Introduction

Within the UK, there are approximately 400 reported obstacle strikes every year. Whilst most of these are trivial, some (< 1%) have potentially serious consequences, and can lead to derailment and passenger fatalities. The scope of work specified in T189 had as its objective the determination of what can be done to minimise the effects of an obstacle strike, by considering the design of obstacle deflectors and lifeguards, and to recommend appropriate changes to Railway Group Standards.

Railway Group Standard GM/RT2100 requires obstacle deflectors to be fitted to the vehicle body structure of all leading vehicles with a maximum speed of 145 km/h and above (160 km/h on third rail DC lines), in order to minimise the risk of derailment on striking a large obstacle such as an animal or car. Leading vehicles with axle loads greater than 170 kN are currently exempt from this requirement. Lifeguards are required to be fitted to leading bogies to prevent smaller objects from passing under the wheels.

Specifications for obstacle deflectors and lifeguards were developed following a derailment at Polmont, near Falkirk, in 1984 in which a high speed train with a lightweight leading vehicle was derailed on striking a cow. The appropriateness of these specifications required re-evaluation in the light of more recent
accidents such as Great Heck in 2001 and Ufton Nervet in November 2004. The latter involved a Class 43 (HST), with a leading axle load of 17.5 tonnes (171.7 kN), and raised the question of whether the exemption is justified.

In early 2010 a revised cost benefit analysis was conducted to consider the justification for installation of obstacle deflectors to HSTs under revised assumptions for their continued service operation.

Aims

The aims of the research were to:

1. Review the effectiveness of current obstacle deflectors and lifeguards in preventing derailment following an obstacle strike.
2. Determine if design improvements would improve the efficacy of deflectors and lifeguards.
3. If necessary, develop improved designs of deflectors and lifeguards.
4. Validate any improved designs.
5. Assess the mechanism leading to the derailment at Ufton Nervet and the likelihood of similar derailments.
6. Undertake a cost-benefit analysis for retrofitting obstacle deflectors to the current HST fleet.

Method

All six aims were addressed by the suppliers. Work on the first four aims was undertaken in four phases:

**Phase One** examined past accident data, reviewed past studies to identify any deficiencies in existing designs of deflectors and lifeguards, and performed risk-based assessments of the safety benefits of deflectors and lifeguards.

**Phase Two** performed a parametric modelling study of deflector and lifeguard designs to identify potential improvements to increase the ability of deflectors and lifeguards to prevent derailment.

**Phase Three** proposed and developed an improved design of lifeguard, based on the conclusions of Phase two.

**Phase Four** tested the proposed improved design of lifeguard and compared the results with modelling predictions.

Work on the fifth and sixth aims assessed the mechanism leading to the derailment at Ufton Nervet and the likelihood of similar derailments. This work used input from the extensive investigative
work which had been undertaken to understand the derailment mechanism. A cost benefit analysis was then performed to examine the practicability of retrofitting deflectors to the current HST fleet. Its outcome was to contribute to the industry deciding whether or not it is reasonably practicable to retrofit deflectors to HSTs.

Figure 2: Lifeguard

Findings

The report included the following:

Phase One

Accident statistics over the period 1991 to 2000 and past studies going back to 1984 were analysed. This data indicated that there were 350 to 450 obstacle strikes per year, resulting in an average of three derailments per year. Almost all of the derailed trains were lightweight multiple units not fitted with obstacle deflectors because their maximum speed was below 145 km/h. Only one derailment occurred with a vehicle having a leading axle load greater than 17 tonnes; this resulted from the train striking a landslip (an obstacle which a deflector would not be expected to remove).

Obstacle deflectors currently fitted to multiple unit stock were estimated to be saving 0.49 FWI (Fatalities and Weighted Injuries). It was estimated that an additional 0.68 FWIs would be saved each year if all multiple unit and driving trailer stock were fitted with obstacle deflectors.

Comparing the capabilities and performance of existing obstacle deflectors and lifeguards revealed that there is a significant gap...
between the capabilities of obstacle deflectors and lifeguards in respect of the type, size and mass of the obstacles that they can successfully remove. Heavy, compact obstacles, such as sleepers, concrete troughing lids and pieces of rail, present a risk of derailment but are not likely to be successfully removed because they typically pass under deflectors and are too heavy for lifeguards to deal with successfully.

Phase Two

This comprised separate parametric modelling studies of obstacle deflectors and lifeguards. These used finite element and vehicle dynamics modelling. The obstacle deflector study used a Class 170 diesel multiple unit (DMU) as the base vehicle to construct a lumped mass model of the deflector and its attachment. The model was also used to assess the propensity to derail the train when impacted by the reference obstacles; these comprised a Land Rover and a 500 kg cow. The deflector parameters considered were the vertical and horizontal rake angles, area and location of the deflector plate (either forward of the headstock or immediately in front of the bogie), energy absorption and axle load. The collision parameters included the obstacle type, orientation relative to the train, impact speed and the wheel rail contact conditions. A mathematical algorithm was developed to assess the risk of derailment as a result of an impulse from the obstacle 'pushing' the train off the track, or of the obstacle getting under the wheel or axle and lifting the train. The study concluded that:

- Current design specifications are adequate with no requirement for them to be changed.
- The deflector should be positioned as far forward as possible.
- Vehicles with high axle loads are less likely to be derailed.

The lifeguard parametric study considered three reference obstacles, namely a 100kg piece of rail, a sleeper and a set of concrete troughing lids, striking an axle box mounted lifeguard. A particularly common design of lifeguard (B2-C0-8202424), fitted to over 300 multiple units across a variety of classes, was chosen for the parametric study. A finite element model of the lifeguard, attachment bolts and axle box, indicated that slippage of the attachment joint occurs at speeds as low as 15 kph, and failure of one or more of the bolts occurs at 35 kph.

The principal conclusions from Phases One and Two indicated that, for obstacle deflectors, there was little more meaningful
research that could be done, but that for lifeguards, current
designs were ineffective against heavy masses and there was
scope for significant improvement. In particular, if the vehicle
wheel could be used as a ‘backstop’, much higher loads could be
applied to the lifeguard without such loads causing failure of the
bolted attachment. As a result of these conclusions, the Phase
Three and Four works concentrated exclusively on lifeguards.

Phase Three

A concept lifeguard was designed that was essentially similar to
the current lifeguard, in that it was bolted to a trailing arm axle
box, but with different geometry such that, after approximately 10
mm of longitudinal displacement, it would make contact with the
wheel; this would then act as a stiff load reaction point. The
design process aimed at ensuring that the lifeguard deformed
back towards the wheel in a controlled and pre-determined
manner and that it did not significantly loosen the attachment
bolts, either as a result of its deformation or as the friction
between the rotating wheel and the lifeguard caused the lifeguard
to be pulled downwards. It was also important that the natural
frequency of the lifeguard was high enough to avoid track induced
excitation.

The reference obstacle was a 100 kg length of rail. Several impact
orientations of the obstacle relative to the lifeguard were
considered. Different impact speeds and coefficients of friction
between the lifeguard and the wheel were also considered.

Force output from the finite element model was used as the input
to a Vampire model of a Class 170 vehicle, to which the lifeguard
was attached, to assess the propensity to derail. The design study
showed that it was possible to design a lifeguard which could
remove the 100 kg rail at an impact speed of 80 kph without the
lifeguard fracturing or becoming torn from its attachment. The
impact at such a speed caused the impacted wheel to lift under
certain orientations of the obstacle but, in all cases, was
insufficient to result in a prediction of derailment. The lifeguard
was also able to remove a 3 kg solid object at 160 kph without
becoming distressed.

Phase Four

A full size dynamic test was devised in which a moving obstacle
was catapulted into a stationary lifeguard and rotating wheel
assembly in a specially built test rig. The rig approximated a real
impact, except that there was a small gap between the rotating
wheelset and the stationary running rail. The running rail also had
a frangible mechanical link which would break and prevent the wheelset from being forced out of its mounting frame if the lifeguard failed and the obstacle and/or the lifeguard tried to pass under the wheel, creating excessive vertical force.

The test achieved a simulated impact speed of 89 kph and indicated that the improved lifeguard design is capable of absorbing the energy from impact of a 100 kg rail impacting at 89 kph, by deforming against the wheel. The lifeguard remained attached to the axle box with sufficient bolt load after impact to prevent the lifeguard immediately becoming loose.

During the test, the lifeguard was forced downwards to the railhead, as well as backwards, causing the frangible link to break. Although a residual derailment risk remains due to this downward movement, it is likely to be considerably less than with existing lifeguards. An 80 kph impact with a 100 kg rail would most likely cause the existing in-service lifeguard design to become detached; this would allow the obstacle and/or the lifeguard to pass under the wheel with a very high risk of derailment. The risk of such derailment with the improved lifeguard design is considerably less.

Ufton Nervet derailment mechanism

It was assessed that the derailment at Ufton Nervet occurred as the HST rode over the car, due to the relative height difference between the vehicles and the backward slope of the underside of the HST cab moulding. These two effects guided the car towards the leading bogie of the HST. As the car disintegrated due to the heavy impact, a solid part of the car, probably the engine block became trapped between the road surface on the crossing and the gearbox on the HST's leading axle. This generated sufficient lift and lateral movement to derail the leading wheelset to the left. The train ran with this single wheelset derailed until a set of facing points derailed the whole train.

Derailments of heavy vehicles following obstacle strikes occur very infrequently. However, road vehicles, particularly heavy vehicles such as lorries, tractors and similar, have the potential to derail a train on a level crossing or on plain track, even one with a leading axle load exceeding 170 kN. Smaller road vehicles, such as cars, also have the potential to derail trains as the combination of high kinetic energy and stiff, strong, components provides a derailment mechanism. Large animals have the potential to roll under the leading axle and generate lift forces, although to a lesser extent than vehicles.
Initial cost-benefit analysis

Sixty obstacle strike derailments for all passenger train types during the period 1991 to 2005 were identified and sorted by type of obstacle. Strikes involving types of obstacle which a deflector is expected to be effective against i.e. cars, large animals, trees and similar objects, constituted a subset of 19, including two HST derailments. Ufton Nervet was the only obstacle strike HST derailment resulting in fatalities in approximately 30 years since the introduction of HSTs.

Benefits from reducing the occurrence of derailments by fitting obstacle deflectors were predicted in terms of FWIs and converted to monetary values using a Value of Preventing a Fatality (VPF) of £1,652,000. Costs saved by reducing the occurrence of derailments were estimated using incident details from the Safety Management Information System (SMIS) database, delay data from the TRUST database, and typical costs from the RSSB Incident Cost Model.

Costs for designing, manufacturing and retrofitting obstacle deflectors to HSTs were estimated and provided to RSSB by a train manufacturer, along with a retrofitting schedule and a remaining fleet life schedule running to 2017. The total estimated present value of the cost per power car, over the expected remaining HST fleet life, was £165,000.

A cost benefit analysis, using only the two HST obstacle strike derailments, gave a cost/benefit ratio of 33:1.

A cost benefit analysis using the 19 non-HST plus the HST obstacle strike derailments, with the non-HST derailments involving leading axle loads less than 170 kN re-assessed as if they involved leading axle loads over 170 kN, gave a cost/benefit ratio of 87:1.

Sensitivity analyses, which considered reducing the numbers of level crossings by 10% over 30 years (pro-rated to 2017), varying the effectiveness of deflectors by type of obstacle, and halving and doubling the incident costs saved, gave cost/benefit ratios ranging from 24:1 to 166:1. The minimum ratio was for the HSTs case, a more effective deflector, and doubles the average incident costs saved. Therefore, the analysis does not support the retro-fit for HSTs.

Revised cost-benefit analysis

In response to a request from the Department for Transport, RSSB undertook a revised cost benefit analysis that considered
revised assumptions on the continued service operation of HSTs. Scenarios analysed included withdrawal of HSTs by 2025 and 2035 and also incorporated updates to the installation programme and VPF (£1,661,000) in line with the latest guidance. For comparative purposes RSSB also considered some extreme cases where all HSTs continued to run until 2025 or 2035 and were withdrawn at once rather than a gradual decline in order to identify the maximum potential benefits from installation.

A cost benefit analysis, using only the two HST obstacle strike derailments, gave a cost/benefit ratio of 18:1 for the 2025 scenario and 9.2:1 for the most beneficial 2035 scenario.

A cost benefit analysis using the 19 non-HST plus the HST obstacle strike derailments, with the non-HST derailments involving leading axle loads less than 170 kN re-assessed as if they involved leading axle loads over 170 kN, gave a cost/benefit ratio of 46.7:1 for the 2025 scenario and 23.9:1 for the most beneficial 2035 scenario.

Sensitivity analysis was again conducted on the effects of halving and doubling the incident costs saved. The case for improving the fitment of obstacle deflectors only improved to 7.0:1 for the most beneficial 2035 scenario.

Conclusions

The work done under T189 was put forward as a response to Recommendation nine of the Formal Inquiry into the train accident at Ufton Nervet in 2004. More recently, the development EN15227 and the updating of Railway Group Standard GM/RT 2100 have also addressed this recommendation. EN15227 has now been adopted, as a mandatory requirement by GM/RT 2100 (which is due for publication in June 2010).

Obstacle deflectors

- The application of EN 15227 within GM/RT2100 addresses the Ufton Nervet recommendation that obstacle deflectors should be fitted to all leading vehicles with a leading axle load of less than 170 kN by requiring all leading end vehicles to be fitted irrespective of axle load.
- Design loads specified in Group Standard GM/RT2100 appear adequate for removing most large obstacles. These will however be replaced by the design load requirements of EN15227 which are essentially equivalent.
- Adoption of EN 15227 supersedes the recommendation that a cost benefit analysis should be undertaken to determine the benefit of fitting deflectors to third rail DC stock.
The parametric study of obstacle deflectors indicated that, apart from positioning deflectors as far forward on the vehicle as possible, there is little to be gained by changing deflector geometry. On this basis, no further development or testing is proposed for obstacle deflectors.

The revised cost-benefit analysis, including sensitivity analyses, for retrofitting deflectors to HSTs gave cost/benefit ratios ranging from 13.1:1 to 88.9:1. As a result the industry has recommended that there is insufficient justification for the appropriate duty holders to consider it reasonably practicable for obstacle deflectors to be retrofitted to HSTs.

The findings from this research will now be considered by the DfT as part of their wider discussion with the rail industry and the appropriate duty holders on the options and issues associated with proposals for continued service operation of HSTs.

Lifeguards

The continued installation of lifeguards is recommended.

Reports

The final report and the research brief for this research have been published. A report for each of the separate related tasks was produced by the supplier. These are referenced in the final report and can be made available from RSSB on request.

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