

Rail Accident Report



**Uncontrolled freight train run-back between
Shap and Tebay, Cumbria
17 August 2010**

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

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Uncontrolled run-back between Shap and Tebay, Cumbria, 17 August 2010

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Summary

In the early hours of Tuesday 17 August 2010, a northbound freight train was travelling uphill on the West Coast Main Line between Tebay and Shap Summit in Cumbria. At 02:04 hrs the train slowed to a stop and then ran back until the driver braked and the train came to a stand at 02:09 hrs. During the run-back the train reached a maximum speed of 51 mph (82 km/h) and travelled 2.2 miles (3.5 km). The incident caused no injuries or damage; however the consequences could have been worse. If the driver had not braked when he did, the rear of the train would have travelled over a turnout into Tebay sidings at an excessive speed, which may have led to derailment, damage and obstruction of the adjacent line on which trains travel south.

The investigation found that DB Schenker's train driver, who was working the first of a series of night shifts, was probably fatigued and not sufficiently alert at the time of the incident. It also found that although DB Schenker had used a recommended mathematical model and industry guidance to plan the shift, the driver had been exposed to a work pattern that was likely to induce high levels of fatigue. The report concludes that the mathematical model adopted by most of the rail industry is likely to under-predict the probability that high levels of fatigue will be experienced by people working a first night shift.

This report makes one recommendation to DB Schenker concerning its management of fatigue, two recommendations to the Office of Rail Regulation concerning guidance on the management of fatigue and the accuracy of mathematical models used to predict fatigue, and one recommendation to RSSB on improving rail industry information on fatigue-related accidents and incidents.

Preface

- 1 The sole purpose of a Rail Accident Investigation Branch (RAIB) investigation is to prevent future accidents and incidents and improve railway safety.
- 2 The RAIB does not establish blame, liability, or carry out prosecutions.

The incident

Summary of the incident

- 3 In the early hours of Tuesday 17 August 2010, northbound freight train 4S25 was travelling uphill on the West Coast Main Line between Tebay and Shap Summit in Cumbria (figures 1 and 2). At 02:04 hrs the train slowed to a stop and then ran back until the driver braked and the train came to a stand at 02:09 hrs. During the run-back the train reached a maximum speed of 51 mph (82 km/h) and travelled 2.2 miles (3.5 km).

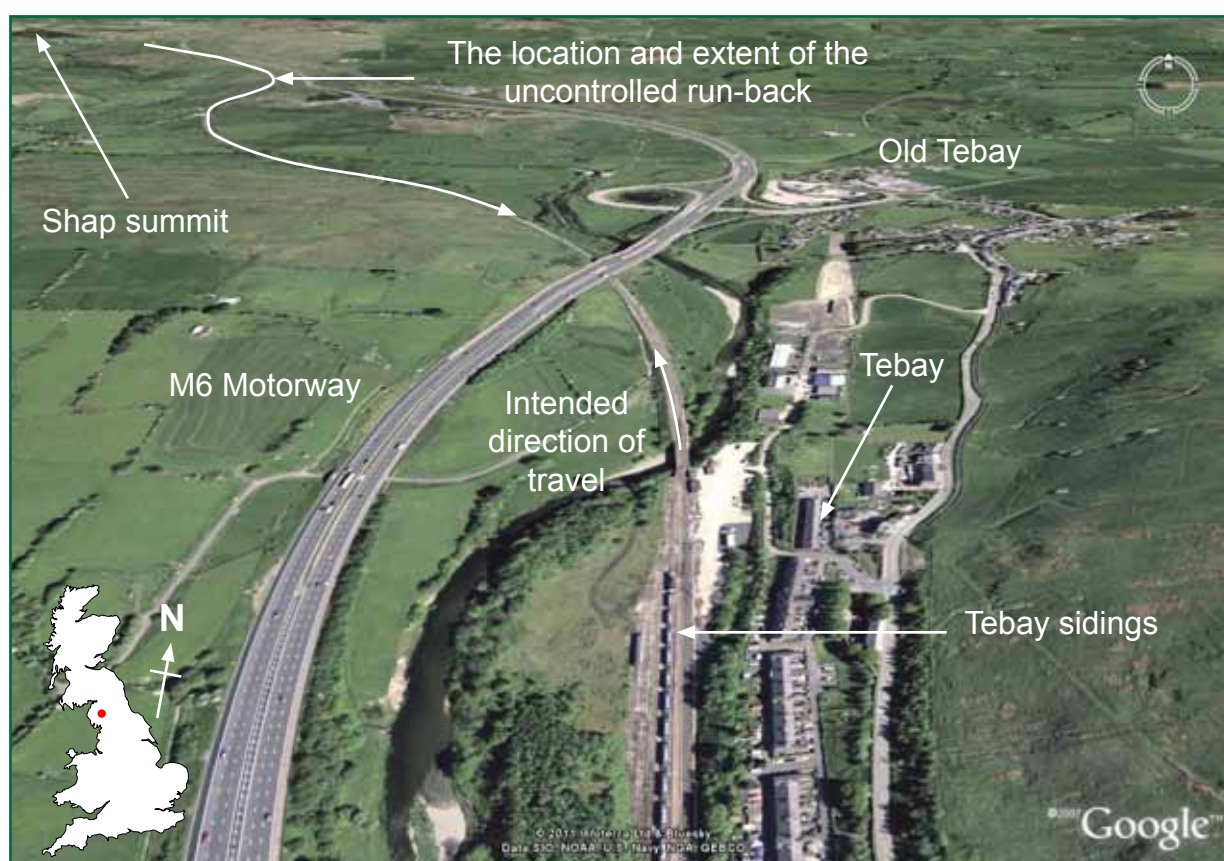


Figure 1: Tebay, Shap Summit and the incident location (courtesy of Google Earth)

The organisations and individuals involved in the run-back

- 4 DB Schenker was the operator of the train and the employer of the train driver. Network Rail is the controller of the infrastructure on which the train ran back and the employer of the signallers that control train movements in the area. Both parties co-operated with the RAIB during its investigation.

The external circumstances and the location

- 5 It was dark, raining and there was a light south-westerly breeze at the time of the incident. At the location of the run-back the West Coast Main Line comprises two lines: the 'down' main line on which trains normally travel north and the 'up' main line on which trains normally travel south. The freight train was permitted to run at a maximum speed of 75 mph (121 km/h) at this location.

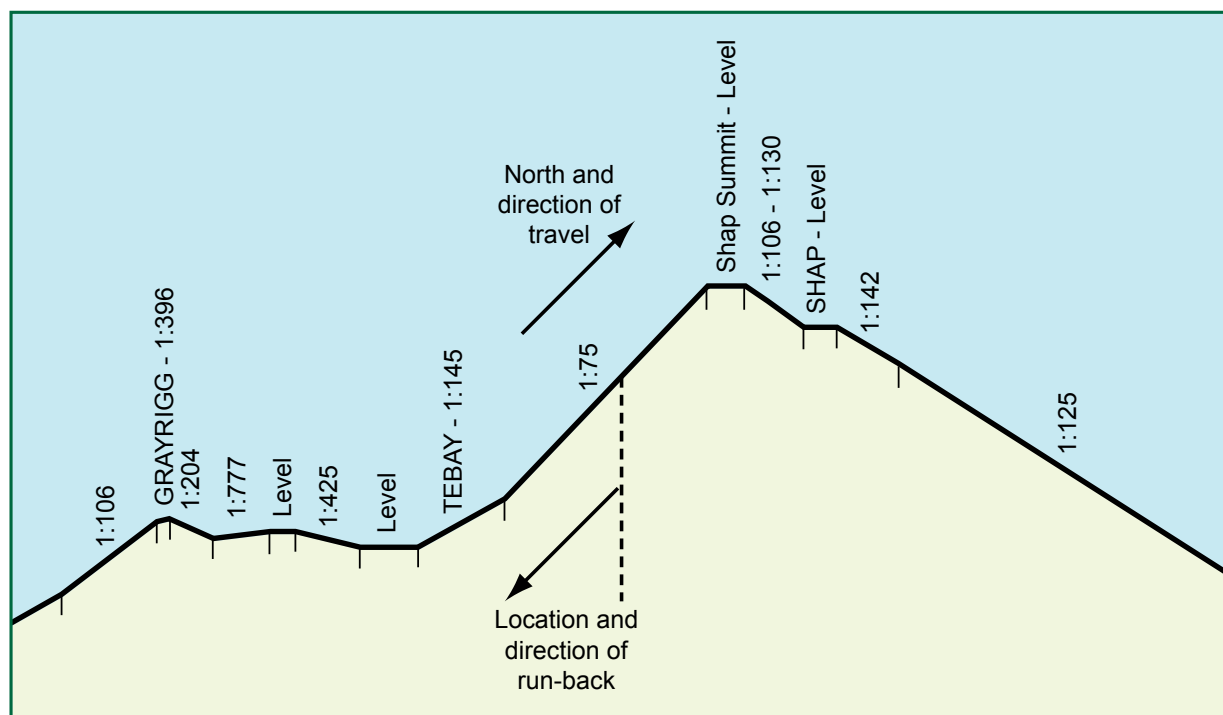


Figure 2: Track gradients in the Tebay area

- 6 Train movements between Tebay and Shap are controlled by four-aspect signalling which operates as shown in figure 3. Signals and trains are fitted with Automatic Warning System (AWS) equipment, the purpose of which is to warn a driver when a train approaches a signal that is not showing a green light. It operates as follows:
- if the signal immediately ahead is green, a bell sounds in the cab, a cab desk indicator shows black (figure 4) and the driver takes no action;
 - if the signal shows any colour other than green, a warning horn sounds in the cab, the indicator shows black; and
 - if the driver does not press a button to acknowledge and cancel this warning in two to three seconds, the brakes automatically apply and bring the train to a stop; but
 - if the warning is cancelled the brakes do not apply and the cab desk indicator shows alternate black and yellow segments to remind the driver that he has cancelled a warning and is now responsible for slowing or stopping the train.
 - If the train runs back past any signal in the wrong direction, the warning horn will sound in the cab, the indicator will show black and the system will operate as described in paragraph 6b.

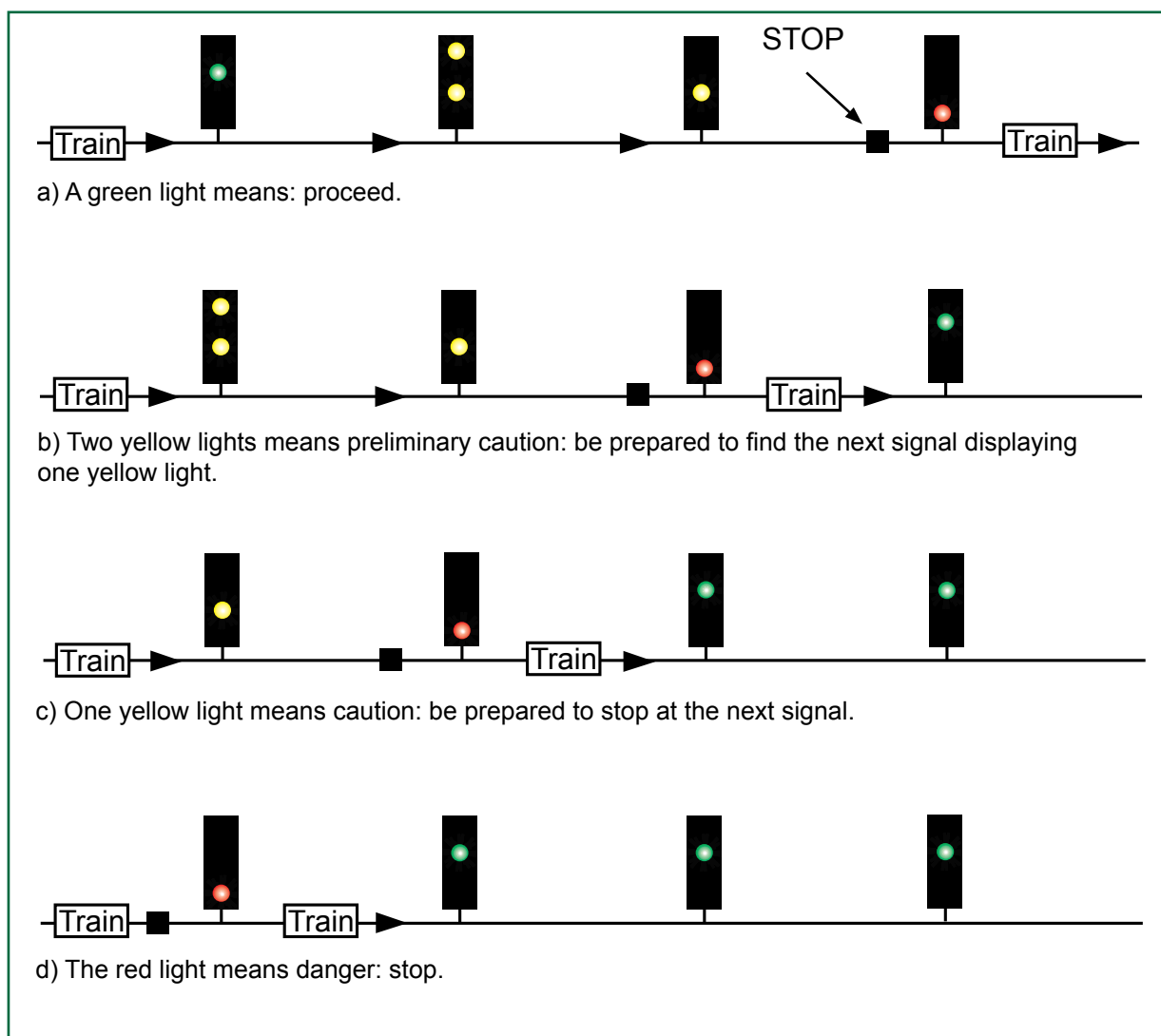


Figure 3: Four aspect signals of the type that control train movements between Tebay and Shap Summit

The train

- 7 Train 4S25 was the 21:32 hrs service from Hams Hall, Birmingham, to Mossend, Glasgow: at the time of the incident it comprised class 92 electric locomotive number 92019 and 13 wagons; including the locomotive the train was 498 metres long and weighed 715 tonnes. Along with automatic warning system equipment, the class 92 locomotive is fitted with a Driver's Vigilance Device (DVD), the purpose of which is to confirm that a driver responds to its warnings. It operates as follows:
 - a. a warning sounds in the cab if the driver releases a foot pedal (figure 4) or, in any 60 second period, does not operate certain cab controls, for example to brake, demand power or cancel the warning horn for a signal; and
 - b. if the driver does not acknowledge and cancel the warning within seven seconds by releasing then depressing and holding down the pedal, the brakes will automatically apply and bring the train to a stop.



Figure 4: The driver's cab of class 92 locomotive number 92019

Events before the incident

- 8 On Monday 9 August 2010 the driver left home around 06:30 hrs to start the first of six shifts. For his final shift on Saturday 14 August 2010 he left home around 02:30 hrs to start work at 03:15 hrs after only being able to sleep for three hours. He had gone to bed earlier than normal the night before this early shift and had tried but was unable to sleep until around 23:00 hrs. The driver was not at work on Sunday 15 August 2010.
- 9 On Monday 16 August 2010 the driver worked the first of five consecutive night shifts. He stated that he tried but was unable to sleep in the day before reporting for duty at 18:34 hrs to work a shift that was scheduled to finish at 05:43 hrs. His first task of the night was driving a freight train from Mossend to Carlisle. From Carlisle he caught a passenger train to Warrington Bank Quay where he had an hour's rest break during which he had a light snack, drank tea and waited for train 4S25 to arrive.
- 10 When the train arrived the driver spoke with the driver he was relieving, got into the cab and drove out of the station at 00:43 hrs. The journey was uneventful until the driver passed through Tebay and saw signal CE112 showing two yellow lights. From experience he correctly assumed he had caught up with a slower freight train so at 01:58 hrs he cancelled the warning for the signal and applied the brake to reduce speed. He then saw signal CE114 showing one yellow light and cancelled its warning. Figure 5 shows the events recorded by the locomotive's data recorder and figure 6 shows the locations at which the events occurred.

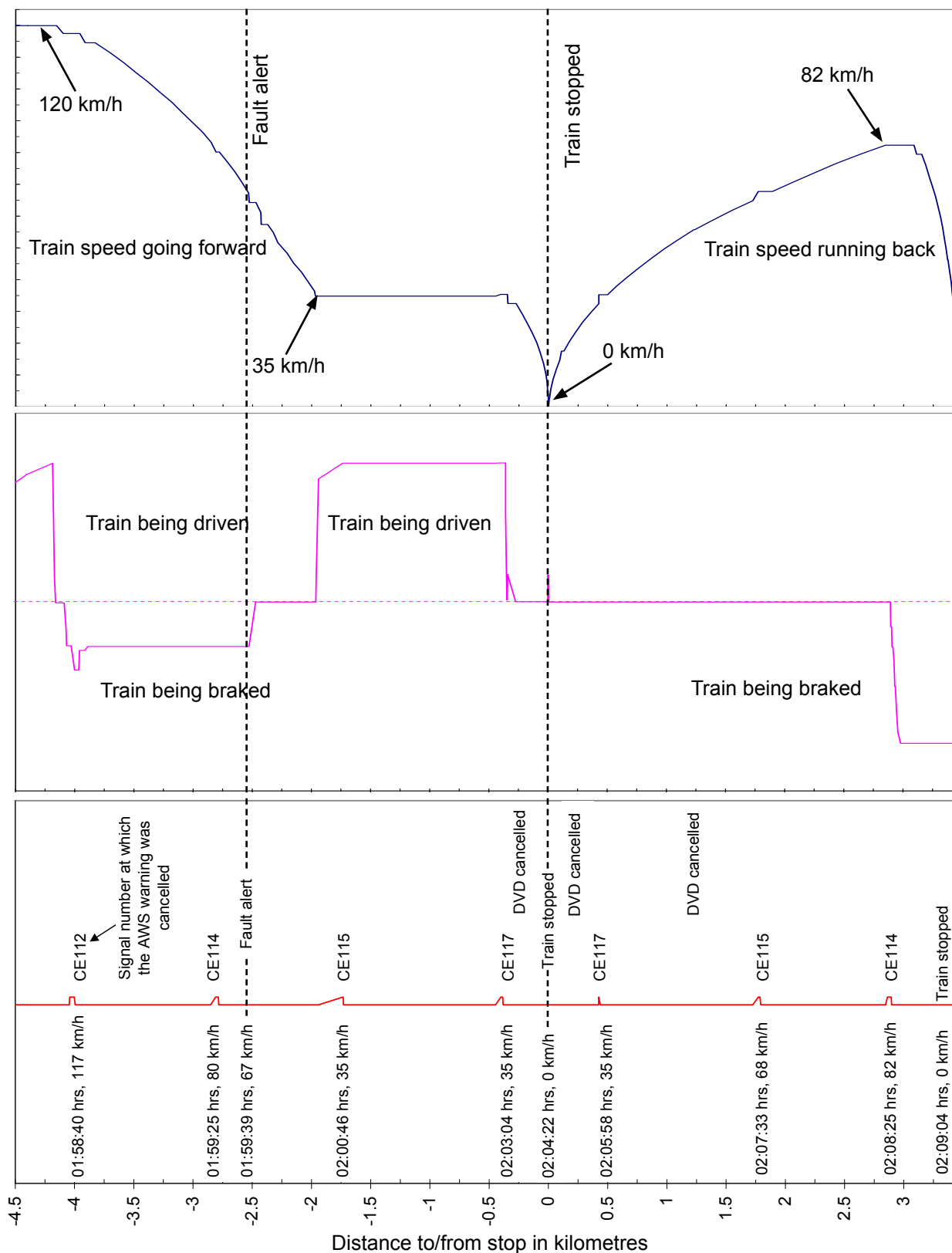


Figure 5: Events recorded by the data recorder

- 11 At 01:59 hrs the cab desk display screen alerted the driver to a fault: one of the two convertors that supply power to the locomotive's motors had shut down. The driver attempted to reset the convertor but could not, so he continued to drive the train normally as its loss had only a small effect on the locomotive's available power. The driver then saw signal CE115 showing one yellow light, cancelled its warning, stopped braking and applied power to maintain speed. The driver then cancelled the warning for signal CE117 which was showing one yellow light and reduced power to slow the train as he travelled up the gradient.

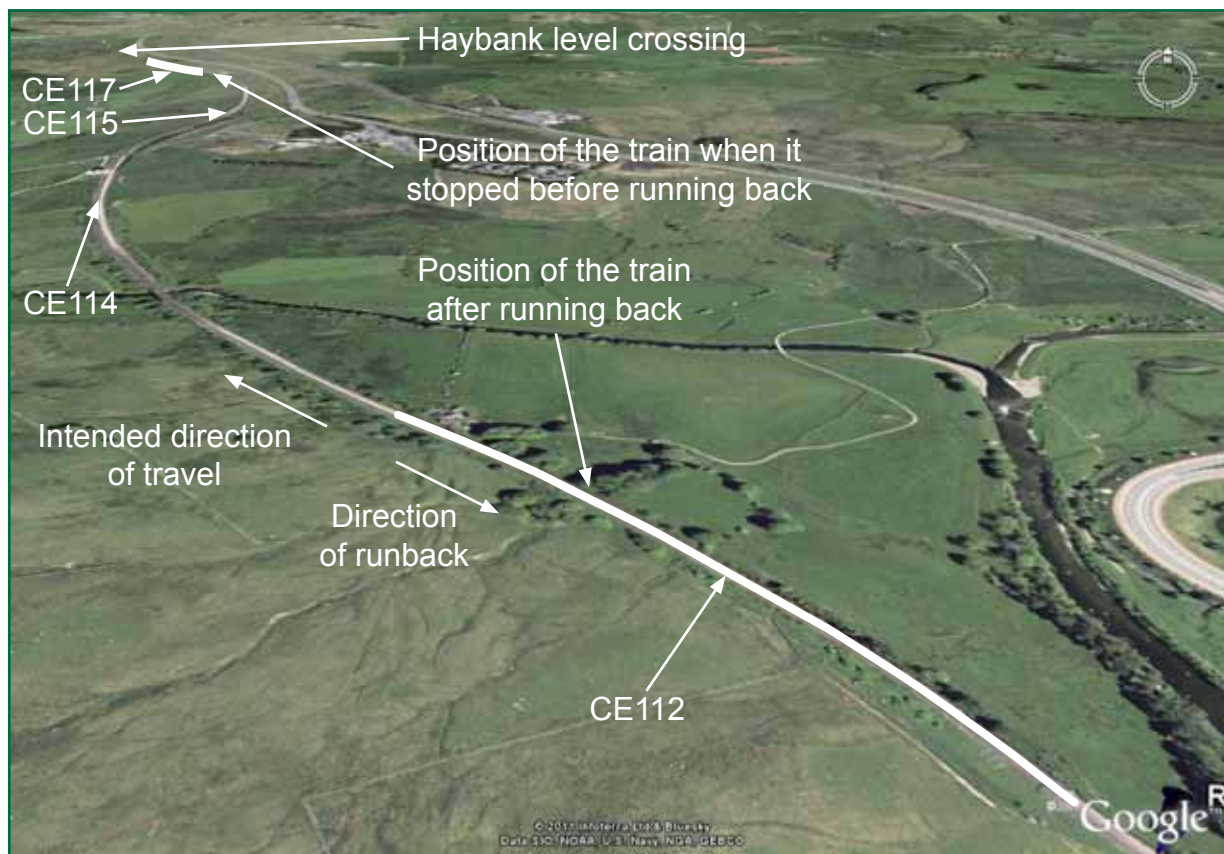


Figure 6: The location of events recorded by the data recorder (courtesy of Google Earth)

Events during the incident

- 12 The train continued to slow as it passed signal CE117, stopping 1025 metres from Haybank level crossing before rolling back down the gradient. During this time the driver cancelled two vigilance device warnings as he had not operated any other cab control to reset the device in over two minutes (paragraph 7a). The locomotive then passed signal CE117 a second time, this time in the wrong direction. The driver cancelled the warning for this signal, another vigilance device warning and the warnings given after the locomotive passed signals CE115 and CE114.
- 13 The train was travelling at 51 mph (82 km/h) when the driver noticed that his train was moving away from the green light of signal CE114 so he applied the brake and brought the train to a stand, by which time the train had run back for over four and a half minutes and had travelled 2.2 miles (3.5 km).

Events following the incident

- 14 Alarms and visual indications in Carlisle signal box alerted the signaller to an unidentified event on the track behind train 4S25. The signaller correctly concluded that train 4S25 was running back and so he:
 - a. blocked the lines between Grayrigg and Tebay to stop other trains, although there were no other trains in the immediate area at the time;
 - b. set a route to divert the train off the main line and into Tebay sidings; and
 - c. arranged for Network Rail's Manchester control centre to send an emergency stop call to the train's driver.
- 15 When the train stopped, its rear wagon was less than 800 metres from the turnout into Tebay sidings. The driver telephoned the signaller from this location at 02:09 hrs to report the incident but the emergency stop call interrupted their conversation. The driver listened to the message and then continued to describe the incident to the signaller. They reached an understanding that the incident was the result of a locomotive fault, after which the driver insisted that he was fit to continue and so the signaller allowed him to drive on to Carlisle, where he was met by a colleague who relieved him of his duties before driving the train from Carlisle to Mossend. The incident driver travelled in the back cab of the locomotive to Mossend where he was tested for alcohol and performance-impairing drugs; the tests did not detect the presence of either.

Consequences of the incident

- 16 The incident caused no injuries or damage; however the consequences could have been worse. If the driver had not braked the train to a stop when he did, 44 seconds later the rear of the train would have been travelling at a speed of 64 mph (103 km/h) over the 20 mph (32 km/h) turnout into Tebay sidings. This may have led to derailment, damage and obstruction of the adjacent line on which trains travel south.

Sources of evidence

- 17 The following sources of evidence were used:
 - a. witness statements;
 - b. information from the train's data recorder;
 - c. site photographs and measurements;
 - d. weather reports;
 - e. a review of similar accidents and incidents;
 - f. DB Schenker information on the train and its driver;
 - g. Network Rail information on the route and driver-signaller voice recordings;
 - h. a reconstruction of the events leading up to the incident;
 - i. a review of the literature on fatigue and sleep research;
 - j. UK organisations with rail industry expertise in fatigue, including the Office of Rail Regulation (ORR), Qinetiq and RSSB (Rail Safety and Standards Board);
 - k. UK and worldwide organisations with expertise in fatigue, including Circadian, Fatigue Science and Clockwork; and
 - l. analysis of shift patterns by mathematical models to estimate fatigue levels in shift workers.
- 18 The following organisations assisted the RAIB with advice and information during its investigation: the United States National Transportation Safety Board (NTSB), the Transportation Safety Board of Canada (TSBC), the European Rail Agency (ERA), the Air Accident Investigation Branch (AAIB) and the Marine Accident Investigation Branch (MAIB).

Key information and analysis

- 19 There was no evidence that the incident was the result of a locomotive fault, deliberate action, distraction or medical impairment of the driver. It was therefore considered likely that the driver allowed the train to stop and run back while cancelling warnings because of reduced alertness. The investigation considered the reasons for this, including the possibility that the driver was fatigued.

Background information

The causes of fatigue

- 20 There are four processes related to sleep that determine the level of fatigue in a person:
- Time spent awake:** when a person has been continuously awake for 14 hours or more their alertness is significantly reduced. On tests for alertness, perception and reaction, a person continuously awake over 21 hours is comparable with a person who is over the UK drink/drive limit (figure 7)¹.

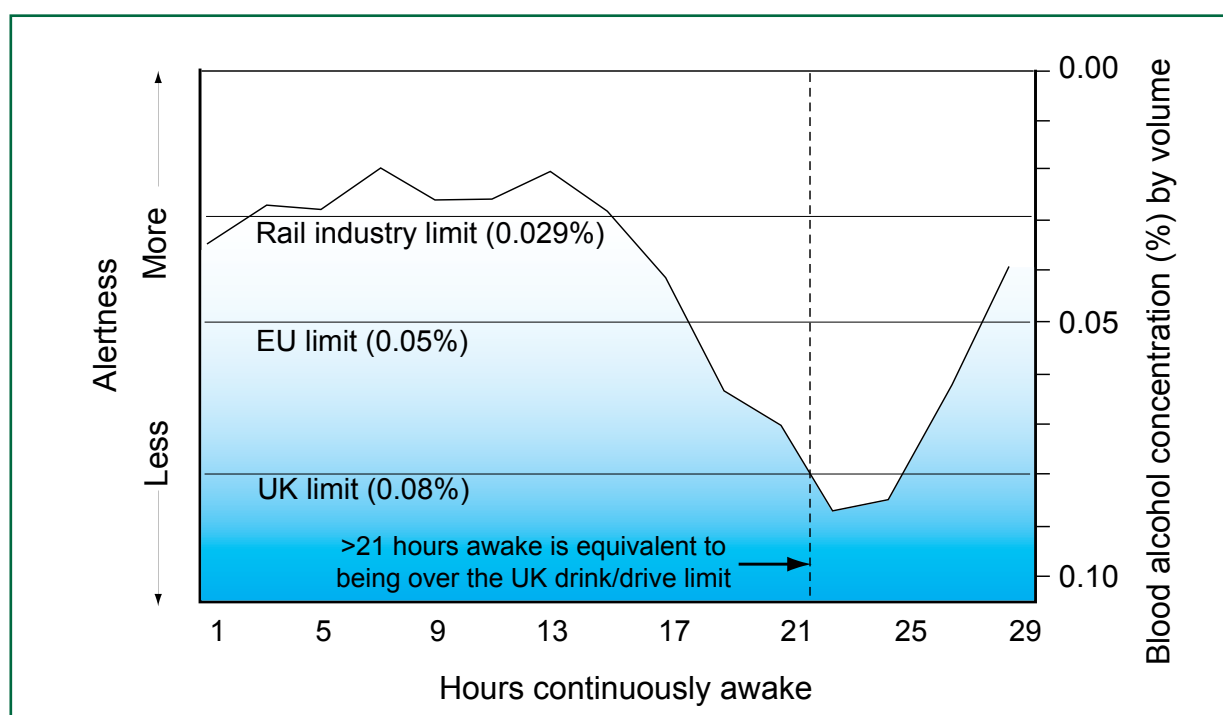


Figure 7: Performance and time spent continuously awake, starting from 08:00 hrs in the morning

- Time spent asleep:** most people need between seven and eight hours sleep each night; sleeping less leads to a slow build up of sleep loss which leads to reductions in alertness and performance on test (figure 8)^{2, 3}.

¹ Fatigue, alcohol and performance impairment. Dawson and Reid. 1997.

² Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. Belenky, Wesensten, Thorne, Thomas, Sing, Redmond, Russo and Balkin. 2003.

³ Sleepiness and performance in response to repeated sleep restriction and subsequent recovery during semi-laboratory conditions. Axelsson, Kecklund, Åkerstedt, Donfried, Lekander and Ingre. 2008.

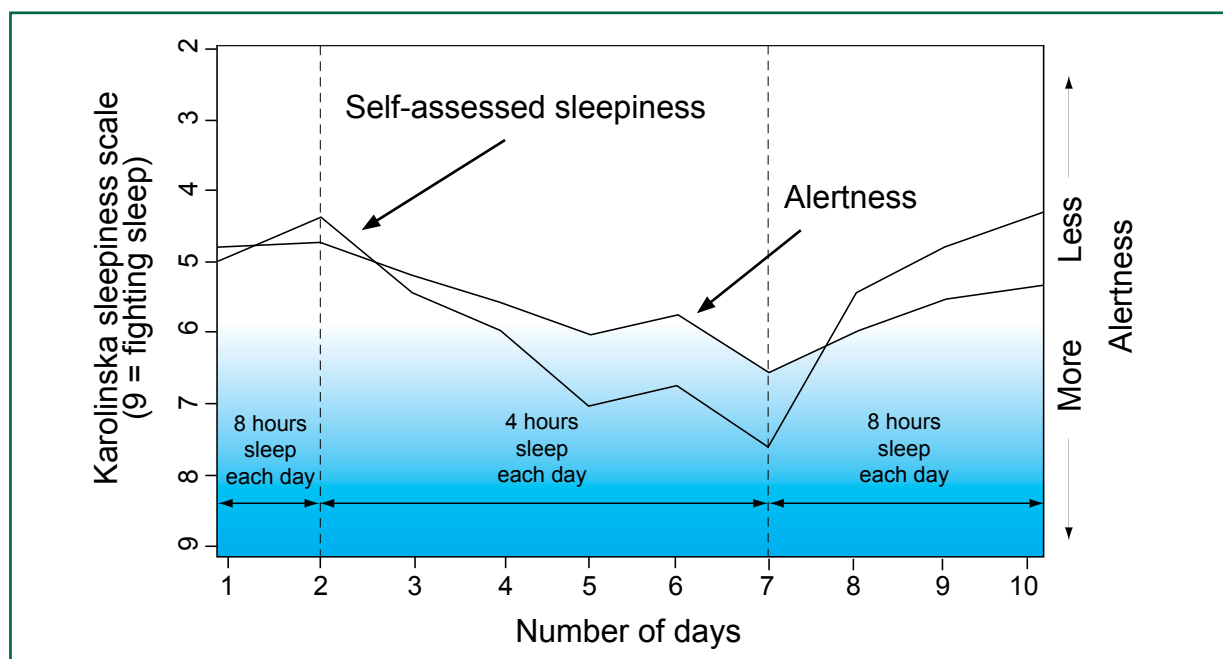


Figure 8: Performance and self-assessed sleepiness

- c. The time of day:** a person's sleep/wake cycle or 'circadian clock' is a strong influence: among other things it affects alertness, performance and body temperature. Alertness and performance are naturally at their highest in the late afternoon and evening when it is most difficult to sleep and at their lowest in the very early morning when it is most difficult to stay awake (figure 9)⁴.

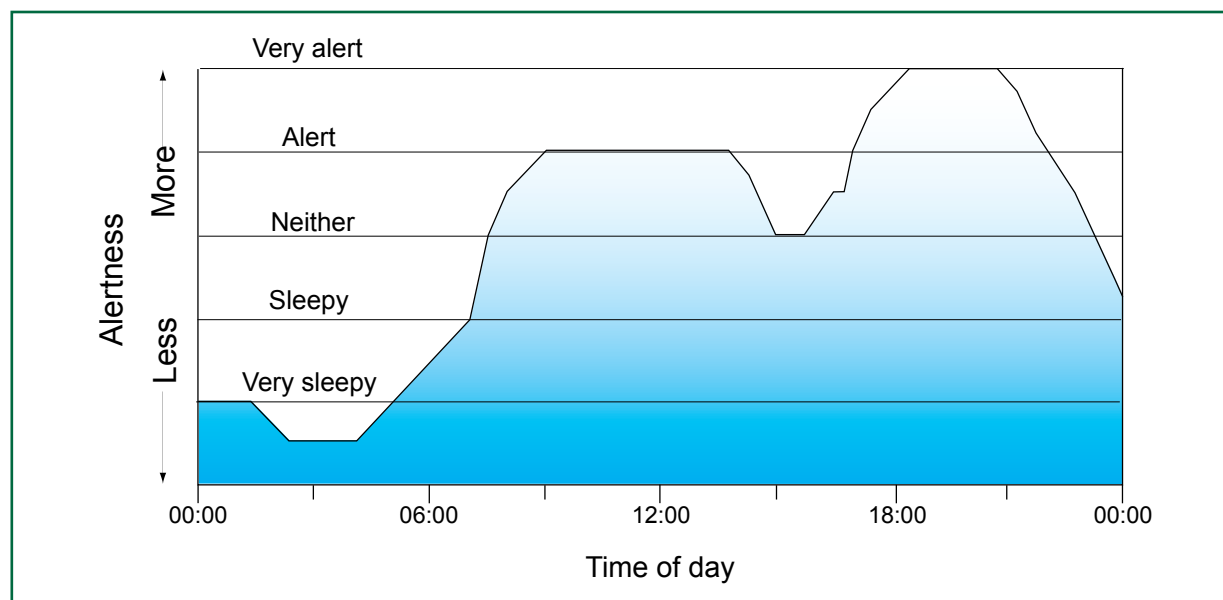


Figure 9: Alertness throughout the day

- d. Sleep inertia:** this is a passing state of reduced alertness and performance that occurs for a period immediately after waking⁵.

⁴ Sleepfaring-a journey through the science of sleep. Horne. ISBN 978-0-19-922837-9. 2006.

⁵ QinetiQ report T699 'Fatigue and shift work for freight locomotive drivers and contract track workers: implications for fatigue and safety'. Published in 2010 by RSSB.

Fatigue management

- 21 Employers and employees have a shared responsibility for ensuring that work is carried out safely and this is recognised in their legal duties and responsibilities:
 - a. working time limits, for example the Working Time Regulations 1998 (as amended), lay down requirements for organising working time, including the maximum number of hours an employer can ask an employee to work, the frequency of rest breaks and their duration; and
 - b. the Railways and Other Guided Transport Systems Regulations (ROGS) 2006, require that safety critical work is not carried out in circumstances where fatigue could significantly affect health and safety.
- 22 Shift workers may experience fatigue on shifts that comply with legal duties and working time limits; they may also be fit for safety critical work on shifts that do not comply. Some employers recognise this and include fatigue risk management within their Safety Management System (SMS). A Fatigue Risk Management System (FRMS) draws together the preventive and protective measures which help an organisation control risks from fatigue⁶.
- 23 QinetiQ report T699, Fatigue and shift work for freight locomotive drivers and contract track workers - implications for fatigue and safety, concluded that the UK railway industry should follow the example of the aviation industry and some railway organisations in the USA, and implement Fatigue Risk Management Systems. These systems depart from a prescriptive approach to duty hours and instead require companies to establish their own procedures for managing the risks associated with fatigue. The purpose of these systems is to ensure that members of staff are sufficiently alert to operate to a satisfactory level of performance and safety.

The Fatigue and Risk Index

- 24 The Fatigue and Risk Index (FRI) is a mathematical model designed to predict fatigue and risk arising from the processes described in paragraph 20. It is widely used in the rail industry to plan shifts, investigate accidents and incidents, and its users include passenger and freight train operators, Network Rail and organisations that work on the railway infrastructure. Produced for the Health and Safety Executive (HSE) by QinetiQ in 2006, the Fatigue and Risk Index was developed from the Fatigue Index Risk Assessment Tool (produced by DERA, now QinetiQ, in 1999).
- 25 The Fatigue and Risk Index constructs its predictions from three separate components: a cumulative component associated with the pattern of work and rest; a duty timing component associated with the shift start time, the time of day throughout the shift and the shift length; and a job type/breaks component associated with the intensity of the work being carried out, the timing of breaks and their duration. The scores are interpreted as follows:
 - a. fatigue scores from 0 to 100 represent the probability that a person is experiencing high levels of fatigue⁷, so a score of 50 is the probability that one in every two people would be fatigued to this extent; and

⁶ Managing rail staff fatigue draft guidance, The Office of Rail Regulation, 2011.

⁷ The Fatigue and Risk Index considers high levels of fatigue to be values of eight or nine on the Karolinska Sleepiness Scale (KSS), a nine point scale ranging from one - extremely alert to nine - extremely sleepy and fighting sleep. The KSS is one of several methods used to subjectively estimate sleepiness.

- b. risk scores represent the relative risk of a fatigue-related event; a score of one represents the average risk on a two-day, two-night, four-off schedule of 12 hour shifts starting at 08:00 hrs and 20:00 hrs; a score of two represents a doubling of risk.
- 26 Health and Safety Executive (HSE) research report 446, the Development of a Fatigue / Risk Index for Shift Workers (2006), explains the derivation of the Fatigue and Risk Index and presents research findings which state:
- a. that performance errors increase and alertness decreases over four consecutive night shifts due to a slow build up of sleep loss (Walsh, 2004); and
 - b. that people can adapt over seven consecutive night shifts with the first night shift carrying the greatest impairment in performance due to being continuously awake for a long period (Lamond, 2003 and 2004).
- 27 The report also refers to studies that correlate reduced alertness and performance with lack of sleep which state:
- a. that reduced performance and poor alertness correlate with being continuously awake for a long period much more closely than with a slow build up of sleep loss (Van Dongen, 2003); and
 - b. that a slow build up of sleep loss leads to fewer decrements in performance and alertness than being continuously awake for a long period (Drake, 2001).

Fatigue and Risk Index thresholds

- 28 Health and Safety Laboratory report RSU/08/03, the Evaluation of the UK Rail Sector Initial Fatigue & Risk Index Thresholds (2008), proposes day and night shift thresholds for scores predicted by the Fatigue and Risk Index. The report found that night shift thresholds of 40 - 45 for fatigue and 1.6 for risk represented good practice at this time.

DB Schenker's management of shift work and fatigue

- 29 DB Schenker manages shift work and fatigue as follows:
- a. it plans shifts that generally follow industry guidance and comply with working time limits less demanding than those in the Working Time Regulations;
 - b. it runs all shifts through the Fatigue and Risk Index and checks each shift's scores with industry good practice thresholds (paragraph 28);
 - c. it aims to manage and reduce fatigue by changing shifts that have scores close to and above those thresholds;
 - d. it consults with its employees and their trade unions on planned shifts;
 - e. it provides drivers with information on ways to manage fatigue and their responsibility to be fit for duty;
 - f. its supervisors periodically assess their drivers for fitness for duty using a checklist that includes checks for fatigue; and
 - g. it allows its drivers to refuse to work if they feel they cannot safely carry out their duties.

Identification of the immediate cause⁸

- 30 **The immediate cause of the incident was that the driver did not demand enough power for the train to climb the gradient, and then did not apply the brakes to stop it from running back (paragraphs 12 and 13).**

Discounted factors

Locomotive performance

- 31 The locomotive's management system automatically shut down one convertor after its sensor detected high oil temperature (paragraph 11). DB Schenker examined the train after the run-back and found the convertor's radiator blocked with leaves and debris, which caused its cooling oil to overheat. It found no other faults with the train's power, braking and control systems. Train performance can be discounted as a factor in the incident because the fault had only a small effect on available power and the driver was not demanding power as his train slowed to a stop before running back.

The train driver's competence and medical fitness for duty

- 32 The driver was ranked among DB Schenker's most capable drivers because he was competent, medically fit for his duties and had not had a safety related accident or incident from when he started driving trains in 1976 to the run-back in August 2010. The driver was most recently assessed to be competent in his duties in accordance with DB Schenker's competence management system on 8 December 2008 and was assessed to be medically fit for his duties on 4 March 2010, his most recent medical before the incident. At his post-incident medical on 23 August 2010 he was found to be generally fit, healthy and able to go back to his duties with no restrictions.

Identification of the causal factor⁹

- 33 **The causal factor was that the driver was not sufficiently alert at the time of the incident because:**
- a. he was probably fatigued;**
 - b. his journey was monotonous;**
 - c. he was in a dark and comfortable environment; and**
 - d. there was little in his field of view to attract his attention.**

The driver was probably fatigued

- 34 The driver stated that he felt fit for duty when he arrived for work at 18:34 hrs and in the weeks before the incident he had been active and at his most alert at this time. The driver stated that he did not feel the train slow to a stop at 02:04 hrs and only became aware that it was running back when he saw the green signal of CE114 receding after he had cancelled its in-cab warning. He accepted that he was disoriented at this time but could not explain why.

⁸ The condition, event or behaviour that directly resulted in the occurrence.

⁹ Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

- 35 Figure 10 shows the driver's shifts and reported sleep patterns. When the RAIB compared the driver's shifts with the processes that influence fatigue (paragraph 20 and figure 11), it concluded that it was foreseeable that the driver may have been experiencing high levels of fatigue at the time of the incident as:
- he had been continuously awake for over 18 hours; he stated that he tried but could not sleep in the day before the first night shift so instead carried out light duties around the home;
 - he was driving his train at 02:04 hrs, a time of day when his alertness and performance levels were at their lowest; and
 - he possibly had some sleep loss due to progressively earlier shift start times from Thursday 12 to Saturday 14 August.

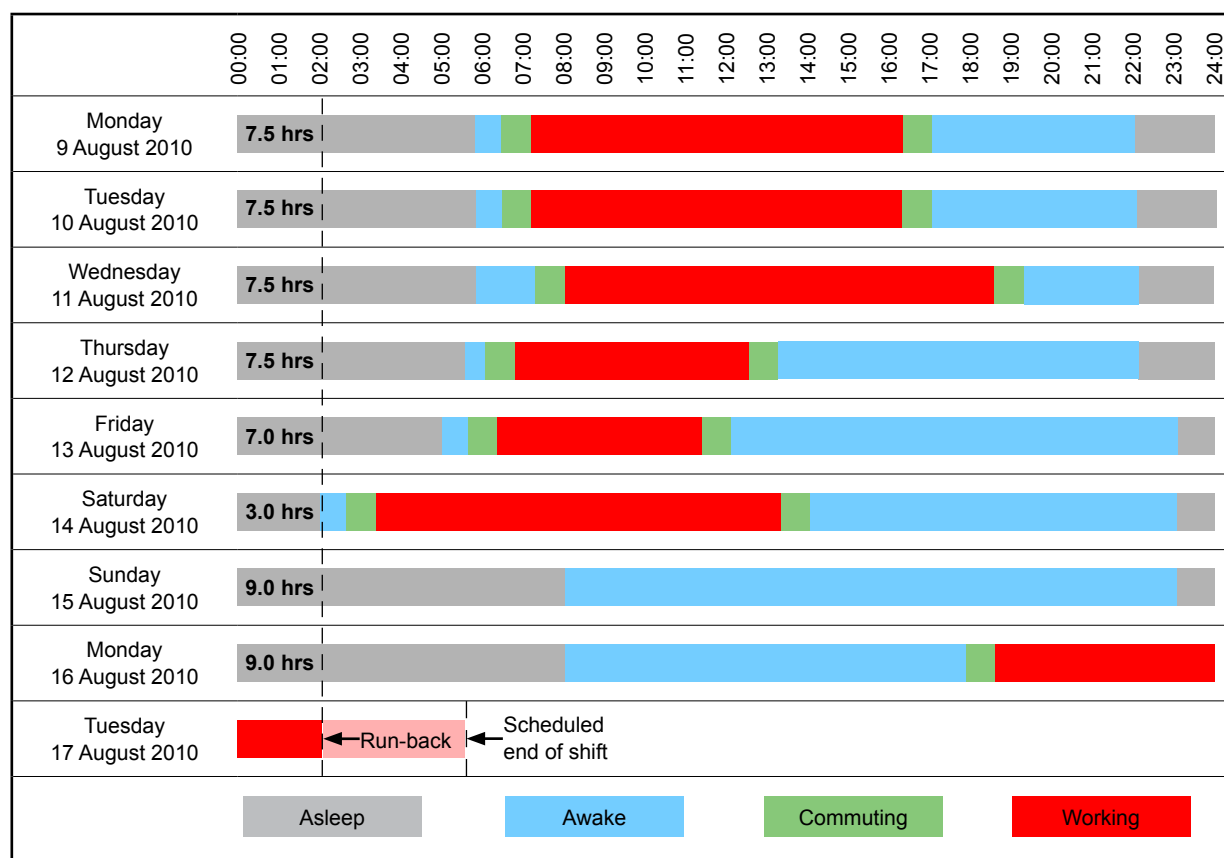


Figure 10: The driver's shifts and reported sleep patterns leading up to the incident

- 36 The RAIB spoke with several freight train drivers in the course of this investigation. All stated that it is most difficult to remain alert on the first night shift and that alertness improves over successive night shifts. This supports the findings of a recent study¹⁰ in which 81% of freight train drivers stated that they found their first night shift the most tiring.
- 37 Between March 2000 and November 2010, fatigue was a factor in 111 rail industry accidents and incidents for which information on shifts was available. Of the 111 events, 57 occurred on night shifts. More accidents and incidents occurred on the first night shift than on the following night shifts, and this was true for the industry as a whole and for freight train operations alone (figure 12).

¹⁰ QinetiQ report T699, fatigue and shift work for freight locomotive drivers and contract track workers: implications for fatigue and safety. Published in 2010 by RSSB.

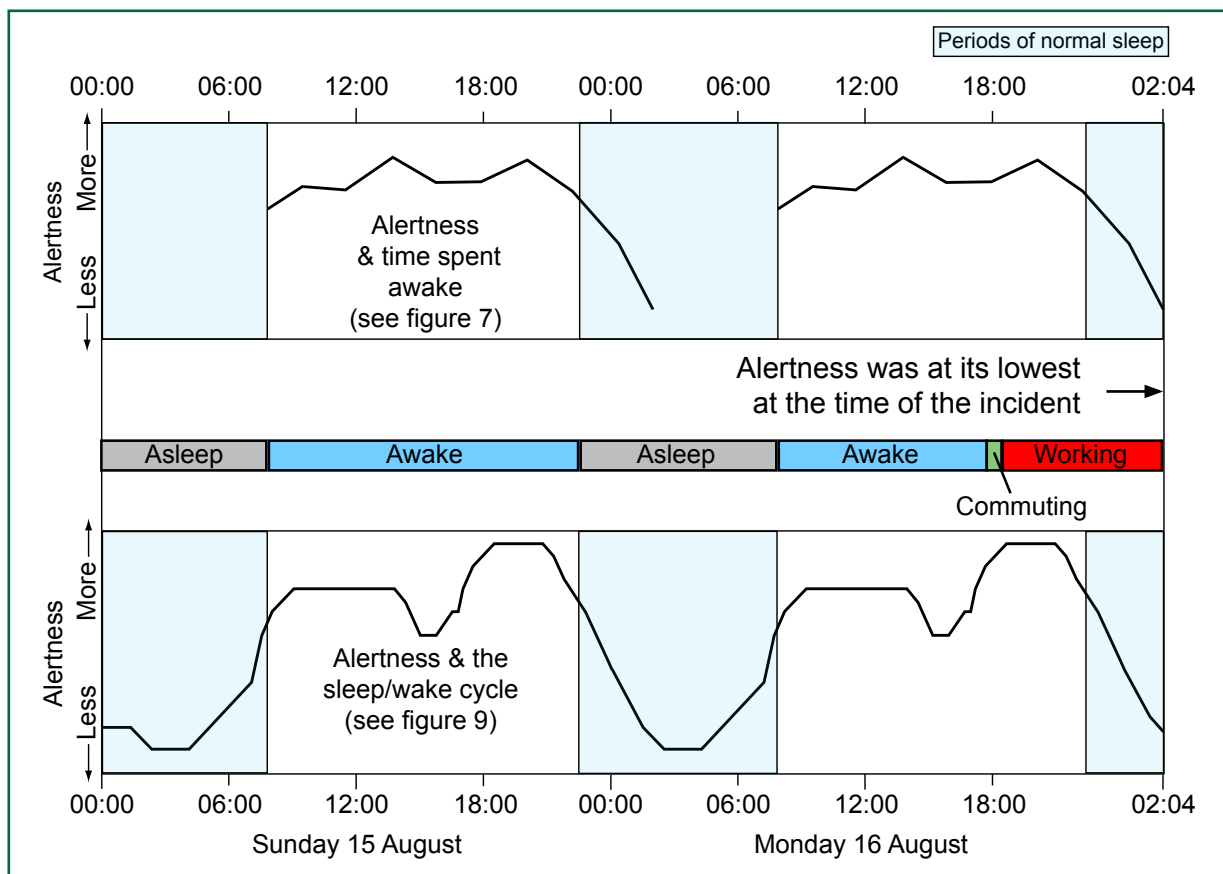


Figure 11: The processes that influenced fatigue leading up to the incident

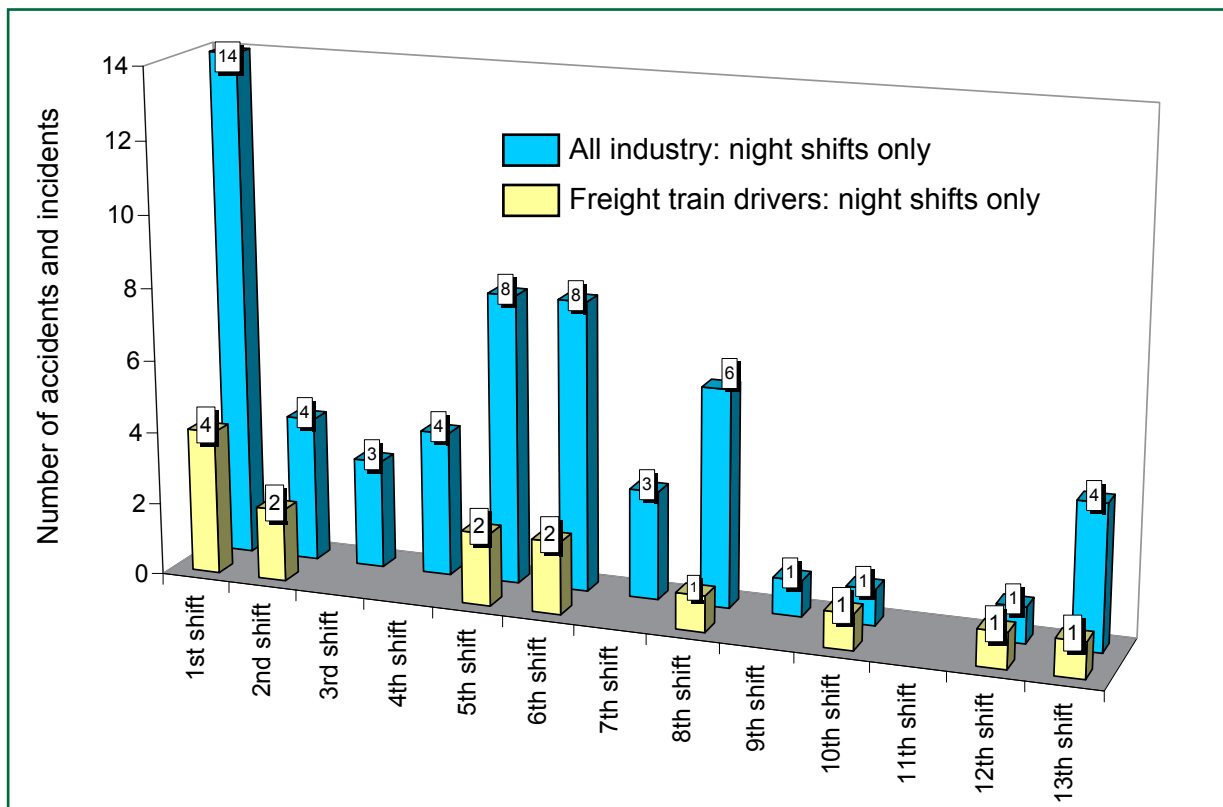


Figure 12: Night shift accidents and incidents with fatigue as a causal factor: years 2000 to 2010. Information courtesy of the RSSB's Safety Management Information System

- 38 The RAIB considered whether a larger population of first night shifts, compared with second and subsequent night shifts, would explain the higher number of freight train driver accidents and incidents. It found that:
- together, DB Schenker and Freightliner employ over 90% of Great Britain's freight train drivers and both normally schedule them to work five consecutive night shifts; and
 - 75% of night shifts worked by freight train drivers comprise between five and six consecutive shifts (figure 13), and this is comparable with the percentage for consecutive shifts relating to day, early and late shifts.

It can therefore be concluded that the slightly greater number of first night shifts, compared with second and subsequent shifts, is insufficient to explain its higher number of accidents and incidents (also paragraphs 50 to 53).

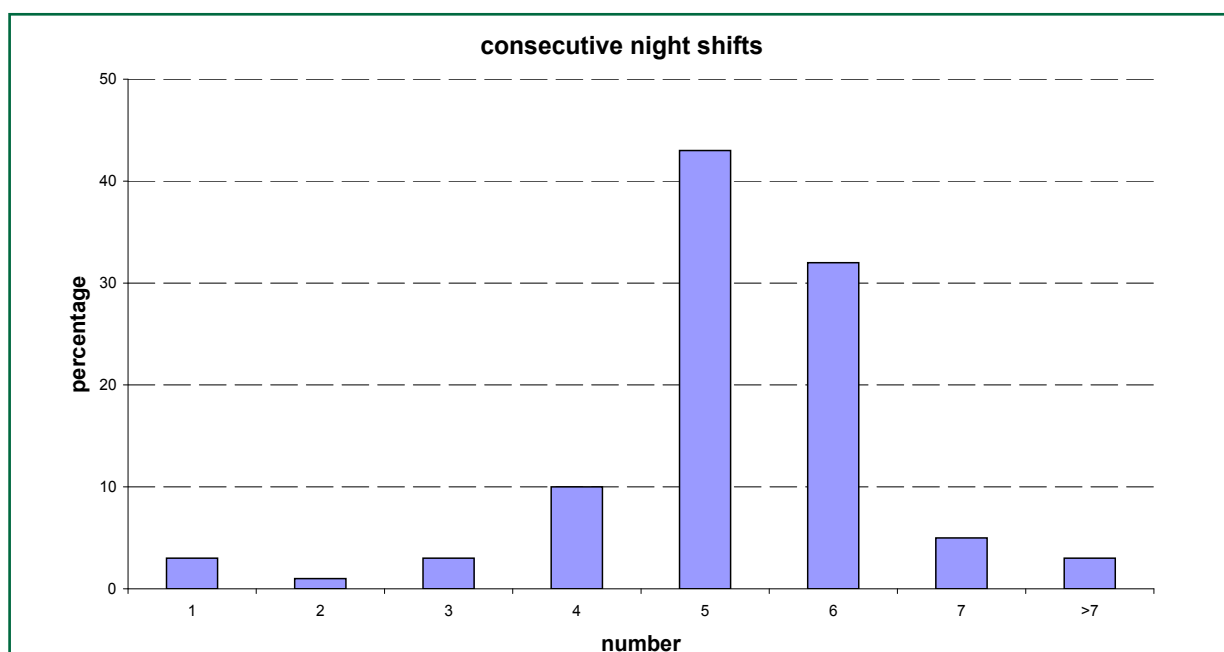


Figure 13: The number of consecutive night shifts worked by freight train drivers. QinetiQ report T699, *Fatigue and Shift Work for Freight Locomotive Drivers and Contract Track Workers: Implications for Fatigue and Safety*. Published in 2010 by RSSB.

The driver's journey

- 39 Leading up to the incident the driver's journey had been monotonous and not particularly demanding, challenging or stimulating because he was familiar with the route and his locomotive; he had driven freight trains on the west coast since 1976 and had driven class 92 locomotives since 1999. The driver stated that the journey became even more monotonous when he caught up with and then followed a slower train. This is a regular occurrence for drivers of train 4S25, and may increase the Warrington Bank Quay to Mossend journey time from three to four and a half hours. During this time the driver acted less frequently to control his train but more frequently to cancel warnings from the driver's vigilance device and the automatic warning system. Cancelling frequent warnings is known to become habitual^{11,12,13}, particularly with reduced alertness and monotony.

¹¹ RSSB Railway Group Guidance Note GO/RT3652.

¹² RSSB report T024 - Driver Vigilance Devices: Systems Review. 2002.

¹³ RSSB report RS/232 - Good Practice Guide on Cognitive and Individual Risk Factors. 2008.

The driver's environment

- 40 Freight train drivers consider the class 92 locomotive cab to be a quiet and comfortable environment at all operating speeds. At the time of the incident only control and instrument panel lighting illuminated the cab, air conditioning equipment controlled the cab's temperature and ventilation and the ride was smooth and quiet as the train followed the slower train at 20 mph (32 km/h) for over 4 miles (6.4 km).

The driver's field of view

- 41 The driver had little in his field of view to attract his attention or to help him perceive the train slowing from low speed to a stop before rolling back, as the train headlights illuminated a small, relatively unchanging scene as he travelled through a rural area in darkness and rain.

The reconstruction

- 42 On 10 November 2010 an RAIB inspector carried out a reconstruction of events leading up to the incident. Although the inspector's preceding work and sleep patterns were not identical to those experienced by the driver, the reconstruction was similar to the incident journey because the RAIB inspector tried but could not sleep during the day, travelled in a class 92 locomotive hauling train 4S25 in darkness and rain, and was slowed on the approach to Tebay after his train caught up with a slower train. The inspector found that he felt alert from the time he reported for duty until around 01:00 hrs, after which he began to experience high levels of fatigue.

The underlying factors¹⁴

- 43 **The underlying factors were:**
- a. the scores predicted by the Fatigue and Risk Index; and**
 - b. the nature of the rail industry's guidance on using mathematical models.**
- As a consequence of these underlying factors, DB Schenker unknowingly planned a sequence of shifts that were likely to induce high levels of fatigue.**

The scores predicted by the Fatigue and Risk Index

- 44 DB Schenker planned the driver's shifts to comply with guidance, legal duties and working time limits and calculated scores for the driver of 13.1 for fatigue and 0.93 for risk at the time of the incident: well below night shift thresholds of 40 - 45 for fatigue and 1.6 for risk. For these reasons it concluded that its driver should have been fit for his duties at the time of the incident.

¹⁴ Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

- 45 The RAIB used the Fatigue and Risk Index to predict the probability of fatigue for different outcomes to understand how its scores compared with the processes that determine fatigue. The Fatigue and Risk Index predicted that the probability of experiencing high levels of fatigue was:
 - a. 13.1 % at the time of the incident;
 - b. 31.3% at the scheduled shift end of 05:43 hrs; and
 - c. 34.4 % at the scheduled shift end if the driver had been active from 09:00 hrs to 16:00 hrs before starting the night shift at 18:34 hrs.
- 46 Probabilities (a) – (c) are below the industry good practice night shift threshold. However, at the end of a first night shift many people have been awake around 24 hours^{15,16,17}, because it is difficult to sleep during the day after regularly sleeping at night. It is therefore likely that more than a third of people would be experiencing high levels of fatigue at this time. See figure 7 for the effect of time spent awake on alertness.
- 47 Studies in 2004¹⁸ and 2009¹⁹ assessed mathematical models used to predict fatigue; both studies found limitations in the ability of existing models to predict the effect of sleep deprivation on performance. These studies were followed, in 2010, by a Department for Transport report²⁰ which reported limitations with mathematical models and quoted flight crews arriving for work stating that they were fatigued to which their employer replied that its fatigue model said that they were not.
- 48 The RAIB had the driver's shift patterns analysed by four other mathematical models for simple comparison, with the following results:
 - a. model one, used to investigate accidents and incidents, predicted a very high probability that the driver was fatigued at the time of the incident;
 - b. models two and three, used to plan shift work, predicted that the driver was more fatigue-impaired on the first night shift than on any previous shifts; while
 - c. model four, also used to plan shift work, predicted that the driver was most fatigue impaired on the shift that started at 03:15 hrs on Saturday 14 August 2010.

¹⁵ Sleepfaring-a journey through the science of sleep. Horne. ISBN 978-0-19-922837-9. 2006.

¹⁶ Fatigue, alcohol and performance impairment. Dawson and Reid. 1997.

¹⁷ Seafarer fatigue-where next? The Centre for Occupational and Health Psychology, Cardiff University. 2007.

¹⁸ Comparison of Mathematical Model Predictions to Experimental Data of Fatigue and Performance. Van Dongen. 2004.

¹⁹ A new mathematical model for the homeostatic effects of sleep loss on neurobehavioural performance. McCauley, Kalachev, Smith, Belenky, Dinges and Van Dongen. 2009.

²⁰ Road Safety research Report No. 120: Interviews with operators, regulators and researchers with experience of implementing fatigue risk management systems.

The nature of the rail industry's guidance on using mathematical models

- 49 Rail industry guidance recommends using QinetiQ's Fatigue and Risk Index to predict fatigue and investigate the contribution it makes to accidents and incidents; it does not describe its limitations or explain that a mathematical model is not an essential part of a fatigue risk management system. For example:
- a. In 2006 RSSB published QinetiQ report T059, a Human Factors Study of Fatigue and Shift Work. The report's guidelines for fatigue monitoring concluded that the Fatigue Index was the best option for assessing the shift patterns of safety critical rail workers when compared with other techniques. Appendix F recommended that it should be used to measure risks associated with shifts and to estimate the contribution of fatigue to accidents.
 - b. In 2010 RSSB published QinetiQ report T699, Fatigue and Shift Work for Freight Locomotive Drivers and Contract Track Workers: Implications for Fatigue and Safety. The report's conclusions stated that mathematical models could be used to estimate the risk of fatigue, and that this could be achieved using the Health and Safety Executive's Fatigue and Risk Index. All four freight train operating companies and fourteen infrastructure companies involved in T699 were found to use the Fatigue and Risk Index.
 - c. In 2006 the Health and Safety Executive published user guidance for the Fatigue and Risk Index. Its cautions for users state that:
 - i. it should be used to identify where the most serious fatigue risks are likely to be before putting into place suitable and sufficient controls for those risks, for example by altering the work pattern, planning the work differently, introducing rest breaks, supervision etc; and
 - ii. it is most effective when used with other arrangements for managing the risks from fatigue, and can be used to compare different work patterns (for example when planning changes to shift work) or to look within a work pattern to identify those duties with a higher potential for fatigue to arise.

Observations²¹

Under-reporting of fatigue-related events and their analysis

- 50 It is likely that fatigue-related accidents and incidents are under-reported and instead attributed to other things including equipment failure, driver error and inattention. This helps to explain why the data set in paragraph 37 comprised only 111 fatigue-related accidents and incidents reported by the rail industry from 2000 to 2010.
- 51 The industry database does not identify all fatigue-related accidents and incidents because fatigue was not stated as a factor when data were entered into the RSSB's Safety Management Information System. When the RAIB compared its fatigue data with reports into fatigue-related accidents and incidents from 2002 to 2008, it found 21 events were missing including the derailment at East Somerset Junction in 2009, the collision at Badminton in 2006 and the collision at Leigh-on-Sea in 2008 (paragraph 65).

²¹ An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the incident but does deserve scrutiny.

- 52 The authors of report T699 expected to find a wide range of fatigue-related accident and incident information to support their work. Instead they found that it was either not available or was in a form unsuitable for analysis so instead they used data from 1728 Signal Passed at Danger (SPAD) events taken from RSSB's Safety Management Information System. The report described the following limitations in the data set:
- there were far fewer fatigue reports than expected so it is extremely likely that the importance of this issue has been considerably understated; and
 - fatigue was identified in only one event involving a freight train operating company, with the cause of fatigue described as a 'lifestyle' issue.
- 53 The authors of T699 used a method of correction on the data set which estimated that the risk of passing a signal at danger remained relatively steady over the first six consecutive days of a shift pattern, despite raw data showing that events decreased over this period. However, the report explained that its method of correction was unlikely to provide an accurate estimate of the true exposure, and hence its results should be treated with some caution.

The Fatigue and Risk Index thresholds

- 54 Monotonous, safety critical lone working, carried out at night in a comfortable environment, should conform to a lower fatigue threshold than that for stimulating, non-safety critical work, carried out in a group in environmental conditions that help combat fatigue, for example bright light. However, there is only one night shift threshold for fatigue (paragraph 28) with no discrimination as to the type of work, the way it is carried out or the environment in which it is done.

Guidance is not appropriate for all types of shift work

Number of consecutive night shifts

- 55 Reports T059 and T699 conclude that no more than three consecutive night shifts should be worked, because consecutive night shifts are associated with increasing sleep loss. This would result in more first night shifts being worked which does not accord with evidence suggesting that:
- with an increasing number of night shifts, some individuals had less difficulty concentrating during the night and found it less difficult to sleep between consecutive shifts (QinetiQ report T699);
 - people can adapt to night work across consecutive duties (paragraph 26b);
 - being continuously awake for a long period correlates most closely with reduced performance and alertness compared with a slow build up of sleep loss (paragraph 27);
 - people find the first night shift the most tiring (paragraph 36); and
 - more accidents and incidents occur on the first night shift than on other nights (paragraph 37).

- 56 The Fatigue and Risk Index predicts that the proportion of workers experiencing high levels of fatigue increases with each successive night shift following the first, however other mathematical models which allow for adaptation over successive nights predict the reverse. Working more first night shifts with no adjustment may be appropriate for stimulating, non-safety critical work, carried out in a group in environmental conditions that help combat fatigue; it may not be appropriate for train drivers working alone, at night, on monotonous journeys.

The transition to a first night shift

- 57 The driver had one day off work before his first night shift, which is not unusual for freight train drivers who routinely work five or six consecutive shifts before a day off (paragraph 38 and figure 13). The driver stated that he tried but could not sleep on the day before his first night shift (he also tried but could not obtain extra sleep ahead of the shift that started at 03:15 hrs on Saturday 14 August 2010). This is understandable because the driver had been awake and at his most alert at those times in the days before his early and night shifts.
- 58 The RAIB believes that the transition to night and early shifts should be the subject of specific and appropriate guidance that includes information on shift start times, durations and duties. For many workers, making the transition to a night or an early shift is very difficult because it goes against the normal sleep/wake cycle, and the transition is not appreciably improved by increasing the number of days off work unless the worker is able to adjust their sleep/wake cycle in this time. Although industry guidance states that a daytime nap may be an effective countermeasure against tiredness during a night shift, the majority of guidance relates only to the transition from night shift working, for example:
- report T059 concludes that the transition from night shifts to early shifts should include a break of at least two days, while all other transitions should include a break of at least one day; and
 - report T699 concludes that where a sequence of consecutive shifts is worked then a single rest day may not provide adequate recovery, for example following a night shift that ends at 06:00, there will be a requirement for more than a single day off to ensure complete recovery.

Office of Rail Regulation Guidance

- 59 The Office of Rail Regulation published Managing Fatigue in Safety Critical Work in July 2006. It provides guidance to help employers ensure that their employees do not undertake safety critical work when fatigued. Like T059 and T699, it recommends minimising the number of consecutive night shifts and allowing two rest days after a block of night shifts, but it has no specific arrangements for managing the transition to night shifts. It also recommends:
- Shift patterns that rotate forward, for example moving from a day to an evening or a night shift rather than backward from a night to an evening or a day shift; and
 - a two hour maximum variation in start time between consecutive shifts, rather than the industry norm of up to four hours.

- 60 While these recommendations may be appropriate in isolation, taken together they may discourage the adoption of shift patterns that help manage the transition from one type of shift to another, for example a worker finishing a series of night shifts at 05:00 hrs and then working a shift from 16:00 hrs to 24:00 hrs. Some research suggests that the worker would be fit for the evening duty because he has been working at night and sleeping in the day, will wake close to the shift start time and will work at a time of day he has recently been alert. However, guidance discourages this transition because:
- the shift start times vary by eleven hours and not two to four hours;
 - the shifts rotate backward not forward; and
 - two rest days are not provided after the block of night shifts.

Napping

- 61 Napping is brief and shallow sleep which can be effective in restoring alertness if done in a controlled manner²², and it is promoted in some industry guidance as a strategy to combat fatigue. Other guidance recommends avoiding a nap on the night shift unless very sleepy if working more than three consecutive night shifts²³. Such guidance is appropriate for road users who can quickly pull over and rest as often as necessary or for aircraft pilots who can nap while their colleagues take on their responsibilities. It is not appropriate for train drivers who may be well into their journey before they feel very sleepy; they are unlikely to stop and rest at this time because they would block a railway line.
- 62 Recommendations arising from the Brentingby derailment (paragraphs 67 and 68) included the use of napping as a fatigue countermeasure. Freight train operating companies responded to the recommendations by stating that they were agreeable to their drivers taking naps during breaks in their duties and this was found to happen in practice: reports T059 and T699 found that 40% of passenger train drivers and 34% of freight train drivers napped at some time during their night shifts.

Individual differences

- 63 Individuals vary in their ability to remain alert for shift work for many reasons; for example because:
- some adapt more easily to changes in their sleep patterns;
 - some are more alert in the mornings, others in the evening;
 - some find their alertness changes with changes in their age, health and fitness;
 - some organise their home and work lives better than others; and
 - all individuals are affected by unexpected events and changes to their personal circumstances from time to time.

The investigation considered the Brentingby and Shap shifts and concluded that the drivers involved would be among many others in experiencing high levels of fatigue on those shifts, regardless of their individual differences (paragraph 46).

²² RAIB report 01/2007: freight train derailment at Brentingby on 9 February 2006.

²³ Feeling Tired? RSSB guidance on fatigue and shift work.

Benefits of a well-designed shift system

- 64 A well-designed shift system reduces absenteeism, sickness, staff turnover, compensation claims and lost-time incidents²⁴; it also reduces the likelihood of fatigue-related accidents and their costs. DB Schenker estimated that the cost of the Brentingby derailment was approximately £50,000 plus the costs associated with replacing the driver who resigned after the accident.

Previous similar accidents and incidents

- 65 The RAIB has investigated several accidents and incidents in which fatigue was a factor. Between 2006 and 2008 these included three derailments, two collisions and a train that passed a signal at danger:
- RAIB report 01/2007: freight train derailment at Brentingby on 9 February 2006 (figure 14);
 - RAIB report 24/2007: freight train derailment at Maltby North on 28 June 2006;
 - RAIB report 27/2007: freight train that passed a signal at danger at Purley station on 18 August 2006;
 - RAIB report 30/2007: collision of two track maintenance machines at Badminton on 31 October 2006;
 - RAIB report 24/2009: collision of two freight trains at Leigh-on-Sea on 26 April 2008; and
 - RAIB report 28/2009: derailment of a freight train at East Somerset Junction on 10 November 2008.



Figure 14: Derailment at Brentingby Junction, 9 February 2006

²⁴ Sleepfaring-a journey through the science of sleep. Horne. ISBN 978-0-19-922837-9. 2006.

- 66 RAIB reports in paragraph 65 (a), (b), (e) and (f) make reference to previous similar accidents and incidents investigated by organisations other than the RAIB so reference to those events is not made again in this report. The derailment at Brentingby in 2006 is the accident most similar to the run-back between Shap and Tebay and so it is considered in more detail in this report.

The derailment at Brentingby - RAIB report 01/2007

- 67 At 05:31 hrs on 9 February 2006, an EWS (now DB Schenker) freight train derailed at Brentingby, near Melton Mowbray, after its driver passed a red signal (figure 14). The driver was coming to the end of his first night shift and had been awake over 22 hours at the time of the accident. During the Shap investigation, the RAIB used the Fatigue and Risk Index and the Brentingby driver's shifts to calculate that he had a fatigue score of 14.8 and a risk score of 0.83 at the time of the accident. These scores are well below industry good practice night shift thresholds.
- 68 Appendix C of the Brentingby report summarised occasions when drivers passed signals at danger because they were fatigued. In the three years to February 2006 there were thirteen such events, four of which (or >30%) occurred on the first night shift; if the Brentingby derailment is included, five events in fourteen (or 36%) occurred on the first night shift. See paragraph 62 and RAIB report 01/2007 for actions arising from the Brentingby derailment.

Actions reported as already taken or in progress relevant to this report

The driver

- 69 The driver underwent a satisfactory return-to-work medical assessment followed by: a re-skilling day on rules, company policies and instructions; a practical assessment of train driving competence; a review of class 92 locomotives; and familiarisation with the 21st Century Driver lifestyle video. The driver was then not allowed to drive between 00:01 hrs and 06:00 hrs, during which time he used a lifestyle diary to keep a record of out of work activities, hours of sleep, hours of duty and any instances of fatigue and tiredness at work. DB Schenker carried out additional fitness for duty checks on the driver during which lifestyle was discussed, his diary was checked and his train data recorder downloads were analysed for fatigue issues. The driver returned to normal duties in April 2011.

Guidance

- 70 The Office of Rail Regulation is updating Managing Fatigue in safety Critical Work, which it originally published in July 2006. It advised the RAIB that its updated guidance will recommend a three-stage process for fatigue management, with shifts planned in accordance with good practice before they are assessed for fatigue and risk. The process will then recommend taking into account the experiences of shift workers. The updated guidance will also warn against the limitations of mathematical models.

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

Incident management

- 71 Network Rail and DB Schenker put in place procedures to ensure that following serious irregular working events:
 - a. the senior DB Schenker on-duty manager must ensure that the staff involved are fit to move the train to a location where it can be taken out of service or to a location where investigations can take place; and
 - b. the signaller must not allow the train to move until positive advice has been received from the Network Rail route control manager.

Roll-back prevention

- 72 The incident described in this report is unusual because trains with functional braking systems rarely run back and when they do, it is typically over a very short distance with low or no consequences. Roll-back prevention would not protect against drivers going forward and cancelling warnings for signals they pass at danger, as happened with the accident at Brentingby in 2006 and the fatal accident at Lenton South Junction in 1971, the latter caused by a driver who cancelled at least three AWS warnings while going forward.
- 73 The class 92 locomotive is similar to all DB Schenker locomotives in that it is designed to immediately brake and bring itself to a stop if it detects forward or reverse movement when its direction selector is in neutral. DB Schenker carried out a cost-benefit analysis into preventing roll-back of their locomotives when direction selectors are in forward and concluded that the change was not reasonably practicable given the cost of modification and the very low incidence of this type of event.
- 74 The RAIB makes no recommendation for DB Schenker to make such a modification to its locomotives. However, it observes that roll-back prevention may be more cost effective if adopted during the design stage of new rolling stock.

Summary of conclusions

The immediate cause

- 75 The immediate cause of the incident was that the driver did not demand enough power for the train to climb the gradient and then did not apply the brakes to stop it from running back (**paragraph 30**).

The causal factor

- 76 The causal factor was that the driver was not sufficiently alert at the time of the incident because he was probably fatigued, his journey was monotonous, he was in a dark and comfortable environment and he had little in his field of view to attract his attention (**paragraph 33, Recommendation 1**).

The underlying factors

- 77 The underlying factors were the scores predicted by the Fatigue and Risk Index (**paragraph 43a, Recommendations 1, 2 and 3**) and the nature of the rail industry guidance on using mathematical models (**paragraph 43b, Recommendations 2 and 3**).

Observations

- 78 The industry database did not identify all fatigue-related accidents and incidents because fatigue was not stated as a factor when data were entered into the system (**paragraph 51, Recommendation 4**).
- 79 There was only one night shift threshold for fatigue, with no discrimination as to the type of work, the way it was carried out or the environment in which it was done (**paragraph 54, Recommendations 1, 2 and 3**).
- 80 Guidance was not appropriate for all types of shift work (**paragraphs 55 to 61, Recommendations 1, 2 and 3**).

Recommendations

81 The following recommendations are made²⁵:

Recommendations to address factors and observations

- 1 *The intention of this recommendation is for DB Schenker to reduce the number of shifts that cause fatigue. This recommendation may apply to other freight train operating companies.*

DB Schenker should, in consultation with its drivers:

- a. identify the shifts on which their drivers experience high levels of fatigue²⁶, and give particular consideration to the impact on drivers working the first in a series of night shifts;
- b. improve the identified shifts, for example by changing the transition to them, their duration and the duties carried out on them, with shifts of the highest risk improved ahead of those of lower risk;
- c. assess the findings of drivers on the changed shifts to confirm that those shifts are improved; and
- d. share its findings with the Office of Rail Regulation.

continued

²⁵ Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to Office of Rail Regulation to enable it to carry out its duties under regulation 12(2) to:

- (a) ensure that recommendations are duly considered and where appropriate acted upon; and
- (b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 167 to 171) can be found on RAIB's website www.raib.gov.uk.

²⁶ High levels of fatigue are values of eight or nine on the Karolinska Sleepiness Scale (KSS), a nine point scale ranging from one - extremely alert to nine - extremely sleepy and fighting sleep.

- 2 *The intention of this recommendation is for the rail industry to provide guidance on how to reduce the number of shifts that cause fatigue.*

The Office of Rail Regulation should take into account the train operator findings from Recommendation 1d and provide updated and enhanced guidance on shifts that cause high levels of fatigue, which should include:

- a. ways to improve those shifts, for example by changing the transition to them, the number of consecutive shifts, their duration and the duties carried out on them;
- b. advice on the limitations of mathematical models used to predict fatigue, and how they may be used as part of a fatigue risk management system.

- 3 *The intention of this recommendation is to provide the rail industry with information on the accuracy of mathematical models used to predict fatigue.*

The Office of Rail Regulation should arrange for a programme of work to analyse and compare existing mathematical models used to predict fatigue, including the Fatigue and Risk Index, and then provide information to the rail industry on the accuracy of those models.

- 4 *The intention of this recommendation is to improve rail industry information on fatigue-related accidents and incidents.*

RSSB should implement measures to improve the quality and quantity of available data relating to fatigue-related railway accidents and incidents. Options for consideration should include an enhancement of the Safety Management Information System to provide more accurate reporting of fatigue-related events.

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