Sotera Risk Solutions

Report for Chiltern Railways

Risk Assessment of Chiltern Railways' ATP Obsolescence

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TABLE OF CONTENTS

1 INTRODUCTION

Chiltern Railways operates over the Automatic Train Protection (ATP) protected route section between Marylebone and Aynho Junction. The trains operated over this section include a range of ATP fitted trains and trains protected with AWS and TPWS only. Approximately 80% of the Chiltern Railways' units are ATP fitted. The system was one of two tested as part of ATP trials following the DoT investigation into the Clapham Junction Rail Accident (1988).

The system is 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 for nearly thirty years, the trainborne components of 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.

A medium-term strategy has been proposed by Chiltern and Network Rail, which maintains or improves on the safety performance of the railway in relation to train accident risk over the entire infrastructure over which Chiltern Railways operates. This strategy is subject to an application for an exemption to RSR 99 in relation to the use of train protection systems (Regulation 3).

A separate exemption is required by Chiltern Railways for the replacement of services that currently operate with ATP, with services that operate using AWS and TPWS only. This covers the situation where the onboard ATP system has failed and cannot be repaired. Sotera Risk Solutions Limited (Sotera) has been commissioned to undertake a detailed, independent, assessment of options for responding to on board ATP failures.

The risk assessment compares the two main options of responding to units with failed and unrepairable ATP:

Option A: Operating the service with ATP isolated and using TPWS as the primary means of train protection.

Option B: Withdrawing the units from service resulting in cancellations and delays.

These options would remain in place until both lineside and train borne TPWS upgrades have been implemented in accordance with the medium-term strategy that is subject to the Network Rail exemption mentioned above.

The risk assessment focusses on three key areas of train accident risk: train-train collisions from SPADs, derailments from overspeeding and buffer collisions. The assessment also analyses the knock-on risk from potential delays and cancellations. Knock-on risk comprises a wide range of personal accidents to passengers, such as trips, slips and falls as well as assaults on railway staff and some train accident scenarios. It is relevant to the case where trains with failed and unrepairable ATP units are taken out of service.

2 SCOPE OF THE ASSESSMENT

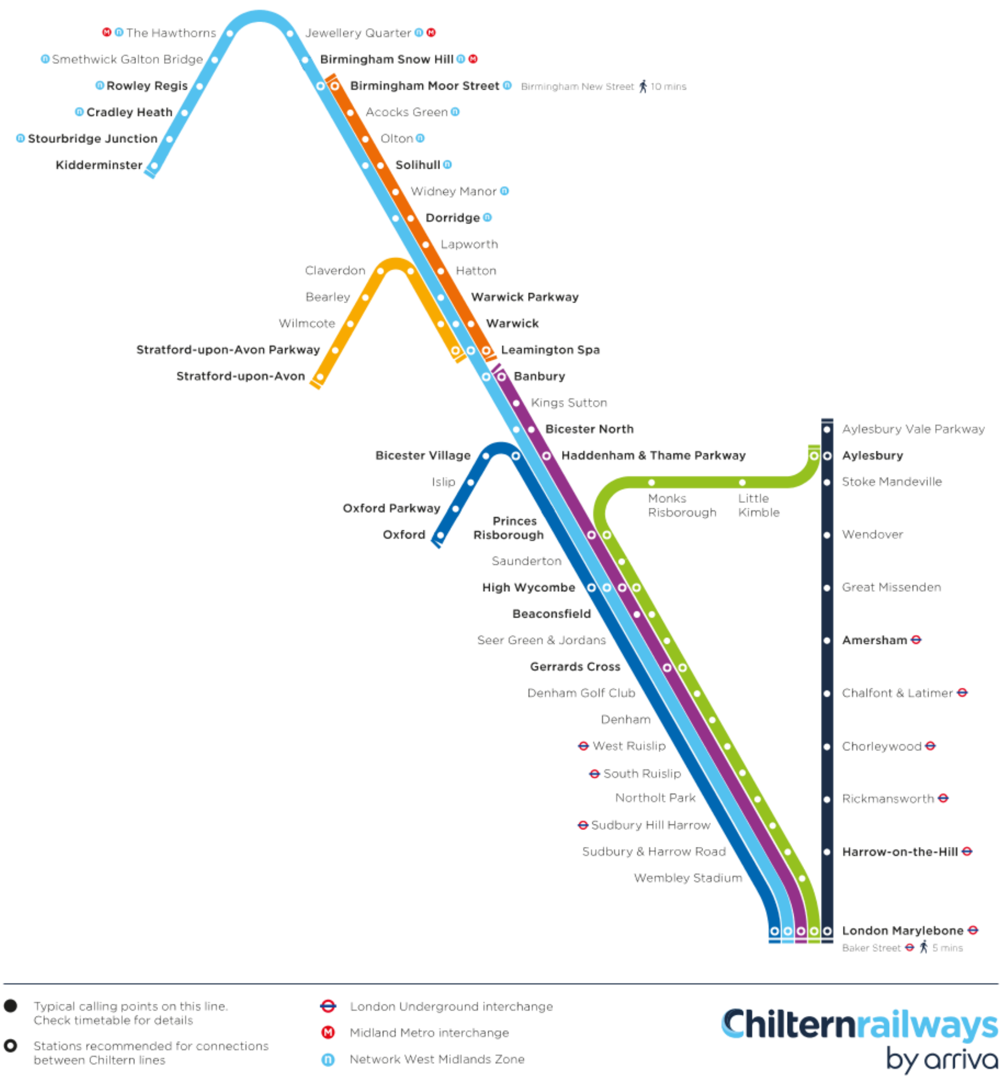
The scope of work is described in the following sections.

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.

The basis of the assessment of these hazards is the previous risk assessment developed to underpin the wider Network Rail exemption [1].

'Knock-on risk' is also assessed; this includes the risk that would result from delays and cancellations from the service disruption as a result of taking units with failed and unrepairable ATP out of service. Knock-on risk comprises a wide range of personal accidents to passengers, such as trips, slips and falls as well as assaults on railway staff.

2.3 Network changes

The risk assessment has, as a Base Case, the current (2019) timetable with all planned ATP services operating with ATP. The risk assessment is evaluated at the end of each year accounting for the following network changes:

- Progressive reduction in the number of ATP trains operating (a reduction of 20% per year as a credible worst case).
- The proposed upgrade to all Chiltern Railways operated stock to have the Mk4 TPWS units as proposed in the Network Rail exemption. This would be implemented progressively in the period 2021 to 2023.
- The proposed enhanced TPWS fitment trackside 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. This is also proposed in the Network Rail exemption and can be achieved in the period 2021 to 2023.
- Progressive passenger growth at 2.5% per year.
- The introduction of HS2 construction traffic in 2021.

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[1] Risk Assessment of the Chiltern Train Protection Strategy, J2044/Doc 01 Rev 03, Sotera Risk Solutions 17th January 2020.

- 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 in 2023.

3 APPROACH TO THE RISK ASSESSMENT

3.1 Overall approach

For train accident risks, the approach to the assessment is identical to that for the assessment used to underpin the exemption application for the Crossrail Paddington to Heathrow project[1] and recent Network Rail assessment[2]. For knock-on risks, the RSSB knock-on risk tool has been used (See *Section 3.6*). The approach for each component of the assessment 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 2*. 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 7*.

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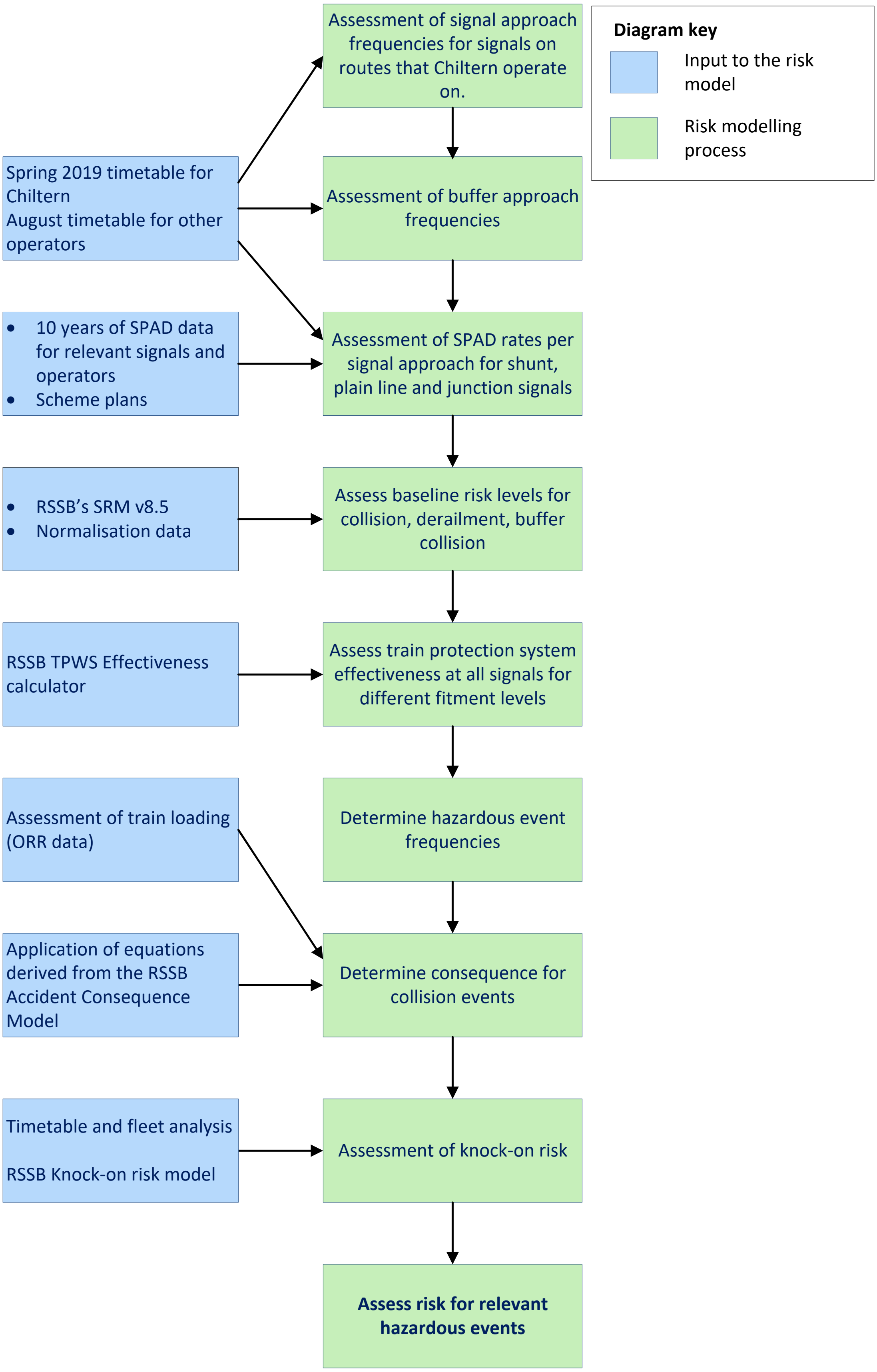
1 Risk Assessment of the Paddington to Heathrow Airport Junction - Crossrail Train Protection Strategy – Options analysis, J2034/Doc002 Rev02, Sotera Risk Solutions 22nd January 2019.

2 Risk Assessment of the Chiltern Train Protection Strategy, J2044/Doc 01 Rev 03, Sotera Risk Solutions 17th January 2020.

Figure 2 The key elements and data inputs the risk model



3.3 Train-train collisions

The train-train collision model is the most complex 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 trains 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 the RAATS 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 crossover.

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, results from the SRM v8.5 have 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 7*).

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 each signal and accounting for the signal type. The assumption is that a junction collision will occur at three quarters of line speed and that 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 (Accident Consequence Model) 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.

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

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 so the risks would be unchanged. 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 1.

Table 1 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	✗	✗	✗

Cause (or cause group)	Rollback protection	ATP	ETCS
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	×	×	×

** ATP can help prevent some causes of runaways as the train brakes cannot be released until the cab is set up.

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 derailment 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).

3.6 Knock-on risk

Knock-on risk covers the risk to passengers and workforce from a wider range of events such as congestion and crowding related events, through passenger personal accidents, such as trips slip and falls as well as verbal and physical assaults on staff.

Knock-on risk is analysed based upon a bespoke RSSB knock-on risk tool. The tool has been used on a range of risk assessment projects and uses delays and cancellation information to estimate the indirect knock-on risk. The assessment has as its foundation, the Safety Risk Model.

The assessment underlying the tool is also based upon prior research undertaken by RSSB, which showed the linkage between delay minutes and the risk from specific hazardous events such as:

- Boarding and alighting accidents
- Slips, trips and falls at stations
- Staff assaults both physical and verbal
- Crowding on trains/platforms/station concourses.

It should be noted that the knock-on risk tool also includes some risk benefit from cancellations due to the reduction in the number of train operating and reduced numbers of passengers travelling. This reduces the risk from some personal accidents and train accident risks.

For this report, the knock-on risk tool is used to assess the risk that would arise in the situation where the ATP system fitted to units fails (irreparably) and the units are withdrawn from service. If trains were not permitted to continue in service, the units would be withdrawn until the lineside and train borne TPWS upgrades have been completed (planned for end 2023). This results in a reduced number of units available with which to operate the train service.

Inputs to the knock-on risk tool are the number of delay minutes, cancelled trains and part-cancelled trains. For this assessment, the in-service failure of the ATP equipment is assumed not to cause delays as it is permitted to continue the remainder of the planned journey under TPWS (and potentially continue until the train in planned to return to a depot). Hence, the modelling focuses on the number of trains that would be cancelled (based upon the Spring 2019 timetable) through the gradual reduction in the number of available units. The modelling is based upon the weekday timetable as this comprises the time when there is highest stock utilisation and normal maintenance allocation.

The analysis calculates how many units are required to deliver the train service throughout the day. This is compared with how many units are available. As the number of units decreases to below a level required for service, during the period 2020 to end 2023, there is a progressing increase in the number of cancellations and knock-on risk. It is assumed that it is not possible to maintain required capacity though running trains in short formation.

Note: The RSSB assessment of knock-on risk, accounts for some benefit from a reduction in trains operated and journeys that are nor taken, but excludes intermodal transfer, eg, passengers choosing to use alternative methods of transport such as the road network, which is inherently less safe than rail. Intermodal transfer is the subject of *Section 5* of this report.

4 RISK ASSESSMENT RESULTS

The risk assessment results presented in this section compare the current level of risk to the level of risk that would result whilst the wider strategy to provide enhanced train borne and trackside TPWS is implemented. The wider strategy enables ATP removal by the end of 2023. Two cases are compared:

- ***Option A – running stock without ATP***. This option is a future case that permits ATP fitted stock to be operated using TPWS and AWS when the ATP unit has failed and is unrepairable. This case includes the progressive fitment of Mk4 TPWS units to trains and enhanced lineside TPWS fitment.

- ***Option B – removing trains from service with unrepairable ATP*** - A future case that does not permit ATP fitted stock to be operated using TPWS and AWS when the ATP unit has failed and cannot be repaired. In this case, the stock is withdrawn from service until TPWS is upgraded to Mk4 (train side) and lineside TPWS upgrades are complete. This introduces knock-on risk as described in *Section 3.6*. This option does not require an exemption.

The train accident risk from Option B is assumed to be equivalent to the case where ATP is maintained until 2023, except where risk reductions are predicted by the knock-on risk tool.

For Option B, units with unrepairable ATP but upgraded TPWS (to Mk4) would not be able to enter service until the infrastructure TPWS enhancements are complete. Services could, however, be operated using the existing fleet that are Mk1 TPWS fitted, but do not have ATP. Hence, the newly upgraded units with the higher level of protection would not be permitted to operate in place, or together with, existing units with MK1 TPWS. This would result in an overall lower level of train protection.

4.1 Degradation of train service

The knock-on risk from Option B has been assessed though determining the number of train services that would be cancelled through failed and unrepairable units being withdrawn from services before the TPWS upgrades are complete. As discussed in *Section 3.6*, the number of units required to maintain the service has been modelled using the May 2019 timetable. No account has been taken of complex factors such as:

- Whether trains would be in the right locations to maintain the assumed service levels.

- Whether one or more units would be required to be out of service for routine maintenance and/or fitment of enhanced Mk4 TPWS units.

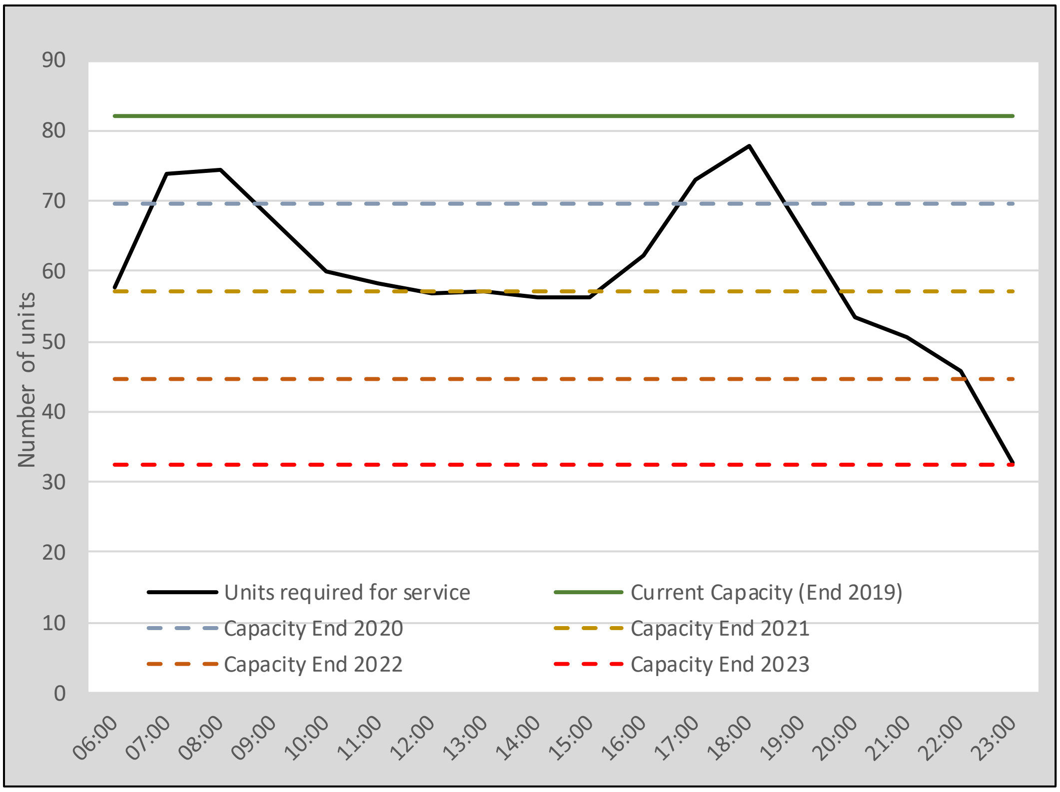
- The reduced availability due to other, unrelated failures.
- The possibility of 'boxing in' some cabs with failed and unrepairable ATP units so that they can be used in a fixed formation.
- The possibility of operating some services with shorter trains.

The number of units required for a full service, throughout the course of the day, is shown in *Figure 3* as a black line. As can be seen, the line has two peaks, representing the morning and evening peak; with a significant reduction in the number required late in the evening.

Also presented on the chart are four dotted lines, indicating the number of units available at the end of each year up until the end of 2023. The assessment assumes there is a 20% reduction in availability of ATP stock available per year. 20% degradation is considered to be a credible worst case and accounts for the current reliability, availability of spares and potential increase in rate of failure in the future.

As can be seen from the chart, after one year, the number of units available (assuming a 20% degradation rate) is insufficient to operate a full service at times during both the morning and evening peaks. By the end of 2021, there would be insufficient units to operate any of the peak only services, i.e. it would only be possible to operate a service equivalent to the current off-peak levels. By mid-2022 and through 2023, the train service would be drastically diminished throughout the day.

Figure 3 Units required and units available at 20% ATP degradation per year



Uncertainty

The degradation rate of 20% is uncertain; to investigate the effect of uncertainty on the assessment, three sensitivity cases have been run to investigate degradation rates at 5%, 10% and 30%. These are shown in *Figure 4* to *Figure 6*.

The inferences that can be made from the analysis are:

- With the much more optimistic 5% degradation rate, there would be a significant reduction in peak service levels by the end of 2022. At this degradation rate, the off-peak service and some peak level services would be maintained until the end of 2023, when the planned TPWS upgrades are introduced.

- With a 10% degradation rate, there would be a significant erosion of peak level service by the end of 2021. It would be possible to operate at off-peak service levels until the end of 2023, when the planned TPWS upgrades are introduced.

- At a 30% degradation rate, provision of even an off-peak would not be deliverable at the end of 2021.

Figure 4 Units required and units available at 5% ATP degradation per year

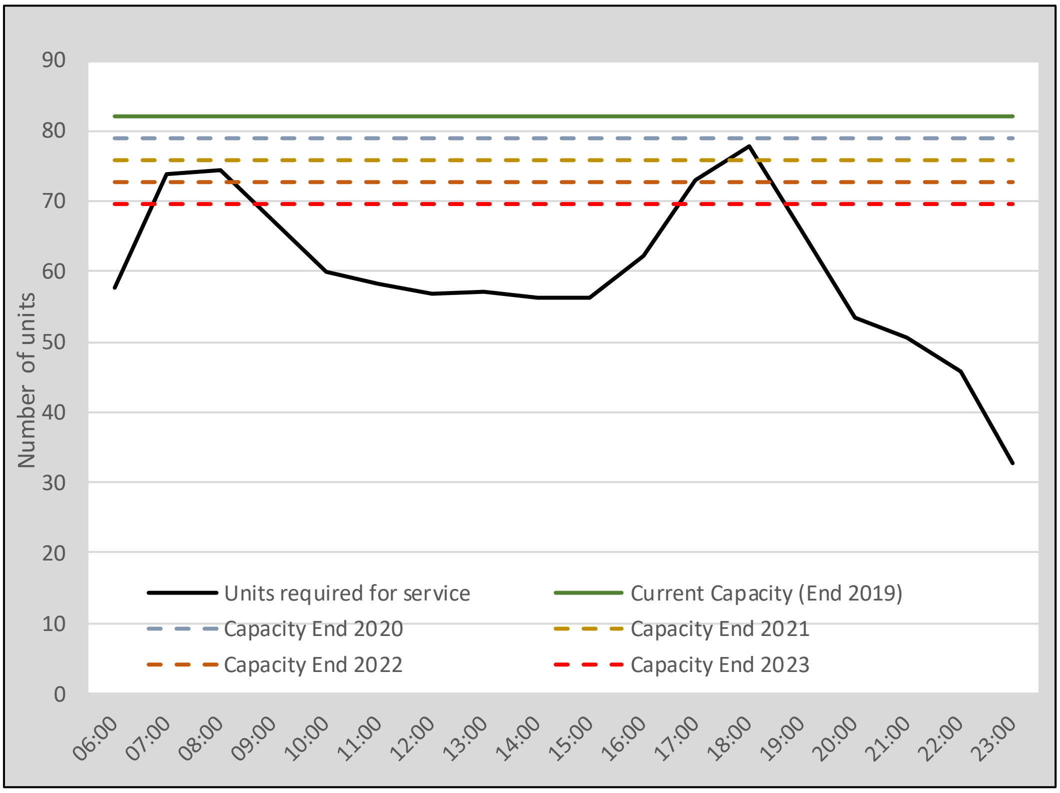


Figure 5 Units required and units available at 10% ATP degradation per year

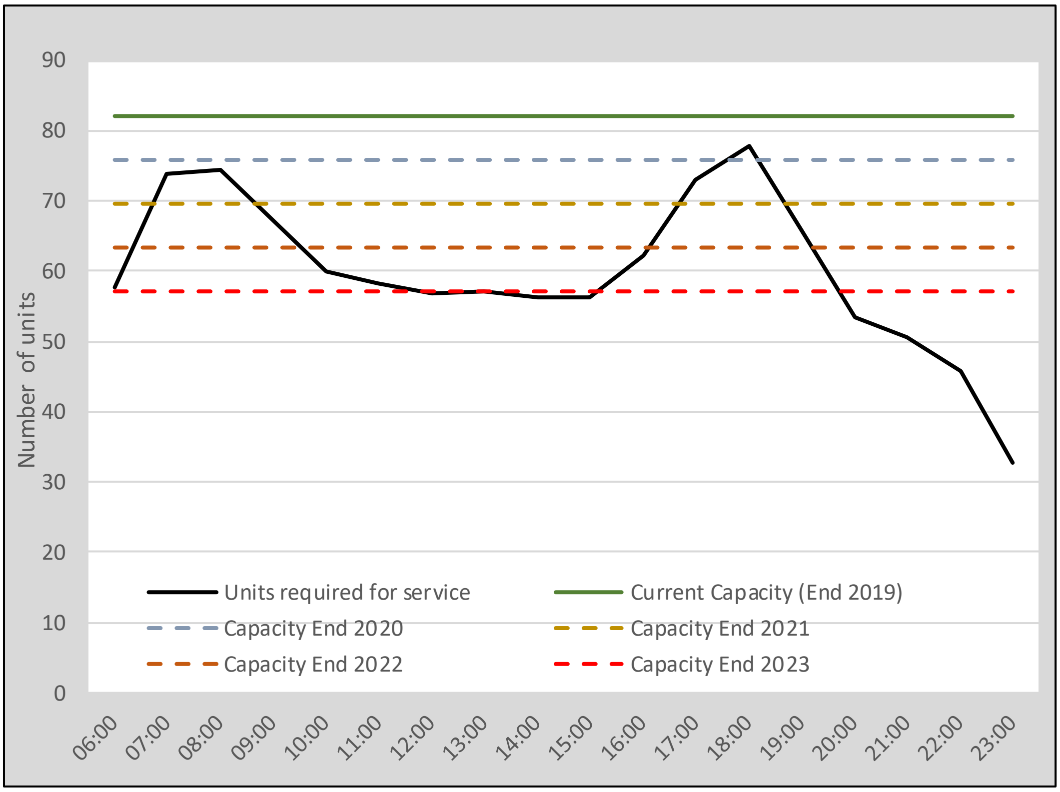
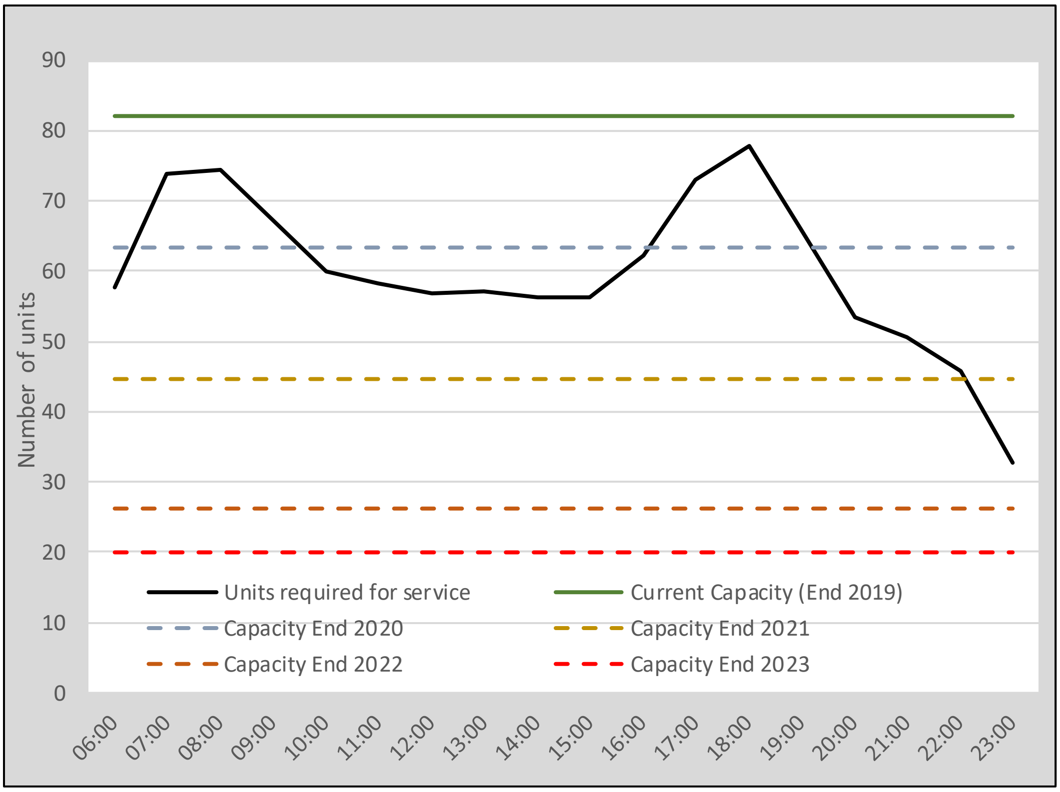


Figure 6 Units required and units available at 30% ATP degradation per year

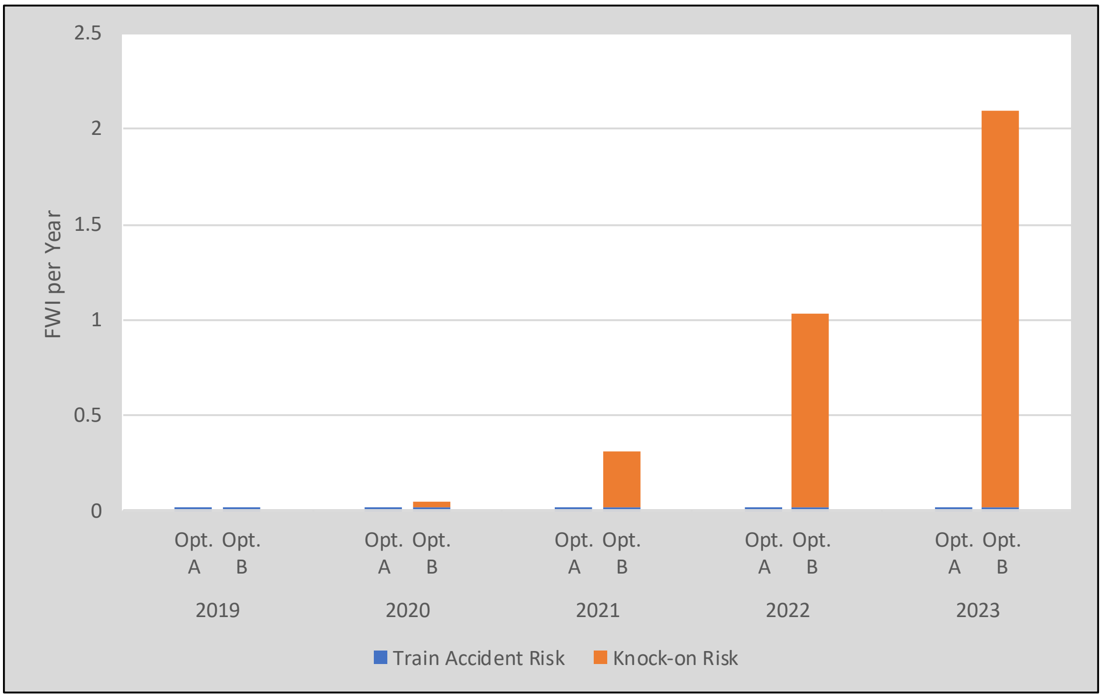


4.2 Overall risk results

The risk that would exist for Option A and Option B for each year up until the end of 2023 are compared in *Figure 7*. The train accident risk from collision, derailment and buffer collision as assessed in previous risk assessment underpinning the Network Rail exemption are shown in blue, orange is used for the knock-on risk from the RSSB tool. As can be seen, at 20% degradation, by the end of 2020, the risk would be 3 times higher gradually increasing to a factor of 140 higher by the end of 2023.

The inference from the assessment at 20% degradation per year is that it is significantly safer to permit trains with failed and unrepairable ATP to operate using TPWS rather than withdrawing the units from service. This does not account for potential intermodal transfer, which would strengthen the case further to permit trains to run with TPWS and AWS.

Figure 7 Comparison of the risk for Option A and Option B at 20% degradation



Uncertainty

The risk assessment results for Option B are very sensitive to the rate of degradation, hence, as with the assessment of the reduction in train services, sensitivity cases have been completed at 5%, 10% and 30% degradation. The results are presented in *Figure 8* to *Figure 10*.

Figure 8 Comparison of the risk for Option A and Option B at 5% degradation

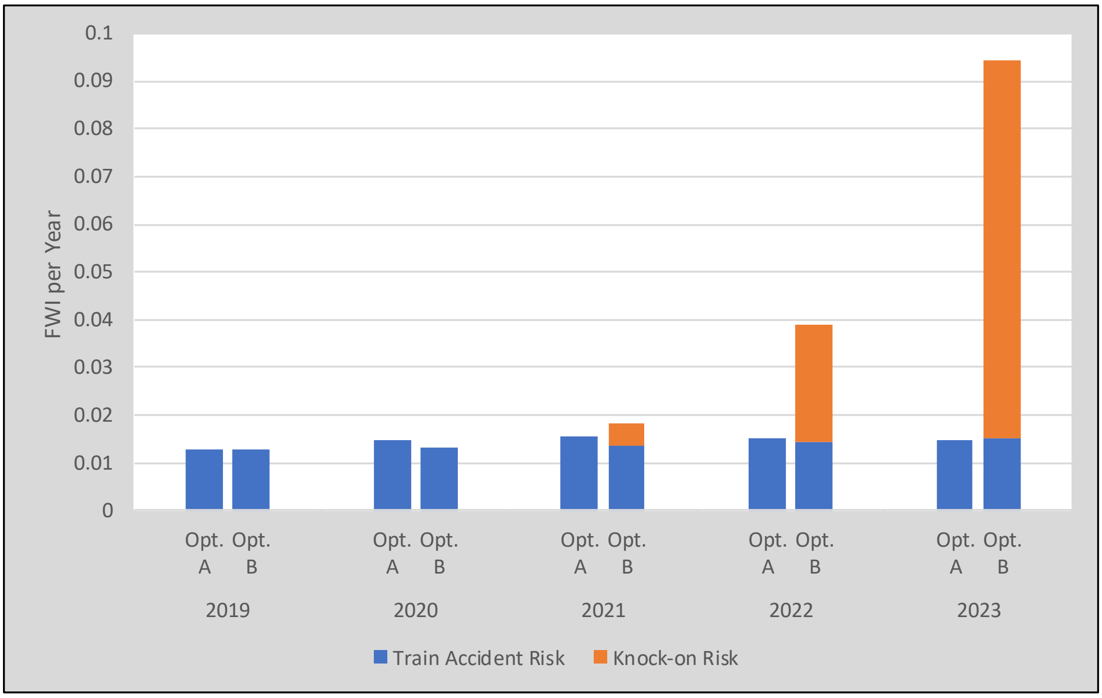


Figure 9 Comparison of the risk for Option A and Option B at 10% degradation

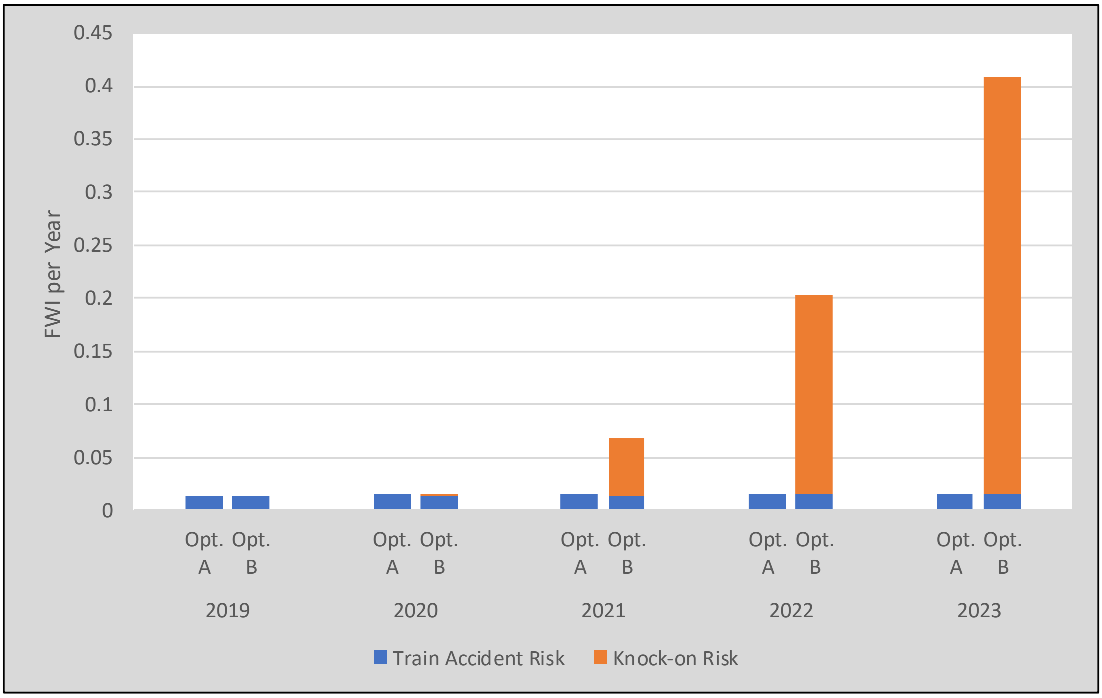
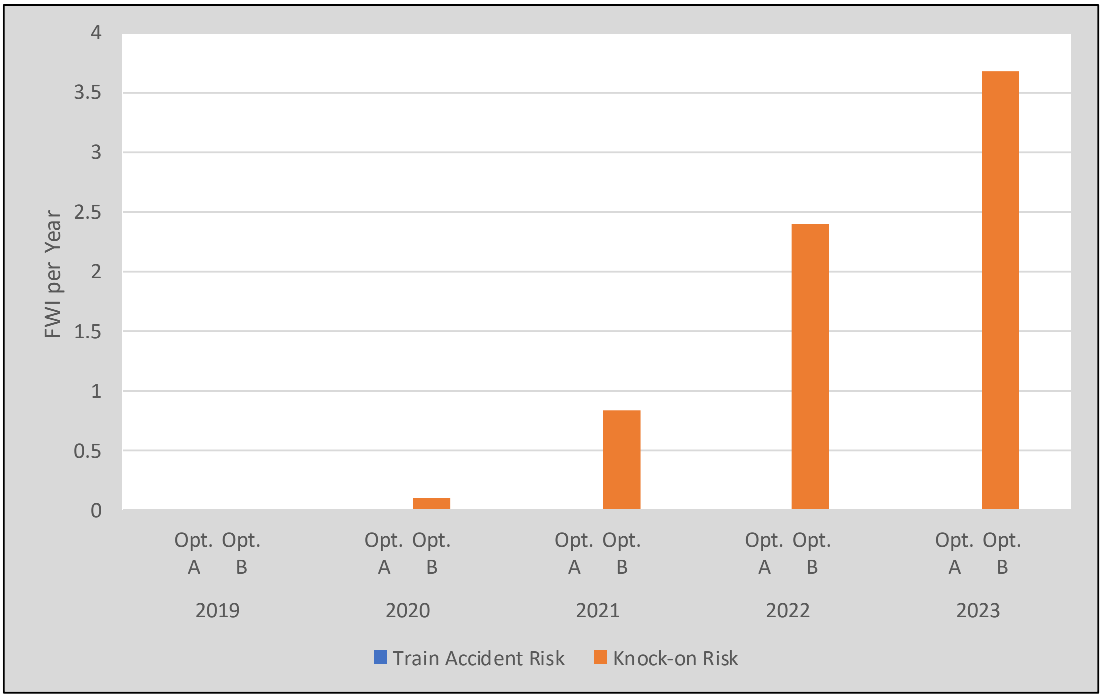


Figure 10 Comparison of the risk for Option A and Option B at 30% degradation



From the sensitivity case is it clear that even for the most optimistic case, with 5% degradation pf ATP units per year, the knock-on risk that would result from withdrawing ATP units from service when they fail is much higher than the risk from permitting them to operated using TPWS and AWS. The knock-on risk results in the risk from Option B being 20% higher than option A by the end of 2021 and a factor of over 6 higher by the end of 2023.

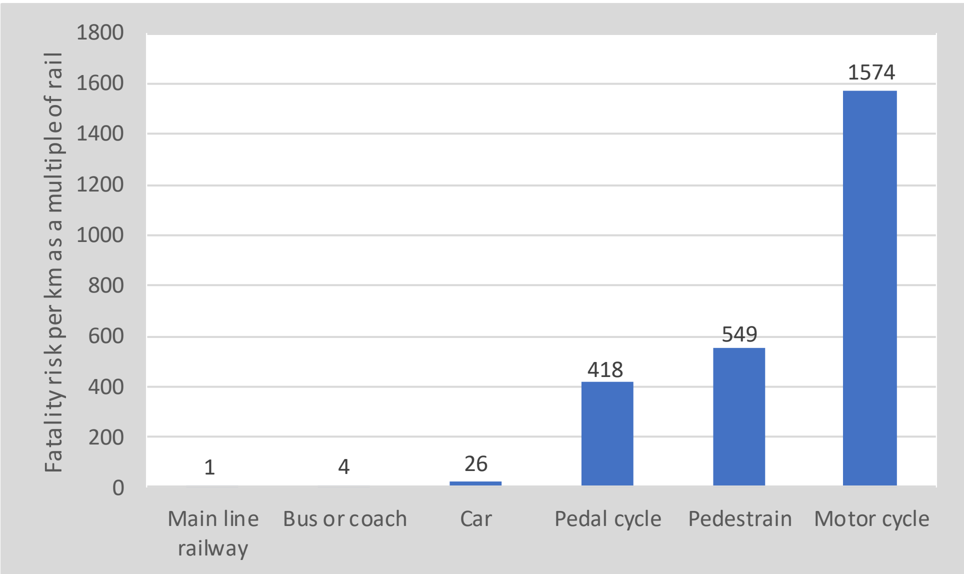
5 CONSIDERATION OF INTERMODAL TRANSFER

A challenge with Option B, involving taking trains out of service when there are failures of the ATP system that cannot be repaired, is that the level of service that can be provided by Chiltern Railways would be significantly diminished. The reduction in services would be in the period 2020 to 2023. As a direct results of the cancellations, some passengers will seek alternative means of transport. The alternative means of transport would include:

- Alternative train services offered by other operators (most which rely on TPWS).
- Bus replacement services, or alternative existing bus or coach travel
- Private transport by car or motorbike.

Figure 11 presents a comparison of each transport mode per train kilometre. The values shown are referenced back to rail and therefore all other transport modes are a multiple of rail. The chart is based upon information provided in RSSB's Annual Health and Safety Report 2018/19 (AHSR).

Figure 11 Comparison of the risk per transport mode on a km travelled basis



In the best-case scenario, some passengers may find alternative methods of travelling to their destination by rail. This would be using services that are mainly protected by TPWS and therefore would carry substantially the same risk as Chiltern Railways services if they were permitted to operate with ATP isolated. In practice, the Chiltern Railways service would be a mix of ATP and TPWS protected journeys, hence travelling with an alternative operator is likely to introduce a slight risk increase.

For passengers that cannot find an alternative, convenient rail service, the most likely alternative forms of transport are bus/coach and car; these are a factor of 4 and 26 higher than rail respectively. Hence, assuming a journey of equivalent distance is made by the alternative mode, the risk to an individual would be much higher for the journey.

The conclusion from this assessment is that maximising the travel by Chiltern Railways should be the priority even if some services have ATP isolated. Hence, operating trains without ATP and relying on TPWS and AWS would reduce individual and societal risk through a reduction in modal transfer to inherently less safe transport modes.

6 CONCLUSIONS

There are two potential strategies to respond to unrepairable failure of ATP units on Chiltern Railways' fleet, for the purposes of this report, these are termed Option A and Option B. Option A involves permitting the trains to operate using TPWS and AWS. Option B involves withdrawing the units from service until the planned TPWS upgrades have been implemented (due for completion by end 2023). This report presents a risk assessment to compare the two options. The following conclusions are made:

- With the credible worst case of the ATP system failing irreparably on 20% of units per year, the safety risk from Option B vastly exceed the risk from Option A due to the knock-on risk that would result from train cancellations. By the end of 2020, the risk would be 3 times higher gradually increasing to a factor of 140 higher by the end of 2023. With this level of degradation, it would also not be possible to operate peak levels of service beyond 2021 (only off-peak levels of service would be deliverable).

- The risk assessment is highly sensitive to the assumption on the rate of ATP unit degradation and hence a range of sensitivity cases has been analysed. Even with the most optimistic case assessed, at 5% degradation, the knock-on risk results in the risk from Option B being 20% higher than option A by the end of 2021 and a factor of over 6 higher by the end of 2023. There would also be a moderate erosion in peak services from 2022 onwards.

- In addition to knock-on risk there is also the potential for passengers, when experiencing progressively lowering levels of service, to use other forms of transport (intermodal transfer). The most likely alternatives are other forms of road transport such as bike, car and bus/coach. Each of these modes carries a higher level of risk per km and per journey. The more likely alternative forms of bus/coach and car are a factor of 4 and 26 higher than rail respectively. Hence, the potential for intermodal transfer would also strongly indicate that the safer option is Option A.

- For Option A, there is safety performance optimisation that can be achieved through the prioritisation of the lineside and train borne TPWS upgrade. The preferred prioritisation would be:

  - Lineside: Starting the upgrade at Marylebone and progressing north.

  - Rolling stock: Prioritising stock that operates higher speed and over the core area (Marylebone to Aynho Junction) with the highest density. Hence the order would be starting with the DVTs, then the Cl. 168, Cl.172 and finally the Cl. 165.

7 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.
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.
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 change.
14	Permissive move	All	ATP and TPWS are ineffective in protecting against permissive move collisions.
15	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.

Ref.	Topic	Case	Assumption
			Reservoir sidings: These will leave/enter the relevant infrastructure at Bordesley 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.
16	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			
17	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.
18	Platform extensions	Future services	See above for train length (14)
19	Additional siding facility at Wembley	HS2 Construction	No significant risk impact.
Passenger loading			

Ref.	Topic	Case	Assumption
20	Passenger growth - Changes through the Chiltern Franchise	Future Chiltern growth in passenger numbers.	Assume 2.5% growth for all operators.
21	Growth for other operators	Future growth in passenger numbers for other operators.	Assume 2.5% growth for other operators
Safety improvement options			
22	Rollback protection		This is assumed to apply to Chiltern stock only and not CrossCountry and London Midland/London Northwestern Railway service.
23	TPWS cab fitment upgraded		This is assumed to apply to Chiltern stock only and not CrossCountry and London Midland/London Northwestern Railway service.
Underlying data			
24	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
Knock-on risk			
24	Knock-on risk	Not running units with failed ATP	The RSSB knock-on risk tool provides a reasonable assessment of the additional risk from delays and cancellations.
25	Knock-on risk	Not running units with failed ATP	The in-service failure of the ATP equipment is assumed not to cause delays as it is permitted to continue the remainder of the planned journey under TPWS (and potentially continue until the train in planned to return to a depot).

Ref.	Topic	Case	Assumption
26	Knock-on risk	Not running units with failed ATP	At the start of the assessment (January 2020) there are four ‘spare’ units.
27	Knock-on risk	Not running units with failed ATP	Once the number of required units falls below that required to operate the service, the number of train cancellations is based upon the shortfall in the number of available units. In practice, the situation may be compounded by the need to decouple units to form new services.
28	Knock-on risk	Not running units with failed ATP	There may be potential to operate a drastically reduced timetable, but the knock-on risk (or intermodal transfer) would still accrue.

8 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	
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.
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	