the issue of TPWS reset and continue only applies to collisions and not buffer approaches as once the train is brought to a stand by TPWS, the TPWS has been effective in managing the train speed.

- Overspeeding derailments shows a significant (25.1%) increase in risk. This due to the Cl. 332s which operate to Heathrow with ATP speed supervision being replaced with the Cl. 387s operating with TPWS.

Taking these three points together, the first factor is dominant such that overall there is a 17.6% reduction in risk from the exemption case timetable to Timetable 1 without any further infrastructure modifications.

Option 1: Comparing Timetable 1 with Timetable 2

For Option 1, the difference between Timetable 2 and Timetable 1 comprises a reduction of two Crossrail trains per hour to Heathrow and a reduction of two trains per hour to Maidenhead. However, there are two additional train services to Maidenhead. Hence there would be, overall, two less trains per hour operated through the layout. This has the impact of reducing the risk by approximately 11.4% across the train accidents. The reduction is commensurate with the reduction in the number of trains operated.

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[3] The term 'Mk1 TPWS' is used to indicate on board TPWS units that do not provide the driver with an indication of the cause of a TPWS activation such that it is possible for the driver to misdiagnose the cause of the activation and reset the TPWS and continue in the event of a SPAD. This erodes the potential benefit from TPWS. These units also do not have in-service, continuous health monitoring. Hence in the event of failure, the state of the equipment is not indicated to the driver. The term is derived from the predominant equipment supplier, Thales although it equally applies to systems that offer the same functionality.

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

Option 1: Comparing Timetable 2 with Timetable 3

Of all the timetable scenarios, overall, Timetable 3 presents the lowest risk, despite having the highest number of trains operating through the layout. Comparing the two timetables (TT3 and TT2):

- Crossrail services to Heathrow increase from 2 to 4 per hour
- Crossrail services to Maidenhead are two per hour (rather than zero)
- Crossrail services to Reading increase from 2 to 4 per hour.
- GWR services to Didcot reduce from 4 to 2 per hour.

The individual changes to the hazardous events are explained as follow:

- Collision risk shows a 25.6% increase in risk; the increase is commensurate with the higher number of train services, accounting for the fact that the Crossrail services do not travel all the way through the layout.
- Buffer collision risk shows a 55.6% reduction in risk, this is a direct result from the much lower number of buffer approaches in the layout due to the Crossrail services approaching the central operating section instead. It should be noted, however, that the services may encounter buffers outside the boundary of the assessment where they will be protected by the Crossrail signalling and train protection system (CBTC).
- Overspeeding derailment risk shows a 34.4% increase in risk, this is due to the increase in train services. The increase is commensurate with the increase in train services and the number of PSRs traversed.

Overall, comparing timetables TT2 and TT3, the reduction in buffer collision risk is slightly greater than then increase in collision and derailment risk. Hence the overall risk from TT3 is 4.1% lower.

5.2 Comparison of Infrastructure Options

For each of the timetables (TT1 to TT3), a comparison has been made of the various infrastructure options to determine the relative safety performance. The results are presented in Figure 4 to Figure 6. The units of risk in the charts are FWI per year. Hence, depending upon the option being considered, the life-span of the option is relevant in terms of the overall risk to passengers, the public and the workforce. Note that in

the charts, options that in risk terms are equivalent to other options are not shown separately to keep the content of the charts manageable.

The options that are equivalent are:

- Option 1 and 1b - the difference between these options being the time when ETCS is completed.
- Options 2a and 3a – the difference being the trains used to provide BR-ATP on Crossrail services
- Options 2b and 3b - the difference being the trains used to provide BR-ATP on Heathrow Express services
- Option 4 and Option 1– where there is unlikely to be a measurable benefit of having a second driver on the footplate of the Cl. 345/C387. Arguably, there could be a disbenefit.

Figure 4 Risk from each option – TT1

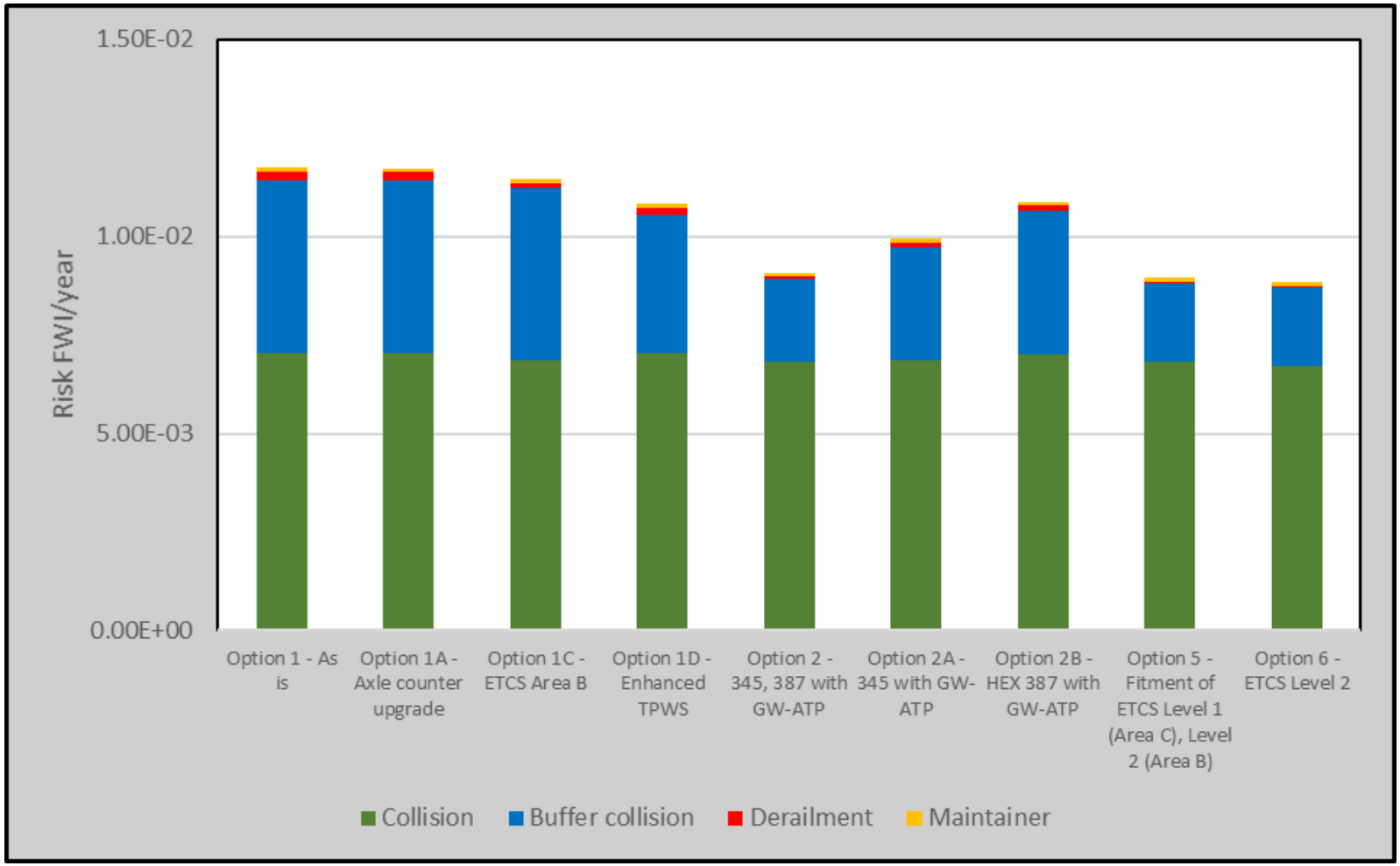


Figure 5 Risk from each option – TT2

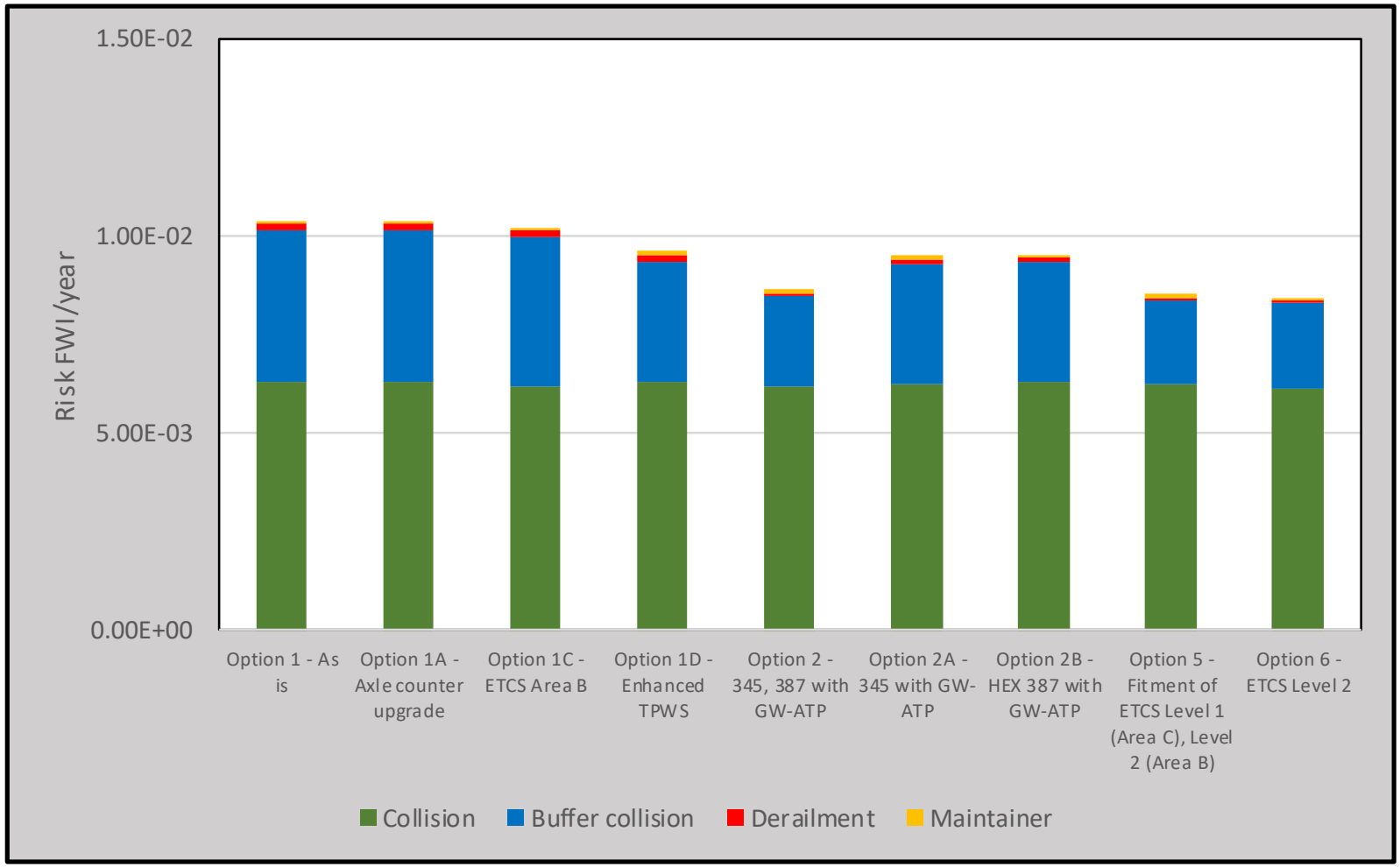
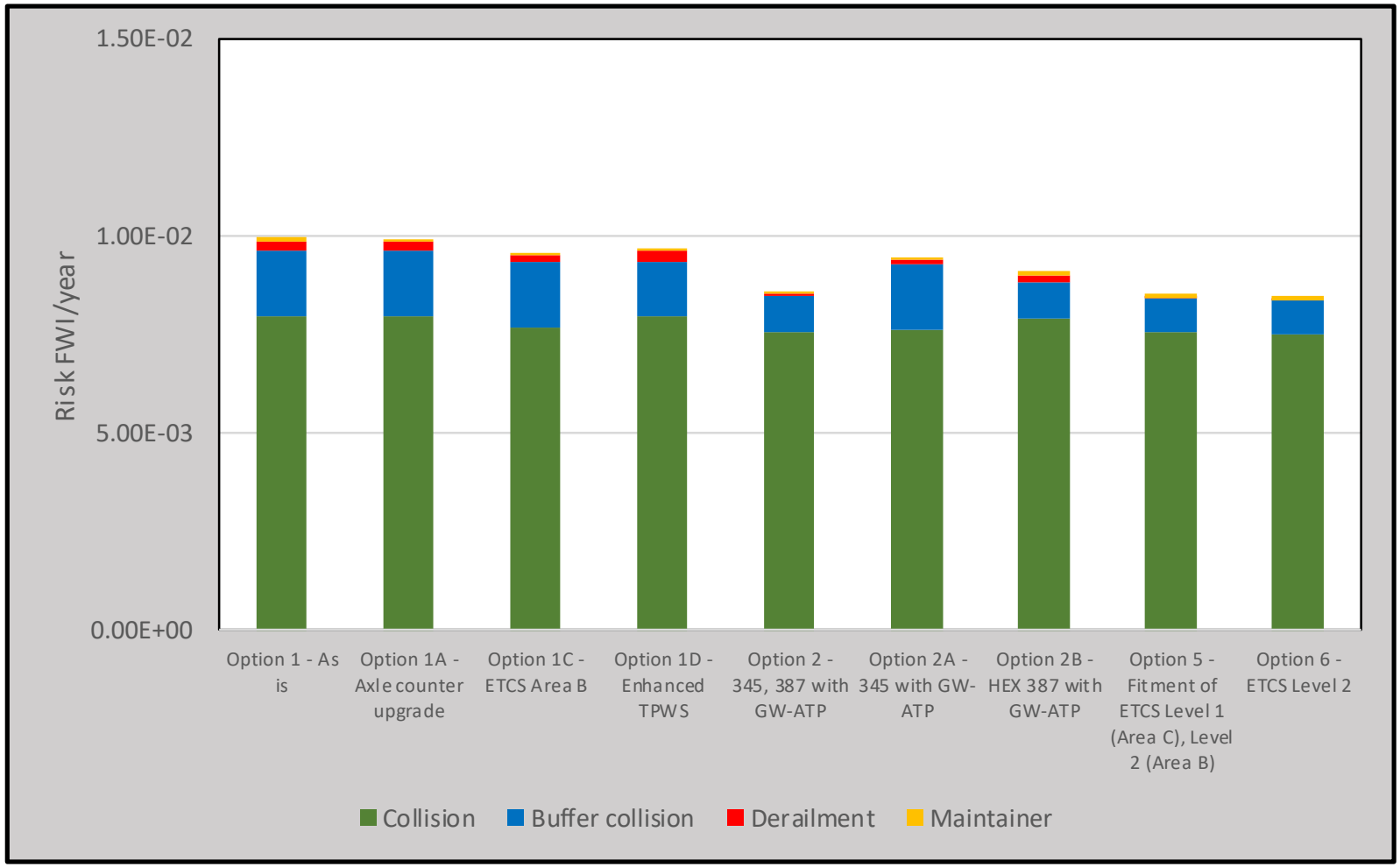


Figure 6 Risk from each option – TT3



5.3 Option 1a: The benefit of providing axle counters

The safety performance improvement from upgrading axle counters results from reducing the exposure of maintainers to trackside risks. A much more significant operational performance impact would also be expected from the upgrade, there would also be a reduction is risk from degraded working. Whilst the performance impact is outside of the scope of this risk assessment, it will be considered by the wider options analysis report. There would also be reduced signaller workload to consider and a potential reduction in degraded working risk, also beyond the scope of this assessment.

The maintainer risk for axle counters has been based upon the expected exposure to trackside risks by taking the axle counter failure rate from national axle counter failure data and expected maintenance duration from the axle counter specification[4]. The track circuit failure rate has been based upon failure data for track circuits between Paddington and Heathrow Airport Junction. The repair time for track circuits has been factored up from the axle counter values based upon an estimated higher time to diagnose and repair faults.

On this basis, the risk to track workers reduces 48% with the implementation of axle counters. However, as maintainer risk is a small contribution to the overall risk profile, the overall level of risk reduces by approximately 0.4%. The overall change in risk will vary slightly between different timetable options.

5.4 Option 1c: Provision of ETCS for Area B

This option refers to the provision of ETCS between Heathrow Airport Junction and Acton, known as 'Area B'. The risk assessment assumes that any change in transitions between different signalling systems and train control systems does not affect the likelihood of driver errors, such as SPADs/exceedance of movement authorities, ie, any transition risks are managed through driver competence and training.

The impact of the having ETCS in this area is to reduce collision risk by 3% and derailment risk by 43%. The overall risk reduction is 2%. There is no impact on buffer collisions as Stage B works do not extend to Paddington.

The modest (3%) reduction is collision risk is due to the high level of protection provided by TPWS and ATP currently in place. Furthermore, the layout to the west of Acton has relatively few conflicts compared to the immediate approach to Paddington.

[4] Network Rail, Product Specification for Axle Counter Equipment, NR/L3/SIG/30082/004 Issue 1.

The relatively high benefit in preventing overspeeding derailments is due to many of the PSRs being in the area between Heathrow Airport Junction and Acton and the current lack of TPWS protection against overspeeding.

5.5 Option 1d: Provision of enhanced TPWS for Buffer Approaches

Introduction of enhanced TPWS on the approach to buffers changes two parts of the risk model:

- Buffer collision risk is reduced 21% due to the additional protection for trains operating in TPWS on the approach to Paddington.
- Maintainer risk is increased by 3% due to the requirement to maintain the additional TPWS loops, it should be noted however, that maintainer risk is only about 0.6% of the overall risk profile.

The combination of these factors means that overall, there is an 8% reduction in risk compared to the 'Do nothing' case. The benefit therefore exceeds that of Options 1a and 1c.

5.6 Option 2: Fit GW-ATP to Crossrail and HEX service trains

This option involves no lineside upgrade, but provision of ATP on the Cl. 345 services to Heathrow, Maidenhead and Reading. This option provides the lowest level of risk for TT1 and TT2, and only slightly above the lowest level for TT3. The main changes from the 'As-is case' with timetable TT1 are:

- Collision risk is reduced by 3% - the relatively small reduction in collision risk is due to the current high level of protection afforded by the existing, optimised lineside TPWS fitment and operation of stock with TPWS units with protection against reset and continue and in-service health monitoring (There are no TPWS Mk1 units operating under timetables TT1 to TT3). Furthermore, ATP is less effective at platform started signals. Hence ATP does not provide a substantial benefit over TPWS for collision risk.
- Buffer collision is reduced 52%, this is due to the enhanced speed monitoring provided by ATP. The current TPWS fitment is also not optimised for buffer approaches.
- Overspeeding risk is reduced by 78% due to the enhanced speed supervision.

Overall, these factors combine to reduce the risk to a level approximately 23% lower than the Option 1 case.

5.7 Option 2a: Fit GW-ATP to Crossrail services

This option is the same as Option 2 except that it excludes fitment of ATP on HEX services. The main changes from the 'As-is case' with timetable TT1 are:

- Collision risk is reduced by 2.7%. Similar to Option 2, the relatively small reduction in collision risk is due to the current high level of protection afforded by the existing, optimised lineside TPWS fitment and operation of stock with TPWS units with protection against reset and continue and in-service health monitoring.
- Buffer collision is reduced 34%, this is due to the enhanced speed monitoring provided by ATP. The current TPWS fitment is also not optimised for buffer approaches.
- Overspeeding risk is reduced by 51% due to the enhanced speed supervision provided by ATP.

Overall, these factors combine to reduce the risk to a level approximately 15% lower than the Option 1 case.

5.8 Option 2b: Fit GW-ATP to HEX service trains

Similar to the other Option 2 scenarios, Option 2b involves no lineside upgrades. The changes from the 'As-is case' with timetable TT1 are:

- Buffer collision is reduced by 18%, this is due to the enhanced speed monitoring provided by ATP.
- Overspeeding risk is reduced by 26% due to the enhanced speed supervision provided by ATP.

There is an insignificant reduction in collision risk. The reason for the insignificant overall reduction in collision risk is a combination of the effectiveness of TPWS (discussed above for the other variants of Option 2). Furthermore, ATP is less effective for Platform starter signals and the platforms used by the Heathrow Express type services are those where ATP is least effective. Hence, the modest risk reduction through the layout is approximately balanced by the platform starter SPAD risk.

Overall, these factors combine to reduce the risk to a level approximately 7% lower than the Option 1 case.

5.9 Option 5: Provision of ETCS Level 1 in Area C (Level 2 in area B)

For the purposes of the assessment it is assumed that ETCS Level 1 provides speed monitoring for Permanent Speed Restriction and effective speed control on the approach to buffers. It is considered to provide a similar level of protection for starter signal SPADs as ATP.

The changes from the 'As-is case' with timetable TT1 are:

- Collision risk is reduced by 3%.
- Buffer collision is reduced 55%.
- Overspeeding risk is reduced by 78% due to the enhanced speed supervision provided by ATP.

Overall, these factors combine to reduce the risk to a level approximately 24% lower than the 'As-Is' case where there are no lineside upgrades and with operation of the Cl. 345 and Cl. 387 stock in Level NTC.

It is valuable to compare this option with Options 2, i.e. extensive use of GW-ATP for services to Reading, Maidenhead and Heathrow. The two options provide a very similar level of safety performance and indicated that an equivalent level of protection can be achieved wither with ATP or ETCS. The safety performance between the two options will depend upon the rolling stock deployment (ie, which stock types are ATP or ETCS fitted).

5.10 Option 6: Provision of ETCS Level 2

For the purposes of the assessment it is assumed that ETCS Level 2 provides the same speed monitoring for Permanent Speed Restriction and effective speed control on the approach to buffers as ETCS Level 1 (Option 5). It is also considered to provide improved protection at platform starter signals.

Hence there is a small additional reduction in collision risk from Option 6, compared to Option 5 (approximately a further 1% reduction in the risk).

6 ASSUMPTIONS

The following assumptions have been made during the course of the risk assessment:

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

2. **TPWS effectiveness:** The TPWS effectiveness calculator, developed by RSSB, provides a reasonable indication of the performance of TPWS in mitigating the risk from train-train collisions. No account is given to the potential upgrade to the trainborne TPWS units.

3. **Routing of trains through Paddington:** The Working Timetable assessed provides details of all the passenger services that operate on the lines between the platforms at Paddington and the Heathrow Airport junction.

4. **Trains approaching buffers on the network:** The Safety Risk Model (SRM) provides a reasonable estimation of the level of risk from train accidents, and application of suitable normalisers can be used to assess a baseline level of risk for Paddington.

5. **Train loading:** The average number of passengers on a train across the network is approximately 100 based upon ORR statistics; the figure is significantly higher at Paddington due the station being a busy terminal station. Based upon station usage values from ORR and the simplified timetable analysis, the typical level of train loading at Paddington is 177.

6. **Variation in train loading:** A range of timetables are analysed within the risk assessment. It is assumed that passenger numbers grow commensurately with increasing train services; such that the number of passengers in a train on average remains constant. The reverse is also assumed to be the case; if there were a reduction in the number of train services, the number of passengers carried would also reduce.

7. **The likelihood of SPADs:** Data over the past ten years at Paddington (historic SPAD performance) represents a reasonable reflection of future performance in the likelihood of a SPAD per signal approached (for plain line and junction signals).

8. **ATP and ETCS Level 1 effectiveness at platform starter signals:** For platform starter signals, GW-ATP and ETCS Level 1 do not provide speed monitoring, only a train stop function. The effectiveness has been assumed to be the same as the TPWS TSS

functionality, based upon the TPWS effectiveness calculator developed by RSSB. For the purposes of the assessment, it is assumed that ATP trains have a two second brake build-up time and an emergency brake effectiveness of 10%g for HSTs and 12% for IEP trains and Cl. 332.

9. **ETCS effectiveness for protecting against rollback collisions:** It is assumed that ETCS is effective at mitigating 50% of roll back collisions caused by train driver errors in set up or shut down.

10. **ETCS effectiveness at platform starter signals:** For ETCS Level 2, at platform starter signals, it is assumed that the system is 99% effective in mitigating collision risk.

11. **Train protection system effectiveness against overspeeding:** It is assumed that ETCS and ATP are 99% at preventing derailment from overspeeding.

12. **Track Maintainer Exposure:** It is assumed that personnel involved in the maintenance and inspection of TPWS and train detection equipment are exposed to typical levels of track worker risk as modelled in RSSB's SRM v8.5.0.2 on a per hour basis.

13. **Determine the collision frequency for each signal:** For both plain line and junction collisions, the vast majority of SPADs do not result in a collision due to a range of factors, such as signal replacement on the confliction route, the effectiveness of train protection systems, train driver mitigating action (applying the brakes to stop in the overlap) and flank protection. These factors can effectively be assessed using the Safety Risk Model (SRM), which analyses the underlying probability of collision per SPAD (separately for junction and plain line signals).

14. **Assessment of line speed and collision speeds:** In the event of a collision, an important factor in assessing the potential consequences is the likely speed of a collision. The likely collision speeds have been assessed by accounting for the typical highest line speed in each route section and accounting for the signal type. The assumption is that a junction collision will result in a collision at three quarters of line speed, plain line collisions will result in a collision at two thirds of line speed.

15. **Assessment of the consequence of collisions:** The likely consequences of a collision were assessed based on RSSB's accident consequence model output which can be used to determine the likely FWI based upon the train type, speed and loading. In order to manage the complexity of the model, a curve was used to fit the output of the ACM and used to apply to each route section accounting for the calculated collision speed (as described above) for each signal type in each route section and the average passenger loading.

16. **Timetable:** The model is based upon detailed assessment of the current working timetable for May 2018, the assessment analyses the twelve-hour period from 07:00 to 19:00. The twelve-hour timetable has been scaled to a full day by multiplying by a factor of 1.38. The 1.38 has been derived from prior research conducted by Sotera on behalf of RSSB and has been verified for this project by assessment of the timetable between Reading and Paddington.

17. **Derailment due to overspeeding**: Within the assessment of derailment due to overspeeding, ETCS is assumed to give the same level of protection as ATP.

18. **Additional signalling transitions:** Options that introduce additional transitions between different signalling systems and train control systems do not increase the likelihood of driver errors, such as SPADs/ exceedance of movement authorities, ie, the additional transition risks are managed through driver competence and training.

19. **Additional workload and communications when dealing with train detection failures:** When train detection failures occur the workload on signallers would be increased and there is increased potential for error through miscommunication. The impact of this is out of scope of the risk assessment.

20. **Knock-on risk from delays**: When train detection failures occur, it would be expected that train delays might result. The impact of this on passenger behaviour and potential for risk impact e.g. through assaults or more red signal approaches is out of scope of the risk assessment.

21. **Assumption – Risk assessment does not require ECS moves SPAD risk to be quantified.**

    Rational: Timetable information that has been used does not cover ESC moves for train to and from depots/sidings.

    The following depots are assumed for future Class 345 – Old Oak Common, IEP – North Pole, Class 387 – West Ealing/Reading.

    The main change in ECS moves will be at Dec 19 when Class 345 train would need to enter the CRL central sections, but this would only require trains to be on Main Lines for 1 or 2 signal sections and so is not likely to be significant change on risk in the area.

    Introduction of Class 387 would move ECS from Old Oak (Class 332) to West Ealing. Although this means that an increase distance ECS moves the quantity of moves for this service is small as only 14 train planned to be used for the Hex service. So again, this is unlikely to have significant impact on risk

    Other ECS moves in the area are likely to remain similar, so will not impact comparison of the risks.

22. **ETCS Level 1 functionality:** ETCS Level 1 provides speed monitoring for Permanent Speed Restriction and effective speed control on the approach to buffers as well as ATP at signals.

23. **Cl. 165 withdrawal:** The Cl. 165 stock currently operated will be withdrawn from operation by December 2019 (apart from that on Chiltern) and is not included in the future timetable cases.

24. **Current train protection fitment:** For the assessment, the train protection is as per the table below.

			Train protection					
Route	Operator	Stock Type	AWS	TPWS Mk1	TPWS Mk3	TPWS Mk4	BR ATP	ETCS
GWR High Speed Services	GWR	80x	Y			Y	Y	Y
Paddington - Hayes and Harlington	XR	345	Y			Y		Y
Paddington - Heathrow - Crossrail	XR	345	Y			Y		Y
Paddington - Heathrow - Hex	HX	322/387	-/Y			-/Y	Y/-	-/Y
Paddington - South Ruislip	Chiltern	165	Y	Y				
Paddington - Reading	GWR	387/345	Y/Y			Y/Y		-/Y
Paddington - Maidenhead	GWR	387/345	Y/Y			Y/Y		-/Y
Paddington - Didcot Parkway	GWR	165/387	Y/Y	Y/-		-/Y		-/Y

7 ACRONYMS AND ABBREVIATIONS

Acronym	Description	Comments
ACM	Accident Consequence Model	
ALARP	As Low As Reasonably Practicable	
ATP	Automatic Train Protection	
CBTC	The Crossrail train control (signalling) and protection system	
ETCS	European Train Control System	
FWI	Fatalities and Weighted Injuries	A measure of safety performance where the predicted rate of fatalities and minor and minor injuries are combined into an overall measure of risk.
NTC	Level National Train Control	An ETCS operational level that permits trains to operate under the management of ETCS, but applying the legacy national train control (for the purposes of this study, AWS and TPWS).
OSS	(TPWS) Over-speed sensor system	
SPAD	Signal Passed at Danger	
SRM	Safety Risk Model	The rail risk model managed on behalf of the industry by RSSB
	(TPWS) Train Stop System'	
TPWS	Train Protection and Warning System	

8 TABLES OF RISK ASSESSMENT RESULTS

The following tables present the detailed risk results for each of the analysed timetables and options. Table 6 presents the options for the Exemption Case, Table 7 to 0 present the results for timetable options TT1 to TT3 respectively. The return period presented in the final column is the expected average number of years between accidents and is based upon frequency rather than risk (accounting for the average consequences for the incident type). The return period for buffer collisions is relatively low as it includes roll-back buffer incidents that are minor by nature.

Table 6 Exemption timetable case

May 19 Timetable				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Exemption	Do nothing to the existing infrastructure or planned train service (i.e. continue with enhanced TPWS and run current Crossrail (CL345) with reliance on Level NTC.)	Collision	1.01E-02	1,011
		Buffer collision	3.88E-03	6
		Derailment	1.72E-04	1,197
		Maintainer	9.23E-05	90
		Total	**1.43E-02**	
Option 1	Do nothing to the existing infrastructure increase train service i.e. continue with enhanced TPWS and run additional Crossrail (CL345) and GWR/HEX(CL387) services as planned with reliance on Level NTC.			
Option 1a	As Per Option 1 but defer trackside ETCS fitment in lieu of axle counter upgrade. ETCS Operation - Dec 2023			
Option 1b	As per Option 1 but fitment of trackside ETCS as early as possible, defer axle counters ETCS Operation - Dec 2021			
Option 1c	As per Option 1 but fitment of trackside ETCS (Area B) as early as possible Area B ETCS Operation - June 2020			

May 19 Timetable				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Option 1d	As per Option 1 but install enhanced TPWS on approach to buffer stops			
Option 2	Do nothing to the existing infrastructure and fit GW-ATP to Crossrail and HEX service trains.			
Option 2a	Do Nothing to the existing infrastructure and fit GW-ATP to Crossrail services only.			
Option 2b	Do nothing to the existing infrastructure and fit GW-ATP to HEX services only.			
Option 3a	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for Crossrail Services (Class 360, 332).			
Option 3b	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for HEX services (Class 360, 332).			

May 19 Timetable				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Option 4	Second Driver on the Footplate of Class 345/387			
Option 5	Provision of ETCS Level 1 in Area C (Level 2 in area B)			
Option 6	Fitment of ETCS Level 2 (Area B and C)			

Table 7 Timetable 1 – Options

Timetable – TT1				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Exemption	Do nothing to the existing infrastructure or planned train service (i.e. continue with enhanced TPWS and run current Crossrail (CL345) with reliance on Level NTC.)			
Option 1	Do nothing to the existing infrastructure increase train service i.e. continue with enhanced TPWS and run additional Crossrail (CL345) and GWR/HEX(CL387) services as planned with reliance on Level NTC.	Collision	7.04E-03	1,452
		Buffer collision	4.39E-03	5
		Derailment	2.15E-04	957
		Maintainer	9.23E-05	90
		Total	**1.17E-02**	
Option 1a	As Per Option 1 but defer trackside ETCS fitment in lieu of axle counter upgrade. ETCS Operation - Dec 2023	Collision	7.04E-03	1,452
		Buffer collision	4.39E-03	5
		Derailment	2.15E-04	957
		Maintainer	4.79E-05	172
		Total	**1.17E-02**	
Option 1b	As per Option 1 but fitment of trackside ETCS as early as possible, defer axle counters ETCS Operation - Dec 2021	Collision	7.04E-03	1,452
		Buffer collision	4.39E-03	5
		Derailment	2.15E-04	957
		Maintainer	9.23E-05	90
		Total	**1.17E-02**	
Option 1c		Collision	6.85E-03	1,493

Timetable – TT1				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
	As per Option 1 but fitment of trackside ETCS (Area B) as early as possible Area B ETCS Operation - June 2020	Buffer collision	4.39E-03	5
		Derailment	1.24E-04	1,670
		Maintainer	9.23E-05	90
		Total	**1.15E-02**	
Option 1d	As per Option 1 but install enhanced TPWS on approach to buffer stops	Collision	7.04E-03	1,452
		Buffer collision	3.48E-03	7
		Derailment	2.15E-04	957
		Maintainer	9.53E-05	87
		Total	**1.08E-02**	
Option 2	Do nothing to the existing infrastructure and fit GW-ATP to Crossrail and HEX service trains.	Collision	6.82E-03	1,499
		Buffer collision	2.12E-03	11
		Derailment	4.80E-05	4,298
		Maintainer	9.23E-05	90
		Total	**9.08E-03**	
Option 2a	Do Nothing to the existing infrastructure and fit GW-ATP to Crossrail services only.	Collision	6.86E-03	1,492
		Buffer collision	2.89E-03	8
		Derailment	1.05E-04	1,972
		Maintainer	9.23E-05	90
		Total	**9.94E-03**	
Option 2b	Do nothing to the existing infrastructure and fit GW-ATP to HEX services only.	Collision	7.01E-03	1,459
		Buffer collision	3.62E-03	7
		Derailment	1.59E-04	1,298

Timetable – TT1				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
		Maintainer	9.23E-05	90
		Total	**1.09E-02**	
Option 3a	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for Crossrail Services (Class 360, 332).	Collision	6.86E-03	1,492
		Buffer collision	2.89E-03	8
		Derailment	1.05E-04	1,972
		Maintainer	9.23E-05	90
		Total	**9.94E-03**	
Option 3b	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for HEX services (Class 360, 332).	Collision	7.01E-03	1,459
		Buffer collision	3.62E-03	7
		Derailment	1.59E-04	1,298
		Maintainer	9.23E-05	90
		Total	**1.09E-02**	
Option 4	Second Driver on the Footplate of Class 345/387	Collision	7.04E-03	1,452
		Buffer collision	4.39E-03	5
		Derailment	2.15E-04	957
		Maintainer	9.23E-05	90
		Total	**1.17E-02**	
Option 5	Provision of ETCS Level 1 in Area C (Level 2 in area B)	Collision	6.83E-03	1,497
		Buffer collision	1.97E-03	12
		Derailment	4.80E-05	4,298
		Maintainer	9.23E-05	90
		Total	**8.95E-03**	

Timetable – TT1				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Option 6	Fitment of ETCS Level 2 (Area B and C)	Collision	6.73E-03	1,520
		Buffer collision	1.97E-03	12
		Derailment	4.80E-05	4,298
		Maintainer	9.23E-05	90
		Total	**8.84E-03**	

Table 8 Timetable 2 – Options

Timetable - TT2				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Exemption	Do nothing to the existing infrastructure or planned train service (i.e. continue with enhanced TPWS and run current Crossrail (CL345) with reliance on Level NTC.)			
Option 1	Do nothing to the existing infrastructure increase train service i.e. continue with enhanced TPWS and run additional Crossrail (CL345) and GWR/HEX(CL387) services as planned with reliance on Level NTC.	Collision	6.33E-03	1,615
		Buffer collision	3.80E-03	6
		Derailment	1.84E-04	1,121
		Maintainer	9.23E-05	90
		Total	**1.04E-02**	
Option 1a	As Per Option 1 but defer trackside ETCS fitment in lieu of axle counter upgrade. ETCS Operation - Dec 2023	Collision	6.33E-03	1,615
		Buffer collision	3.80E-03	6
		Derailment	1.84E-04	1,121
		Maintainer	4.79E-05	172
		Total	**1.04E-02**	
Option 1b	As per Option 1 but fitment of trackside ETCS as early as possible, defer axle counters ETCS Operation - Dec 2021	Collision	6.33E-03	1,615
		Buffer collision	3.80E-03	6
		Derailment	1.84E-04	1,121
		Maintainer	9.23E-05	90
		Total	**1.04E-02**	
Option 1c		Collision	6.22E-03	1,646

Timetable - TT2				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
	As per Option 1 but fitment of trackside ETCS (Area B) as early as possible Area B ETCS Operation - June 2020	Buffer collision	3.80E-03	6
		Derailment	1.23E-04	1,682
		Maintainer	9.23E-05	90
		Total	**1.02E-02**	
Option 1d	As per Option 1 but install enhanced TPWS on approach to buffer stops	Collision	6.33E-03	1,615
		Buffer collision	3.03E-03	8
		Derailment	1.84E-04	1,121
		Maintainer	9.53E-05	87
		Total	**9.64E-03**	
Option 2	Do nothing to the existing infrastructure and fit GW-ATP to Crossrail and HEX service trains.	Collision	6.21E-03	1,646
		Buffer collision	2.28E-03	10
		Derailment	7.19E-05	2,868
		Maintainer	9.23E-05	90
		Total	**8.65E-03**	
Option 2a	Do Nothing to the existing infrastructure and fit GW-ATP to Crossrail services only.	Collision	6.25E-03	1,638
		Buffer collision	3.04E-03	8
		Derailment	1.29E-04	1,605
		Maintainer	9.23E-05	90
		Total	**9.51E-03**	
Option 2b	Do nothing to the existing infrastructure and fit GW-ATP to HEX services only.	Collision	6.30E-03	1,623
		Buffer collision	3.03E-03	8
		Derailment	1.27E-04	1,620

Timetable - TT2				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
		Maintainer	9.23E-05	90
		Total	**9.55E-03**	
Option 3a	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for Crossrail Services (Class 360, 332).	Collision	6.25E-03	1,638
		Buffer collision	3.04E-03	8
		Derailment	1.29E-04	1,605
		Maintainer	9.23E-05	90
		Total	**9.51E-03**	
Option 3b	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for HEX services (Class 360, 332).	Collision	6.30E-03	1,623
		Buffer collision	3.03E-03	8
		Derailment	1.27E-04	1,620
		Maintainer	9.23E-05	90
		Total	**9.55E-03**	
Option 4	Second Driver on the Footplate of Class 345/387	Collision	6.33E-03	1,615
		Buffer collision	3.80E-03	6
		Derailment	1.84E-04	1,121
		Maintainer	9.23E-05	90
		Total	**1.04E-02**	
Option 5	Provision of ETCS Level 1 in Area C (Level 2 in area B)	Collision	6.23E-03	1,643
		Buffer collision	2.16E-03	11
		Derailment	7.19E-05	2,868
		Maintainer	9.23E-05	90
		Total	**8.55E-03**	

Timetable - TT2				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Option 6	Fitment of ETCS Level 2 (Area B and C)	Collision	6.14E-03	1,667
		Buffer collision	2.16E-03	11
		Derailment	7.19E-05	2,868
		Maintainer	9.23E-05	90
		Total	**8.46E-03**	

Table 9 Timetable 3 - Options

Timetable – TT3				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Exemption	Do nothing to the existing infrastructure or planned train service (i.e. continue with enhanced TPWS and run current Crossrail (CL345) with reliance on Level NTC.)			
Option 1	Do nothing to the existing infrastructure increase train service i.e. continue with enhanced TPWS and run additional Crossrail (CL345) and GWR/HEX(CL387) services as planned with reliance on Level NTC.	Collision	7.96E-03	1,286
		Buffer collision	1.69E-03	14
		Derailment	2.47E-04	834
		Maintainer	9.23E-05	90
		Total	**9.98E-03**	
Option 1a	As Per Option 1 but defer trackside ETCS fitment in lieu of axle counter upgrade. ETCS Operation - Dec 2023	Collision	7.96E-03	1,286
		Buffer collision	1.69E-03	14
		Derailment	2.47E-04	834
		Maintainer	4.79E-05	172
		Total	**9.94E-03**	
Option 1b	As per Option 1 but fitment of trackside ETCS as early as possible, defer axle counters ETCS Operation - Dec 2021	Collision	7.96E-03	1,286
		Buffer collision	1.69E-03	14
		Derailment	2.47E-04	834
		Maintainer	9.23E-05	90
		Total	**9.98E-03**	
Option 1c		Collision	7.68E-03	1,331

Timetable – TT3				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
	As per Option 1 but fitment of trackside ETCS (Area B) as early as possible Area B ETCS Operation - June 2020	Buffer collision	1.69E-03	14
		Derailment	1.34E-04	1,535
		Maintainer	9.23E-05	90
		Total	**9.60E-03**	
Option 1d	As per Option 1 but install enhanced TPWS on approach to buffer stops	Collision	7.96E-03	1,286
		Buffer collision	1.42E-03	17
		Derailment	2.47E-04	834
		Maintainer	9.53E-05	87
		Total	**9.72E-03**	
Option 2	Do nothing to the existing infrastructure and fit GW-ATP to Crossrail and HEX service trains.	Collision	7.57E-03	1,351
		Buffer collision	9.17E-04	26
		Derailment	4.19E-05	4,920
		Maintainer	9.23E-05	90
		Total	**8.62E-03**	
Option 2a	Do Nothing to the existing infrastructure and fit GW-ATP to Crossrail services only.	Collision	7.60E-03	1,345
		Buffer collision	1.69E-03	14
		Derailment	9.85E-05	2,094
		Maintainer	9.23E-05	90
		Total	**9.48E-03**	
Option 2b	Do nothing to the existing infrastructure and fit GW-ATP to HEX services only.	Collision	7.92E-03	1,291
		Buffer collision	9.17E-04	26
		Derailment	1.91E-04	1,082

Timetable – TT3				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
		Maintainer	9.23E-05	90
		Total	**9.12E-03**	
Option 3a	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for Crossrail Services (Class 360, 332).	Collision	7.60E-03	1,345
		Buffer collision	1.69E-03	14
		Derailment	9.85E-05	2,094
		Maintainer	9.23E-05	90
		Total	**9.48E-03**	
Option 3b	Do Nothing to the existing infrastructure and utilise GW-ATP on existing train fleets for HEX services (Class 360, 332).	Collision	7.92E-03	1,291
		Buffer collision	9.17E-04	26
		Derailment	1.91E-04	1,082
		Maintainer	9.23E-05	90
		Total	**9.12E-03**	
Option 4	Second Driver on the Footplate of Class 345/387	Collision	7.96E-03	1,286
		Buffer collision	1.69E-03	14
		Derailment	2.47E-04	834
		Maintainer	9.23E-05	90
		Total	**9.98E-03**	
Option 5	Provision of ETCS Level 1 in Area C (Level 2 in area B)	Collision	7.59E-03	1,348
		Buffer collision	8.32E-04	29
		Derailment	4.19E-05	4,920
		Maintainer	9.23E-05	90
		Total	**8.55E-03**	

Timetable – TT3				
Ref.	**Technical Options**	**HE**	**Risk**	**Return period**
			FWI/yr	**Years**
Option 6	Fitment of ETCS Level 2 (Area B and C)	Collision	7.53E-03	1,358
		Buffer collision	8.32E-04	29
		Derailment	4.19E-05	4,920
		Maintainer	9.23E-05	90
		Total	**8.50E-03**	