

**Rail Safety - Train Protection and Warning  
System (TPWS)  
Fitment at Permanent Speed Restrictions**

**January 2007**



OFFICE OF RAIL REGULATION

## RAIL SAFETY - TRAIN PROTECTION AND WARNING SYSTEM (TPWS) FITMENT AT PERMANENT SPEED RESTRICTIONS

January 2007

RAILWAY SAFETY REGULATIONS 1999: Application by Network Rail for an exemption in respect of the provision of TPWS at certain permanent speed restrictions.

Network Rail are applying to remove TPWS at permanent speed restrictions where it has been demonstrated that TPWS provides no safety benefit in mitigating over-speed risk due to other measures already in place.

ORR is minded to grant an exemption in respect of this application, subject to conditions, and seeks your views on this approach. This consultation paper explains the kind of exemption ORR is minded to grant and the reasons for this suggested approach. Responses to the consultation will inform ORR's final decision on whether an exemption should be granted. This decision is likely in Spring 2007.

Consultation period: until 2 March 2007

Responses to: [PSR.Exemption@orr.gsi.gov.uk](mailto:PSR.Exemption@orr.gsi.gov.uk)

Or write to:

Mrs Chandrika Shah

Office of Rail Regulation, 2<sup>nd</sup> Floor, One Kemble Street, London WC2B 4AN.

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## Executive summary

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1. Network Rail has applied for an exemption from the requirements of the Railway Safety Regulations 1999 (the Regulations) to fit the Train Protection and Warning System (TPWS) at certain permanent speed restrictions (PSRs) on their infrastructure.
2. The Regulations require that the over-speed elements of TPWS shall be fitted and in service where the permitted speed on an approach to a PSR is 60 miles per hour or more. In order to comply with the restriction, a train traveling at the permitted speed on that approach would need to have its speed reduced by one third or more. The objective is to reduce the risk of derailment caused by trains going too fast around curves.
3. When the Regulations were introduced, Railtrack (Network Rail's predecessor organisation) developed and agreed a protocol with Health and Safety Executive (who at the time were the health and safety regulator for the railways) for fitment at speed restrictions. There are approximately 1150 speed restrictions fitted with TPWS over-speed sensor loops. Of these 1,100 are fitted at PSRs and are primarily intended to mitigate over-speed derailment risk. Emerging evidence has shown that TPWS provides little or no additional protection from the risk of overturning/derailment at some 40% of the PSR sites at which it is fitted.
4. Network Rail's application for exemption relates to those PSRs on plain line curves. This type of PSR site has been assessed by Network Rail to determine the probability that a train might derail in consequence of having failed to reduce its speed on the approach to the PSR. Where their assessment shows no derailment risk, and therefore that TPWS provides no safety benefit, Network Rail believes that the TPWS fitments should be removed. Where TPWS provides a discernible safety benefit at a PSR site Network Rail believes that it should be retained.
5. ORR has independently reviewed Network Rail's case for an exemption and agrees that TPWS has proved less effective and suitable for mitigating over-speed risk than anticipated when the Regulations were introduced. ORR is

minded to grant an exemption with conditions but a final decision will only be taken after views from this consultation exercise have been considered.

### **The exemptions provision**

6. Regulation 6 of the Regulations provides ORR with wide powers to grant exemptions. It allows ORR to consider all the circumstances of a case in reaching a decision.
7. In deciding whether to grant an exemption, ORR must consider whether to attach conditions to the exemption. The regulations require ORR to consult with such persons as it considers appropriate and to have regard to any other relevant legal requirements that apply to the case. A list of companies and organisations we are consulting is at Annex 3.

# 1. What is TPWS?

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- 1.1 TPWS is not a fail-safe system. It is designed to automatically apply a train's brakes if it approaches a designated point (for example on the approach to a set of signals) too fast, or if it fails to stop at a signal set to "danger" (red) – an event known as a SPAD (signal passed at danger). It won't always be able to stop the train at the designated point but – depending on the speed of the train and its braking capability - will do so within the signal overlap. (On Network Rail controlled infrastructure the overlap is a nominal over run distance of around 180m for signals.)
- 1.2 At higher speeds (above about 70mph), TPWS will not ensure that the train stops in the overlap but it may still stop the train before it enters a point of conflict (for example before it could collide with another train). TPWS+ is effective at higher speeds of up to 100 mph and has been installed at key locations.

## TPWS at PSRs

- 1.3 The over-speed element of the TPWS comprises of two over-speed sensor (OSS) loops fixed on the track, which are detected by the passing train. The first "arming" loop starts a timer on the train. If the second "trigger" loop is reached before the timer runs out, then train-borne TPWS equipment applies the emergency brake and brings the train to a halt. All passenger trains have the same timer setting and freight trains generally have the same (but different from passenger trains) setting.
- 1.4 The braking capacities of trains vary between the different classes of train. This means that they can approach a speed restriction at different speeds and still achieve the required speed reduction before the PSR actually starts. The TPWS settings are not adjustable to cope with these variations. The distance between the loops determines the trigger speed above which TPWS will operate. How much time/track there is for TPWS to stop the train depends on the distance of the OSS loops from the start of the speed restriction.





## 2. Network Rail's case for exemption

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- 2.1 Network Rail has applied for TPWS to be removed from PSRs where it can be demonstrated that TPWS provides no safety benefit. Network Rail considers that the removal will actually increase the safety benefit of TPWS by reducing the number of inappropriate TPWS activated brake applications at PSRs, so increasing driver confidence in TPWS. Network Rail argues that this will reduce the potential for 'reset and continue'<sup>1</sup> events following SPADs. Network Rail has estimated that over-speed derailment risk at PSRs is not significant as compared to SPAD risks. Network Rail proposes that TPWS is not a proportionate risk mitigation measure in relation to over-speed derailment at a large number of PSRs. In fact they argue that it contributes to an overall reduction in safety.
- 2.2 Network Rail has presented evidence that the proportion of the over-speed derailment risk (which fits into the total number of reported derailments on the British rail network) is falling (Figure 4 of the Application, Annex1). This is attributed to other technical and operational improvements that have been applied to mitigate this risk (Paragraph 3.3 and Figure 5 of the Application, Annex 1).
- 2.3 Network Rail estimates that, based on the Railway Safety and Standards Board (RSSB) Safety Risk Model, the system-wide safety benefit provided by TPWS is 1.8 equivalent fatalities per year<sup>2</sup>. The upper bound estimate for over-speed derailment risk mitigation being provided at PSRs is 0.01 equivalent fatalities per year. Currently the TPWS safety benefit being lost as a result of 'reset and continue' equates to approximately 0.1 equivalent fatalities per year. Network Rail's estimate of the safety benefit over the 20-year period of the proposed option is 0.6 equivalent fatalities.
- 2.4 Additionally, Network Rail argues that the current fitment criteria create considerable cost to the industry due to delays associated with the brake

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<sup>1</sup> If a train is brought to a halt by TPWS the driver can over ride (or 'reset') the system and 'continue'. The driver should seek clearance from the signaller before a reset and continue' to ensure it is safe to proceed.

<sup>2</sup> This means the quantified risk that would not be mitigated if TPWS is not fitted.

demands. The estimated performance gain achieved by reducing the number of inappropriate TPWS brake demands would be in the region of £16 million over the 20 year period. This estimate is based on the average revenue cost of £25 per minute delay. (£25 per minute is the figure used to determine compensation claims in the application).

- 2.5 Network Rail are concerned that driver confidence in TPWS may be eroded where the system intervenes even though drivers are driving appropriately and within the braking capabilities of the train. Network Rail believe that this could increase the risk of drivers disregarding valid TPWS interventions when signals are passed at danger by resetting the TPWS on the train and continuing into a dangerous situation. Network Rail argue that this erosion of confidence has the potential to negate the safety benefits of the entire TPWS programme (Paragraph 3.5 of the Application, Annex 1)
- 2.6 Finally, Network Rail consider that the increased risk to trackside workers due to installation and maintenance of the equipment contributes to the negation of the safety benefits of TPWS at PSRs (Paragraph 5 of the Application, Annex 1).

## 3. Network Rail's Proposal

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- 3.1 Network Rail has estimated that there is a potential to remove between 400 and 500 fitments from some 40% of PSR locations (see Figure 9 of the Application, Annex 1). Network Rail used the Railway Group Standards guidance (RT/GC 5021: Track System Requirements) as the basis for calculating the risk of over-speed derailments on the British rail network. The key issues relating to the prevention of derailment are the applied cant<sup>3</sup> and the over-speed cant deficiency<sup>4</sup> on the curved sections of railway track.
- 3.2 Network Rail propose to remove TPWS from those curves where the levels of over-speed cant deficiency will not increase the risk of derailment and would have no detrimental effect on safety. The removal programme would be aligned to existing maintenance schedules to limit the number of additional trackside visits. This approach aims to minimise the cost and risk to the workforce.
- 3.3 Network Rail considers that for those PSRs where it can be demonstrated that TPWS should be retained that as few trains as possible, when driven appropriately, should be stopped by TPWS. This could be achieved by either moving both OSS loops toward the start of the PSR or by increasing the separation of OSS loops to raise the speed at which TPWS demands a brake application. The RSSB study (Annex 1, Reference 5) indicates that it should be possible to modify the settings of up to 50% of the total number of fitments at PSRs, leaving 10% of the TPWS fitments as they are at present.

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<sup>3</sup> Cant is a measure of how much more the outer rail would have to be elevated, relative to the inner rail, so that no lateral force acts on the train as it traverses the curve at a set speed. The PSR is then set at the optimum speed to ensure cant balance.

<sup>4</sup> Over-speed cant deficiency is how much less than the optimum cant the track has relative to the speed of the train and the radius of curve. If a train traverses the curve above the PSR it will result in a cant deficiency.



## 4. ORR's assessment of Network Rail's case for exemption

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4.1 ORR has examined Network Rail's application (Annex1) and has discussed the rationale behind the application with RSSB and Network Rail. ORR's views on Network Rail's main arguments are summarised below.

- ORR agrees that if there is no safety benefit, the cost of maintaining TPWS equipment cannot be justified at PSRs. ORR consider that in these circumstances that TPWS may in fact reduce the overall levels of safety where other trains are held at danger due an unnecessary brake demand on the train in front.
- ORR supports Network Rail's outline plan for the removal of TPWS for those PSRs sites where the over-speed cant deficiency (for trains running at the maximum line speed plus 10 miles an hour) does not cause a derailment risk.
- ORR agrees that, at those sites where TPWS will be removed, adequate mitigation already exists in the form of the PSR itself; the Permissible Warning Indicator; the Automatic Warning System (AWS), and; the driver-related mitigation measures in place (these include professional driving programmes and an increased use of On Train Monitoring Recorder Outputs).
- On the basis of its considerations, ORR is minded to grant an exemption request with conditions, subject to the views expressed in this consultation.

### Economic appraisal

4.2 Network Rail's application estimates the cost of implementing their proposal at £2.2m. However, they also claim that by removing TPWS from 40% of PSRs and modifying the TPWS installation at a further 50% that there will be an estimated:

- reduction in the system wide risk by 0.6 equivalent fatalities over 20 years; and,

- performance benefit of £16 million (by reducing the number of TPWS brake demands) over the same 20-year period.

### **Draft exemption and conditions**

4.3 In addition to being minded to grant this exemption request, ORR is also minded to attach the following conditions:

- (a) that the cant deficiency at that site meets the requirements set out in section C5 of the relevant Railway Group Standard (CG/RT 5021); and
- (b) that Network Rail maintains records of any removals of or modifications to TPWS equipment carried out in consequence of this exemption, and makes those records available to ORR at its request.

4.4 The draft exemption certificate with conditions can be found in Annex 2.

### **ORR consultation questions**

4.5 Subject to conditions, ORR is minded to grant Network Rail an exemption to remove TPWS fitments at PSRs that have an over-speed cant deficiency that is in line with the specifications of the Railway Group Standard 5021: Track System Requirements. Do you agree with the proposed action? If not, why not?

4.6 Are there any other conditions you feel might be imposed?

## 5. How to respond

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- 5.1 In order to take this application forward, we welcome comments on any aspect of this document, but in particular on the specific questions that we have raised in paragraphs 4.5 and 4.6.
- 5.2 Responses to this consultation exercise can either be submitted by e-mail to [PSR.exemption@orr.gsi.gov.uk](mailto:PSR.exemption@orr.gsi.gov.uk) or by post to:
- Mrs Chandrika Shah,  
Office of Rail Regulation,  
1 Kemble Street,  
London  
WC2B 4AN
- 5.3 The consultation period ends on 2 March 2007. Please contact us if responding to this deadline causes you a problem. Please address your response to Mrs Chandrika Shah (rather than any other contacts in ORR/HMRI), as she is responsible for coordination of the responses in the first instance.

### Open government

- 5.4 All responses will be acknowledged and made available in our library, published on our website and may be quoted from by us. If a respondent wishes all or part of their response to remain confidential they should set out clearly why this is the case. Where a response is made in confidence, it should be accompanied by a statement summarising the submission, but excluding the confidential information, which can then be used as above. We may publish the names of respondents in future documents or on our website, unless a respondent indicates that they wish their name to be withheld.
- 5.5 Copies of this consultation paper are available from our website at <http://www.rail-reg.gov.uk/server/show/nav.1172> and in our library.
- 5.6 After the close of this consultation, we will consider all responses received and decide whether there should be any change to the proposed policy. We would anticipate our final decision on the proposed exemption to be made as soon as possible after the consultation period has ended.





# **Annex 1 – Network Rail’s application for exemption from the Railway Safety Regulations (1999) for the removal of TPWS at PSRs**

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This document has been prepared by RSSB on behalf of Network Rail.



Rail Safety & Standards Board

**Submission to Her Majesty's  
Railway Inspectorate (HMRI) for  
exemption from the Railway  
Safety Regulations: 1999 to  
allow TPWS removal from PSRs  
where it provides no material  
safety benefit**

**January 2006**

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## Exemption Request Summary

### Purpose

1. This document describes a request for an exemption from the requirement established in the Railway Safety Regulations: 1999 to fit the Train Protection and Warning System (TPWS) to a sub-set of permissible speed reductions (PSRs). This exemption application has been developed by RSSB on behalf of Network Rail. This document is also supported by ATOC on behalf of their members.
2. The request is to allow the removal of TPWS from PSRs where it can be demonstrated that TPWS provides negligible safety benefit.
3. The objective of the request is to increase the safety benefit of TPWS by reducing the number of unnecessary TPWS brake demands and increasing driver confidence in TPWS thus reducing the potential for a reset and continue event<sup>1</sup> following Category A signal passed at danger (SPAD). There will be an associated improvement in network performance and a reduction in the number of unnecessary signals held at danger.

### Background to TPWS

4. TPWS was originally conceived as a train collision mitigation tool for use in reducing the severity of SPADs and consequential accidents. TPWS has proved to be effective in achieving this design objective and has significantly reduced collision risk at signals. TPWS was not initially intended to provide protection from a derailment due to overspeeding.
5. The Railway Safety Regulations: 1999 mandated the use of TPWS at PSRs. Although this appeared to be a simple change it did not recognise a fundamental shift in the operational requirement of TPWS. The overspeed sensor (OSS) is a pair of loops placed at a distance apart that enables the TPWS system to activate the brakes of a train if it is travelling above a single set speed. This concept works well on the final approach to a red signal where there is a common expectation of a gentle brake application to finally bring the train to a halt at the signal. However, at PSRs there is a wide range of variables affecting the acceptable speed on the approach. Invariably this requires the OSS loops to be set for the highest intended operational speed. This limits the effectiveness of TPWS at PSRs, as rolling stock with lower achievable speeds are sometimes unable to attain the set speed and are therefore not protected.

<sup>1</sup> For a description of 'reset and continue' events, go to section 3.5.

6. The Railway Safety Regulations: 1999 required Railtrack to fit TPWS to approximately 1,100 PSRs for which overturning is the primary derailment mechanism. The fitment criteria are that the permissible approach speed is 60 mph or greater and the required speed reduction is 1/3 or more. These PSRs were already fitted with enhanced protection in the form of an Automatic Warning System (AWS) magnet and a permissible speed warning indicator (PSWI).

### **Reliability of TPWS**

7. A key design criterion for TPWS was that it should be 'invisible' to the driver of a train driven correctly. Due to the nature of TPWS, it was necessary to make assumptions regarding the braking capabilities of trains. The set speed and location of TPWS OSS loops were determined assuming a full service braking capability of 9%g and an emergency braking capability of 12%g. However a significant proportion of trains actually exceed these capabilities. As a result drivers are forced to adapt their driving, not to the capability of their train, but to the position of the OSS loops. The key design criterion of invisibility is no longer fulfilled. The TPWS now produces a significant number of unnecessary brake demands from minor speed or braking infringements on the approach to PSRs. This is not an issue at signals where all drivers are taught and expected to approach a red signal at a uniformly low braking rate.
8. It is estimated that 85% of TPWS brake demands at PSR locations are unnecessary. Whilst this itself is not a safety concern, there is evidence to suggest that the large number of unnecessary TPWS brake demands at PSRs has contributed to a decrease in the confidence of drivers in the reliability of TPWS. This lower level of confidence in TPWS is considered to be a major factor in increasing the propensity for drivers to 'reset and continue' following a SPAD. It is hypothesised that if TPWS were modified so that it only intervenes when necessary, with time driver confidence in the system would increase. Since August 2003 there have been 17 'reset and continue' events following Category A SPADs. These events had the potential to result in train collisions.

### **Probability of overturning derailment**

9. The critical factor in determining the probability of overturning derailment for a train traversing a curve is the cant deficiency that it experiences relative to its resistance to overturning. The cant deficiency is a measure of how much more than the applied cant the outer rail would have to be elevated, relative to the inner rail, so that no lateral force acts on the train as it traverses the curve. The applied cant is the actual elevation of the outer rail with respect to the inner rail. Cant deficiency depends on the speed of the train, the radius of the curve and the applied cant.
10. The term overspeed cant deficiency is used to describe the cant deficiency a train would experience if it continued at the speed permissible immediately in



advance of the PSR. RSSB has been able to categorise 439 of the 1,100 PSRs according to this overspeed cant deficiency.

11. A passenger train overspeed derailment is a very rare event. In the absence of TPWS one is estimated to occur at the rate of one in every 14 years. With TPWS in operation, this is reduced to an estimated one every 44 years. Following the strategy proposed herein, the frequency of such a derailment would remain an estimated one every 44 years.
12. Derailment protection at all TPWS-fitted PSRs already exists in the form of the PSR itself, an Automatic Warning System (AWS) magnet and a permissible speed warning indicator (PSWI). Also a number of driver-related mitigation measures have been implemented over recent years such as professional driving programmes and an increased use of On Train Monitoring Recorder outputs.
13. Approximately 26% of PSRs would experience an overspeed cant deficiency of 6° or less. This means that even in the rare event that the train failed to slow down for the PSR, the probability of overturning derailment would be negligible. TPWS provides negligible safety benefit at these PSRs and could be removed.
14. Railway Group Standards (RGS) mandate that passenger trains are designed to resist rollover up to 21° cant deficiency and state that for all vehicles that operate at a cant deficiency greater than 6° particular attention shall be given to maximising, so far as is reasonably practicable, the margin between the operating cant deficiency and the roll over resistance.
15. Tilting trains<sup>1</sup> are allowed to operate regularly at up to 11.5° cant deficiency. A speed supervision system is mandated for tilting trains by GE/RT8012 which protects the train from overturning derailment by limiting the speed of the train. The tilting functionality of a train makes no significant difference to the ability of the train to traverse a curve.
16. A further 22% of PSRs would experience an overspeed cant deficiency between 6° and 11.5°. There is still a very low probability that passenger trains will derail at cant deficiencies within this range though the safety margin to rollover is nevertheless reduced. RGS GC/RT5021 sets out acceptable values for cant deficiency dependent on the curve radius<sup>1</sup>. In accordance with these it is proposed that TPWS fitments at these PSRs also provide little additional safety benefit and could be removed. Again the retention of the PSR, AWS magnet, the PSWI and driver related measures will continue to mitigate the very low level of overspeed derailment risk.
17. For the PSRs with an overspeed cant deficiency of between 6° and 11.5°, an assessment will be made of any characteristics that are likely to significantly increase the probability of a train overspeeding on the approach to a PSR. The decision of which TPWS fitments to remove will be made by Network Rail in conjunction with relevant train operators.

<sup>1</sup> For a description of tilting trains and limits of cant deficiency, go to section 4.4.

18. For those PSRs with an overspeed cant deficiency of greater than 11.5°, TPWS should be set so that as few trains as possible that are in the control of the driver, are stopped by TPWS. Criteria are currently being developed for determining the optimum settings for TPWS. Although there is no requirement for an exemption from the Railway Safety Regulations: 1999 to undertake this work, HSE will be fully consulted before any fitments are modified.

### **Safety benefit of TPWS**

19. Given the relatively low permissible speeds and poorer brake performance of freight trains when compared to passenger trains TPWS is considered to provide very little protection to freight trains in relation to overturning derailments at PSRs. Therefore any removal of TPWS will have little impact on the safety of freight trains.

20. Based on the Safety Risk Model (SRM), the system wide safety benefit provided by TPWS is 1.8 equivalent fatalities per year. The upper bound estimate of overspeed derailment risk mitigation being provided by TPWS at PSRs is 0.01 equivalent fatalities per year. Currently the TPWS safety benefit being lost as a result of 'reset and continue' equates to approximately 0.1 equivalent fatalities per year.

### **Exemption request**

21. Network Rail is therefore seeking exemption from the Railway Safety Regulations: 1999 for those PSRs that exhibit an overspeed cant deficiency of less than 11.5° on the basis that:

- Overspeeding derailment risk is very low.
- Adequate mitigation exists in the form of the PSR itself, the PSWI and the AWS magnet.
- In the event the train does fail to slow down for the PSR, the probability of derailment at these locations is negligible.
- The subsequent reduction in the number of unnecessary TPWS brake demands should have a positive effect on drivers' propensity to 'reset and continue'.

22. It is estimated that the proposed strategy would

- Have the potential to remove between 400 and 500 TPWS fitments from the network
- Reduce the number of brake demands at PSRs by approximately 85%
- Reduce the number of resultant signals held at danger
- Reduce the system-wide risk by 0.6 equivalent fatalities over 20 years
- Cost approximately £2m more than would otherwise be spent over 20 years.
- Provide a performance benefit of £16m over the same period.

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# 1 Introduction

## 1.1 Purpose

This report forms an Exemption application to Her Majesty's Railway Inspectorate (HMRI) against the Railway Safety Regulations: 1999. If granted, the exemption will allow the removal of TPWS from certain Permissible Speed Reductions (PSRs), where a disproportionately high number of TPWS brake demands are experienced, which erode driver confidence in the TPWS system and cause delays. Overall there is a detrimental effect on safety.

## 1.2 Background

Since August 2003 concerns have been raised regarding the number of occasions following a SPAD that drivers have reset TPWS and continued their journey without knowing that a SPAD had occurred. 17 such events out of a total of 229 occasions when TPWS has intervened to stop a train following a SPAD have been recorded to the end of October 2005 (Ref. 1). It is clear that the effectiveness of TPWS in SPAD mitigation, which accounts for 97% of all TPWS protection, has been significantly eroded through an application of TPWS to mitigate the relatively low risk associated with overspeeding at speed restrictions and also at buffer stops. Data for the four-month period October 2004 to January 2005 indicate that, on average, of the total of about 277 reported TPWS brake demands per month there are currently around 49 at PSRs and 62 at buffer stops. However, a survey of drivers carried out as part of a recent RSSB review of TPWS fitment indicates that at PSRs and buffer stops there are of the order of 4 unreported events for every 1 event that is reported, *ie* potentially around 246 brake demands per month at PSRs and 310 brake demands per month at buffer stops.

The high number of TPWS brake demands in very low risk situations is thought to be giving rise to a loss of driver confidence in the operation of the system, thereby increasing the likelihood of drivers resetting and continuing following a TPWS brake application. This is of particular concern in higher risk situations following SPADs.

Approximately 1,100 PSR and 50 TSR locations are currently fitted with TPWS overspeed loops.

## 1.3 Scope

This exemption application applies to regulated<sup>1</sup> PSRs on Network Rail-controlled infrastructure. This document demonstrates that TPWS provides no safety benefit at some PSRs and should be removed, and that for other PSRs, TPWS provides a discernible safety benefit and fitment should be retained.

<sup>1</sup> PSRs for which TPWS fitment is mandated by Railway Safety Regulations: 1999.

The PSRs considered for this exemption are related to plain line curves and an assessment has been undertaken to determine the probability that a train will derail having failed to reduce its speed on the approach to a PSR.

## **1.4 Definitions**

### **Cant**

Expressed as the design difference in level, measured in millimetres, between rail head centres of a curved track.

### **Cant deficiency**

The difference between actual cant angle of the track and the theoretical angle to which the track would have to be canted to just counterbalance the centrifugal forces acting on a vehicle. For the purposes of this document, cant deficiency is expressed in degrees (°).

### **Curvature**

The reciprocal of the radius of a curve.

### **Enhanced Permissible Speed**

The speed at which tilting trains are permitted to operate (higher than the permissible speed) over a section of track.

### **Equivalent fatalities**

All fatalities and injuries are expressed in terms of equivalent fatalities where 10 major injuries and 200 minor injuries equate to 1 fatality.

### **Overspeed cant deficiency**

The cant deficiency a train would experience if it continued at the speed permissible immediately in advance of the PSR.

### **Overtuning derailment or rollover**

The situation reached when all the wheels on one side of a vehicle reach 100% unloading with their running rail and the whole weight of the vehicle is supported by the wheels on the other running rail.

### **Permissible approach speed**

The maximum allowed linespeed on the approach to a permissible speed reduction.

### **Permissible speed**

The maximum permissible speed over a section of line (excludes tilting trains)

### **Permissible Speed Indicator**

The lineside sign provided for every increase or decrease in permissible speed, positioned where the change of speed occurs.

### **Permissible Speed Reduction**

A reduction in the maximum permitted speed over a section of line, also referred to as a 'permitted speed restriction' at the time of the Railway Safety Regulations: 1999

### **Permissible Speed Warning Indicator**

The lineside sign provided on the approach to each speed reduction, where the permissible speed on the approach is 60mph or greater and the required reduction in speed is one third or more of that permissible speed. It is positioned as close as possible to (but not less than) the appropriate deceleration distance to the permissible speed indicator (previously known as an Advanced Warning Indicator (AWI)).

### **Set speed**

Set speed relates to the fitment of TPWS overspeed sensor loops. Trains traversing the loops at speeds greater than the set speed will experience an emergency brake application caused by the TPWS system which will bring the train to a complete standstill.

### **Tilting trains**

A train which tilts its body on curves to reduce the lateral acceleration experienced by passengers, allowing the train to operate at higher speeds through curves than non-tilting trains.

## **1.5 Abbreviations**

AWS	Automatic Warning System
HMRI	Her Majesty's Railway Inspectorate
NRCI	Network Rail controlled infrastructure
OSS	Overspeed sensor
PSI	Permissible speed indicator
PSR	Permissible speed reduction
PSWI	Permissible speed warning indicator
RGS	Railway Group Standard
RSSB	Rail Safety and Standards Board
SPAD	Signal passed at danger <sup>1</sup>
TPWS	Train Protection and Warning System

## **1.6 Relevant regulations**

In the case of certain PSRs an exemption from the Railway Safety Regulations:1999 is being sought from paragraph 3 (1) which states that "No person shall operate and no infrastructure controller shall permit the operation of, a train on a railway unless a train protection system is in service in relation to that train and railway."

<sup>1</sup> Relates solely to Category A SPAD for the purposes of this document.

A train protection system is defined in Regulation 2 of the Railway Safety Regulations: 1999 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 the relevant approach;
  
- (b) is installed so as to operate at every 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.”

A “relevant approach” in relation to this exemption is defined in Regulation 2(1) as:

“an approach to part of the railway where there is a speed restriction if-

- (i) the permitted speed on that approach is 60 miles per hour or more; and,
  
- (ii) in order to comply with the restriction, a train travelling at the permitted speed on that approach would need to have its speed reduced by one third or more”

The same criteria used for fitment of TPWS were previously used for fitment of AWS. Therefore all PSRs for which TPWS protection became mandatory according to Railway Safety Regulations:1999 were already protected by an AWS magnet and a PSWI, in accordance with RGS GK/RT0038.

There are no other qualifications in the Railway Safety Regulations: 1999 with regard to PSRs.

## 2 TPWS design

TPWS was conceived as a train collision mitigation tool for use in reducing the severity of SPADs and consequential accidents. TPWS was not initially intended to provide protection from overspeeding. However during the development the designers proposed that to maximise SPAD benefit there was a need for an overspeed sensor on approach to red signals. Subsequently it was suggested that this could also be used to mitigate the risk from train derailment caused by overspeed at locations other than signals.

Although this appears to be a simple change it failed to recognise a fundamental shift in the operational requirement of TPWS. The overspeed sensor (OSS) is a pair of loops placed at a distance apart that enables the TPWS system to compare the train's speed against a single fixed value. This concept works well on the final approach to a red signal where there is a common expectation of a gentle brake application to finally bring the train to a halt at the signal. Such a 'one size' concept does not work well when there is a wide range of different variables affecting the 'acceptable speed on approach' as is the case with the application of TPWS at PSRs.

The design of TPWS relies on discrete speed monitoring locations. Therefore it cannot effectively warn a driver before an intervention. As a result a number of fundamental objectives were set for the design:

1. It should be invisible to the driver if driving correctly and not interfere with acceptable driving standards.
2. It should be independent of traffic patterns to avoid the need for redesign and installation as trains are reallocated to different routes or services.
3. It should maximise protection, particularly for passengers
4. It should have a single set of design standards to ensure consistent application.

In order to ensure consistent application a detailed design standard was developed to define the location of the loops in relation to their associated signals, speed restrictions and buffer stops and to set the speed of TPWS installations. For application at signals, and buffer stops, this was a simple look up table (currently included in the Network Rail Company Standard that controls application design). However there is a wider range of parameters controlling the design for PSRs so a design tool was also developed to ensure that the application of TPWS at PSRs is in accordance with an agreed methodology.

The key parameters in determining the speed setting and location of a PSR OSS include:

1. Train acceleration capabilities leading to achievable approach speed
2. Permissible speed of the PSR
3. Gradients and speed restrictions in rear of the PSR
4. Acceptable braking rate
5. Emergency braking rate
6. Margin of acceptable overspeed



This is a substantial list of variables for a system that was conceived to perform a simple task associated with SPAD mitigation. The Railway Safety Regulations: 1999 allowed the possibility of seeking exemptions from fitment at specific types of location but required the production of a suitable and satisfactory case to demonstrate that the cost of TPWS fitment was grossly disproportionate to the risk. During the fitment programme the provision of such a demonstration for each individual situation was considered to be too difficult within the available timescales for fitment and costly, so after achieving a number of generic exemptions it was decided that fitment according to a defined set of rules would be applied to the remaining installations. The principle variables not defined by railway geography are items four to six above. Following discussion these were set as follows:

1. Acceptable braking rate = 9%g (nominal new train design requirement)
2. Emergency braking rate = 12%g (nominal new train design requirement)
3. Permissible margin of overspeed = 50% above PSR limit.

The spreadsheet was developed to plan the position of each OSS and its associated speed setting using all six of the parameters defined above.

Figure 1 shows the rationale for the positioning and set speed of the OSS loops for two PSRs, PSR 1 (60mph to 15mph) and PSR 2 (60mph to 40mph). It shows the fact that TPWS will reduce the speed of a train travelling at up to 10mph over the permitted approach speed to within the safety margin of 50% above the PSR set speed. The position of the loop is based on an assumed emergency braking capability of 12%g and the set speed is based on a 9%g full service brake capability.

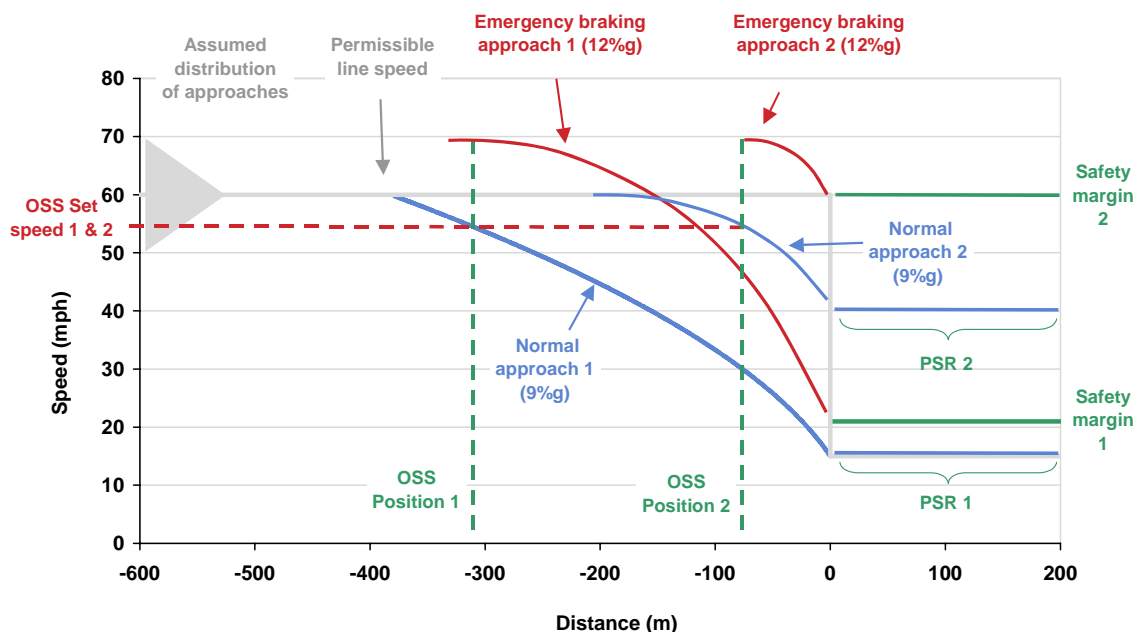


Figure 1 - Design assumptions related to the fitment of TPWS to two example speed restrictions

However, modern passenger rolling stock, especially those types built since privatisation, have brakes that are designed to exceed the nominal 9%g for normal service and 12%g for emergency. When driving these trains the driver can quite legitimately reduce speed later than the TPWS design rules permit if adopting a full service brake application technique for approaching PSRs. Thus the system starts to influence driver behaviour and is no longer the 'invisible' system originally conceived. Design requirement '1' is no longer fulfilled.

### 3 TPWS application

There are a number of key issues related to TPWS brake demands at PSRs that have led to the development of this application for exemption from the Railway Safety Regulations: 1999

- The safety benefit from TPWS in relation to derailment mitigation at PSRs is variable and generally fairly limited.
- The fitment criteria of TPWS at PSRs means that they are not “invisible” to drivers and has resulted in drivers being forced to alter their approach to PSRs, especially for new types of rolling stock.
- The number of brake demands at PSRs are adding to delays on the network.
- The number of TPWS brake demands experienced by drivers at PSRs is eroding their confidence in the TPWS system and may be contributing to drivers’ propensity to ‘reset and continue’ following a Category A SPAD.

The data presented in Section 3 provides an indication of the scale of the issues described above.

#### 3.1 TPWS brake demands

RSSB publishes a TPWS brake demands report each month, providing details related to the operation of the TPWS system. A considerable amount of investigation is undertaken to identify the causes of TPWS brake demands and particular attention is paid to whether TPWS operated correctly or whether the operation was the result of a fault on either the train or the track-based hardware.

Figure 2 shows two pie charts based on brake demand statistics from the TPWS interventions report from October 2004 to January 2005<sup>1</sup>. The left hand chart shows only those interventions listed in the TPWS brake demands report. The right hand chart also includes an estimate of the number of brake demands that are currently going unreported for PSRs and buffer stops<sup>2</sup>. These estimates come from a recent industry survey of approximately 450 drivers. Drivers suggested that there are approximately four unreported brake demands for every one reported for PSRs. Although the right hand chart is based on anecdotal evidence this is considered to be a more reliable representation of the actual numbers of brake demands currently being experienced each month. From the left hand chart it can be seen that brake demands at PSRs represent 18% of the total number of TPWS brake demands. Including the unreported brake demands, the proportion related to PSRs increases to 34%.

Approximately 21% of reported TPWS brake demands are classified as ‘unwarranted’ in Figure 2. These are incidents where TPWS has not operated correctly, due to technical reasons, operating errors, etc. The vast majority of these unwarranted brake demands occur at signals.

<sup>1</sup> Brake demand data for the period April 2005 to July 2005 have been analysed. There is little change in the profile presented here other than an increase in the number of correct brake demands as a percentage of all brake demands thought by drivers to be TPWS from 64% to 72%.

<sup>2</sup> Buffer stop brake demands are being addressed, but not as part of this exemption application.

Although correct interventions at PSRs are 'warranted' by the design rules virtually all PSR interventions are within 3mph of the trip speed with the train braking. It is conservatively estimated that only 15% of the brake demands at PSR locations are necessary.

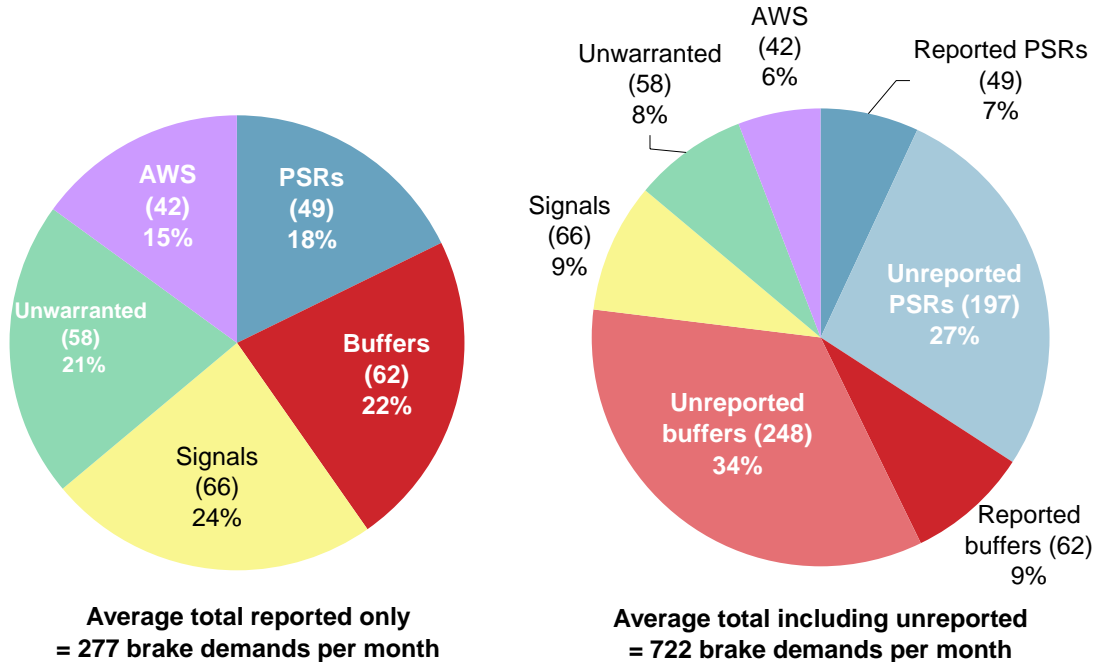


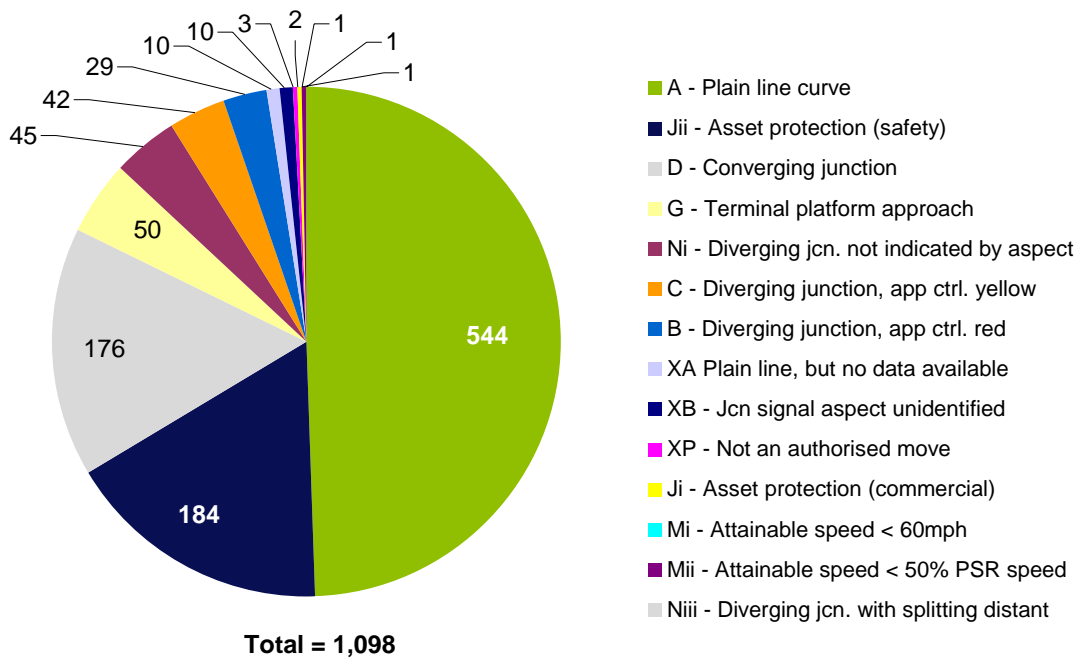
Figure 2 – Average numbers of brake demands for October 2004 to January 2005

There is a disproportionately high rate of brake demand per TPWS fitment at PSR locations. If the drivers' estimate of the number of unreported brake demands is accepted, it can be demonstrated that for a rate of one brake demand per signal TPWS fitment there would be 74 brake demands per PSR TPWS fitment.

### 3.2 PSR classification

According to TAMAR<sup>1</sup>, there are 1,145 PSRs across the network fitted with OSS loops. PSRs are categorised according to their reason for provision. 1,098 of all TPWS fitments at PSRs are primarily intended to mitigate derailment risk. The remaining 47 were installed to prevent a collision (eg level crossing category 'E') and are not displayed in Figure 3. A summary of the numbers of PSRs per category can be seen in Figure 3.

<sup>1</sup> A database of information on signals and PSRs eligible for TPWS fitment.



**Figure 3 – The number and reason for provision of all TPWS fitted PSRs preventing derailment**

The TAMAR database contains little justification for the PSR other than the categorisation seen in Figure 3. At the time of fitment, a number of exemptions from the Railway Safety Regulations: 1999 were sought and accepted, but due to the lack of data and time constraint, the TPWS fitment project team decided not to progress an exemption on the subject of this application.

### 3.3 Overspeed derailment incidents and mitigation

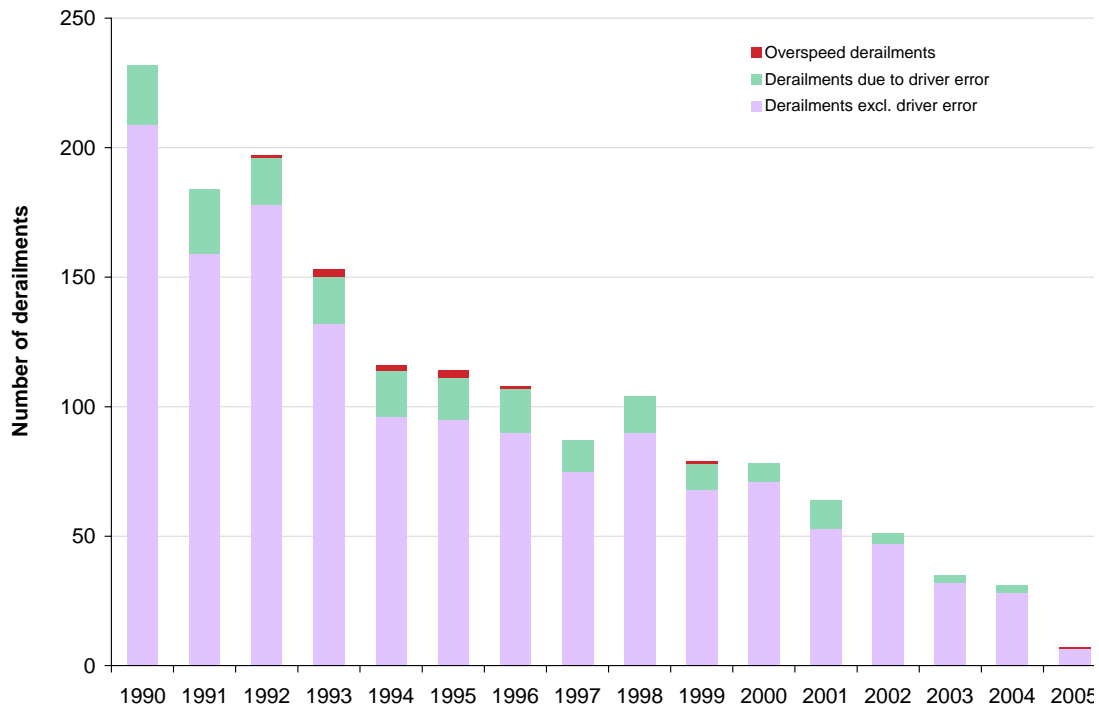
Over the last 40 years there have been a number of overspeed derailments that have resulted in fatalities. A record of these events are presented in Table 1.

Location	Year	Fatalities	Track Circumstances
Appledore	1980	1	Crossover 20 mph
Nuneaton	1975	6	TSR
Eltham Well Hall	1972	6	PSR at curve (65mph over 20mph)
Morpeth	1969	6	PSR at curve (80mph over 50mph)
Ashchurch	1969	2	Plain line track twist
Hatfield	1968	2	Over-run
Didcot	1967	1	Crossover 25 mph

**Table 1 – Table of fatal overspeed derailments since 1967**

During this period two out of the seven (28%) of the fatal overspeed derailments occurred at PSRs relevant to this application. Those two events resulted in a total of 12 fatalities (60%). In addition to the fatal derailments there are also a number of less serious overspeed derailments in the records that have not resulted in fatalities. Since 1990 seven such events have occurred at PSRs.

However not all overspeed events are TPWS-preventable. If the linespeed at a location is below 60mph or the speed reduction is less than one third, TPWS would not be fitted. An analysis undertaken by TTAC (Ref. 2) indicated that none of the non-fatal overspeed derailments at PSRs since 1990 would have been prevented by TPWS.



**Figure 4 – Records of the number of reportable derailments on the UK rail network over time**

Figure 4 clearly indicates how the records of overspeed derailments fit into the total number of reported derailments that have occurred on the UK rail network over the past 15 years. It can be seen that there is a significant downward trend in the number of derailments. This is in conjunction with a reduction in the numbers of derailments caused by driver error and overspeeding. Figure 4 also demonstrates the small percentage of the total number of derailments that are attributable to overspeed incidents.

The small number of overspeed derailments from the beginning of the 1990s to the present day should be considered in light of the large number of technological and operational improvements that have been made in order to mitigate this risk. Figure 5 demonstrates the various projects that have been undertaken. The majority of improvements were made during the 1980s and this has had the effect of reducing overspeed risk to its current low level.

Figures 4 and 5 also demonstrate an issue related to TPWS which is relevant to this application for exemption. The previously imposed safety measures have reduced the level of overspeed derailment risk to a low level. Therefore the additional benefit to be derived from TPWS can only be directed towards this low initial level of risk. This issue is discussed further in Section 3.4 below.

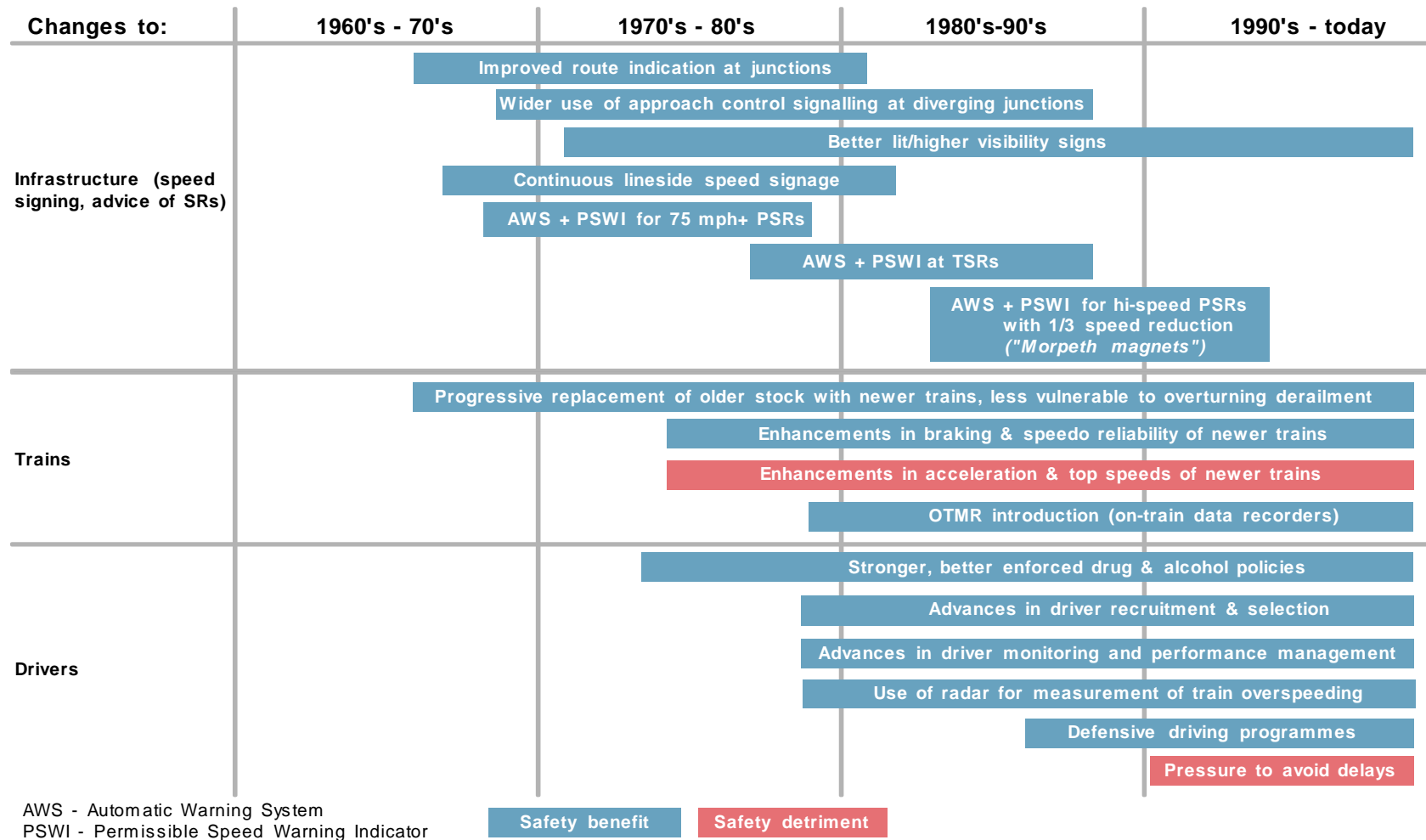
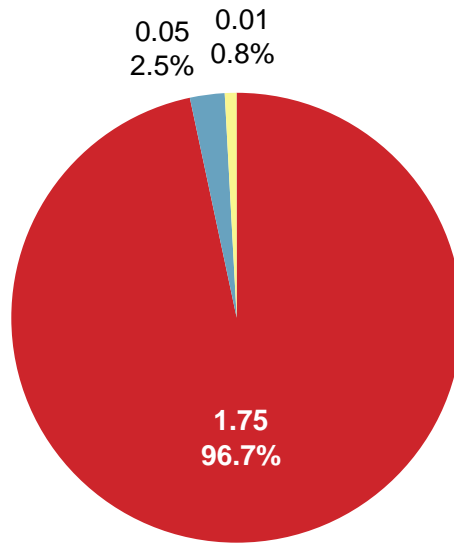


Figure 5 – Evolution of factors affecting overspeeding risk (Ref. 2)

### 3.4 Train accident risk

Gaining a good understanding of the risk implications is a key aspect of any application for exemption to the Railway Safety Regulations: 1999. The Safety Risk Model (SRM) (Ref. 3) has been developed by RSSB to provide a structured representation of the causes and consequences of potential accidents arising from railway operations and maintenance on the mainline railway. Version 4 of the SRM was published in RSSB's Risk Profile Bulletin in January 2005 and the figures provided below have been derived from this document.

■ SPAD risk    ■ Buffer stop collision risk    ■ Overspeed derailment risk



**1.8 equiv. fats./yr.**

**Figure 6 – Safety benefit provided by TPWS**

Figure 6 depicts the current safety benefits of TPWS. TPWS reduces risk on NRCI by approximately 1.8 equivalent fatalities per year. The benefits of TPWS can be seen most clearly in its reduction of SPAD risk which comprises train collisions and derailments following a SPAD. Train collision risk is reduced by 1.5 equivalent fatalities annually through the use of TPWS.

TPWS only reduces the risk of overspeed derailment at PSRs by an upper bound estimate of 0.01 eq.fats./yr.



There are two issues that are highly pertinent to this application for exemption:

1. The primary risk reduction generated by TPWS is related to train collisions following a SPAD. Any reduction in SPAD benefit, such as has happened with 'reset and continue' (see section 3.6), significantly affects the overall benefit provided by TPWS and devalues the system.
2. Overspeed derailment risk at PSRs equates to just under 1% of the SPAD risk. Therefore any benefit derived from TPWS in relation to overspeed derailment at PSRs will be addressing a much smaller portion of risk.

### 3.5 'Reset & Continue' events

Since the completion of implementation of TPWS at the end of 2003 the rail industry has become increasingly concerned about a number of incidents known as 'reset and continue' events. There are a number of scenarios in which a driver can reset TPWS and continue and it is possible in some cases for 'reset and continue' not to result in an increase in risk. For example, if a brake demand occurs at a PSR and the train is brought to a standstill, the risk will have been mitigated and a 'reset and continue' event would not reintroduce the risk. But, if the 'reset and continue' event involves passing a signal at danger, as has happened 16 times since the implementation of TPWS, there is the very real potential for a train collision. There are a number of reasons why a driver might 'reset and continue':

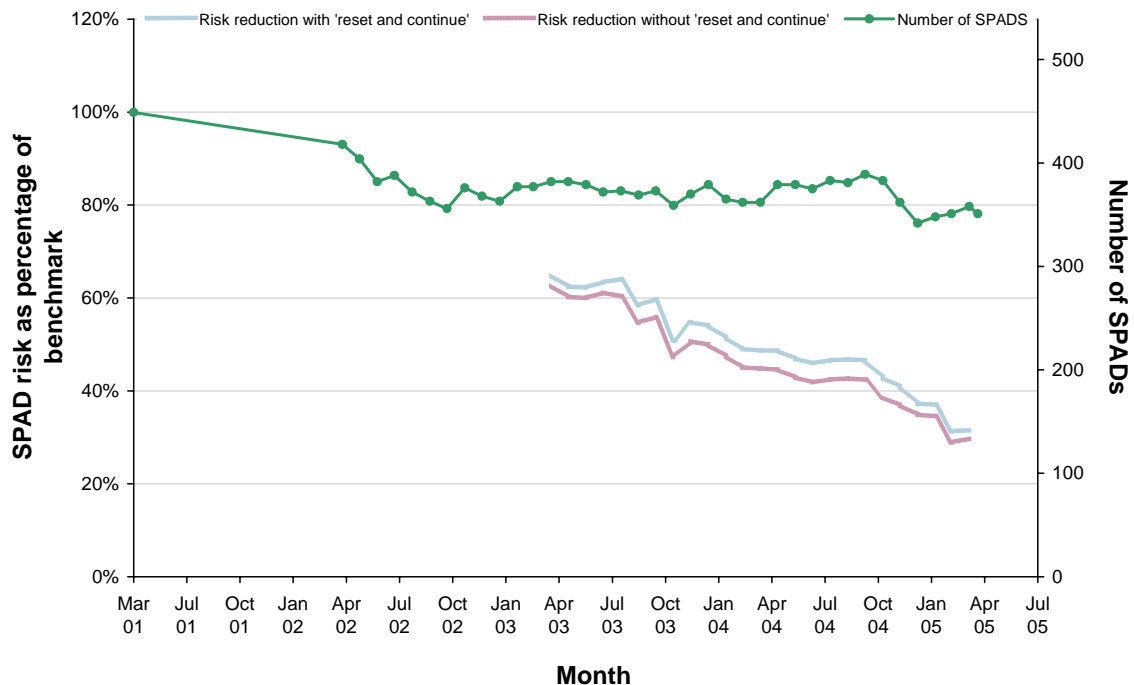
- Confusion
  - On some trains the TPWS brake demand light is not found in the driver's primary field of vision. Unless he looks at the brake demand light within 60 seconds of pressing the TPWS acknowledgement button, it is possible that the driver might not know that the brake application was caused by TPWS.
  - The TPWS brake demand light is the same as that used to indicate a brake application caused by AWS, allowing for confusion between the two systems.
  - Assuming the driver has correctly identified a TPWS brake demand, with the current configuration it is not possible merely by looking at the TPWS control panel for the driver to determine whether TPWS applied the brakes after passing over a train stop sensor or an overspeed sensor (i.e. after passing a signal at danger or on the approach to a PSR).
  - If the driver misdiagnoses a potentially high risk TPWS brake demand as a low risk AWS brake demand, the driver could believe that that he does not have to contact the signaller before proceeding and may reset and continue.
  - A driver can misdiagnose a TPWS brake demand following a SPAD as having occurred at a PSR, believe the event to be low risk, be unaware that he has to contact the signaller and reset TPWS and continue.

- Violation
  - There are currently a large number of TPWS brake demands per month (235 reported but possibly many more unreported). Many of these are perceived by the driver to be unnecessary. Consequently there is the potential for drivers to reset TPWS in frustration.
  - A driver can misdiagnose a TPWS brake demand following a SPAD as having occurred at a PSR, believe the event to be low risk and choose not to contact the signaller and reset TPWS and continue.
  - Fear of disciplinary action: Drivers concerned with the consequences of reporting what they believe to be a low risk event may be tempted to let an incident go unreported.

Information available for 16 of the 17 'reset and continue' events<sup>1</sup> suggests that 75% should be attributed to the violation category of 'reset and continue' incident, 25% to the confusion category.

### 3.6 'Reset & Continue' risk

The question of how much TPWS benefit is lost as a result of 'reset and continue' events following SPADs depends on the number of events, the significance of those events and the effectiveness of TPWS. Figure 7 below is based on RSSB's SPAD risk ranking methodology (SRR) which uses an estimate of the risk from each SPAD on the UK rail network to provide an indication of the total risk from SPADs.



**Figure 7 - Effect on the safety benefit derived from TPWS as a result of 'reset and continue'**

Using the SPAD Risk Ranking methodology it has been possible to estimate the potential for collision for each of the 16 'reset and continue' events over

<sup>1</sup> The 17<sup>th</sup> event occurred on 20 October 2005 and is under investigation.

approximately the last four years. Figure 7 provides an indication of the combined effect of these 16 'reset and continue' events on the safety benefit derived from TPWS. The solid green (top) line provides an indication of the total number of SPADs which has fallen slightly since April 2002. The solid blue and maroon lines are both two-year moving averages which show a significant percentage reduction in SPAD risk over the last four years. The blue line represents TPWS benefit achieved with the phenomenon of 'reset and continue'. The maroon line represents the TPWS benefit that could have been achieved if 'reset and continue' were not part of the system.

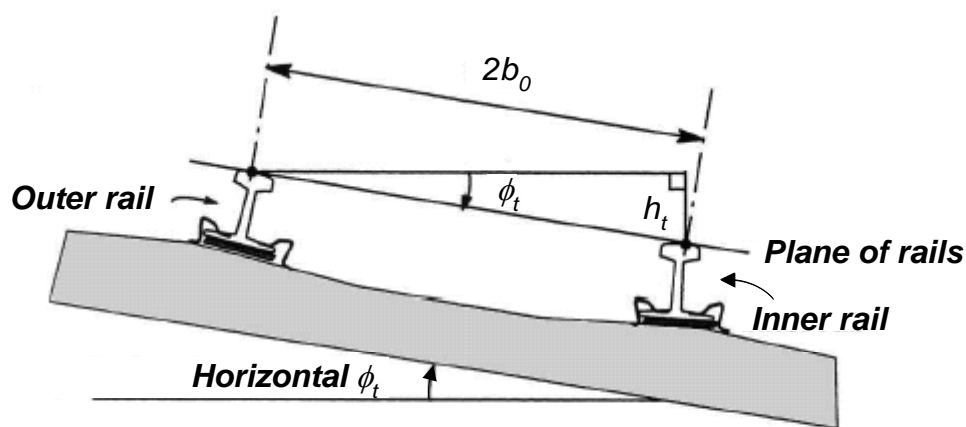
It can be seen that there is a divergence between the 'with' and 'without' 'reset and continue' lines. For the time period measured the average difference between the 2-year moving averages is approximately 3.4%, which equates to a loss in the benefit achieved through use of TPWS of the order of 6.3% or 0.1 eq.fats./yr. This loss in TPWS benefit due to 'reset and continue' outweighs the estimated 0.01 eq.fats./yr. benefit derived from TPWS risk mitigation of overspeed derailments by a factor of 10.

## 4 Overtuning derailment risk

To determine whether a train can safely traverse a curve at a given speed it is vital to gain a clear understanding of the interaction between a train and track geometry in order. This section provides a summary of the primary parameters involved, the relevant Railway Group Standards currently in place and a classification of PSRs covered by the Railway Safety Regulations: 1999.

### 4.1 Track cant

Track cant ( $h_t$ ) is the vertical height the outer rail of a curve is raised with respect to the inner rail relative to the horizontal.



**Cant  $h_t$  and cant angle  $\phi_t$**

**Figure 8 – Demonstration of the components of cant ( $h_t$ ) and cant angle ( $\phi_t$ ) (Ref. 4)**

Figure 8 demonstrates the primary components of cant and cant angle. Cant is measured in mm and cant angle is measured in degrees. The angle can be determined using the following equation:

Where:

$$2b_0 \approx 1.50 \text{ m on standard } 1,435\text{mm gauge tracks}$$

The purpose of cant is to balance the lateral forces that act upon a train as it traverses a curve.

## 4.2 Cant deficiency

The cant deficiency is a measure of how much more than the applied cant the outer rail would have to be elevated, relative to the inner rail, so that no lateral force acts on the train as it traverses the curve. Cant deficiency depends on the speed of the train, the radius of curvature of the curve and the applied cant ( $h_t$ )<sup>1</sup>.

The cant deficiency of a train traversing a curve is critically important in determining the probability of overturning derailment.

## 4.3 Railway Group Standards

Railway Group Standards provide cant deficiency limits for regular operation of trains on the UK rail network. It should be noted that the overspeed situations considered in this exemption are very rare events. RGS GM/RT2141 provides a design requirement for the resistance of trains to rollover that states that:

“Vehicles shall be designed with mass distribution and suspension characteristics which ensure the capability to run round smooth curves at constant speed without rolling over (*ie* overturning) at:

- not less than 16.5° cant deficiency for freight vehicles designed to operate at speeds no greater than 75 mph;
- not less than 21° cant deficiency for all other vehicles.”

Within the acceptable range of cant deficiencies defined by GM/RT2141, locations which do not generate cant deficiencies of greater than 6° ( $\approx 150\text{mm}$ ) do not incur any further constraints. However GM/RT2141 states that; “where vehicles are intended to operate at cant deficiencies greater than 6° ( $\approx 150\text{mm}$ ) additional measures to control the risk of rollover are required. These are set out in GC/RT5021, GE/RT8012 and GM/RT2142.”

The referenced standards provide a number of potential additional measures which should be considered at specific locations. The measures include:

- Eliminating potential sources of misalignment (for example by provision of a fully welded layout).
- Increasing the fixity of the track alignment and crosslevel (for example concrete slab track).
- Undertaking a risk assessment to ensure that the margin between the operating cant deficiency and the resistance to rollover is maximised.

<sup>1</sup> See glossary.

## 4.4 Tilting trains

Tilting trains have the capability to tilt the body of the train to reduce the lateral force experienced by passengers as the train traverses a curve. This functionality has been developed to enable the trains to run at higher speeds through curves.

GC/RT5021 (track system requirements) section C5.10.3 states that the exceptional limiting design values for cant deficiency at enhanced permissible speed (ie. relevant to tilting trains only) shall be:

- a) 150mm for curves under 400m radius
- b) 225mm for curves with radii less than 700m but greater than or equal to 400m.
- c) 300mm for curve radii greater than or equal to 700m.

However, GC/RC5521 (calculation of enhanced permissible speeds for tilting trains) section 5.1 states that a tilting train may have a maximum design service cant deficiency of up to 12°.

Equations to convert from degrees to millimetres of cant deficiency and vice versa are set out in section six of GC/RC5521. Using these conversion equations to calculate the equivalent of 300mm cant deficiency in degrees for a rail head centre distance of 1500mm produces a figure of 11.537° (referred to as 11.5° elsewhere in this document).

At cant deficiencies in excess of 11.5°, the margin of safety between the force acting on the train and the force required to make the train rollover becomes significantly reduced. Use of a speed supervision system, mandated by GE/RT8012, limits the speed of the tilting train in order to maintain this margin. This margin allows for track geometry irregularities and the effect of wind on the train.

Studies have been carried out to demonstrate that an adequate level of safety will be maintained by tilting trains operating at these increased cant deficiencies. The tilting of these trains makes no significant difference to the ability of a train to traverse a curve.

## 4.5 Overspeed cant deficiency

The primary reason for the imposition of many PSRs is to reduce the probability of overturning derailment and therefore it is fundamentally important to identify the maximum cant deficiency that trains might be exposed to at these locations. Effective reduction in the risk from overturning derailment can only be achieved where the cant deficiency has been reduced to an acceptable level.

A spreadsheet-based model was produced in order to determine the maximum cant deficiency measured at each location. The results were then categorised based on a framework developed in accordance with the rules set out in the Railway Group Standards described above.

Table 2 describes this framework.

Group	Cant deficiency, x	Comments
1	$x \leq 6^\circ$	On the rare occasion the train has failed to slow down for the PSR, the cant deficiency of the train is less than or equal to $6^\circ$ . Under current Railway Group Standard rules there are no further constraints apply as the train will be able to traverse the curve safely. TPWS could be removed from this group of PSRs.
2	$6^\circ < x \leq 11.5^\circ$	Railway Group Standards specify that further measures are required to allow trains to traverse curves regularly at up to $11.5^\circ$ . In the case of the PSR locations the additional measure has been to introduce the PSR, the AWS magnet and the PSWI. In the vast majority of traverses, the train will slow down for the PSR successfully. $11.5^\circ$ is the maximum cant deficiency specified for tilting trains. The difference in the allowable level of cant deficiency between tilting and non-tilting trains is based purely on passenger comfort. The 'tilt' functionality of tilting trains makes no significant difference to the ability of a train to traverse a curve. TPWS could be removed from this group of PSRs.
3	$11.5^\circ < x$	Railway Group Standards do not permit any trains to operate regularly at greater than $11.5^\circ$ cant deficiency (although this may occur due to track geometry irregularities, wind etc). The margin of safety between the operating cant deficiency and the resistance to rollover is significantly reduced and the probability of overturning derailment increases significantly. TPWS would remain fitted at these PSRs.

**Table 2 - PSR categorisation based on cant deficiency**

In order to determine cant deficiency, information related to the following parameters is required for each location:

- The radius of the curve
- The achievable approach speed
- The design cant.

The required information was sourced from TAMAR<sup>1</sup> and track geometry data were provided from Network Rail's track recording machine. At the time of

<sup>1</sup> Permissible approach speeds were used to calculate the cant deficiencies rather than achievable approach speeds.

publishing valid data were available for 584 of the 1,145 PSRs on the UK rail network (51%). For 439 of the 584 analysed (75%), the PSR exists solely to prevent overturning derailment.

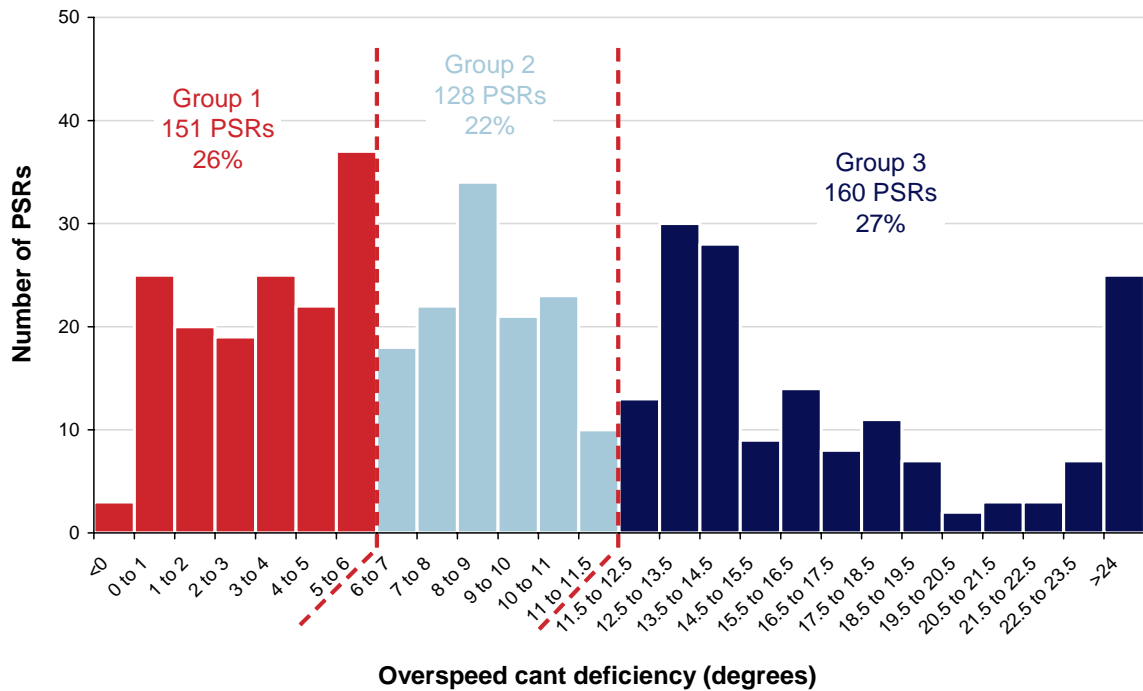


Figure 9 –Overspeed cant deficiency for 439 PSRs

The percentages in Figure 9 are expressed relative to the total number of PSRs for which valid data existed, 584. It shows that if a train failed to slow down for approximately 48% of the 584 PSRs the train would experience a cant deficiency of less than 11.5°. If a similar cant deficiency profile were displayed by the remaining PSRs for which overturning is the primary derailment mechanism, which is not unreasonable to assume, this indicates that TPWS could be removed from 40% of PSRs.

As previously stated, these PSRs themselves are in place to combat overturning derailment and each one is additionally protected by a permissible speed warning indicator and an AWS magnet to advise the driver of the speed at which he is allowed to traverse the PSR. Therefore if TPWS were to be removed from the aforementioned PSRs, these locations would still be provided with overspeed derailment protection.



## 5 Proposed strategy

The justification for requiring an exemption to the Railway Safety Regulations: 1999 is that the current fitment criteria

- Produce a high number of unnecessary TPWS brake demands, reducing driver confidence in the TPWS leading to an increased potential for 'reset and continue' incidents.
- Create considerable cost to the industry due to the delays associated with these TPWS brake demands.
- Potentially increase SPAD risk due to an increase in the number of unnecessary signals held at danger.
- Expose track workers to unnecessary risk during maintenance whilst providing negligible safety benefit at many PSR locations.

On behalf of the industry RSSB has developed estimates of the financial costs and safety benefits associated with a number of potential changes to the current fitment criteria. A comprehensive description of the risk assessment process used and a comparison of the various options analysed can be found in the RSSB 'Review of TPWS fitment at PSRs and buffer stops' (Ref. 5). This work is summarised in the proposed strategy described below.

In section 3.5 it was mentioned that 75% of the 16 events analysed have been attributed to the violation category of 'reset and continue' incident and 25% to the confusion category. A reduction in the violation segment of 'reset and continue' risk is the target of the proposed strategy.

### Removal of TPWS from selected PSRs

It is proposed that the TPWS OSS loops be removed from up to 40% of PSR locations, where it can be demonstrated that this removal would have no detrimental effect on safety. This would be a low cost way of reducing the number of brake demands, thus providing a probable safety benefit and an improvement in the operational performance of the network.

It is envisaged that in the short term TPWS loops would be turned off to achieve the required effect. Actual removal of the TPWS loops would be programmed to align with existing maintenance schedule to limit the number of additional visits to site, thus minimising both cost and the risk to the workforce concerned.

It should be noted that currently there are no proposals to remove any of the permissible speed reductions themselves from the network.

The removal of TPWS from selected PSRs requires an exemption to the Railway Safety Regulations: 1999.

## Modification of TPWS

For those PSRs for which it can be demonstrated that TPWS should be retained, TPWS should be set so that as few trains as possible that are in the control of the driver, are stopped by TPWS. This may be achieved by either

- Moving both OSS loops closer to the start of the PSR
- Increasing the separation of the OSS loops in order to raise the speed at which TPWS demands a brake application.

The RSSB study (Ref. 5) indicates that it should be possible to modify the settings of up to 50% of the total number of TPWS fitments at PSRs, leaving 10% of the TPWS fitments as they are at present.

There would be an increase in risk to track workers charged with making the modifications and the financial cost of effecting the modifications. But, this would be countered by a reduction in the number of brake demands, reducing both network delay and the number of signals held at danger and providing an increase in driver confidence in the TPWS.

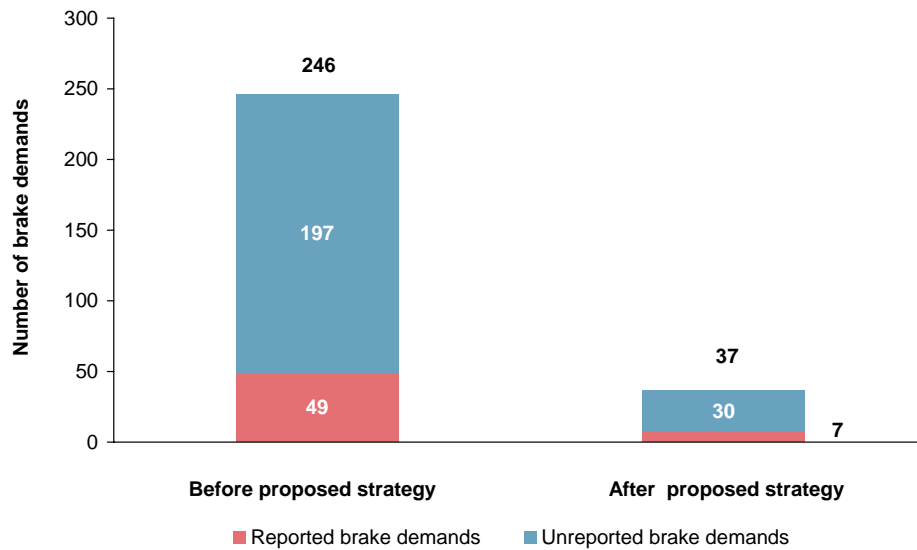
Modification of TPWS does not require an exemption from the Railway Safety Regulations: 1999 but is introduced here because it is an integral part of the optimum strategy proposed herein.

### 5.1 Effect on the number of brake demands

The primary reason for requesting an exemption from the Railway Safety Regulation: 1999 is to reduce the number of unnecessary TPWS brake demands in order to improve drivers' confidence in the TPWS system and thereby reduce their propensity to 'reset and continue'. Figure 10 displays the estimated reduction in the number of TPWS brake demands at PSRs expected to result from the proposed strategy.

Both columns in Figure 10 show the number of reported and unreported<sup>1</sup> brake demands. The number of reported brake demands per month is based on data from October 2004 to January 2005 (similar numbers have been seen for the period April to July 2005). The proposed measures are expected to reduce the total number of reported TPWS brake demands at PSRs by approximately 85%.

<sup>1</sup> A survey of 400 drivers indicated that for every one reported brake demand at a PSR, four went unreported.



**Figure 10 – Predicted effect of proposed strategy on the number of TPWS brake demands at PSRs**

It is not possible to make an accurate assessment of what effect a reduction of 85% in the number of brake demands would have on driver confidence in the TPWS system. However it seems logical to suppose that if the TPWS is modified so that it only intervenes when necessary, with time driver confidence in the system will increase. It is hypothesised that this in turn will reduce a driver's propensity to 'reset and continue'.

## 5.2 Effect on safety and cost

The elements of safety that have been considered are as follows:

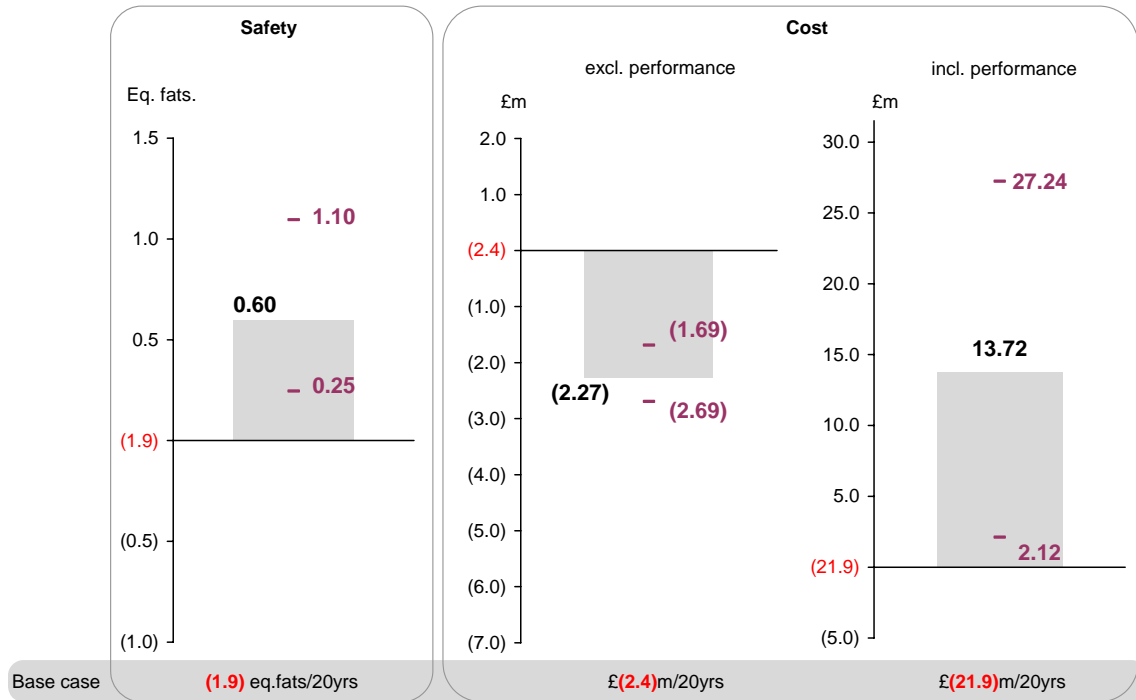
- The risk from train derailments caused by overspeed incidents.
- The risk caused by train collisions as a result of 'reset and continue' incidents following SPADs.
- The risk to track workers during the movement or removal of the OSS loops.
- The risk to track workers during maintenance of the OSS loops.

There is an assumed relationship between the overall number of TPWS brake applications and driver confidence in the TPWS system as a whole (**Ref. 5**).

The costs considered include:

- The cost of a collision expected to occur as a result of 'reset and continue' incident following a SPAD.
- The cost of an overspeed derailment.
- The cost of removing TPWS from a PSR.
- The cost of modifying TPWS fitment at a PSR (including possession costs, redesign costs and testing costs).
- The cost of maintaining the OSS loops at a PSR.

The net costs and benefits related to proposed strategy are presented in Figure 11. The total value of all of the factors has been evaluated over a 20-year period in order to determine the predicted whole life costs and benefits for the TPWS system. No value for preventing a fatality has been assumed. Risk is expressed in equivalent fatalities per year and all financial costs remain monetary.



**Figure 11 - Safety benefit and monetary cost of proposed strategy**

It should be noted that the horizontal axes of each of the three charts in Figure 11 (labelled as the 'Base Case') represent the estimated situation if no changes were made to the current fitment criteria. The estimate predicts that over a 20-year period the current situation will result in a safety risk of 1.9 equivalent fatalities. In terms of cost, the base case will result in a cost of £2.4 million excluding the cost of delays caused by TPWS brake demands. Including the performance aspect the base case costs rise to approximately £21.9 million over the 20-year period.

The best estimate of the effect of the proposed strategy is represented by the height of each column in Figure 11, and should be thought of as a change relative to the base case. The dashes above and below each column represent the upper and lower bounds of the range of results that might be reasonably expected.

## **Safety**

The best estimate of the safety benefit over the 20-year period of the proposed option is 0.6 equivalent fatalities. At worst, it would provide a safety benefit of 0.25 equivalent fatalities. Optimistically the proposed strategy could result in a safety benefit approximately one equivalent fatality. This safety benefit is most sensitive to the assumed relationship between any reduction in the number of brake demands and an associated reduction in 'reset and continue' risk.

## **Cost excluding performance**

Excluding any performance aspects the works required to deliver the proposed strategy would increase industry financial outlay over the 20-year period by just over £2.2 million with an uncertainty of approximately £1 million. The key uncertainty in these figures is due to the uncertainty in the assumed relationship between any reduction in the number of brake demands and an associated reduction in the number of collisions following a 'reset and continue' incident.

## **Cost including performance**

The performance argument stems from a consideration of the delays incurred following a brake demand at a PSR whilst the driver identifies the cause of the brake demand, checks the integrity of the train and contacts the signaller. An industry average revenue cost of £25 per minute delay is used to determine compensation claims on the UK rail network and has been used to estimate the benefit gained by reducing the number of TPWS brake demands over a 20-year period.

The effect of performance benefits overshadows the other cost implications of the proposed option. The mid-estimate is that there will be a performance gain of the order of £16 million over the 20-year period, with the most pessimistic and optimistic estimates also predicting an improvement of the order of £5 million to £30 million respectively. Due to the significant uncertainty over the actual number of TPWS brake demands, and the associated delay minutes at PSRs, the time value of money has not been taken into account.

The cost of delay per adjusted approach, where the driver has slowed down the train to compensate for the location of the OSS loops, has not been quantified, although it is clear that this would only increase the performance benefits.

## **5.3 Other 'reset and continue' projects**

The justification for the proposed modifications presented assumes that no other project significantly affects the safety and performance issues related to TPWS brake applications at PSRs. Currently this is a valid approach as there are no other approved projects that could significantly reduce the level of safety risk associated with TPWS at PSRs. However there is one other project related to the confusion element of 'reset and continue' risk. A short description this project is presented below.

### 5.3.1 TPWS driver interface improvements

RSSB's research and development team is currently sponsoring a project with TPWS manufacturer Thales Communications Ltd in order to determine the feasibility of improving the TPWS driver interface. At present the TPWS on-train equipment provides a series of visual and audible warnings to alert the driver that they have experienced a TPWS brake demand. However at the moment there is no differentiation between the warning provided by TPWS and other operations such as AWS. Additionally the warning provided by TPWS at a signal is the same as if the system activates at another type of location eg PSRs.

Following driver acknowledgement of the brake application, TPWS also times out after 60 seconds leaving the driver with no indication of the cause of the train brake demand. This scenario is confusing to the drivers as they are not required to contact the signaller following an AWS brake demand. The current displays provided to the driver have been blamed for a number of the recorded 'reset and continue' incidents.

The ongoing project is to determine the practicability of altering the configuration of the visual warnings to differentiate between brake demands that have been caused by TPWS and those that are the result of another train system such as AWS. The objective of the project is to remove those 'reset and continue' incidents that are the result of driver confusion.

This project is currently at a stage where Thales are designing and building a prototype of the new TPWS control unit. This, along with the results of simulation testing to model the potential improvements from the upgrade, will then be presented to the industry and a decision will be taken on whether it is reasonably practicable for upgraded units to be rolled out across the network.

Evidence suggests that if successful this project would remove almost all of the confusion category of 'reset and continue' event at a signal at danger. If approved, the modifications will mean that the driver will know that their train has been stopped by a TPWS brake demand at a PSR and that to carry on without contacting the signaller would be to contravene the rule book and may also place their train at risk from a train accident.

The removal of the majority of the risk associated with the confusion category of TPWS 'reset and continue' would not affect the justification for this exemption application.

The industry rollout of the driver interface modifications has yet to be approved. If the modifications are agreed as the way forward by industry, the current timescales indicate that fitment would commence at the earliest at the beginning of 2007 and be completed by the end of 2008.

## **6 Summary of the case for exemption**

The summary of the case for the exemption is presented as the exemption request summary at the beginning of the document.

## 7 Exemption request

Her Majesty's Railway Inspectorate is requested to grant a certificate of permanent exemption from the Railway Safety Regulations 1999 for fitment of TPWS at PSRs for those PSRs that would experience an overspeed cant deficiency of less than 11.5° on the basis that:

- Overspeeding derailment risk is very low.
- The existing PSWI enhanced PSR protection will be retained and will provide adequate mitigation for any residual overspeed derailment risk.
- In the event the train does fail to slow down for the PSR, the probability of derailment at these locations is negligible
- The subsequent reduction in the number of unnecessary TPWS brake demands will have a positive effect on drivers' propensity to 'reset and continue.'

It is estimated that the proposed options would

- Have the potential to remove between 400 and 500 TPWS fitments from the network
- Reduce the number of brake demands at PSRs by approximately 85%
- Reduce the system-wide risk by 0.6 equivalent fatalities over 20 years
- Cost approximately £2 million more than would otherwise be spent over 20 years.
- Provide a performance benefit in the region of £16 million over the same period.



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## References

- Ref. 1 Rail Safety and Standards Board (2005): TPWS Interventions Report.
- Ref. 2 TTAC (November 2004): TPWS effectiveness for Overspeed Mitigation.
- Ref. 3 Rail Safety and Standards Board (January 2005): Profile of Safety Risk on the UK Mainline Railway issue 4.
- Ref. 4 Lindahl, M. (2001) Track Geometry for High-speed Railways. Railway Technology Department of Vehicle Engineering. Royal Institute of Technology. Sweden.
- Ref. 5 Rail Safety and Standards Board (January 2006): Review of TPWS Fitment at PSRs and buffer stops – SP-RSK-74.01/Issue 1.



## **Annex 2 - Draft certificates of exemption**

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### **THE RAILWAY SAFETY REGULATIONS 1999 (S.I. 1999/2244) Certificate of Exemption**

#### **Grant**

1. The Office of Rail Regulation, in exercise of the power conferred on it by regulation 6(1) of the Regulations, having consulted those persons it considers appropriate in accordance with regulation 6(2) of the Regulations and having had regard to the matters specified in regulation 6(3) of the Regulations, grants the following exemption.

#### **Definitions**

2. In this exemption -

“Network Rail” means Network Rail Infrastructure Limited whose registered office is at 40 Melton Street, London NW1 2EE;

“the Regulations” means The Railway Safety Regulations 1999 as amended;

“TPWS” means a train protection system defined by regulation 2 of the Regulations;

“the relevant Railway Group Standard” means Railway Group Standard GC/RT 5021 Issue 2 dated October 2003.

Terms used in this exemption, which are used in the relevant Railway Group Standard, have the meaning that they have in that document.

#### **Exemption and Conditions**

3. Network Rail is exempt from the prohibition contained in regulation 3(1) of the Regulations (prohibition on permitting the operation of a train on a railway unless a train protection system is in service) in relation to a site on the railway where there is a permanent speed restriction, subject to the conditions that:
  - (a) the cant deficiency at that site meets the requirements set out in section C5 of the relevant Railway Group Standard; and

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Fitment at permanent speed restrictions

- (b) Network Rail maintains records of any removals of or modifications to TPWS equipment carried out in consequence of this exemption, and makes those records available to ORR at its request.
4. This exemption comes into effect at 00:01 hours on [date]. In accordance with section 6(1) of the Regulations, it may be revoked by ORR at any time by a certificate in writing.

Signed by .....

[Job title]

On behalf of the Office of Rail Regulation

Date .....

## Annex 3 - List of organisations and people consulted

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AEA Technology  
ADVENZA  
AMEC  
Angel Trains  
Arriva Trains Plc  
ASLEF  
Association of Train Operating Companies  
Chair, Railway Industry Advisory Committee Freight Group  
c2c Rail Ltd  
Cadvent Rail  
Central Trains Limited  
Centre for Transport Studies  
Centro West Midlands PTE  
Chiltern Railways  
Confederation of Passenger Transport UK  
Department for Transport  
Direct Rail Services  
Eurostar (UK) Limited  
English, Welsh and Scottish Railway  
EWS  
First Capital Connect  
First Group plc  
First Great Western  
First ScotRail  
First TransPennine Express  
Freightliner Ltd  
Gatwick Express Railways Company Ltd  
Great Britain Railfreight  
Great North Eastern Railway (GNER)  
Greater Manchester PTE  
Health and Safety Executive/Commission  
Heritage Railways Association  
House of Commons Transport Select Committee  
House of Lords  
HSBC Rail UK  
Hull Trains  
Institution of Civil Engineers  
Institution of Mechanical Engineers (ImechE)  
Institution of Railway Signal Engineers (IRSE)  
London Travel Watch  
London Underground  
Merseytravel PTE  
Metro West Yorkshire PTE  
Midland Mainline Limited

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National Assembly for Wales  
Network Rail  
NEXUS Tyne and Wear PTE  
Northern Rail Ltd  
National Union of Rail, Maritime and Transport Workers (RMT)  
One Railway Ltd  
Parliamentary Advisory Council for Transport Safety (PACTS)  
Passengerfocus  
Passenger Transport Executive Group (PTEG)  
Porterbrook Leasing  
Rail Freight Group  
Railway Forum  
Railway Industry Association  
Railway Safety and Standards Board  
Serco Metrolink  
Silverlink Train Services Ltd  
Southern  
Southeastern  
South West Trains  
South Yorkshire PTE  
Strathclyde PTE  
Transport and General Workers Union (TGWU)  
Transport Salaried Staffs' Association (TSSA)  
Transport Scotland  
Trade Union Congress (TUC)  
Virgin Trains Ltd  
VTG Rail UK Ltd  
West Coast Railway Company Ltd