NetworkRail

Infrastructure Projects

ETCS "Plan B" Study

Enhanced TPWS - Paddington to Heathrow Airport Junction 2017

Train Protection Effectiveness Calculation Summary Report

Project Name: Enhanced TPWS – Paddington to Airport Junction 2017	Business Unit: Infrastructure Projects
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Version History

Version	Date	Author	Comments
0.1	30-05-2014	D Smart	Interim issue for Down Relief and Up Relief signals
0.2	20-06-2014	D Smart	Added Down Main and Up Main signals
0.3	26-06-2014	D Smart	Added details of buffer stop protection in GW-ATP and Paddington-Ladbroke Grove signals desktop review
1.0	27-06-2014	D Smart	Initial Issue
2.0	18-07-2015	D Smart	Updated for completion of GRIP3

1 SUMMARY

The aim of this GRIP3 study is to compare “enhanced TPWS” with Great Western Automatic Train Protection (GW ATP) to assist others in establishing if “enhanced TPWS” is a viable contingency plan if ETCS cannot be commissioned between Paddington and Heathrow Tunnel Junction by April 2017. This report describes the results of the train protection effectiveness calculations undertaken for the Relief and Main lines. Output at this stage is for feasibility purposes.

2 INTRODUCTION

2.1 Purpose of Document

This report describes the results of the train protection effectiveness calculations undertaken for the Relief and Main lines.

Output at this stage is for feasibility purposes. Full design and independent verification will be undertaken at a later stage. Feasibility of providing TPWS failure indications, IECC/data changes, availability of components, constructability and adequacy of SSI I/O is to be considered by others at a later stage.

Provision of an additional OSS for PSR on plain line and PSR OSS for speed restrictions through divergences protected by MAY-FA junction signalling have been reviewed as required by the study remit [122271-ISD-ASS-ESG-000001 v2.0, appended to this report]. A desktop review of sighting point of junction indicators for signals using MAR junction signalling has been undertaken to find where the aspect could be released before the train has passed the outermost OSS for the junction signal.

2.2 Background

The aim of this project is to establish if enhanced TPWS is a viable fall-back option to permit Crossrail Paddington-Heathrow services using class 345 trains to replace the existing Heathrow Connect class 360 services if ETCS cannot be commissioned between Paddington Station and Heathrow Tunnel Junction by April 2017. To find out, a TPWS effectiveness study has been carried out to identify those signals which would need TPWS modifications and to identify those signals which would need initial fitment to achieve similar effectiveness to that provided by GW-ATP. This study will evaluate each signal between 0MP and 12MP for fitment and apply TSS and OSS(s) for optimal effectiveness to mimic ATP functionality.

This effectiveness study must help to establish the following:

- How safe is the enhanced TPWS option compared to existing?
- Does this option result in a net reduction in risk between 0-12MP? To achieve a net reduction, the study will focus on improving TPWS effectiveness for all non-ATP fitted trains.

Paddington platform starters will be excluded from the assessment because TPWS already provides a higher level of protection against SAS-SPAD compared to GW-ATP.

The study results will be incorporated in a safety case to be compiled by others and used to support justification for exemption to *Railway Safety Regulations 1999* from the Office of Rail & Road (ORR).

3 METHODOLOGY

The GRIP3A study was undertaken using the following approach:

1) Establish criteria for assessment:
   a) Enhance lineside TPWS equipment to achieve similar functionality to the GW-ATP system for TPWS-only class 345 Crossrail rolling stock, principally by:
      i) Fitting TPWS to all signals currently fitted with ATP lineside equipment on Main, Relief and Airport lines (up to NR boundary at SN321, SN323 & SN325). Extent of ETCS fitment on the Heathrow Branch is not yet confirmed, so these signals are assumed to be the furthest boundary between TPWS-ETCS.
      ii) Configuring the TPWS installations to protect against rear-end collisions by class 345 trains by designing it to stop a 90mph class 345 train in the overlap at 12%g.
      iii) Standard (TI-022) TPWS performance will be made to stop other 12%g trains at up to 110mph within the Safe Overrun Distance (SOD). An existing study has identified five signals between Paddington and Stockley that do not meet TI-022 requirements.
   b) Agree items of significance to be highlighted either during the study or in the report, for example cases where the TPWS design is:
      i) Unable to achieve 95% effectiveness in overlap for class 345 trains.
      ii) Unable to achieve net increase in train protection effectiveness for a given signal.
      iii) Unable to achieve TI-022 compliance (without infrastructure or interlocking changes) i.e. TPWS effectiveness within SOD for 12%g.
   c) The criteria were reviewed and agreed at a meeting held on 1st May 2014. Details are given in *Comparison of GW-ATP and TPWS Functionality*, reference 122271-ISD-ASS-ESG-000001 version 2.0.

2) Gather 2018 layout and Working Timetable (WTT) data. Identify each signal and any current TPWS fitment. Establish train types and numbers past each signal.

   a) Train flows for a 0700hrs-1900hrs typical weekday were compiled with the assistance of the NR Capability Analysis team and the Crossrail project. The simplified timetable used is based on the Iteration 5 timetable with Relief line flows adjusted for the pre- and post-May 2018 alterations to Heathrow stopping services. This timetable includes the IEP service enhancements, but excludes full Crossrail service introduction. The train numbers used are given in *TPWS Plan B 2018 Timetable Simplifier*, reference 122271-ISD-SKE-ESG-000001 version 0.3.
3) Enter the details gathered in the NR approved TPWS effectiveness spreadsheet to establish a base case for comparison. All ATP fitted trains to be entered as 99% effective for all ATP-equipped signals.
   a) The base case “April 2018” spreadsheets are available on ProjectWise:
      i) 122271-ISD-CAL-ESG-000002 *Heathrow Tunnel-Ladbroke Grove, Up Relief*
      ii) 122271-ISD-CAL-ESG-000003 *Heathrow Tunnel-Ladbroke Grove, Up Main*
      iii) 122271-ISD-CAL-ESG-000004 *Heathrow Tunnel-Ladbroke Grove, Down Relief*
      iv) 122271-ISD-CAL-ESG-000005 *Heathrow Tunnel-Ladbroke Grove, Down Main*
4) Use the NR approved TPWS design tool to design new fitments for all signals to meet new criteria agreed with client (step 1c above).
   a) The TPWS Placer calculations for “Plan B” are available on ProjectWise:
      i) 122271-ISD-CAL-ESG-0001xx (Down Relief)
      ii) 122271-ISD-CAL-ESG-0002xx (Up Relief)
      iii) 122271-ISD-CAL-ESG-0003xx (Down Main)
      iv) 122271-ISD-CAL-ESG-0004xx (Up Main)
      v) 122271-ISD-CAL-ESG-0005xx (Bi-Directional Signals)

5) Enter proposed TPWS details in a copy of the base case spreadsheet and amend train flow to remove 2 tph ATP fitted class 360 Heathrow Connect service and replace with 4 tph class 345 Crossrail service. Calculate net change in effectiveness per signal.
    a) Spreadsheets for "May 2018" without TPWS enhancement for comparison:
        i) 122271-ISD-CAL-ESG-000006 *Heathrow Tunnel-Ladbroke Grove, Up Relief*
        ii) 122271-ISD-CAL-ESG-000007 *Heathrow Tunnel-Ladbroke Grove, Up Main*
        iii) 122271-ISD-CAL-ESG-000008 *Heathrow Tunnel-Ladbroke Grove, Down Relief*
        iv) 122271-ISD-CAL-ESG-000009 *Heathrow Tunnel-Ladbroke Grove, Down Main*
6) Complete proposed fitment spreadsheets for remaining signals following client review. Calculate net change per signal.
    a) Spreadsheets for "May 2018" with "Plan B" TPWS enhancement:
        i) 122271-ISD-CAL-ESG-000010 *Heathrow Tunnel-Ladbroke Grove, Down Relief*
        ii) 122271-ISD-CAL-ESG-000011 *Heathrow Tunnel-Ladbroke Grove, Up Relief*
        iii) 122271-ISD-CAL-ESG-000012 *Heathrow Tunnel-Ladbroke Grove, Down Main*
        iv) 122271-ISD-CAL-ESG-000013 *Heathrow Tunnel-Ladbroke Grove, Up Main*
        v) 122271-ISD-CAL-ESG-000018 *Heathrow Tunnel-Ladbroke Grove, Bi-Directional Signals*
    b) Proposed fitment requirements are summarised in 122271-ISD-REP-ESG-000002 *ETCS "Plan B" TPWS Summary Sheet.*
7) Hold review meeting with client to discuss results and any items of significance
8) Compile report highlighting all items of significance and include all calculations. Hand over to client for preparation of safety case.
9) Establish best Crossrail (CRL) stageworks for implementation and compile remit for CRL scheme designers (largely consisting of TPWS placer tool outputs) to supersede existing Crossrail TPWS designs.

4 COMMENTARY

4.1 Comparison of GW-ATP and TPWS Functionality

The TPWS fitment criteria for the study were agreed at a peer review meeting between representatives of the NR IP ETCS team (R Evans and P Hingley), NR IP Crossrail team (C Bray) and Signalling Design Group (D Smart and D Johnson) on 1st May 2014 as described in section 3 item 1)c) above. Version 1.0 of *Comparison of GW-ATP and TPWS Functionality* [122271-ISD-ASS-ESG-000001] was used as the basis for discussion, being the output of a desktop study into the features of the two systems. The aim of enhancing the TPWS infrastructure is to converge on GW ATP functionality for the Class 345 trains, but the peer review concluded that certain features of GW ATP could not be duplicated with TPWS:

- Monitoring changes in permanent speed restrictions (PSR): the attendees concluded that an additional OSS set for the passenger train PSR+10% at the commencement of the PSR should be considered for "Regulated PSR", i.e. speed reductions of greater than $^1/_3$ where the initial speed is equal to or greater than 60mph, to ensure the reduction had been complied with. Reductions of less than $^1/_3$ were viewed as bringing greater likelihood of spurious trips for freight trains, the attendees concluding that imposition of differential speed restrictions for freight throughout the study area would bring significant performance problems and objections from train operators.
- Monitoring adherence to maximum permitted speed: achieving this with TPWS would require TPWS OSS to be provided at intervals on plain line, again requiring imposition of differential speed restrictions for freight. The attendees felt that over-speeding was a lower risk, but suggested TOC consultation to establish the extent (if any) of over-speeding.

- Monitoring diverging speed at junctions: the attendees agreed that extending the standard TPWS divergence PSR OSS fitment to include MAY-FA junction signalling sequences [where the reduction is equal to or greater than $^1/_3$ from a starting speed of 60mph or greater] would be a reasonably practicable option for further TPWS coverage. Providing a switchable OSS set for PSR+10% at the toes of the points would intervene too late to achieve a reduction in speed over the points. For MAR junction sequences, the junction signal TPWS OSS will ensure that the train is under control while the signal is held at red; therefore the attendees agreed that the study should identify cases where the sighting point of the signal (approximately equal to earliest MAR release point) is passed before the junction signal's outermost OSS.
- Monitoring of temporary speed restrictions: the attendees agreed that enhancement for TPWS at temporary speed restrictions should be excluded from the study owing to the complexity of providing and powering additional (but temporary) OSS. Consultation with train operators was suggested.
- Stop train if it passes a signal at danger: the attendees agreed that the enhanced TPWS should be designed to stop the 12%g 90mph Class 345 train within the overlap of the signal because GW ATP is configured to stop trains within the overlap. *(Note: the train protection effectiveness calculations for the study measure effectiveness for all trains within the overlap rather than TPWS SOD to allow comparison with GW ATP.)*
- Monitor position light moves at reduced speed: the attendees agreed that the Class 345 train is too long to join in or share Paddington platforms, so this facility would be unlikely to be used.
- Monitor for train rolling away: the TPWS equipment is unable to perform this function, which would usually be provided by the train's onboard control system.

The agreed criteria for the study were tabulated in version 2.0 of the *Comparison* document, hereafter referred to as the "study remit" and appended as section 8 of this report.

4.2 Paddington to Ladbroke Grove Signals

The TPWS fitment in the six-track section between Ladbroke Grove and Paddington Station (MLN1 1M 60ch to 0M 00ch) has been designed to stop a 12%g train in the overlap: this requirement is to be maintained as part of the Crossrail and IEP scheme programme specifications. The TPWS 12%g MOD given on the scheme plan was checked against the overlap lengths, confirming the MOD is less than the overlap length for all signals on Lines 1 to 6 between Paddington and Ladbroke Grove.
TPWS effectiveness for the Paddington platform starter signals was reviewed as part of the IEP scheme GRIP4 Signal Overrun Risk Assessment (SORA) process. That SORA concluded the existing TPWS TSS+OSS provides superior protection for SAS-SPAD at Paddington because the GW-ATP functions equivalent to a TPWS TSS only in this situation. (The departing train cannot initialise the GW-ATP equipment until it passes over the starter signal beacon.) For more information, please refer to *Paddington to Old Oak Common Signal Overrun Risk Assessment Report* BS026/029/D141 revision C.

4.3 Down Relief Signals

Generally, there is a small reduction of calculated train protection effectiveness at all signals when the class 360 trains are replaced by class 345 trains without GW-ATP: this is driven by the reduction in maximum effectiveness achievable from 99% for ATP to 95% for TPWS. It should be noted that the effectiveness percentage is the effectiveness for all the timetabled trains past the signal to stop within the overlap for that signal. (*Note: TPWS is normally designed to stop 12%g trains within the TPWS Safe Overrun Distance; the* *proposed TPWS installation has been designed to stop the class 345 trains within the overlap rather than the Safe Overrun Distance.*)

Those signals fitted with GW-ATP but not fitted with TPWS fall to 0.0% effectiveness when no GW-ATP trains run and show a predictable substantial increase in effectiveness when Enhanced TPWS is provided, with the system benefiting all trains past that signal.

Were ETCS available for the Class 345 services, the effectiveness is slightly greater than with GW-ATP and Connect services, because the higher 4 tph Class 345 service frequency increases the proportion of trains with 99% maximum effectiveness. (It is assumed that only Class 345 trains are using the ETCS equipment.)

Signal Number	Overall TPWS+ATP % Effectiveness			
	Pre-May 2018	*Post-May 2018*		
	With GW-ATP & Class 360 services	**Existing TPWS & Class 345 services**	**With Enhanced TPWS & Class 345 services**	**With ETCS & Class 345 services**
SN111 (1)	96.0%	95.0%	95.0%	96.6%
SN123	94.6%	93.1%	95.0%	95.4%
SN127	94.9%	93.9%	94.6%	95.7%
SN137	91.8%	89.8%	94.6%	93.2%
SN153	91.1%	88.8%	94.5%	92.6%
SN163	91.7%	89.2%	95.0%	93.1%
SN175	96.0%	95.0%	95.0%	96.6%
SN187	92.9%	90.8%	95.0%	94.1%
SN199	95.9%	94.9%	95.0%	96.5%
SN203	94.3%	93.8%	93.8%	95.1%
SN209	20.8%	0.0%	92.4%	34.4%
SN211	92.4%	91.8%	92.9%	93.5%
SN215	88.3%	87.0%	92.5%	90.2%
SN225	91.0%	90.3%	92.5%	92.4%
SN233	90.1%	89.2%	92.5%	91.6%
SN239	88.6%	87.3%	92.5%	90.4%
SN243	94.1%	93.3%	94.6%	94.9%
SN253	20.8%	0.0%	93.1%	34.4%
SN265	91.8%	91.2%	92.4%	93.0%
SN273	20.8%	0.0%	93.1%	34.4%
SN283	93.7%	93.2%	93.2%	94.6%
SN287	90.7%	90.1%	92.4%	92.1%
SN303	87.7%	86.3%	92.3%	89.7%
SN323	99.0%	0.0%	95.0%	99.0%

Table 1- Variation of TPWS+ATP Effectiveness - Down Relief

The TPWS installation at SN243 is proposed to be adjusted and enhanced to protect the 170m Restricted Phantom Overlap (RPOL) with a line speed approach for the class 345: the existing SN239A (W) aspect release requires the 178m berth track circuit (P)RL occupied for 20 seconds which would be sufficient to time the train “nearly at a stand” (see NR/L2/SIG/11201/ModB7 issue 6 figure 8), but the arrangement allows for any future relaxation of the controls.

4.4 Up Relief Signals

The results for the Up Relief mirror those of the Down Relief: generally a small reduction of calculated train protection effectiveness for each signal, driven by the change from GW-ATP to TPWS only.

SN248 Restricted Overlap (ROL) of 63m length has been taken into account. The proposed TPWS fitment is 90% effective for a linespeed (90mph) approach for the class 345 trains and fully effective for up to 35mph approach following a delayed yellow at SN258. SN258 is proposed on the Crossrail GRIP4 scheme plan to receive an extra OSS to prove train speed is below 25mph before releasing the yellow aspect for the Warning class route.

Signal Number	Overall TPWS+ATP % Effectiveness			
	Pre-May 2018	*Post-May 2018*		
	With GW-ATP & Class 360 services	**Existing TPWS & Class 345 services**	**With Enhanced TPWS & Class 345 services**	**With ETCS & Class 345 services**
SN316	99.0%	56.6%	97.3%	99.0%
SN292	99.0%	86.5%	95.0%	99.0%
SN284	94.5%	93.9%	93.9%	95.3%
SN276	93.2%	92.8%	92.8%	94.2%
SN266	21.4%	0.0%	92.4%	35.2%
SN258	93.3%	92.3%	94.0%	94.3%
SN248	95.0%	94.2%	95.0%	95.7%
SN244	21.4%	0.0%	92.4%	35.2%
SN238	93.5%	93.1%	93.1%	94.5%
SN232	93.7%	93.0%	93.4%	94.7%
SN224	92.1%	91.6%	92.4%	93.4%
SN214	21.4%	0.0%	92.5%	35.2%
SN210	88.8%	87.6%	92.4%	90.6%
SN206	75.2%	69.4%	92.6%	79.4%
SN202	94.7%	94.0%	94.0%	95.4%
SN192	96.0%	95.0%	95.0%	96.6%
SN186	95.5%	94.3%	95.0%	96.2%
SN174	96.0%	95.0%	95.0%	96.6%
SN164	92.4%	90.2%	95.0%	93.7%
SN156	94.7%	93.3%	95.0%	95.6%
SN144	75.8%	68.1%	95.0%	80.4%
SN134	96.0%	95.0%	95.0%	96.6%
SN114	96.0%	95.0%	95.0%	96.6%
SN112	96.0%	95.0%	95.0%	96.6%

Table 2 - Variation of TPWS+ATP Effectiveness - Up Relief

4.5 Down Main Signals

The Down Main is not affected by the change in Paddington-Heathrow service rolling stock types during normal working: the proposed TPWS enhancement is for those occasions when the Crossrail Heathrow service is diverted to the Main lines. There is an increase in train protection effectiveness at signals not currently fitted with TPWS, where the new fitment provides protection for non-ATP EMU services in the post-Electrification timetable (which are not considered in detail as part of this study).

The approach speed to SN135 is constrained by the 85/MU100 PSR commencing only 679m on the approach to the signal. The attainable speed using the acceleration table for a five-car electric IEP at SN135 is calculated as no more than 75mph for passenger trains; the proposed OSS(2) is also pulled in to 600m from the signal with set speed of 61mph to improve effectiveness.

For the following Down Main signals where the linespeed is higher than 90mph and there is no existing TPWS fitment, the new TPWS fitment has been designed only for the 90mph maximum speed of the Class 345 trains to stop within the overlap: SN151, SN159, SN173, SN179, SN191, SN207, SN213, SN231, and SN237.

Signal Number	Overall TPWS+ATP % Effectiveness	
	GW-ATP and Existing TPWS	GW-ATP and Enhanced TPWS
SN107	98.8%	98.8%
SN125 (1)	98.1%	98.1%
SN125 (2)	98.8%	98.8%
SN135	98.3%	98.7%
SN151	91.3%	98.7%
SN159	91.3%	98.7%
SN173	91.3%	98.7%
SN179	91.3%	98.7%
SN191	91.3%	98.7%
SN201	98.7%	98.7%
SN207	91.3%	98.7%
SN213	91.3%	98.7%
SN231	91.3%	98.7%
SN237	91.3%	98.7%
SN249	98.7%	98.7%
SN255	98.7%	98.7%
SN271	98.6%	98.7%
SN285	98.7%	98.7%
SN319	99.0%	99.0%
SN321	99.0%	99.0%

Table 3 - Variation of TPWS+ATP Effectiveness - Down Main

The SN151 and SN159 OSS proposed positions are adjusted to avoid clash with previous signal TSS.

4.6 Up Main Signals

Similar to the Down Main, the Up Main is enhanced for those occasions when the Crossrail Heathrow service is diverted to the Main lines. As with the Down Main, the TPWS fitment on signals currently only equipped with GW-ATP gives an increase in effectiveness for post-Electrification non-ATP EMU services running on the Up Main.

Signal Number	**Overall TPWS+ATP % Effectiveness**	
	GW-ATP and Existing TPWS	**GW-ATP and Enhanced TPWS**
SN316	99.0%	97.3%
SN300	99.0%	99.0%
SN280	98.5%	98.7%
SN270	98.5%	98.7%
SN254	98.7%	98.7%
SN246	91.3%	98.7%
SN234	91.3%	98.7%
SN222	91.3%	98.7%
SN212	91.3%	98.7%
SN204	98.7%	98.7%
SN194	91.3%	98.7%
SN178	91.3%	98.7%
SN160	91.3%	98.7%
SN146	91.3%	98.7%
SN120	98.7%	98.7%
SN106 (2)	98.8%	98.8%

Table 4 - Variation of TPWS+ATP Effectiveness - Up Main

The Crossrail TPWS fitment for SN280 was designed and approved to an earlier version of TI-022 and requires an additional OSS for compliance with the current version.

Signals SN120 and SN106 have multiple overlaps; the shortest overlap has been used for checking the TPWS effectiveness for Class 345.

For the following Up Main signals where the linespeed is higher than 90mph and there is no existing TPWS fitment, the new TPWS fitment has been designed only for the 90mph maximum speed of the Class 345 trains: SN246, SN234, SN222, SN212, SN194, SN178, SN160, and SN146.

4.7 Permanent Speed Restrictions: Regulated PSR & MAY-FA Junction Signalling

Three regulated Permanent Speed Restrictions (PSR) meet the study remit criteria of $^1/_3$ or greater reduction in speed from a starting speed of 60mph or greater for provision of additional OSS set at PSR+10% at commencement of the PSR:

- Up Relief: SI-UR U 2M+3CH 25/50 PSI at Ladbroke Grove (from 50/MU80)
- Up Main: SI-UM U 2M+6CH 25/50 PSI at Ladbroke Grove (from 85/MU100)
- Down Airport: MLN007 PSR 11m77ch 50 PSI at Heathrow Tunnel Junction (from 75)

The following routes using Flashing Yellow (MAY-FA) junction signalling arrangements meet the study remit criteria of $^1/_3$ or greater reduction in speed from a starting speed of 60mph or greater for provision of a conventional PSR OSS. The proposed PSR OSS details have been produced using the TI014_6.xls TPWS Positioning Form worksheet:

- SN202B-1(M) & B-2(M), 30 diverging from 60/MU80 at Acton West
    - *Switchable PSR OSS 550m on the approach to points 8133 with passenger set speed of 76mph (freight 60.5mph) and spacing of 33.0m. Note that 8141 points are between the OSS and the divergence at 8133, so additional control is required.*
- SN233B(M), 40 diverging from 90 at Hanwell Bridge
    - *Switchable PSR OSS 522m on the approach to points 8166B with passenger set speed of 79mph (freight 63.5mph) and spacing of 34.5m.*
- SN248B(M) & C-1(M), 40 diverging from 85/MU90 at Hanwell Bridge
    - *Switchable PSR OSS 580m on the approach to points 8176A with passenger set speed of 81.5mph (freight 65mph) and spacing of 35.5m.*
- SN254B(M), 70 diverging from 125 at Southall East
    - *For the 90mph Class 345, this divergence is not a $^1/_3$ reduction in speed.*
- SN255B(M) & C(M), 50 diverging from 125 at Southall West
    - *For the 90mph Class 345, fitment would be a switchable PSR OSS 450m on the approach to points 8190B with passenger set speed of 80.5mph (freight 64.5mph) and spacing of 35.0m. It is proposed that this OSS is installed to provide a benefit for Class 345 trains.*
    - *Linespeed fitment would be a switchable PSR OSS 1215m on the approach to points 8190B with passenger set speed of 115.0mph (freight 92mph) and spacing of 50.0m. It is not proposed to fit this OSS because it is set above the design speed of the Class 345 trains.*
- SN276B(M) & G(M), 50 diverging from 85 at Southall West
    - *Switchable PSR OSS 365m on the approach to points 8192A with passenger set speed of 76.0mph (freight 60.5mph) and spacing of 33.0m.*
- SN303A(M), 60 diverging from 80/MU90 at Heathrow Airport Junction
    - *Switchable PSR OSS 325m on the approach to points 8210B with passenger set speed of 80.5mph (freight 64.5mph) and spacing of 35.0m.*

SN199A(M) at Acton West and SN243D(M) at Southall East do not meet the criteria for a $^1/_3$ or greater reduction in speed.

4.8 Permanent Speed Restrictions: MAR Junction Signalling

The study remit requires the approach release point for the junction signal to be checked against the position of the first signal OSS, to ensure the train is under control before the signal is cleared for the train to approach the divergence. The sighting point of the route indicator (Route Indicator Reading Distance – RI RD) for each MAR signal in the study area was checked as a desktop exercise; using the Crossrail signal sighting forms where available or estimated using Omnicom survey (dated 2009) where no Crossrail sighting form exists. (The Crossrail signal sighting forms have been completed using virtual reality modelling of the post-Crossrail track and structures so are more reliable indicators of the May 2018 situation than Omnicom survey.)

Using the proposed OSS positions from this study, the following signals have route indication reading distances greater than the outermost OSS on the signal:

- SN70: existing OSS at 250m, RI RD at 397m.
    - *A signal OSS at 400m would be set at 50.5mph, which is higher than the 40mph PSR applicable at this signal. The reduction in speed is 15mph and therefore may not present a significant risk, given that this is only 5mph greater than current permitted differential of 10mph for use of MAF junction signalling. The divergence is 104m beyond SN70.*
- SN127: Crossrail design OSS at 200m, RI RD at 245m.
    - *Relocating the signal OSS to 250m (set speed 39mph) should be achievable with negligible impact on train protection effectiveness.*
- SN232: study proposal OSS at 450m, RI RD estimated from Omnicom at 800m.
    - *SN232 is 388m from the divergence, so a PSR OSS may be more appropriate in this case. However, SN224 OSS+ is 306m from the divergence with set speed 65mph, which already offers some of the benefit of a PSR OSS against over-speed (the TI014_6.xls tool proposes a PSR OSS at 530m from the divergence set at 72.5mph).*
- SN243: study proposal OSS at 675m, RI RD at 700m.
    - *With allowance for equipment operation time, SN243 may step up after the train has passed over the 675m OSS.*
- SN265: study proposal OSS at 725m, RI RD estimated from Omnicom at 800m.
    - *SN265 is 543m from the divergence, so a PSR OSS may be most appropriate. The TI014_6.xls tool proposes a PSR OSS at 450m from the divergence set at 80.5mph.*
- SN321 & SN323: study proposed OSS at 150m, RI RD at 180m and splitting banner repeater signals provided to allow earlier aspect release. The transition to ETCS is expected to take place at these signals, so the 25mph diverging speed restriction beyond should have some protection from that system to mitigate the risk of approaching the divergence at excessive speed.

Assuming that altering the aspect release controls will have an intolerable impact on performance, either an additional signal OSS or a switchable PSR OSS could be provided for these speed restrictions if further mitigation is deemed necessary. Further investigation is required to establish where the actual aspect release takes place in relation to OSS positions.

4.9 Approach to Buffer Stops

GW-ATP at the signals reading into the platforms at Paddington (effectively buffer stop beacon “B1”) treats the buffer stop as a red signal with a nil overlap. Two further buffer stop beacons are provided in the platform: “B2” is 175yd from the stopping point and behaves as another yellow signal to provide an odometry update; “B3” is 44yd from the stopping point and tells the train it is approaching a zero mph speed restriction commencing at the stopping point. The GW-ATP would allow a driver, ignoring all the system warnings in the cab, to reach the buffer stops at a speed less than 6mph. However, the health of the buffer stop beacons is not monitored (other than periodic maintenance checks), so in failure situations without the updates from beacons B2 and B3 a release speed of 20mph would be given to the train driver.

RT/E/S/10138 section 10 as amended by TI-025 describes the arrangements for standard TPWS OSS provision for buffer stops. The standard assumes that a defensive driving policy is in use, which is “interpreted as a maximum speed at entry to the platform of 20mph”. The buffer stop OSS is positioned at 55m from the buffer and set at 12.5mph, intended to provide protection for trains passing the OSS at between 12.5mph and 20mph. The standard continues that the “positioning of the transmitter loops has been uniformly set despite variations in permitted speed along terminal/bay platforms ranging from 15mph to 40mph”. (The permitted speed approaching Paddington platforms 1 to 9 is 40mph; for platforms 10 to 14, it is 25mph.) The buffer stop OSS at Paddington are set for 12.5mph as described in TI-025. From review of IPT.DAT files for PADDMN01 and PADDRF11 interlockings, there do not appear to be any input bits allocated specifically for monitoring the health of buffer stop OSS in the interlocking.

12.5mph has been found in practice (according to TI-025) to be the minimum set speed possible using the buffer stop mini-loop to avoid spurious trips, which is a hardware constraint preventing achieving the same “less than 6mph” achieved by GW-ATP. Assuming 12%g brake rate and a brake delay of 2 seconds, a TPWS intervention would be needed at a point approximately 170m from the buffer stop to reduce a train’s speed from a 40mph approach to 6mph at the buffer stop: an OSS at 175m set for 33.5mph is assumed. Three OSS (at 175m set for 33.5mph, 125m set for 27.5mph and 75m set for 22mph) would be required to add protection for the full range of approach speeds to the existing buffer stop OSS set for 12.5mph. (Proximity constraints for OSS less than 60m apart would need to be overcome by use of “opposite” direction frequencies.) Caution is required in positioning OSS in terminal platforms to ensure they are not under the departure-end cab of any train; options are constrained at Paddington owing to the variety of train lengths and types in use. Positioning additional OSS in the platform without conflict with departing cab positions therefore looks unlikely, particularly for 3-car Turbo DMU (69m long), 4-car EMU (80-82m long), 5-car IEP (130m long), 6-car Turbo DMU (138m long) and 8-car EMU (160-164m long). A development of the “zero OSS” concept used for Leicester signals LR415 & LR417 or similar interlocking controls to inhibit the additional OSS when no route is set into the platform would be required to overcome the problem with the TPWS train-borne equipment Power Up Test (PUT), if additional buffer stop OSS are to be installed.

Platforms 10-14 have an approach speed of 25mph and the existing buffer stop OSS at 55m set for 10mph intended to be effective at a nominal 20mph may be sufficient. An additional OSS at 75m set for 22mph (9.5m separation) is a possible enhancement, but may conflict with departing 3-car Turbo DMU and 4-car EMU cab positions.

5 CONCLUSION

The design criteria to stop a 12%g 90mph Class 345 train within the overlap on the Relief and Main lines can be met without extending overlaps or making infrastructure changes, other than provision of additional TPWS equipment. There is a less than 1% reduction in calculated train protection effectiveness for stopping within the overlap for most signals on the Relief lines, except for up to 3% reduction on the Airport lines where all trains are currently fitted with GW-ATP. On the Relief lines there is an increase of at least 71% at signals currently not fitted with TPWS, while the improvement for the similar signals on the Main lines is just over 7% because the proportion of GW-ATP fitted trains to non-ATP trains is significantly higher.

Three PSR on plain line and six at divergences protected by MAY-FA junction signalling have been identified as requiring an additional OSS under the revised fitment criteria used for this study.

Seven signals protecting divergences using MAR junction signalling have been identified as having the route indicator visible before the outermost signal OSS is passed. Further investigation is necessary to establish whether these present a hazard requiring further mitigation.

Comparable protection for maximum speed at buffer stops can not be achieved using TPWS equipment owing to hardware constraints. Conflicts with departing cab positions limit significantly the possibilities for additional OSS over and above standard provision without introducing interlocking controls.

The client’s current proposal is to include the additional TPWS fitments on Crossrail Stage K (Christmas 2016) scheme plans with appropriate highlighting to differentiate those installations requiring interlocking data changes and those that do not.

6 REFERENCES

- Crossrail GRIP4 Scheme Plans:
  - 10-GW-033-01 version B, Crossrail ONW & IEP Paddington to Westbourne Park
    - *Amended by 12-GW-002-07 v0.4, Paddington to Westbourne Park Stage K*
  - 10-GW-033-02 version B, Crossrail ONW & IEP Old Oak Common
  - 10-GW-033-03 version A4, Crossrail ONW Acton to Ealing Broadway
    - *Amended by 10-GW-037-08 v0.8, Acton to Ealing Broadway Stage I*
  - 10-GW-033-04 version B1, Crossrail ONW West Ealing, Hanwell & Elthorne
  - 10-GW-033-05 version A1, Crossrail ONW Hanwell Bridge to Southall Station
  - 10-GW-033-06 version A2, Southall West to Dawley
    - *Amended by 11-GW-033-013 v0.7, Southall West to Dawley Stage I*
- Other Documents:
  - 122271-ISD-ASS-ESG-000001 v2.0 *Comparison of GW-ATP and TPWS Functionality*
  - *Capability Analysis: Paddington – Reading May 2018 High Level Analysis*
  - Crossrail scheme signal sighting forms, latest versions at 20th June 2014
  - NR/SP/SIG/10137 *TPWS – Selection of New Signals And Other Locations For Provision of TPWS*
  - RT/E/S/10138 *TPWS – Transmitter Loop Requirements and Positioning*
  - Guidance on *TPWS System Functionality - Use of Zero OSS* version 4 04-04-2011
  - 122271-ISD-REP-ESG-000002 *ETCS "Plan B" TPWS Summary Sheet*

7 ASSUMPTIONS

- Class 345 Crossrail trains are assumed to meet 12%g emergency braking rate and have a top speed of 90mph (145km/h).
- All GW ATP-fitted stock including class 360 is assumed to achieve 99% effectiveness in all situations, in line with the standard assumption used for the SORAT overrun risk assessment tool.
- Crossrail derogation for TPWS design to maximum 110mph (177km/h) speed on the Up and Down Main lines can be applied to this study (Tracker 11003) and derogation for OSS up to 950m (Tracker 15006).

8 APPENDIX: Comparison of GW-ATP and TPWS Functionality

Comparison of GW-ATP and TPWS Functionality

ProjectWise reference: 122271-ISD-ASS-ESG-0000001. Version: 2.0.

References:
RT/E/S/10137 issue 3 "*Train Protection & Warning System – Selection of Signals and Other Locations for Provision of Track Sub-System*"
IRSE Technical Paper 14/02/1992 "*ACEC Transport's Automatic Train protection System*"
Report "*The Southall and Ladbroke Grove Joint Inquiry into Train Protection Systems*" (2001)

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

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

Updated following review meeting held 01/05/2014 (CB, PH, RE, DJ, DS).

DJS 06/05/2014