Sotera Risk Solutions

Report for Network Rail

Risk Assessment of the Chiltern Train Protection Strategy

Doc: J2044/Doc001

Rev: Rev 03

Date: 17th January 2020

Sotera Risk Solutions Limited
22 Glanville Road
Bromley
Kent BR2 9LW
United Kingdom
Tel: +44 (0)20 82890384
Email: peter.dray@sotera.co.uk
Internet: www.sotera.co.uk

REVISIONS

Revision No	Prepared by	Checked by	Issue date	Comments
Rev 00	Peter Dray			Internal version
Rev 01	Peter Dray	David Harris	17/12/2019	Issued for Network Rail review
Rev 02	Peter Dray	David Harris	14/01/2020	Issued to Network Rail accommodating comments
Rev 03	Peter Dray	David Harris	17/01/2020	Issued to Network Rail accommodating comments

APPROVAL

Prepared by: 	Name: Peter Dray
	Job Title: Risk Specialist
	Date: 17/01/20
Accepted by: Barry Lawson Digitally signed by Barry Lawson DN: cn=Barry Lawson, o=IP Signalling, ou=Signalling Northern, email=barry.lawson2@networkrail.co.uk, c=GB Date: 2020.01.21 08:43:59 Z	Name: Barry Lawson
	Role: Project Manager
	Date: 21/01/2020

TABLE OF CONTENTS

1 INTRODUCTION

Following the DoT investigation into the Clapham Junction Rail Accident (1988), recommendations were made in regard to the fitment of Automatic Train Protection on the GB railway. Two pilot schemes for ATP were identified covering Chiltern and Great Western and these schemes were implemented in the early 1990s.

The two installed systems are compliant with the current legislative requirements for train protection systems as described in the Railways Safety Regulations 1999 (Termed RSR 99).

Included in RSR 99, is the mandated requirement on the mainline network to provide a track side and train borne train protection system. A 'train protection system' is defined in Regulation 2(1) of RSR 99 as:

> *"equipment which*
>
> *(a) causes the brakes of the train to apply automatically if the train–*
>
> *(i) passes without authority a stop signal such passing of which could cause the train to collide with another train, or*
>
> *(ii) travels at excessive speed on a relevant approach;*
>
> *(b) is installed so as to operate at every stop signal referred to in sub-paragraph (a), except a stop signal on the approach to an emergency crossover, and at an appropriate place on every relevant approach;*
>
> *except that where it is reasonably practicable to install it, it means equipment which automatically controls the speed of the train to ensure, so far as possible, that a stop signal is not passed without authority and that the permitted speed is not exceeded at any time throughout its journey".*

Following the regulations, there was an acceptance that ATP would be required across the mainline railway and, in the interim, TPWS would be provided. Since the 1999 regulations, there have been significant developments in the industry:

- Completion of the installation of TPWS at junction signals (circa. 2003), which, in conjunction with other risk reduction measures, has reduced SPAD risk across the network by 90%.
- The incremental improvement to the deployment of both trackside and trainborne TPWS to improve reliability, availability and effectiveness in stopping trains before they reach a conflict point.
- The development of ERTMS, which is planned for installation across the entire main line railway, which will provide an enhanced level of protection compared to TPWS.

Having been installed as part of a trial for nearly thirty years, the ATP system fitted to Chiltern is now obsolete; spares are no longer available, and the equipment is not manufactured. Hence, maintaining the existing system is becoming infeasible and alternative train protection strategies need to be considered for the future.

As a consequence of the obsolescence and reliability issues, Network Rail has identified a range of alternative risk control strategies to manage the risk over the area of the rail network over which Chiltern services operate. Sotera Risk Solutions Limited (Sotera) has been commissioned to undertake a detailed, independent, risk assessment of these potential future train protection strategies for Chiltern. The work will help determine the strategy that provides the optimum balance between safety and operational performance. The risk assessment provides the basis for an application under Regulation 6 of RSR 99 for an exemption in relation to the use of train protection systems (Regulation 3).

The risk assessment analyses the current operation of the railway and consideration of the following future changes, that potentially impact the underlying level of risk:

- Passenger growth.
- The implementation of Phase 2 of East West Rail (EWR), which will provide additional services over parts of the railway that Chiltern operates. EWR will develop routes from Oxford to Cambridge via Bicester and between Milton Keynes and Aylesbury.
- The impact of HS2 for construction traffic and changes to train stabling arrangements.
- Degradation of ATP reliability resulting in increased reliance of Class 2 systems (TPWS).

Several risk controls strategies are evaluated, including:

- Enhanced levels of trackside TPWS provision at plain line and junction signals.
- Upgrading in cab TPWS units.
- Provision of roll-back protection.

- Upgrading the infrastructure to provide ETCS L2 Limited Supervision[1].
- Upgrading to Full Supervision ETCS.
- Selected combinations of the above.

The risk assessment focusses on three key areas of risk: train-train collisions from SPADs, derailments from overspeeding and buffer collisions. These are considered to be the hazardous events significantly affected by the different train protection strategies.

[1] The ETCS L2 Limited Supervision referenced in this report is not the Limited Supervision mode defined in ETCS standards. The term is used to describe a method of train protection where the aspect of approached signals are communicated to the train. A modified version of TPWS (termed TPWS Mk5) would apply the train brakes if the speed profile of the train exceeds that required to stop the train at the signals that are being approached. TPWS Mk5 is not yet available and would need significant development.

2 SCOPE OF THE ASSESSMENT

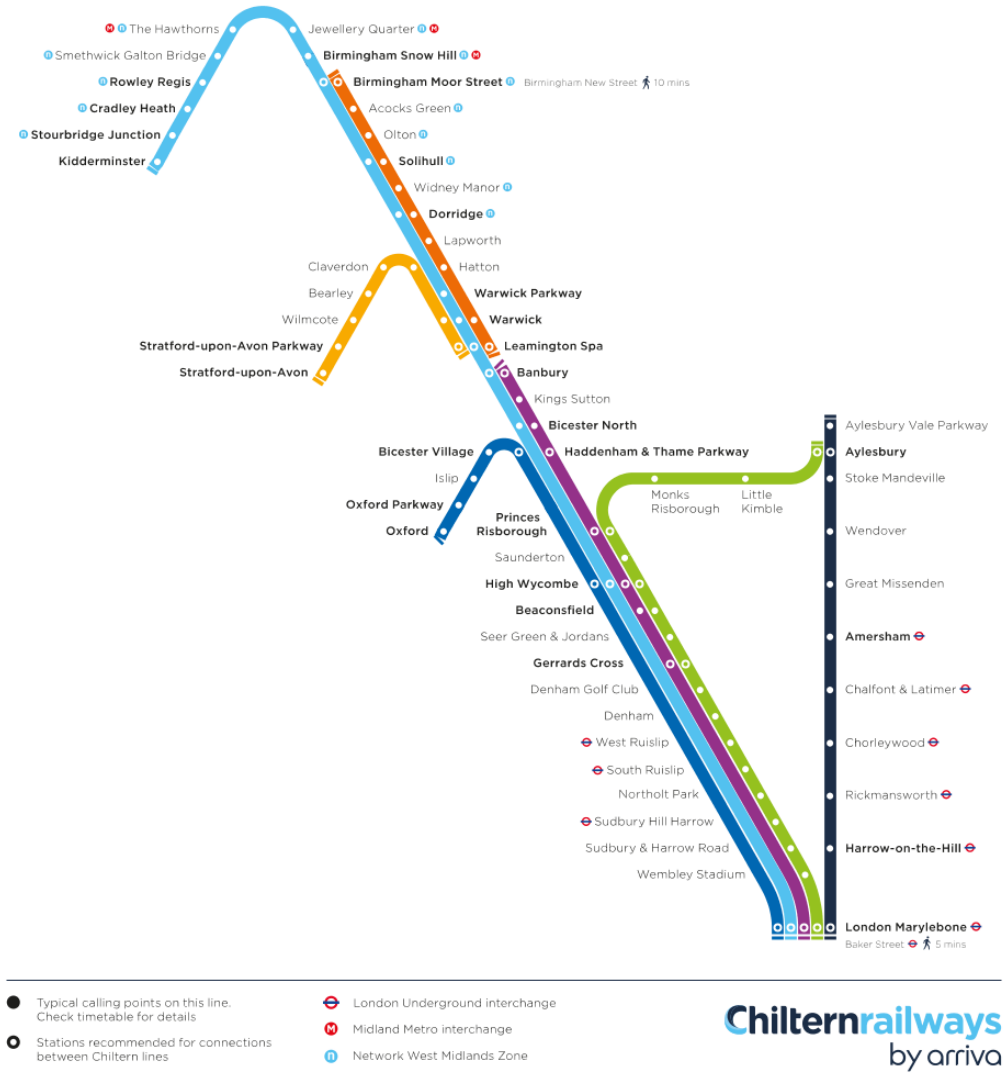
The scope of work is described in the following sections.

2.1 Physical boundary of the operation

The boundary covers passenger and freight train services over the Network Rail infrastructure that Chiltern Railways operates. Specifically, this includes the routes to/from Marylebone, Oxford, Aylesbury, Aylesbury Vale Parkway, Stratford-upon-Avon, Birmingham Moor Street and Kidderminster (see Figure 1).

Note: The LUL infrastructure between Marylebone and Amersham is not included in the assessment.

Figure 1 Schematic of route covered by the base case assessment



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.

There is also a potential increase in risk to maintainers and installers commissioning and managing trackside equipment. The risk from this has been previously assessed for a similar project in the Paddington area and the risk increase was found to be insignificant compared to the train operating risks, where it presented just 0.6% of the assessed risk. Hence, the occupational track worker risk is not included in this study as it would not be a significant contributor even if there was a higher level of trackside working.

2.3 Service Levels and options

Four service levels are considered by the study, these are defined as follows:

SL19: This reflects the current level of passenger and freight services. For Chiltern train services, the analysis was based upon the Spring 2019 timetable. The train services for CrossCountry and London Northwestern Railway were taken from the timetable for August 2019.

Freight service levels were based upon characteristic train running in August 2019. Note, for freight services, train running rather than train paths were used.

For passenger numbers, details were taken from published ORR statistics for 2018/19 for each operator.

SL21: This reflects the level of train service in 2021. Train frequencies are as per SL19 with the addition of HS2 construction traffic.

For passenger numbers, growth from 2019 has been based upon recent trends in passenger growth of 2.5% per year.

SL23: This is as per SL21, with the addition of Phase 2 of East West Rail, including the relevant parts of the route between Oxford and Cambridge via Bicester and Milton Keynes to Aylesbury.

Passenger numbers are considered to continue to grow at 2.5% per year.

SL26: This is the end case for the assessment and is identical to SL23 with continued growth in passenger numbers. This option is likely to be the point where there may be major changes from the full opening of

EWR, rolling stock cascade/end of life and the end of a possible 5-year extension to the Chiltern franchise.

2.4 Infrastructure fitment and options

Several lineside infrastructure options were considered by the assessment, these include:

- The current ATP and TPWS fitment.
- ATP switched off with the current TPWS fitment.
- ATP switched off with enhanced TPWS fitment between Marylebone and Aynho Junction (similar to the area provided with ATP currently). The enhanced TPWS fitment includes provision at plain line signals and enhanced junction fitment to provide protection for trains with 9%g and 12%g emergency braking.
- ATP switched off with enhanced TPWS fitment between Marylebone and Birmingham Snow Hill. Similar to the previous option, enhanced TPWS fitment includes plain line signals and enhanced junction fitment to provide protection for trains with 9%g and 12%g emergency braking.
- ETCS L2 Limited Supervision (where the train is provided with the status of signals ahead and uses ETCS onboard functionality to manage train speed in accordance with any required braking profile).
- ETCS L2 with Full Supervision.

2.5 Rolling stock fitment and options

The trainborne train protection cases assessed include:

- The existing fleets with the current levels of ATP and TPWS fitment.
- Provision of roll-back protection on Chiltern stock.
- Upgrading Chiltern stock to have TPWS units with equivalent functionality to the Thales Mk4 units (with continuous health monitoring and separate indications of whether an activation was caused by an overspeed or SPAD). The Mk4 units are compliant with current RSSB standards.
- Upgrading **Chiltern stock** to have ETCS L2 Limited Supervision (effectively TPWS Mk5 units, which have yet to be designed). The

Mk5 units would provide both ETCS L2 Limited Supervision and the same TPWS performance improvements as Mk4 TPWS.

- Upgrading **all stock** (all TOCs and FOCs) operating over the infrastructure to have ETCS L2 Limited Supervision.
- ETCS for Chiltern stock.
- ETCS for all traffic operating over the infrastructure.

Based upon the above options, there are many combinations of trackside systems, trainborne protection, service levels and growth. In order to manage the scale of the risk assessment, 80 scenarios have been progressed. There are defined in *Table 1*, where a case is defined in terms of service level, infrastructure fitment, ATP degradation and train fitment.

Table 1 Options assessed by the risk assessment

Case	Service level	% Chiltern ATP operational	TPWS (Marylebone to Aynho Jn)	TPWS (Aynho Jn to B'ham Moor Street)	Chiltern TPWS fitment	Rollback protection	ETCS
1.	2019	100%	Current	Current	Current	×	×
2.	2019	0%	Current	Current	Current	×	×
3.	2019	0%	Enhanced	Current	Current	×	×
4.	2019	0%	Enhanced	Enhanced	Current	×	×
5.	2019	0%	Current	Current	Current	✓	×
6.	2019	0%	Enhanced	Current	Current	✓	×
7.	2019	0%	Enhanced	Enhanced	Current	✓	×
8.	2019	0%	Current	Current	Mk4	×	×
9.	2019	0%	Enhanced	Current	Mk4	×	×
10.	2019	0%	Enhanced	Enhanced	Mk4	×	×
11.	2019	0%	Current	Current	Current	×	Limited
12.	2019	0%	Current	Current	Current	×	Full
13.	2019	50%	Current	Current	Current	×	×
14.	2019	50%	Current	Current	Mk4	×	×
15.	2019	50%	Enhanced	Current	Current	×	×
16.	2019	50%	Enhanced	Current	Mk4	×	×
17.	2019	50%	Enhanced	Enhanced	Current	×	×
18.	2019	50%	Enhanced	Enhanced	Mk4	×	×
19.	2019	0%	Enhanced	Current	Mk4	×	Limited – Chiltern core
20.	2019	0%	Enhanced	Current	Mk4	×	Limited – Chiltern all
21.	2021	100%	Current	Current	Current	×	×
22.	2021	0%	Current	Current	Current	×	×
23.	2021	0%	Enhanced	Current	Current	×	×
24.	2021	0%	Enhanced	Enhanced	Current	×	×

Case	Service level	% Chiltern ATP operational	TPWS (Marylebone to Aynho Jn)	TPWS (Aynho Jn to B'ham Moor Street)	Chiltern TPWS fitment	Rollback protection	ETCS
25.	2021	0%	Current	Current	Current	✓	×
26.	2021	0%	Enhanced	Current	Current	✓	×
27.	2021	0%	Enhanced	Enhanced	Current	✓	×
28.	2021	0%	Current	Current	Mk4	×	×
29.	2021	0%	Enhanced	Current	Mk4	×	×
30.	2021	0%	Enhanced	Enhanced	Mk4	×	×
31.	2021	0%	Current	Current	Current	×	Limited
32.	2021	0%	Current	Current	Current	×	Full
33.	2021	50%	Current	Current	Current	×	×
34.	2021	50%	Current	Current	Mk4	×	×
35.	2021	50%	Enhanced	Current	Current	×	×
36.	2021	50%	Enhanced	Current	Mk4	×	×
37.	2021	50%	Enhanced	Enhanced	Current	×	×
38.	2021	50%	Enhanced	Enhanced	Mk4	×	×
39.	2021	0%	Enhanced	Current	Mk4	×	Limited – Chiltern core
40.	2021	0%	Enhanced	Current	Mk4	×	Limited – Chiltern all
41.	2023	100%	Current	Current	Current	×	×
42.	2023	0%	Current	Current	Current	×	×
43.	2023	0%	Enhanced	Current	Current	×	×
44.	2023	0%	Enhanced	Enhanced	Current	×	×
45.	2023	0%	Current	Current	Current	✓	×
46.	2023	0%	Enhanced	Current	Current	✓	×
47.	2023	0%	Enhanced	Enhanced	Current	✓	×
48.	2023	0%	Current	Current	Mk4	×	×
49.	2023	0%	Enhanced	Current	Mk4	×	×

Case	Service level	% Chiltern ATP operational	TPWS (Marylebone to Aynho Jn)	TPWS (Aynho Jn to B'ham Moor Street)	Chiltern TPWS fitment	Rollback protection	ETCS
50.	2023	0%	Enhanced	Enhanced	Mk4	×	×
51.	2023	0%	Current	Current	Current	×	Limited
52.	2023	0%	Current	Current	Current	×	Full
53.	2023	50%	Current	Current	Current	×	×
54.	2023	50%	Current	Current	Mk4	×	×
55.	2023	50%	Enhanced	Current	Current	×	×
56.	2023	50%	Enhanced	Current	Mk4	×	×
57.	2023	50%	Enhanced	Enhanced	Current	×	×
58.	2023	50%	Enhanced	Enhanced	Mk4	×	×
59.	2023	0%	Enhanced	Current	Mk4	×	Limited – Chiltern core
60.	2023	0%	Enhanced	Current	Mk4	×	Limited – Chiltern all
61.	2026	100%	Current	Current	Current	×	×
62.	2026	0%	Current	Current	Current	×	×
63.	2026	0%	Enhanced	Current	Current	×	×
64.	2026	0%	Enhanced	Enhanced	Current	×	×
65.	2026	0%	Current	Current	Current	✓	×
66.	2026	0%	Enhanced	Current	Current	✓	×
67.	2026	0%	Enhanced	Enhanced	Current	✓	×
68.	2026	0%	Current	Current	Mk4	×	×
69.	2026	0%	Enhanced	Current	Mk4	×	×
70.	2026	0%	Enhanced	Enhanced	Mk4	×	×
71.	2026	0%	Current	Current	Current	×	Limited
72.	2026	0%	Current	Current	Current	×	Full
73.	2026	50%	Current	Current	Current	×	×
74.	2026	50%	Current	Current	Mk4	×	×

Case	Service level	% Chiltern ATP operational	TPWS (Marylebone to Aynho Jn)	TPWS (Aynho Jn to B'ham Moor Street)	Chiltern TPWS fitment	Rollback protection	ETCS
75.	2026	50%	Enhanced	Current	Current	×	×
76.	2026	50%	Enhanced	Current	Mk4	×	×
77.	2026	50%	Enhanced	Enhanced	Current	×	×
78.	2026	50%	Enhanced	Enhanced	Mk4	×	×
79.	2021	0%	Enhanced	Current	Mk4	×	Limited – Chiltern core
80.	2021	0%	Enhanced	Current	Mk4	×	Limited – Chiltern all

3 APPROACH TO THE RISK ASSESSMENT

3.1 Overall approach

The approach to the assessment was identical to that for the assessment used to underpin the exemption application for the Crossrail Paddington to Heathrow project[1]. The approach is described in the following sections.

3.2 Risk assessment stages

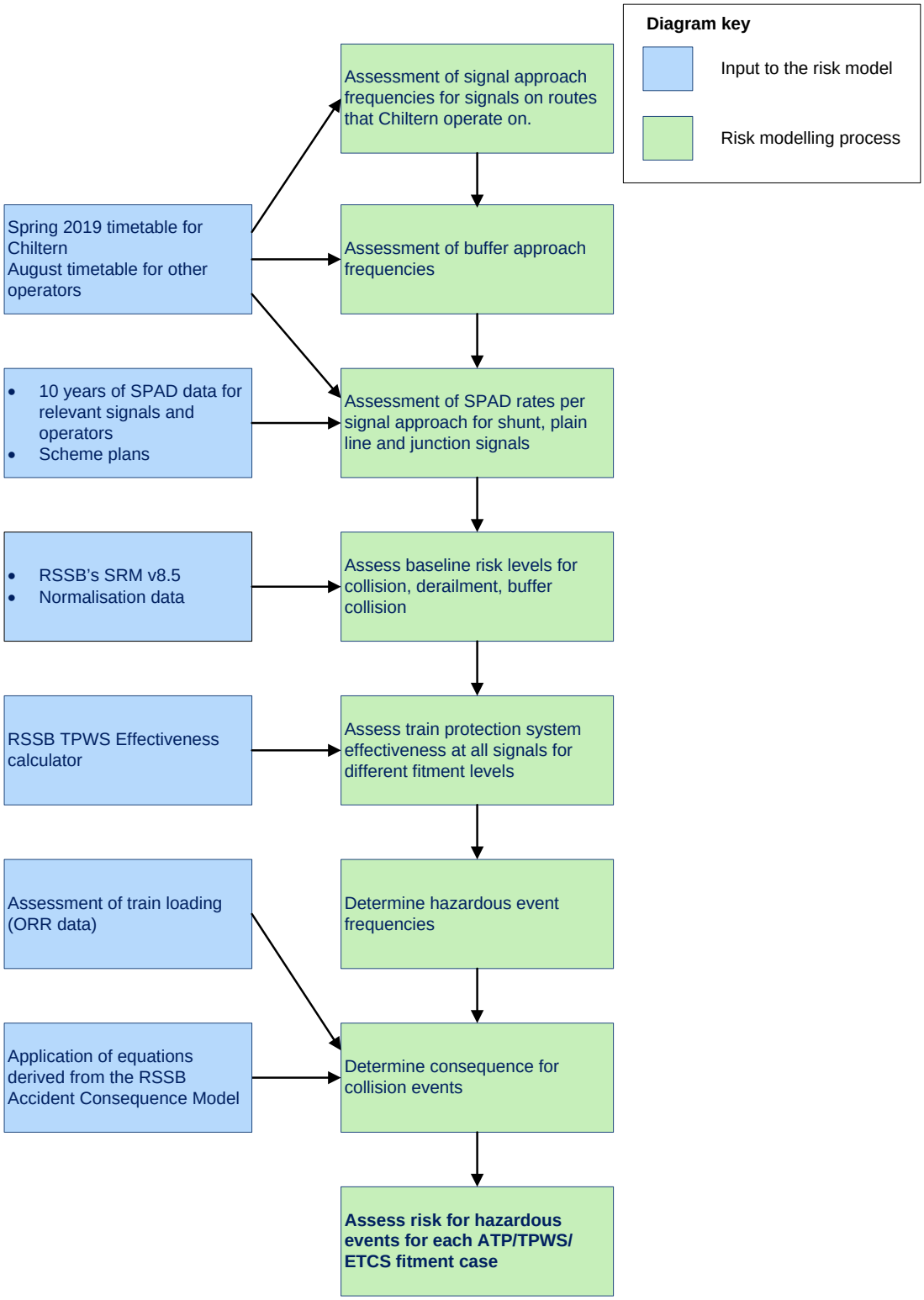
A range of data analysis techniques were used to determine the risk from each of the hazardous events analysed by the study. Separate models were developed for each of the hazardous events assessed.

The main stages to the assessment are presented in *Figure 1*. The inputs are shown in blue and the main process stages shown in green. The following subsections describe the approach for each hazardous event.

The key study assumptions are presented in *Section 6*.

[1] Risk Assessment of the Crossrail Train Protection Strategy – Paddington to Heathrow for 2018, Sotera Risk Solutions 2018.

Figure 2 The key elements and data inputs the risk model



3.3 Train-train collisions

The train-train collision model is the most complicated of all the hazardous events assessed. The reasons for this are the need to account for the number of train approaches to each signal, the wide range of rolling stock and the effectiveness of ATP, TPWS or ETCS at each signal for the trains operating past the signal. The main elements of the model are described below:

The likelihood of SPADs at each of the signals

This assessment is based upon the signal type (shunt, plain line or junction), the number of approaches to the signal and the likelihood of a SPAD per approach. The likelihood of a SPAD per approach has been based on historic SPAD performance at the signals subject to assessment accounting for ten years of SPAD performance data in the relevant route sections over which Chiltern operates. The predicted SPAD rate is apportioned to each signal based upon the frequency with which train approach the signals displaying a red aspect.

The likelihood that each signal is approached at red is based upon RSSB's RAATS (Red Aspect Approach Tool) application. The tool analyses numerous approaches to each signal and identifies the number of approaches that are at Red. It is important to note that the RAATS tool does not cover every signal. For signals covered by the model that are not included in RSSB's tool and for those that are included but rarely approached, generic likelihoods are used for the likelihood that the signal is approached at red. The generic probabilities are developed separately for plain line, junction and shunt signals. For junction signals, two probabilities are used to account for different types of junction; those that are relatively likely to be at red due to being at a busy junctions, eg, on the approach to Marylebone and those that protect an infrequently used junctions such as goods loops or crossovers.

The likelihood of a collision following a SPAD

The model has been developed to investigate escalation of a SPAD into a train-train collision. The starting point for this is determining the likelihood that a SPAD results in a collision (for shunt, junction and plain line signals) excluding the benefit from any train protection system. Using this approach the benefit of the various train protection systems can be layered on the assessment to determine the benefit they provide at each signal. In order to determine the likelihood that a SPAD results in a collision, the SRM v8.5 has been used. The benefit of TPWS is inherently included in the SRM and therefore the benefit of it was factored-out by accounting for the typical performance of TPWS at plain line and junction signals.

The effectiveness of the prevailing train protection system at each signal for each of the cases accounts for the trains that pass each signal and the fitment options for TPWS and the installation of ATP. TPWS effectiveness

is assessed using the TPWS effectiveness calculator developed by RSSB. The TPWS effectiveness calculator accounts for the train's braking performance, track gradient, the overrun distance required to cause a collision, the line speed, train braking performance and TSS and OSS fitment (distance from the TSS and set speed). Enhanced levels of protection are provided by Mk3 and Mk4 TPWS in-cab units (see Assumptions in *Section 6*).

The effectiveness of ETCS L2 Limited Supervision and Full Supervision has been accounted for by taking the results of analysis performed by RSSB and the consulting firm ADL. The benefit of ETCS from this analysis is based upon the degree of risk reduction from the 'Current National Baseline' to the two ETCS cases (see *Table 2*)

Table 2 RSSB / ADL assessed benefit of ETCS

Configuration	Safety Risk (FWI per year)
Current National Baseline Risk	0.993
Safety risk with ETCS L2 Limited Supervision	0.387
Safety risk with ETCS Full Supervision	0.263

Note the above assessment by RSSB/ADL is not specific to the hazardous event, the degree of benefit has therefore been applied to all relevant events.

Assessment of passenger loading on trains

The passenger train loading for all services have been taken from ORR statistics[1] by dividing the number of passenger journeys for each of the operators and dividing by the number of train services.

The assessment gives an average loading figures of:

- 135 passengers per train for Chiltern
- 114 passengers per train for CrossCountry, and
- 114 passengers per train for London Northwestern Railway.

For reference, the average across all GB operators is 128.

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 at

[1] ORR Data Portal, ORR annual statistics 2013/14 - entrances plus exits plus interchanges.

each signal and accounting for the signal type. The assumption is that a junction collision will occur at three quarters of line speed, plain line collisions will occur at two thirds of line speed. This is the same assumption as used for the Paddington to Heathrow train protection risk assessment and compatible with other models used to assess collision risk.

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 passenger 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.

This is considered to be an assumption that is balanced between being realistic, but also slightly pessimistic as it gives consequences that are slightly higher than predicted by the SRM.

3.4 Buffer collisions

The underlying level of risk (with TPWS) has been calculated based upon the SRM. The national risk profile has been normalised to the relevant levels, based upon the frequency of buffer approaches.

There are a large number of terminal approaches at Marylebone (approximately 214 per day) and a smaller number at the following locations:

- High Wycombe (Platform 1).
- Princes Risborough (Platform 1).
- Aylesbury Vale Parkway.
- Leamington Spa (Platforms 1 and 4).
- Birmingham Moor Street (Platforms 3 and 4).
- Stratford upon Avon (Platform 3).
- Oxford (Platforms 1 and 2).

It should be noted that some terminal approaches are permissive moves and for these, TPWS and ATP are ineffective. Such moves are not assessed by the model as none of the train protection systems are effective. Chiltern provided details of permissive moves so that these could be removed from the buffer approach frequency.

Some of the causes of buffer collisions are potentially mitigated by the current ATP and potential future train protection strategies. The impact

of additional control measures on the causes of buffer collisions is summarised in Table 3.

Table 3 The causes of buffer collision and potential for further mitigation

Cause (or cause group)	Rollback protection	ATP	ETCS
Cases related to roll-back collisions (inherently low speed)	✓	×	✓
Causes related to train set-up, coupling and uncoupling	×	×	×
Driver selects reverse instead of forward	×	×	✓
Communication error	×	×	×
Driver error while propelling	×	×	×
Defective brakes	×	×	×
Low adhesion	×	×	×
Driver medical condition on approach	×	✓	✓
Driver inexperience	×	✓	✓
Defective train control system	×	×	×
Driver loss of concentration	×	✓	✓
Runaway train	×	×	✓
Error in possessions	×	×	×

3.5 Derailment due to overspeeding

There are many causes of derailment that are analysed within RSSB's Safety Risk Model. The only cause assessed for this study is derailments due to overspeeding as these are influenced by the train protection strategy.

Derailment from overspeeding is assumed to be as a result of exceeding the permitted line speed for a particular train type and route section. For the purposes of this assessment, where ATP is fitted, there is considered to be negligible potential for overspeeding related derailments. For services not protected by ATP, the underlying rate of derailments per train km from the SRM is used for passenger and freight trains.

The consequences of a derailment have been taken as the average for the SRM, but scaled-up to account for the higher than average calculated train loading (see Section 3.3).

Within the assessment of derailment due to overspeeding, ETCS is assumed to give the level of protection as indicated by the RSSB and ADL analysis.

4 RISK ASSESSMENT RESULTS

The risk assessment results presented in this section compare the various potential future train protection strategies in terms of their relative safety performance. The safety performance is considered, for the future service levels, against the background of additional train services for HS2 constructions traffic, Phase 2 of East West Rail and future growth in passenger numbers.

The following sections consider the effect on risk of:

- Trackside enhancement to TPWS
- Trackside enhancements together with rolling stock upgrades
- The impact of additional train services and growth
- The effect of degradation of existing ATP.

4.1 Trackside enhancement to TPWS

The trackside enhancements only scenarios present the level of risk for four cases, in all cases the risks refer to the current (2019 service levels):

1. The base case (the first bar on the chart). This represents the current level of risk from all operators, with the existing TPWS and ATP fitment and no upgrades to the on board TPWS units.

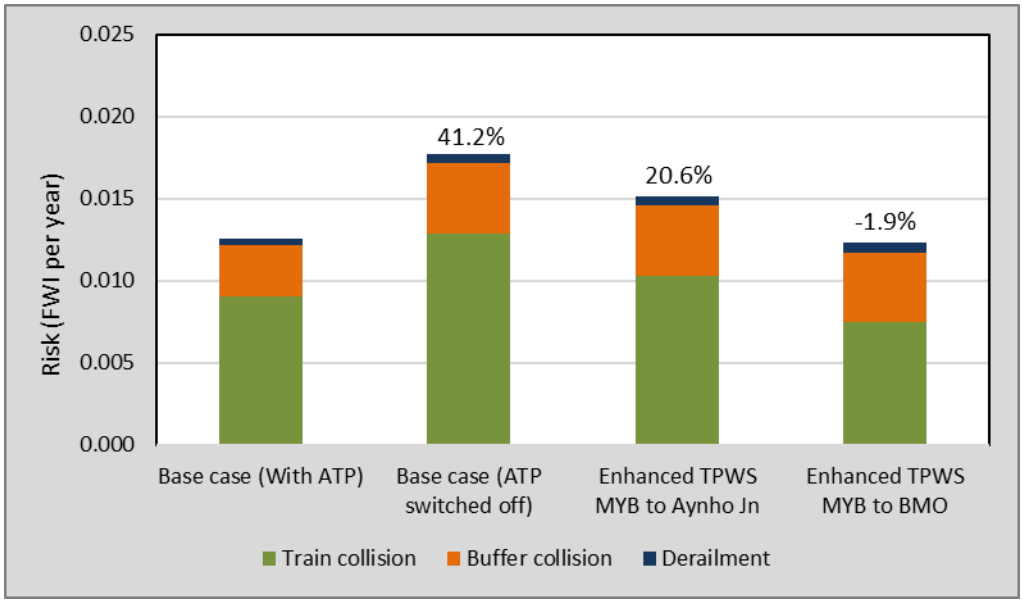
2. The base case with ATP switched-off: This is the level of risk that would exist if the ATP on the existing Chiltern stock was isolated and the stock instead operated with the installed TPWS units (a mix of Mk1 and Mk4).

3. Enhanced TPWS Marylebone to Aynho Jn – this refers to the situation where ATP is switched off, but TPWS is enhanced lineside with TPWS at plain line signals and TPWS at junction signals to modern standards.

4. Enhanced TPWS Marylebone to Birmingham Moor Street. This is the same as (3) but additionally with the TPWS enhancements north of Aynho Junction to Birmingham Moor Street.

The results of the analysis are provided in *Figure 2*, below. This also shows the overall percentage change in risk from the base case for each option.

Figure 3 The effect of enhancements to lineside TPWS on risk



The following inferences can be made from the assessment:

- The most significant contributor to risk is train-train collision, then buffer collision. Overspeeding derailment is only a minor contributor to the risk profile.
- Both buffer collision and train collision show a significant increase in risk from switching-off ATP.
- Enhancing the TPWS alone between Marylebone and Aynho junction does not offset the risk increase from switching-off ATP, even though some Chiltern trains do not currently have ATP fitted.
- Providing enhanced TPWS all the way to Birmingham Moor Street would achieve a level of safety performance similar to the current levels (the risk is assessed to be nearly 2% lower with the enhanced TPWS).

The causes of the enhanced TPWS between Marylebone and Aynho junction not lowering the risk to below the current level, despite the enhanced TPWS benefitting all the trains in the section are:

- The contribution to the risk from 'Reset and Continue' type events that can occur with the older TPWS units.
- TPWS also provides less protection approaching buffers than ATP.

The enhanced TPWS to Birmingham Moor Street benefits all train operators so the collision risk is significantly lower than the current situation; the buffer collision risk is however somewhat greater than now with a large proportion of the buffer approaches occurring within the ATP fitted area.

It should be noted that neither ATP nor TPWS provide protection for permissive moves into Marylebone (and other) terminal station platforms. There are a significant number of these per day.

4.2 Trackside enhancements together with rolling stock upgrades

The trackside enhancements together with trainborne system upgrades present the level of risk for seven additional cases. The five upgrade cases all have ATP switched off, but include:

1. Current lineside TPWS fitment with Mk4 TPWS fitted to Chiltern cabs.

2. Enhanced TPWS Marylebone to Aynho Jn with TPWS at plain line signals and TPWS at junction signals to current standards. Mk4 TPWS fitted to Chiltern cabs.

3. Enhanced TPWS Marylebone to Birmingham Moor Street with TPWS at plain line signals and TPWS at junction signals to current standards. Mk4 TPWS fitted to Chiltern cabs only (not other TOCs).

4. ETCS L2 Limited Supervision fitted to all signals and cabs.

5. ETCS Full Supervision fitted to all signals and cabs.

6. ETCS L2 Limited Supervision fitted to all Chiltern trains and all signals between Marylebone and Aynho Junction.

7. ETCS L2 Full Supervision fitted to all Chiltern trains and all signals between Marylebone and Aynho Junction.

In *3*, the seven cases are shown in addition to the two reference cases of current operation and current operation with ATP switched-off (the first two bars of the chart). In all cases the risks refer to the current (2019 service levels). Note that in the chart, the ETCS L2 Limited and Full Supervision cases are shown without a breakdown by hazardous event, this is because the RSSB/ADL assessment does not provide details of effectiveness for each event.

The conclusions that can be made from the assessment are:

1. Upgrading the Chiltern TPWS units and upgrading the lineside TPWS fitment between Marylebone and Aynho Junction provides a level of risk lower than current operation with ATP (approximately 2% lower).

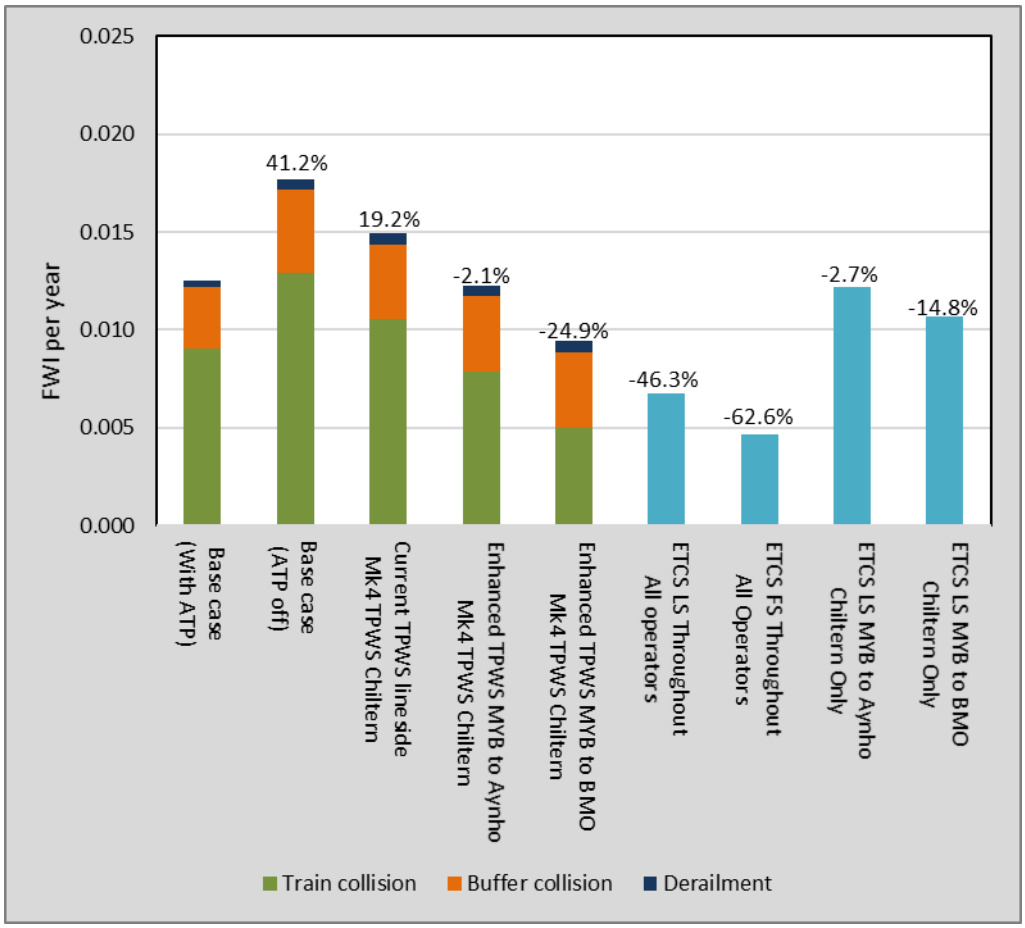
2. Upgrading the Chiltern TPWS units and upgrading the lineside TPWS fitment between Marylebone and Birmingham Moor Street provides a level of risk nearly 25% lower than current operation with ATP.

3. Providing ETCS L2 Limited Supervision between Marylebone and Aynho Junction for Chiltern trains provides a similar level of risk to (1) i.e. a slight risk reduction compared to current operation with the existing lineside and trainbourne TPWS and ATP fitment.

4. Provision of ETCS across all routes and for all operators would results in a significant risk reduction.

The significant benefit from ETCS is that it provides continuous speed monitoring, health checks and does not have the 'reset and continue' issues that exist with the Mk1 TPWS units that would still be operated for some non-Chiltern stock in the above cases.

Figure 4 The effect of enhancements trackside and train upgrades



4.3 The impact of additional train services and growth

Four service levels are considered by the study, as described in *Section 2.3*. In summary, these include:

SL19: This reflects the current level of passenger and freight services.

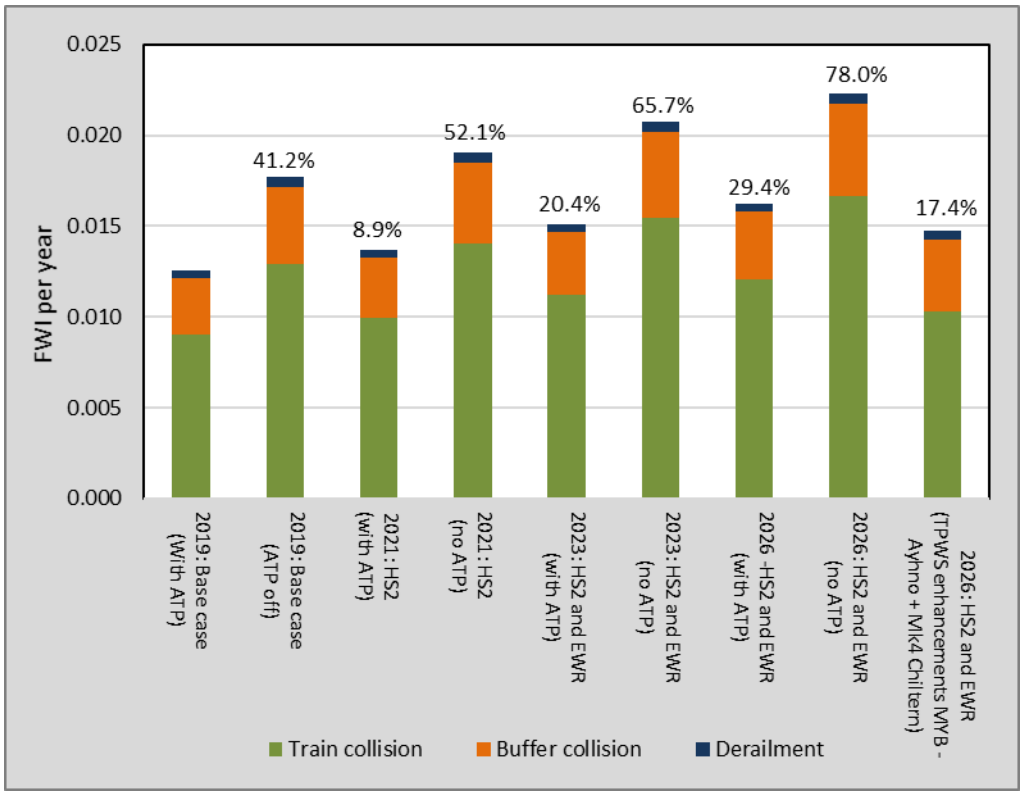
SL21: This reflects the level of train service in 2021. Train frequencies are as per SL19 with the addition of HS2 construction traffic. Growth in passenger numbers is assumed to be 2.5% per year.

SL23: This is as per SL21, with the addition of Phase 2 of East West Rail, including the relevant parts of the route Oxford to Cambridge via Bicester and Milton Keynes to Aylesbury. Passenger numbers are assumed to continue to grow at 2.5% per year.

SL26: This is the end case for the assessment and is identical to SL23 with continued growth in passenger numbers.

Each of these cases is presented in *Figure 4*, for the situation with and without ATP switched off. The final case is in the chart is a reference case showing the level of risk that would be present with growth and additional services up to 2026, but with enhanced TPWS between Marylebone and Aynho Junction, ATP switched off, but with Mk4 TPWS fitted to Chiltern cabs.

Figure 5 The effect of additional services and growth



The conclusions that can be made from the assessment of the additional services and passenger growth are:

- The combination of HS2 construction traffic, East West Rail Phase 2 and passenger growth, results in a significant increase in risk over the current levels, especially for the case where ATP is no longer operational. Most of the increase is through passenger growth rather than the additional trains operating.

- If enhanced TPWS is provided between Marylebone and Aynho Junction and Chiltern trains fitted with the Mk 4 TPWS units, the level of risk would be about 17% higher than the current level due

to the level of growth in traffic and passengers, but the risk would be about 9% lower than retaining the existing ATP.

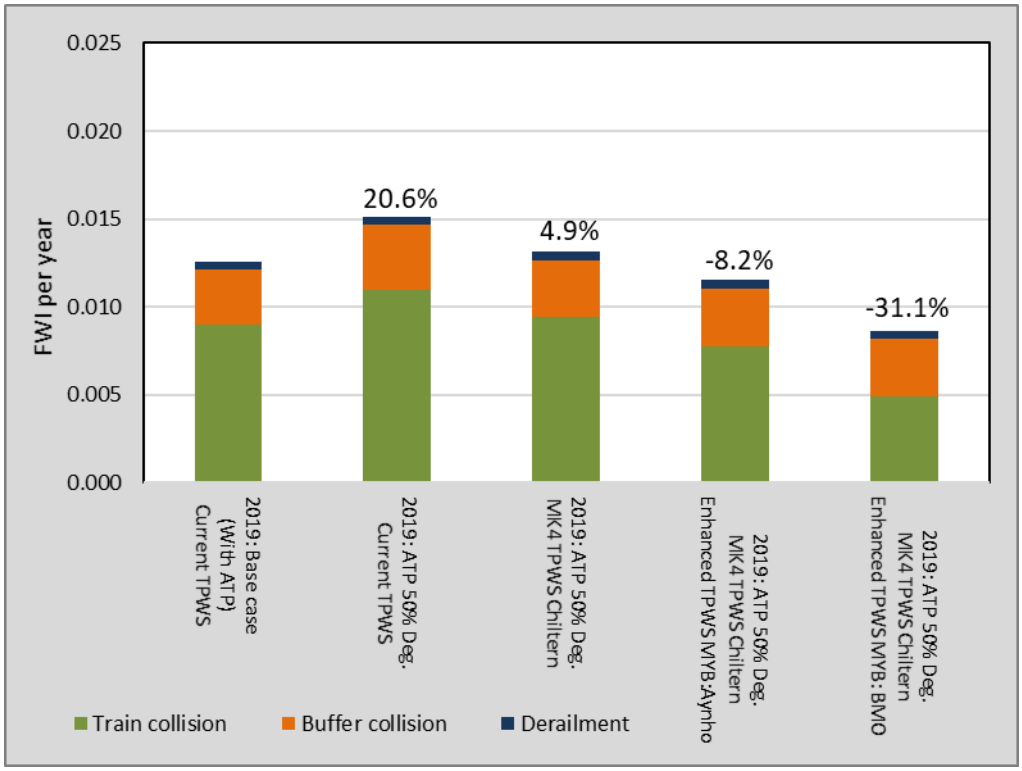
4.4 The effect of degradation of existing ATP

The obsolescence of the existing ATP system will result in increasing number of trains being operated without ATP and hence, potentially relying on AWS and TPWS for train protection. The rate at which services will not have operational ATP is not known. For the purposes of the risk assessment, a case has been assessed reflecting the theoretical position where half of the services with ATP have to be operated with AWS and TPWS only. The following cases are assessed:

- With half of the Chiltern fleet not operating ATP and with the existing Mk1 TPWS units.
- With half of the Chiltern fleet not operating ATP and with **upgraded Mk4** TPWS units.
- With half of the Chiltern fleet not operating ATP and with **upgraded Mk4** TPWS units and enhanced lineside TPWS between Marylebone and Aynho junction.
- With half of the Chiltern fleet not operating ATP and with **upgraded Mk4** TPWS units and enhanced lineside TPWS between Marylebone and **Birmingham Snow Hill**.

For the purposes of the theoretical case, the comparison has been made based upon 2019 service levels.

Figure 6 The effect of ATP degradation and potential mitigations



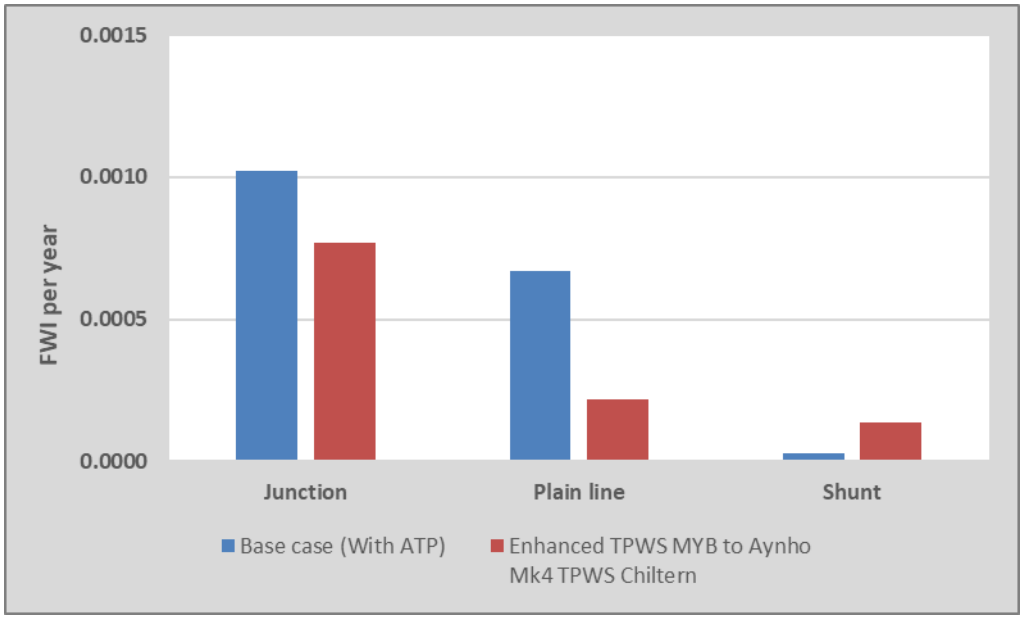
Whilst this is a theoretical case only as the level of ATP degradation is unknown, the following inferences are made:

- Significant degradation in the availability of ATP stock would result in a moderate increase in risk over current levels (a 20.6% increase).
- Provision of enhanced lineside TPWS between Marylebone and Aynho junction and upgrading the Chiltern cabs to have Mk4 TPWS would more than compensate for 50% degradation.

4.5 Plain line Vs Junction signals

The potential upgrade of lineside TPWS delivers benefits to plain line, and junction signals, but only a small proportion of shunt signals. The risk between Marylebone and Aynho junction has been analysed to determine the level of risk for each signal type. This has been achieved for the current operation with ATP and also the situation with enhanced lineside TPWS and Mk4 TPWS fitted to Chiltern cabs. The results are shown in *Figure 6*.

Figure 7 The risk from SPADs from different signal types



The following inferences can be made:

- Junction risk is moderately higher than plain line risk for the base case. Enhanced TPWS has a more significant benefit at plain line signals, this is likely to be due to most plain line signals not currently being fitted with TPWS.

- There is likely to be a number of plain line signals that rarely display a red aspect and are inherently low risk, such that the benefit of adding TPWS is relatively small. In such situations, it may be possible to optimise the plain line TPWS fitment to exclude some plain line signals. Determining the scope for optimisation would require more detailed assessment of each signal although it is not clear that such an exercise would be worthwhile given the low cost of lineside TPWS fitment.

It should be noted that shunt signals between Marylebone and Aynho Junction are currently provided with ATP protection.

4.6 Changes in risk with alternative train protection strategies

TPWS enhancement vs ETCS L2 Limited Supervision

Three potential strategies for future train fitment are compared:

- Enhancing TPWS fitment between Marylebone and Aynho Junction together with updating the TPWS cab fitment to Mk 4 TPWS units

- Providing ETCS L2 Limited Supervision for Chiltern trains between Marylebone and Aynho Junction.

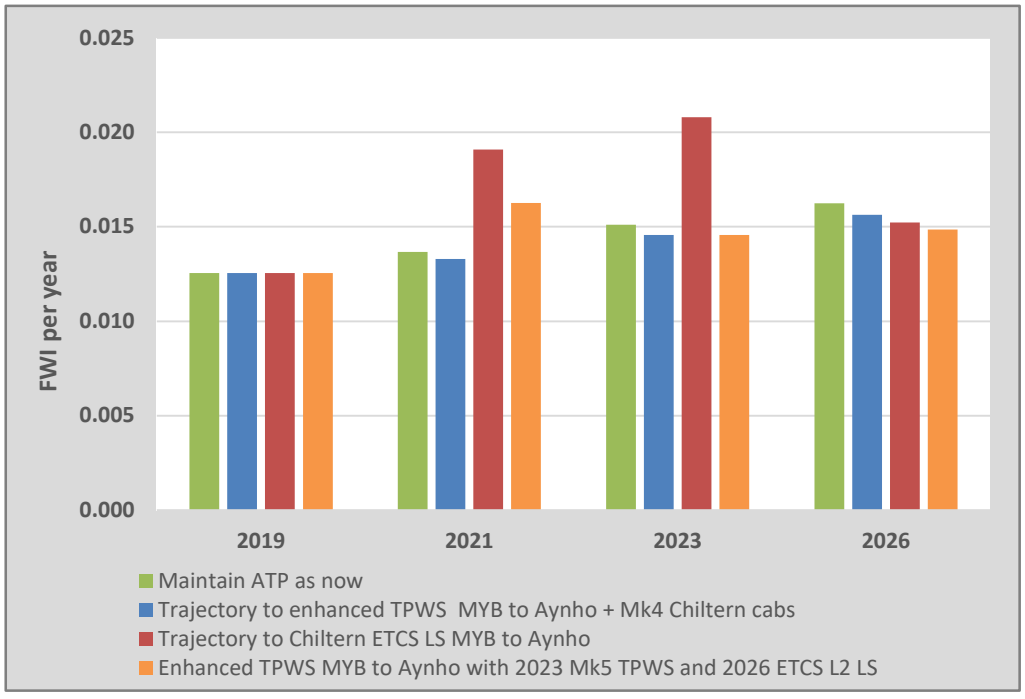
- Enhancing TPWS fitment between Marylebone and Aynho Junction together with providing ETCS L2 Limited Supervision for Chiltern trains between Marylebone and Aynho Junction.

The risk of these three options for the service levels in 2019, 2021, 2023 and 2026 are shown in Figure 7. There are four important assumptions underpinning the assessment:

- TPWS enhancements, including cab upgrades for Chiltern to the Mk4 TPWS units can be implemented by 2021.
- Providing ETCS L2 Limited Supervision could not be implemented before 2023 due to the design, engineering and approval that would be required so the benefits would only be provided in the 2026 case.
- The TPWS Mk5 units that deliver ETCS L2 Limited Supervision could be provided by 2023, effectively providing Chiltern trains with TPWS Mk4 benefits ahead of 2026.
- For the enhanced TPWS and ETCS L2 Limited Supervision cases, ATP is switched off by 2021.

In the assessment the reference case of the existing ATP fitment is shown (the green bar). Whilst it may be impractical to maintain the existing ATP until 2026, it shows the level of safety that would be achieved if it could be maintained throughout.

Figure 8 The risk from different train protection strategies



The inferences that can be made are:

- For 2026 onwards, the lowest overall risk is from the enhanced TPWS trackside, together with upgrade ETCS L2 Limited Supervision for Chiltern trains. This solution provides the lowest overall level of risk. The reasons for this are:
    - Chiltern trains in the section from Marylebone to Aynho junction benefit from ETCS L2 Limited Supervision.
    - Other trains in this section benefit from enhanced lineside TPWS fitment.
    - Chiltern trains benefit from enhance in cab TPWS north of Aynho Junction.
- For the ETCS L2 Limited Supervision cases, in the period between ATP being switched off and the implementation TPWS Mk5, there would be a significant increase in risk.

Lineside TPWS upgrades vs in cab upgrades

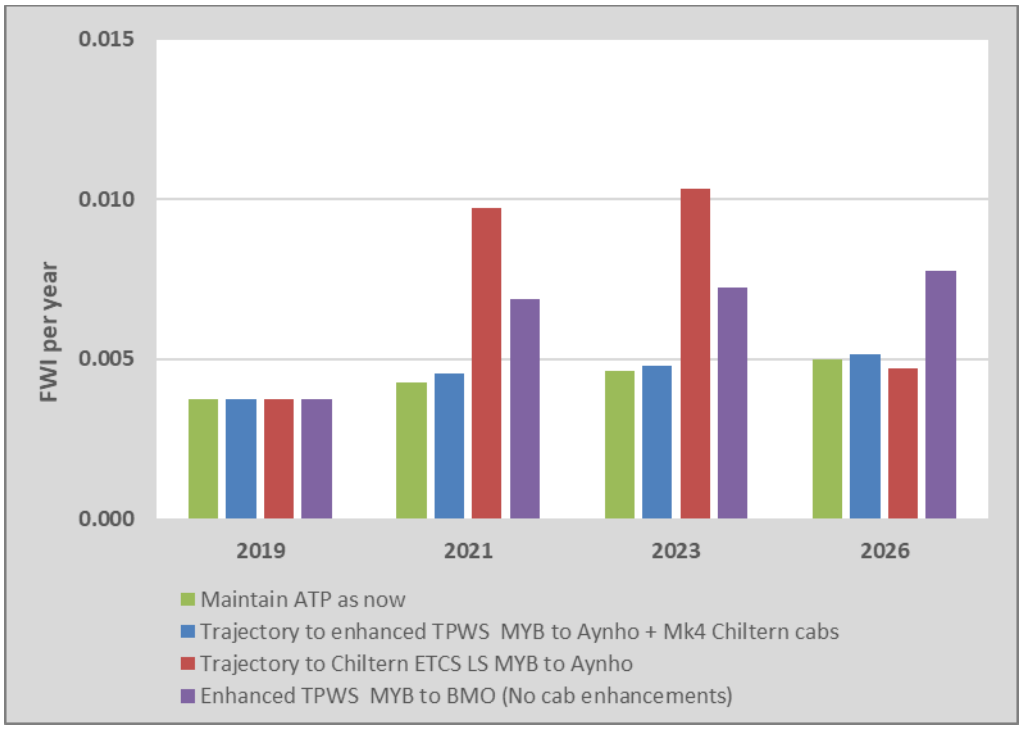
From the above analysis, three options that provide a similar level of safety performance by 2026 are:

- Enhancing trackside TPWS fitment between Marylebone and Aynho junction together with upgrades to the Chiltern TPWS units.
- Providing ETCS L2 Limited Supervision for Chiltern Trains between Marylebone and Aynho Junction.
- Enhancing trackside TPWS fitment between Marylebone and Birmingham Moor Street **without** upgrades to the Chiltern TPWS units.

An important difference between these options is how the safety risk is distributed over the railway sections. An assessment of this is presented in Figure 8, which shows the level of risk that would exist in the section between Marylebone and Aynho junction i.e. the area where ATP is currently fitted. The above three cases are presented in the chart together with the reference case of maintaining existing ATP. As mentioned above, this is an academic case as the existing ATP system is not sustainable.

An important inference from the chart is that the option to install enhanced TPWS between Marylebone and Birmingham Moor Street (the last bar) results in a significant increase in risk South of Aynho Junction. The acceptability of the risk increase in this area is a factor that would need consideration in the viability of the option.

Figure 9 The effect of different train protection strategies on risk between Marylebone and Aynho Junction



5 CONCLUSIONS

The risk assessment analysed a wide range of potential future risk control strategies for the section of the national rail network over which Chiltern Railways operates. It also assesses the changes in risk that would be introduced through future changes including East West Rail Phase 2, HS2 construction traffic, future passenger growth and the obsolescence of the existing Chiltern ATP system.

The assessment found that:

1. There are three risk controls strategies that overall provide a broadly similar, but lower, level of risk to that of the existing ATP fitment. These include:

    - Upgrading the lineside TPWS fitment between Marylebone and Aynho Junction together with upgrading the Chiltern cabs to Mk4 TPWS units.

    - Upgrading the lineside TPWS fitment between Marylebone and Birmingham Moor Street without upgrading the Chiltern cabs to Mk4 TPWS units.

    - Providing ETCS L2 Limited Supervision for Chiltern Railway services between Marylebone and Aynho Junction.

2. Whilst upgrading the TPWS to Birmingham Moor Street without upgrading the Chiltern Cab TPWS units delivers a similar level of risk overall, the section that is currently operating with ATP would see a significant increase in risk, with a commensurate risk reduction north of Aynho Junction.

3. ETCS L2 Limited Supervision is not yet a commercially available solution ready for deployment, therefore, in the time between ATP being switched off and deployment of the system, there would be a significant increase in risk. This could be reduced by maintaining the existing ATP system where reasonably practicable in the interim, but there would likely be some degradation of availability.

    Alternatively, if it is possible to provide the TPWS Mk5 units in Chiltern cabs in advance of lineside deployment of ETCS L2 Limited Supervision, the increase can be mitigated by enhancing the TPWS lineside fitment.

4. Cost benefit Analysis and Option Selection should be performed to determine the most practical and cost-effective solution, accounting for issues wider than safety, such as the performance impact and the deliverability of the options.

6 ASSUMPTIONS

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

Ref.	Topic	Case	Assumption
1	Chiltern train service levels	Base case	The train routes from the Spring 2019 timetable are characteristic of current operation for Chiltern.
2	Freight, CrossCountry and London Midland/London Northwestern Railway service levels.	Base case	The levels of passenger and freight services taken from August 2019 are representative of current operation. Operational services taken from the Realtimetrains website. Note: for freight, operated freight, rather than freight paths has been used.
3	Determining train paths and signal approach frequencies through the areas covered by the model.	Base case	Much of the railway is two track rail, therefore Up direction trains are assumed to travel on the Up line and Down direction trains on the down line. The exception to this is are: > Stations - where the approach to platform starter signals are based upon detailed analysis of the timetable. > Signals for wrong direction moves - where these are assumed to be approached by 2% of services. > Where are there more than two routes, the number of services using each is taken as evenly spread amongst the lines. > Nominal levels of use are applied to freight loops and sidings.
4	Approach to buffer	Base case	The frequency of the approach to terminals has been determined through analysis of the timetable for the following termini: • Marylebone (Platforms 1 to 6). • High Wycombe (Platform 1). • Princes Risborough (Platform 1). • Aylesbury Vale Parkway. • Leamington Spa (Platforms 1 and 4). • Oxford (Platforms 1 and 2). • Birmingham Moor Street (Platforms 3 and 4). • Stratford upon Avon (Platform 3). The number of approaches includes both buffer approaches and permissive moves into platforms. Data on permissive moves was provided by Chiltern.

Ref.	Topic	Case	Assumption
5	TPWS fitment of freight and non-Chiltern passenger services	Base case	TPWS fitted to non-Chiltern trains is assumed to be equivalent to the Thales Mk 1 unit, eg, with no in-service health checking and no indication of the cause of an activation. Some London Northwestern Railway stock has the MK2 units, which are assumed to have equivalent functionality to the Mk1 units.
6	Lineside TPWS fitment - south of Aynho Jn	Base case and possible enhanced future fitment.	The TPWS fitment between Marylebone and Aynho Junction is as per the provided signalling plans (15-NW-0042/1-11 V3.2) - excluding the red changes, which reflect the potential case with additional TPWS and removal of ATP. The future case also includes changes identified in the TI22 reports.
7	Lineside TPWS fitment - north and west of Aynho Jn	Possible enhanced future fitment	The TPWS north and west of Aynho Junction for the enhanced TPWS case will reflect current TPWS standards. This will provide adequate braking for junction signals to stop trains before reaching the conflict point for 12% and 9%g braking trains. For plain line signals, the TPWS will provide protection by stopping trains short of the conflict point for 12%g braking trains.
8	Assessment of TPWS effectiveness	Base case	The TPWS effectiveness calculator, developed by RSSB, provides a reasonable assessment of TPWS effectiveness.The inputs have been based on TPWS tables in the signalling plans, so TPWS effectiveness is based on the first conflict.
9	Maximum effectiveness of TPWS		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.
10	SPAD rates	Base case Future service level case	Past SPAD rates are a reasonable indication of future levels per approach to a red signal. SPAD data for the past 10 years for all operators over the infrastructure have been used. Increasing train services linearly increases the number of red signals approached.

Ref.	Topic	Case	Assumption
11	The likelihood that a signal is approached at red	Base case	The likelihood that plain line and junction signals are approached at red has been taken from the RSSB tool RAATS (Red Aspect Approach Tool). This provides, from historic data, the number of approaches and approaches at red for each signal. The tool does not provide information for all signals on the layout; where the signals are not included, average rates have been applied for junction and plain line signals. The tool does not cover shunt signals, therefore a generic probability is applied.
12	Overall levels of risk	Base case	SRM v8.5 presents a reasonable assessment of risk for train accidents - the model is normalised against the SRM rates. For buffer collision, the normalisation is based upon the number of approaches to buffers, and modified to account for train loading on the section and the level of protection, accounting for the train protection fitment case. For collisions due to SPADSs, the SRM is only used to reference the underlying likelihood that a SPAD, without TPWS would result in a collision. This is modified to account for the train protection cases.
13	Anticipated changes to Chiltern train service levels	Future train service levels	Chiltern does not plan any major changes to train service levels over the remainder of the franchise. Therefore assume no service growth.
14	Projected future Chiltern fleet - increase in train length	Future train service levels	There are already some nine car trains operating on the network. The TPWS effectiveness calculator is based upon the maximum train length, which is already 9 car. Hence, the increase in exposure from longer trains will be via the linear increase in the number of exposed personnel from the increase in passenger numbers with the future service levels.

Ref.	Topic	Case	Assumption
15	Permissive move	All	ATP and TPWS are ineffective in protecting against permissive move collisions.
16	HS2 Construction traffic to depot at West Ruislip		There are three routes used by HS2 construction traffic, which include: Calvert sidings: These will leave/enter the relevant infrastructure at Aylesbury Vale Parkway and take a route via Acton. The route includes South Ruislip, West Ruislip, Denham, Gerrards Cross, High Wycombe, Princes Risborough and Aylesbury. There will be two train per day per direction. Reservoir sidings: These will leave/enter the relevant infrastructure at Bordersley Junction and travel as far as Banbury. The route includes Leamington Spa, Warwick, Hatton, Lapworth, Dorrige, Solihull, Acocks Green, Tyslsey and Small Heath. There will be one train per direction per day. The delivery of tunnel sections: These are assumed to approach the relevant section from via Greenford and Northolt, and travelling on the relevant infrastructure between South Ruislip and West Ruislip. There will be two trains per direction per day.
17	Speed restrictions	All	Derailment at speed restrictions (including PSRs, TSRs and ESRs) are included in the assessment. The level of benefit from TPWS is already factored into the assessment as these are implicit in the SRM. The benefit from ATP and ETCS is analysed by the model.
Infrastructure changes			

Ref.	Topic	Case	Assumption
18	East-West Railway	Future services	There are two relevant services as follows: Services between Oxford and Cambridge, these will travel over the same infrastructure as Chiltern between Oxford and Bicester Village. There will be three trains per hour per direction. Services between Milton Keynes and Aylesbury. These will travel over the same infrastructure as Chiltern between Aylesbury Vale Parkway and Aylesbury. There will be one train per hour per direction. EWR trains will have approximately the same loading as Chiltern trains.
19	Platform extensions	Future services	See above for train length (14)
20	Additional siding facility at Wembley	HS2 Construction	No significant risk impact.
Passenger loading			
21	Passenger growth - Changes through the Chiltern Franchise	Future Chiltern growth in passenger numbers.	Assume 2.5% growth for all operators.
22	Growth for other operators	Future growth in passenger numbers for other operators.	Assume 2.5% growth for other operators
Safety improvement options			
23	Rollback protection		This is assumed to apply to Chiltern stock only and not CrossCountry and London Midland/London Northwestern Railway service.
24	TPWS cab fitment upgraded		This is assumed to apply to Chiltern stock only and not CrossCountry and London Midland/London Northwestern Railway service.
ETCS			
25	A new Limited Supervision version of ETCS is being developed, which is not the ETCS standard LS mode. The		RSSB/ADL assessment of the percentage benefit will be used for the limited and Full Supervision cases.

Ref.	Topic	Case	Assumption
	version assessed for this report is termed ETCS L2 Limited Supervision). The system will rely on a new system that will detect the status of the signal ahead, the onboard ETCS system will then check that the speed of the train is on a speed profile compatible with making a controlled stop at the next red signal. If this is not the case an intervention will occur. The onboard equipment is termed *TPWS Mk5*.		
Future timeline			
26	There are a few different potential changes to operation and infrastructure, eg: Chiltern Franchise ending in December 2021 EWR planning operation for 2023 (from Milton Keynes) HS2 construction traffic - Construction due to start end 2019 (West Ruislip and	Future case	The cases to assess in term of dates and usage include: 2019 - Current 2021 - HS2 Construction traffic included 2023 - East West Rail phase 2 operational 2026 - end state

Ref.	Topic	Case	Assumption
	Wembley upgrade),		
Underlying data			
27	Signalling and layout information	Base case	The provided signalling plans provide an accurate representation of the current signal positions, gradient, linespeed, TPWS and ATP fitment. These include the documents with the following drawing numbers and version: 15-NW-0042/(1 to 11) Ver. 3.2 12-NW-0108/1 Ver. A WSC/02/0024/002 Ver. KA1 WSC/02/0024/ 003) Ver. KD1 WSC/02/0024/ 004) Ver. EK1 13-NW-0032/1 Ver 0.02 14-GW-062/04 Ver. 6.0 14-GW-062/05 Ver 6.0 13-NW-0027 (Sheets 1 to 5) Ver. A WSC-02-0048-007 Ver. DA5 07-NW-0047 (Sheets 1 to 3) Ver. C

7 ACRONYMS AND ABBREVIATIONS

Acronym	Description	Comments
ACM	Accident Consequence Model	
ALARP	As Low As Reasonably Practicable	
ATP	Automatic Train Protection	
ETCS	European Train Control System	
ETCS L2 Limited Supervision	The ETCS Limited Supervision referenced in this report is not the Limited Supervision mode defined in ETCS standards. The term is used to describe a method of train protection where the aspect of approached signals are communicated to the train. A modified version of TPWS (termed TPWS Mk5) would apply the train brakes if the speed profile of the train exceed that required to stop the train at the signals that are being approached. TPWS Mk5 is not yet available and would need significant development.	
EWR	East West Rail	
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
TSS	(TPWS) Train Stop System'	
TPWS	Train Protection and Warning System	