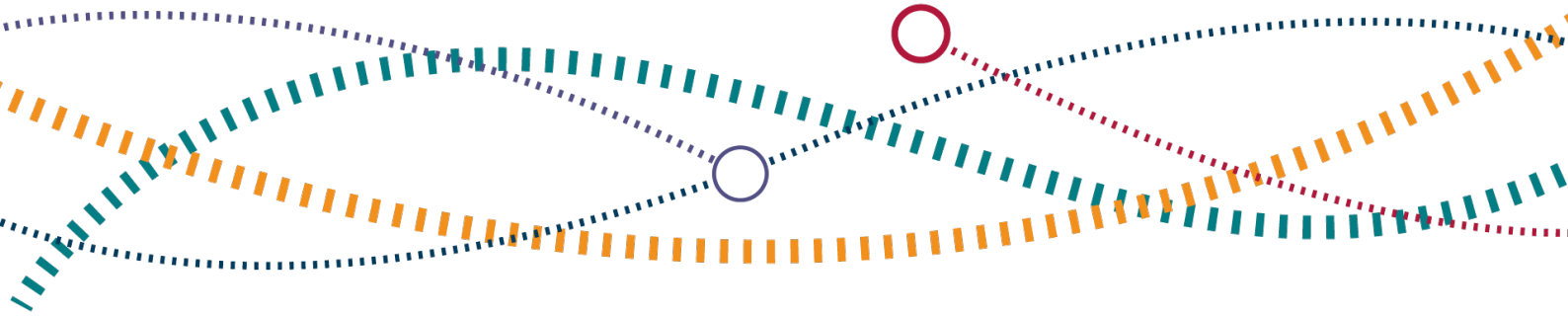
Learning the lessons:

ORR review into Hitachi AT200 & AT300 rolling stock cracking

Interim report

09 September 2021



Contents

Executive summary

1. On 8 May 2021, Hitachi Class 800, 801 and 802 trains operated by London North Eastern Railway (LNER), Great Western Railway (GWR) and TransPennine Express (TPE) were withdrawn from service as a safety precaution after cracks were identified in some carriages of the trains, specifically those in service with GWR and LNER, but not TPE. The disruption caused by the events on 8 May had an impact on passengers travelling or expecting to do so using the services of these train operators.

2. On 7 June 2021, Office of Rail and Road (ORR) informed the Minister of State of our plan to complete a lessons learnt review into the safety and passenger impact of the cracking issues on Hitachi Class 800 trains. This interim report covers the safety elements of this review and findings to date, against the following aims:

   - to determine the root cause of the cracking at the lifting end of the bolster and around the yaw damper / anti-roll bar connections to the body;
   - to examine how the industry went about identifying the problem, assessing the safety risk, withdrawing the trains from service and returning trains to service; and
   - identify areas for improvement.

3. We have also worked closely with the train operating companies and passenger groups to review the impact on passengers from the withdrawal of trains, with a specific focus on the operators of Hitachi Class 800 trains. We published the 'Passenger Impact review – Hitachi Class 800 trains' on 25 June 2021.

4. The industry is still working on the recovery programme to identify solutions and timescales for the permanent rectification and management of the cracks.

5. The full remit of this lessons learnt review is provided at **Annex 1**.

The trains affected

6. Class 800, 801 and 802 units are members of the AT300 family of Hitachi rolling stock. The first Class 800 trains entered service in October 2017 with GWR.

7. During scheduled maintenance activities, cracks were found in the area of the bolster, a critical area where the load of the vehicle and other forces are transferred to the wheel assembly, commonly referred to as the bogie. Specifically, cracks were found close to the yaw damper bracket and anti-roll bar fixing points on vehicles in these classes. In this report we will now refer to the cracking in this area as the 'yaw damper

cracks'. Eight trains that were significantly affected were withdrawn from service and on 11 April 2021 GWR issued a National Incident Report (NIR) 3761, describing these yaw damper cracks.

8. Subsequently, on 7 May 2021, cracks were also identified at the other end of the bolster assemblies, along weld lines where the lifting plates attach to the vehicle body. Initial assessment concluded that there was a risk of the lifting plates detaching. In this report we will now refer to the cracking in this area as the 'lifting plate cracks'.

9. The prevalence of the yaw damper and the lifting plate cracks on many vehicles in both the GWR and LNER fleets resulted in the decision on 8 May 2021 to withdraw all Class 800, 801 and 802 rolling stock from service until all vehicles had been checked and a case for safe operation of vehicles with cracks had been made. These actions were fully supported by ORR.

10. ScotRail operates a fleet of Hitachi Class 385 units on suburban, commuter and regional services. London & South Eastern Railway (L&SER) operates a fleet of Hitachi Class 395 units on its high-speed services in the south-east of England.

11. Class 385 and Class 395 trains were not withdrawn from service on 8 May 2021, but the subsequent investigation and analysis identified both the potential and actual incidences of related failures on Class 385 and 395 rolling stock. These trains are now included within the scope of Hitachi's work to understand and address the problems.

Lessons learnt safety review methodology

12. We structured our approach to addressing the aims of this review around two themes:

    (i) the capability of the operators' safety management systems (SMS) to manage the withdrawal and reinstatement of vehicles; and

    (i) a technical review, from root cause analysis to rectification and modification progress.

13. We met with Hitachi, operators, Department for Transport (DfT), Rail Safety and Standards Board (RSSB) and vehicle owners. We attended industry forums and working groups and reviewed documentation such as safety certificate applications, risk assessments, and detailed technical analysis and reports.

Progress to date

14. With reference to the aims for our safety review, our summary to date is set out below.

Aim 1: Determine the root cause

15. At present, this root cause has not yet been established and the technical investigation continues. However, as part of the process, it is essential to understand the mechanisms of failure. Our technical review has confirmed the findings of the industry technical investigation, and that the yaw damper cracking was caused by fatigue and that the cause in the lifting plate area was stress corrosion cracking (SCC).

16. Work is continuing to determine the root cause and establish the rectification plan. We will report on these areas in our final report.

Aim 2: How the industry went about identifying the problem and assessing the safety risk and returning vehicles to service

17. Our evidence to date shows that the industry has collaborated and communicated effectively to identify and understand the cracking problem, making appropriate challenge where necessary. This collaboration has continued through assessing and managing the safety risks, defining appropriate mitigation and criteria to allow vehicles to return to service safely.

18. On withdrawal of the AT300 rolling stock Hitachi initiated meetings with stakeholders. In addition to their own technical organisation at Kasado in Japan, Hitachi appointed third-party engineering consultancies Ricardo Rail and The Welding Institute (TWI) to challenge their analysis, assumptions and support their proposals, sharing this information with the other stakeholders, including ORR.

19. From this work, Hitachi developed inspection processes and pass/fail criteria for identifying which vehicles were safe to return to service. ORR inspected the defects on trains in depots and reviewed the inspection processes and criteria, observing these inspections and processes on site.

20. We have reviewed and are content with the inspection processes and criteria developed by Hitachi, which defined limits to permit trains with lifting plate cracks to return to passenger service from 14 May 2021, and trains with cracks in the yaw damper / anti-roll bar area to be used from 12 June 2021.

21. The operators of the AT300 trains understood it was their decision whether to deploy trains in service. They demonstrated to ORR how they capably applied their own safety management systems to assess the risks using the information from Hitachi, and elsewhere, and make the decision about returning vehicles to service.

22. Operators applied internal governance processes to ratify the proposals by Hitachi, and this permitted trains with lifting plate cracking within defined limits to return to service.

23. We found that all operators were able to demonstrate that they had appropriate SMS arrangements in place to manage fleet stand-down, to liaise appropriately with Hitachi, and to make suitable and sufficient risk assessments for returning trains with minor defects back into passenger service.

24. There have been no failures that resulted in the trains not performing as specified while in service, no unsafe conditions and no harm arising from the cracking phenomena.

25. We have completed our review of the industry's immediate response to this issue, and considered the roles of Hitachi, the train operating companies (TOCs), DfT and ORR. We have also completed our assessment of the communication flows between Hitachi and the operators and our work to look at cooperation between all parties.

Aim 3: Identify areas for improvement

26. We will identify any areas for improvement in our final report, following completion of our review.

Next steps

27. We have further work to undertake before we can complete our review:

Aim 1: Determine the root cause

28. Hitachi has provided an initial contribution to the investigation, in addition to the material it has made available through the ongoing engagement in respect of the management of the technical issues. Hitachi proposes to provide a detailed response to ORR by 30 September 2021, once its ongoing investigations are concluded and a clear course of action has been established for the recovery programme. This will include:

- how the design, manufacturing and testing processes addressed the potential for SCC and fatigue cracking in the design;
- the criteria for selecting the materials, the joining methods and any post-joining treatment when designing vehicles to operate for the life of the contract;
- Hitachi's processes to identify cracking in components during the life of the train;

- the background to the identification of the yaw damper and lifting plate cracks, and how Hitachi managed the subsequent investigation and development of solutions; and
- whether the lifting plate cracks could have been found earlier.

29. We will also seek commentary on these engineering aspects from other stakeholders.

Aim 2: How the industry went about identifying the problem and assessing the safety risk and returning vehicles to service

30. We plan to undertake a detailed assessment of the contractual responsibilities in place, including a review of those set out in Train Service Agreements, in order to identify areas for improvement. This assessment is dependent on contract information being provided to us.

31. Most operators have not completed their own lessons learnt reviews. We want to gain further evidence on how they have met their duty to review and continuously improve their SMS by a critical appraisal of how their processes, procedures and people managed the withdrawal and reintroduction of the AT200/300 vehicles.

32. We will report on Hitachi's internal communications arrangements and plan for long term rectification and management in our final report.

Aim 3: Identify areas for improvement

33. As explained in paragraph 25, we will identify any areas for improvement in our final report, following completion of our review.

Publication of our final report

34. We plan to publish our final Lessons Learnt Review report in December 2021, this timescale is reliant on ORR receiving the remaining information and analysis from industry.

Background

When and where cracks were found

35. During scheduled maintenance activities on GWR Class 800 and Class 802 units, cracks were found in the area of the bolster close to the yaw damper bracket and anti-roll bar fixing points on vehicles in these classes.

36. On 11 April 2021 GWR issued NIR 3761 in accordance with Railway Industry Standard RIS-8250-RST *Reporting High Risk Defects* Issue 1, describing the cracks in the yaw damper. These cracks were initially suspected to result from fatigue, which was subsequently confirmed by the technical investigation. Eight trains that were significantly affected were withdrawn from service.

37. Subsequently, on 7 May 2021, cracks were also identified along the weld line where the lifting plates attach to the vehicle body. Initial assessment concluded that there was a risk of the lifting plates detaching.

38. The prevalence of the cracks on many vehicles in both the GWR and LNER fleets resulted in the decision on 8 May 2021 to withdraw all Class 800, 801 and 802 rolling stock from service until each had been checked and a case for safe operation of vehicles with cracks had been made. Overnight, GWR had issued NIR 3766 that described the lifting plate cracks. These cracks were initially suspected to result from SCC, which was then confirmed by the technical investigation.

The Hitachi AT200/300 trains affected

39. The trains, also known as rolling stock, referenced in this report are manufactured by Hitachi. The different classes are variants of the Hitachi A-train family of passenger rolling stock and have common design features. Six operators have Hitachi trains in their fleet that are in the scope of this report:

    - LNER
    - GWR
    - TransPennine Express
    - Hull Trains
    - L&SER
    - ScotRail

40. The AT200 designation applies to suburban, commuter and regional trains. In the UK, there is one fleet of AT200 rolling stock, the Class 385. These are three and four-car, 100mph AC electric multiple unit trains operated by Abellio ScotRail for suburban and inter-urban services in the Central Belt of Scotland. The trains are owned by Caledonian Rail Leasing Ltd. They entered service during 2018-2019.

41. The AT300 designation is used for intercity high speed and long-distance trains. One type of AT300 train is the Class 395. These are high-speed (140mph) six-car AC/DC electric multiple unit trains, operated by L&SER, on conventional and high-speed lines in the southeast of England. The trains are owned by Eversholt and were introduced in the years 2007-2009.

42. The Intercity Express Programme (IEP) is a DfT initiative for rolling stock to operate intercity services on the Great Western and East Coast Main Lines, replacing the existing fleets from 2017. These AT300 variants are:

    - Class 800. Five and nine-car intercity diesel & AC electric bi-mode multiple unit trains forming part of the IEP and operated by GWR and LNER on routes in England, Scotland and Wales. The trains are owned by the Agility Trains consortium. They entered service between 2017 and 2019; and
    - Class 801. Five and nine-car intercity AC electric multiple unit trains forming part of the IEP and operated by LNER on routes in England and Scotland. The trains are owned by the Agility Trains consortium. They entered service between 2017 and 2019.

43. Further variants of the AT300 design have been, and continue to be, introduced on related routes although they are not part of the IEP. These include:

    - Class 802. Five and nine-car intercity diesel & AC electric bi-mode multiple unit trains operated by GWR, Hull Trains and TPE on routes in England, Scotland and Wales. The trains are owned by Angel and Eversholt. They entered service between 2018 and 2020.

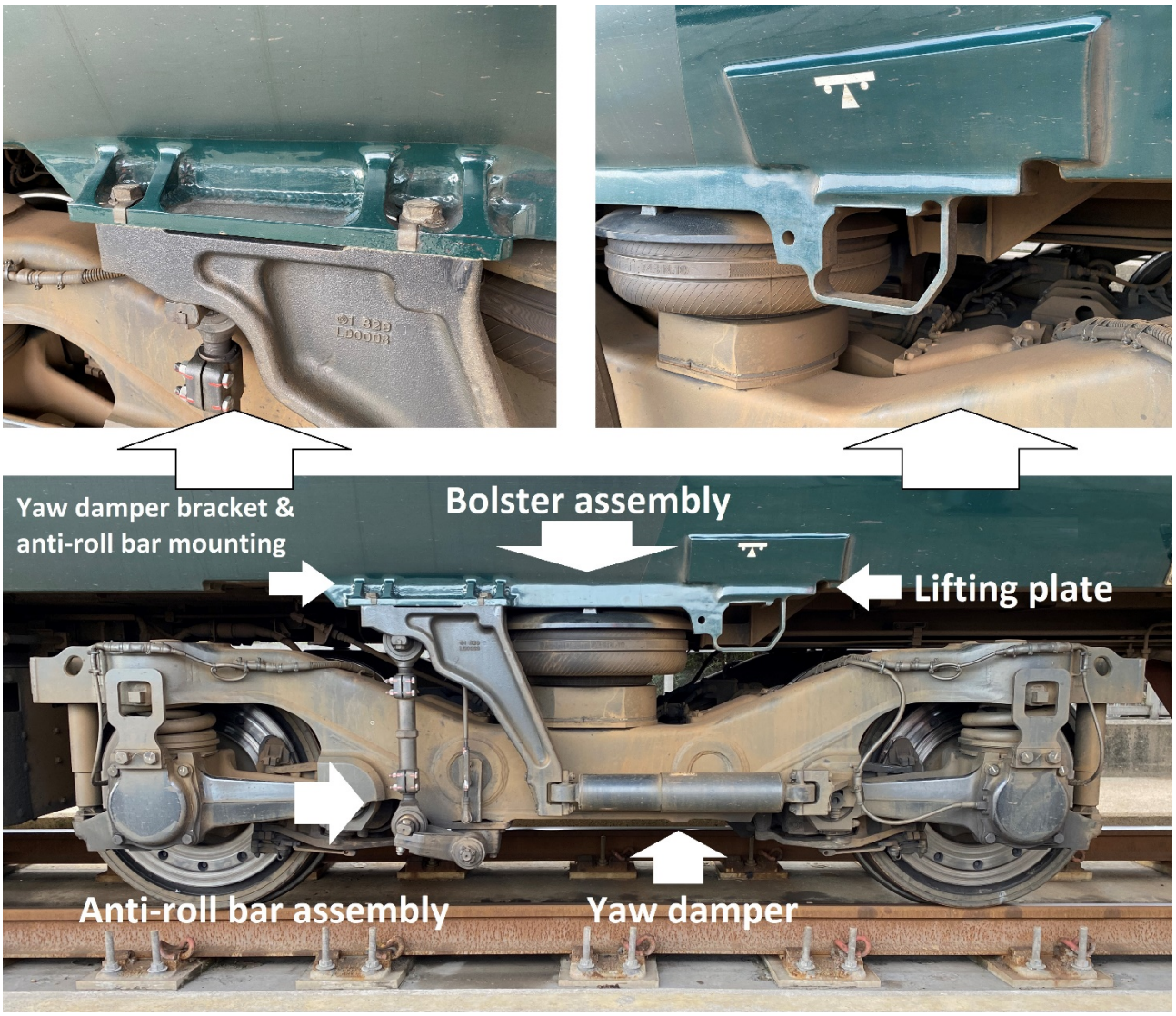
44. For clarity, the Class 800, 801 and 802 trains have been designed for 140mph operation but are currently authorised for a maximum speed of 125mph, the highest permitted speed on any of the routes over which they operate.

45. The trains are manufactured from a combination of medium strength (6000 series) and high strength (7000 series) aluminium alloys, which Hitachi describes as having a proven track record across a number of different train designs and within other industries, including marine, defence and aerospace. 7000 series aluminium alloys provide the benefit of having high strength, enabling weight reduction within the design.

46. The car body is assembled by welding together basic aluminium components to form the structure. This uses metal inert gas (MIG) and friction stir welding techniques in line with common manufacturing practices. Any rail vehicle body requires additional strength in the areas where bogie loads are transferred to the bodyshell. This is achieved on the AT200/300 trains by welding additional structural components in the part of the bodyshell above the bogie. This strengthened area is referred to as the bolster.

47. **Figure 1**, below, shows the particular features to note, including the connection points for the anti-roll bar and the yaw damper between body and bogie, and a lifting plate used when the vehicles are being lifted for maintenance.

Figure 1: Anti-roll bar & yaw damper connection points, and lifting plate



Collaboration by Hitachi and operators to return vehicles to service

48. On withdrawal of the Class 800, 801 and 802 variants of AT300 rolling stock, Hitachi initiated meetings with stakeholders. Attendees included Hitachi's engineering organisation both in the UK and in Japan, operators, rolling stock companies (RoSCos), Agility Trains, technical consultancies, DfT and ORR. These meetings provided a forum for Hitachi to present the activities it was undertaking for feedback and challenge.

49. As technical reports and proposals for fleet inspections were developed, they were shared with stakeholders. Many of the meetings were held using video conference facilities, which allowed many attendees from across the country and for the meetings to be scheduled at times outside of the normal working pattern. When it was required, a physical meeting was arranged at the North Pole maintenance facility in order to show all the parties involved the cracks and what was being done to evaluate the cracks.

50. Initially, efforts were made to define acceptable criteria for both the lifting plate and yaw damper cracks to permit trains to return to service. It became clear that understanding the latter was more complex, however yaw damper affected a much smaller number of trains. The focus then became on developing criteria to permit vehicles with lifting plate cracks return to service. Initial proposals included measurement of crack sizes, but the difficulty of measuring crack length quickly and accurately prompted simplification to assess only whether any visible crack was present in each location.

51. Hitachi and the TOC engineers made use of independent technical advice, including The Welding Institute, Ricardo and Professor Rod Smith of Imperial College, London for Hitachi, SNC-L for LNER and First Group's central engineering organisation that supports its individual TOCs. A factor in Hitachi's selection of Ricardo was the absence of previous technical involvement with the introduction of AT300 rolling stock to service.

52. The operators understood that their role as safety certificate holders made them responsible for the decision whether to deploy trains. They were able to demonstrate to ORR how they had applied their own safety management systems to assess the risks using information from Hitachi and elsewhere, and to make the decision about the deployment of trains.

53. Hitachi developed inspection processes and criteria that permitted trains with cracking within defined limits to return to passenger service from 14 May 2021. The investigation and analysis identified both the potential and actual incidences of related failures on Class 385 and 395 rolling stock, which were brought within the scope of Hitachi's work to address the problems.

How we structured our review

54. We structured our evidence collection around two themes:

    (i) the capability of the operators' safety management systems to manage the withdrawal and reinstatement of vehicles; and

    (ii) a technical review, from root cause analysis to rectification and modification progress.

55. **Annex 1** includes the terms of reference for this lessons learnt review and **Annex 2** sets out our progress against these terms of reference, identifying activities which are complete and those where further work is needed before we complete our review.

56. Our summary of evidence from our SMS capability and technical reviews are set out in the following two sections.

Technical review

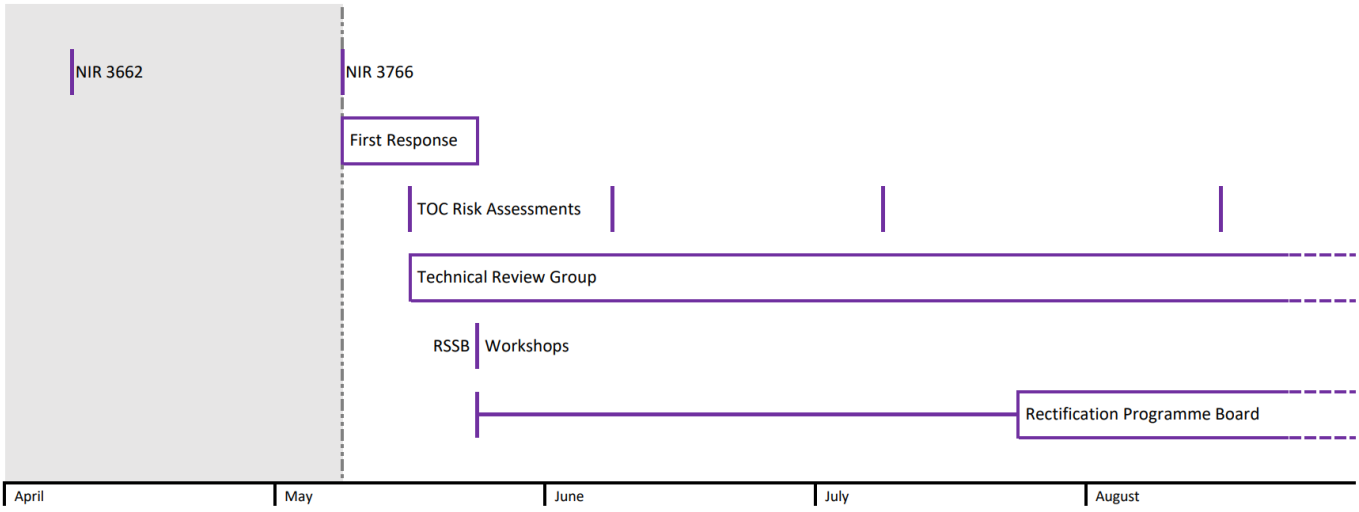
How we collected evidence

57. The technical aspects of the review have been derived predominantly from the activities that took place from 8 May 2021. From this point onward ORR has been observing, and scrutinising aspects of, the industry's management of the safe operation of AT200 and AT300 rolling stock in the context of fatigue and SCC. As simplified in **Figure 2** below, this has predominantly drawn on the material arising from:

    - Hitachi's initial engagement with stakeholders immediately following the withdrawal from service of Class 800, 801 and 802 units on 8 May 2021;
    - Operators' activities to assess the risks of returning to trains to service with cracks;
    - Hitachi's Technical Review Group including TOCs, RoSCos, technical consultancies and other parties;
    - RSSB workshops to review Hitachi's management of the problems; and
    - the Rectification Programme Board, recently established following Hitachi commissioning Nichols to provide oversight of the programme management in May.

58. It recognises that the technical work is continuing and that most workstreams have not yet been concluded. While Hitachi has made an initial contribution to this interim report, the final report will draw upon greater detail Hitachi's and others' perspectives on the management of the technical aspects through the whole timeline to the point at which the long-term rectification programme commences.

Figure 2 Timeline for sources of material for the technical review



Root causes

59. The investigation is seeking to identify the root cause of the cracking taking place in the vehicle structure, to understand the actions that – if undertaken differently – would have prevented the circumstances leading to the cracks from arising.

60. At present this root cause has not yet been established. However, as part of the process, it is essential to understand the mechanisms leading to the development of the cracks, and these are discussed below. The root cause will be addressed in the final report.

Stress corrosion cracking in the jacking plate

61. Stress corrosion cracking is a mechanism whereby cracks develop in susceptible materials when they are exposed to a specific corrosive substance while subject to stress. It has been likened to the fire triangle where fuel, heat and oxygen must all be present for combustion to take place; if any of the three elements are missing then there is no fire. In the case of SCC the three elements are: the susceptible material; the specific corrosive substance to which the material is susceptible; and mechanical stress in the material.

62. The susceptible material in this case is the 7000 series aluminium alloy that has been used in specific parts of the AT200 & AT300 vehicle bodyshells. The corrosive

environment for the material is one containing chlorides, which is commonly encountered in the UK – particularly in coastal areas and during cold weather when salt-containing products are used to manage snow and ice. Stress may be present in various forms, but notably can be introduced during the welding process when fabricating assemblies containing the susceptible material.

63. Hitachi produced report OPE-ETR-2021-0053 *AT200 and AT300 Bolster Lifting Point Cracks*, drawing on specialist advice from TWI, subject to updates as the investigation continued. The report confirmed that the crack mechanism in the lifting plate is SCC.

64. It identified that the 7000 series aluminium alloy used in the lifting plate has greater susceptibility to SCC than other aluminium alloys also used in the construction of the vehicles. This susceptibility can be heightened by thermal effects giving rise to metallurgical changes within the alloy, by the alignment of the grain within the material, and by machining of the rolled aluminium alloy sections to expose grain boundaries.

65. The specific corrosive environment for the alloy is considered to be endemic in the UK, arising from high humidity, rain and seawater exposure.

66. The stress input into the SCC mechanism was identified as arising from residual welding stresses. While the bolster assembly was subject to stress-relieving processes following welding, the lifting plate itself was not and therefore retained inherent residual stresses. Service-induced loads in this area were considered to be at such a low level as to be disregarded for the SCC mechanism.

67. The growth characteristics of SCC make it difficult to identify when the cracking occurred, but the initiation was thought most likely to have occurred at the manufacturing stage. Hitachi and its technical advisers have identified no obvious correlation between the extent of cracking and the age or mileage of a train. As the growth mechanism is aligned with the grain structure of the material, propagation beyond the material of the plate itself into adjacent weld areas subject to low stress and composed of a different type of aluminium alloy is unlikely.

Fatigue cracking at the yaw damper

68. Fatigue is a mechanism whereby cracks propagate through a material that is subject to cyclic loading. This is where the load changes in size, alternately opening and closing cracks at a microscopic level, such as the loads imparted by an anti-roll bar as a train moves from a curve to straight track and back onto a curve. For fatigue to occur the loads must be above a threshold level but are typically much lower than the load required to cause an immediate structural failure of the material. This means that the affected component is initially able to function without breaking, but over time the crack

grows and reduces the strength of the component until the remaining uncracked material is not strong enough to take the loads being imparted. At this point, the component fails. The cracks typically initiate at stress concentration points such as those caused by defects in the material, metallurgical features, or the geometric characteristics of the material such as small radius corners.

69. Engineering Technical Report OPE-ETR-2021-0055 *AT300 Bolster Cracks* records the early technical analysis of the yaw damper cracks found on AT300 rolling stock. The cracks were found to occur in the weld material.

70. The analysis identified a maximum permitted crack length of 200mm for the rolling stock to remain in service.

71. In addition, the analysis considered the consequences of a complete failure of the affected welds which run longitudinally. It concluded that there would be no increased stresses imposed on the transverse welds and no risk of the cracks propagating into the rest of the welded structure.

72. The cracks were investigated using non-destructive testing (NDT) methods and by removing metal from the weld to observe the material characteristics within the body of the weld. The latter method exposed voids and areas of the joint without weld fusion, features that were considered in the stress analysis of the bolster structure. Hitachi quoted advice from TWI that the imperfections observed in the welds that were inspected are not uncommon in any welded structure, and do not denote a likely failure.

73. The purpose of this analysis was to provide a basis for the safe reintroduction to service of vehicles with fatigue cracks at yaw damper bracket / anti-roll bar end of the bolster while the technical investigations continued and proposals for short- and long-term repair were developed.

Investigation and analysis activities following return to service

74. In order to identify criteria for the reintroduction of the rolling stock to passenger service Hitachi initiated a range of activities to understand the causes of the cracking and the means available for managing it. After achieving the initial aim of returning trains to service the workstreams continued and were strengthened to feed into the ongoing justification for operation of vehicles with cracks and the development of repair processes. These activities were reported to, and scrutinised by, the Technical Review Forum composed of TOCs, RoSCos and other stakeholders with technical expertise and interest in the activities (see below).

75. Simple pass/fail visual inspections were implemented to be carried out on all vehicles to provide ongoing reassurance that they were safe for passenger service.

76. Evaluation of potential crack growth was required in order to support the case for return to service and to optimise inspection frequencies, comparing:

- theoretical propagation rates – predictions of worst-case propagation behaviour of the cracks were developed based on analysis of the design; and
- measured propagation rates – monitoring of growth of cracks found on vehicles was undertaken to confirm that the theoretical values were conservative.

Non-destructive testing (NDT)

77. Both yaw damper and lifting plate cracks were initially identified when they became visible to the naked eye. This required the cracks to be present on the surface of the material and to be sufficiently large to be observed. Test methodologies were developed to improve the ability to identify cracks:

- Dye penetrant testing – the technique uses visible dyes that penetrate the crack in order to improve the detection of cracks that are present at the surface of the material, improving the reliability of detection and measuring. However, there was potential for the paint reapplied to the cleaned metal surface on completion of testing to enter the crack and reduce the accuracy of future detection.
- Eddy current testing – relying on a magnetic field, the method generates eddy currents within the body of the test piece. Defects in the material cause changes to the eddy current that can be measured. The technique can detect defects within the material that do not break the surface and therefore can identify cracks that are developing beneath the outer surface. Having successfully used the process to identify such cracks, it was subject to further development at the time of writing in order to be used for the inspection of welds during repair processes.
- Phased array ultrasonic testing – the observation of the reflection of ultrasonic waves within a material can identify defects. The complex geometry of the bolster in the area experiencing cracks makes this challenging. A phased array made up of multiple probe elements with timed pulses to enable them to cover more of the inspection area was proposed by TWI as having potential to be effective in this scenario. Work was ongoing to develop effective processes at the time of writing.

Extraction of cracked material for analysis

78. The bulk material of welds that contained cracks was removed in its entirety from two vehicles to allow laboratory examination of the cracks, including scanning electron

microscopic analysis of the microstructure on the fracture face, measurement and analysis of the crack geometry, and chemical analysis of the constituents of the aluminium alloy.

Pre-emptive risk assessment

79. Having identified the characteristics that appeared to have given rise to cracking, the design of the rest of the vehicles was evaluated to find other areas where those characteristics were also present. This considered experience with Class 395 rolling stock.

80. SCC was identified as possible at several locations on AT200 and AT300 vehicles. A 10% fleet check was carried out to assess the areas at risk and concluded that the following areas were not exhibiting SCC currently:

- Centre pin base plate
- Centre sill bracket
- Main transformer beam plate
- Yaw damper bracket / anti-roll bar stiffener

81. SCC was identified at the following locations:

- Coupler support plates
- Lifting plate (already identified)
- Obstacle deflector bracket (already identified on Class 395)

82. The coupler support plates were added to the scope of the activities managing the cracking issues.

83. ‘At risk’ welds were defined in respect of the level of NDT carried out during welding processes, the technical characteristics and difficulty of the welding activity, and the factor of safety present in the design. This activity identified further areas for inspection.

Structural analysis

84. Finite Element Analysis (FEA) is a process of computerised modelling of the behaviour of the complex structure of the vehicle by considering it as many small and simple elements that can each be evaluated, and the results combined in order to predict the behaviour of the overall system.

85. Hitachi’s principal engineering team at Kasado, Japan, undertook FEA of the affected areas of the vehicles. This activity built on the work done for the vehicle design by

using measured data from vehicle operation. The analysis considered the fatigue performance of the vehicle elements taking into account the variable loads imposed during vehicle operation, notably the anti-roll bar and yaw damper forces. The evaluation included consideration of weld quality and the effects of proposed repair methods. It was refined as further information became available from the range of activities taking place to understand the development of the cracks.

86. Ricardo was commissioned by Hitachi to develop an independent structural model of the bolster for comparison with Hitachi's analysis. This was still ongoing at the time of writing.

Strain gauge testing

87. In order to obtain empirical data for the structural analyses, trainsets were fitted with strain gauges to monitor the loads being imposed in the areas affected by cracking. The trains were operated on the Great Western and East Coast Main Line routes. The latter are also used by TPE and Hull Trains services. The testing has recorded higher loads from the yaw damper and anti-roll bar than had been expected based on the track data provided to Hitachi as an input to the vehicle design. The testing was still under way at the time of writing, being conducted with tare and crush loading, and with worn and new wheel profiles. Testing was also proposed to take place at 137.5mph, 10% faster than the current service speed limit.

Short-term repair processes

88. Proposals were evaluated for short-term repairs intended to permit trains with cracks to return to service before being subject to the more intrusive permanent repair processes. It was identified that the heat input to the aluminium alloy components of the bodyshell had the potential to degrade the metallurgical properties and therefore any such repairs could only be performed a limited number of times at a given location. A trial repair was carried out on a lifting plate, forming the basis of a submission to stakeholders for acceptance, and further repair procedures were developed for other configurations, including the rectification of the vehicles where bulk material had been removed for detailed crack analysis.

Surface treatments to protect against SCC

89. Treatment of the SCC-susceptible areas was evaluated, having identified that paint treatment was not effective in preventing SCC in the UK environment. Hitachi had already established the potential to use:

    - 'peening' – residual stresses are modified by a process of mechanical treatment; and

- ‘weld buttering’ – a layer of weld material is applied to the parent metal surface to prevent the exposure to potentially corrosive atmospheres.

Industry processes

Identification of the problem

Cracks in Class 395 obstacle deflector bracket

90. London & South Eastern Railway (L&SER) issued NIR 3662 in March 2020 to advice the discovery of cracks in an obstacle deflector support bracket. The cracks were identified while repairs were taking place following an incident that caused damage to the nose cone. Further investigation found that cracks were also present on other units. Initial analysis concluded that the bracket remained secure. Following further analysis, Hitachi concluded that the impact force requirements of the assembly were not compromised. The investigation identified that the principal cause of the defects was SCC. A modified bracket was developed and was in the process of being implemented across the fleet at the time of writing this interim report.

Cracks in anti-roll bar / yaw damper bracket area of bolster of GWR Class 800

91. In April 2021, whilst undertaking visual inspections in line with regular maintenance procedures, Hitachi’s maintenance team detected what appeared to be hairline cracks in the paintwork of GWR AT300 rolling stock in the vicinity of the anti-roll bar and yaw damper bracket attachments to the bolster. These were initially thought to be light surface scoring, but monitoring indicated that the cracks had substantial depth. An inspection programme using eddy current testing was put in place and affected rolling stock was withdrawn from service, initially affecting eight units. NIR 3761 was issued by GWR.

Cracks in lifting plates on GWR Class 802

92. On 7 May 2021, during visual inspections of yaw damper bracket mounts, cracks were found in an adjoining area along the weld line where the lifting plates are welded to the car body at the lifting points on GWR AT300 rolling stock. Concerns about the potential for the cracks to result in complete structural failure of the affected area resulted in the decision to withdraw all Class 800, 801 and 802 rolling stock from service pending inspection. All trains with cracks in the lifting plate remained out of service awaiting further analysis. NIR 3766 was issued by GWR.

Cracks in coupler support plate

93. Following the discovery of the cracks in the lifting plates, Hitachi assessed the potential for SCC to occur in other areas of the AT200 and AT300 rolling stock. A number of areas met criteria derived from analysis of the factors relevant to the cracks in the lifting plates. Sample checks were implemented on all fleets, covering the anti-roll bar bracket and stiffener, the obstacle deflector bracket, the centre sill bracket, the centre pin base plate and the coupler support plate. Cracks were found in coupler support plates, which were added to the scope of the investigation and rectification work.

Assessment of the safety risk

Withdrawal of affected rolling stock following identification of yaw damper cracks

94. Hitachi withdrew from service any vehicle found to have a yaw damper crack pending analysis and development of criteria to permit operation with cracks. Reasonably foreseeable outcomes of uncontrolled cracking in this area are detachment of components from the train, with the potential to strike persons or infrastructure, and loss of dynamic stability with the potential to result in derailment.

Withdrawal of all Class 800, 801 and 802 rolling stock following identification of lifting plate cracks

95. The scale of the cracking in the lifting plates led Hitachi to withdraw all Class 800, 801 and 802 vehicles as there could be no confidence that vehicles that had not been checked did not have cracks, and the cracks appeared to have the potential to result in detachment of part of the vehicle. Vehicles that were subsequently checked and found to have cracks remained withdrawn. The principal safety concern was the possibility of a lifting plate becoming detached from a vehicle at high speed and striking persons or infrastructure. Detachment was considered unlikely to affect the safe operation of the train itself.

Reinstatement of rolling stock with lifting plate cracks

96. Hitachi carried out a technical analysis of the lifting plate cracks, drawing on expertise from TWI, and produced report OPE-ETR-2021-0053 *AT200 and AT300 Bolster Lifting Point Cracks* that justified the operation of vehicles with cracks in up to two of the three visible faces of the lifting plate but continued to prohibit operation with other cracks in the bolster area. This was supported by engineering fleet checks of the lifting plate and anti-roll bar / yaw damper bracket bolster areas. Hitachi commissioned Ricardo to carry out an independent review of its work; Ricardo produced report 768235-101-C *Running with Cracked Lifting Point*, which supported Hitachi's conclusions. Hitachi engaged with stakeholders during this process, including the affected TOCs and RoSCos. The TOCs

used the Hitachi material to inform the risk assessments they carried out before returning the vehicles to service. LNER commissioned further third-party review from SNCL, which did not reject Hitachi's approach.

Reinstatement of rolling stock with yaw damper cracks

97. Hitachi carried out FEA modelling of the affected area of the vehicle and made a case that safe operation was possible with yaw damper crack lengths of up to 200mm. Alongside this, Hitachi developed special checks for visual and NDT inspection of the area. Using Hitachi's material to support their own risk assessments, the TOCs made their individual decisions to return to service vehicles with cracks that met the criteria. LNER commissioned a technical review from SNC-L which recommended a more conservative crack length limit value of 50mm; Hitachi produced an additional check procedure for LNER rolling stock to respect this.

Reinstatement of rolling stock with cracks in coupler support plate

98. Hitachi evaluated the stress in the two types of coupler support plate and considered the way the assembly was welded to the body structure and secured with bolts to the coupler assembly. The risks were mitigated by visual inspection backed up by NDT and torque checks of the associated bolts. The TOCs made use of the Hitachi material in their own risk assessments to support operation with cracks in the support plates.

Reinstatement of rolling stock with cracks in obstacle deflector bracket

99. Hitachi carried out a technical analysis of obstacle deflector cracks in 2020 following the initial identification of cracking on the Class 395 fleet. This can provide a basis for permitting continued operation with similar cracks on other AT200 and AT300 vehicles.

Withdrawal of the trains from service

100. Concerns about the potential for the cracks to result in complete structural failure of the affected area resulted in the decision to withdraw all AT300 rolling stock from service pending analysis. Trains that were subsequently inspected and found to have no cracks were returned to service. Trains with any cracks remained out of service until the safety justification for the cracks in question had been produced.

Return of the trains to service

101. Initial return of trains to service was based on fleet check HRE-OPE-EFC-2021-00058 *Bolster Plate – Detailed Inspection* Issue 2, 12 May 2021. This check defined an ongoing inspection regime for both the yaw damper bracket / anti-roll bar area of the bolster, and the lifting plate. The criteria permitted trains to operate with lifting plate cracks present but not yaw damper cracks.

102. Hitachi commissioned Ricardo to review its engineering decisions. Ricardo supported Hitachi's proposals to permit operation with cracks in the lifting plate.

103. The TOCs carried out their own engineering assessment of the material provided to them by Hitachi before accepting the case for the return to service. As part of this LNER commissioned SNC-L to carry out an independent review of the package of information provided to the TOCs by Hitachi.

104. Further investigation and assessment of the risks relating to the cracks in the yaw damper bracket / anti-roll bar area resulted in limit criteria being defined for these cracks, thus permitting additional trains to return to service. Fleet checks *Yaw & ARB Car Body Bolster Plate Inspection* with reference numbers HRE-OPE-EFC-2021-00062 and HRE-OPE-EFC-2021-00076 were developed, the former covering the GWR, Hull Trains and TPE fleets and the latter for the LNER fleet. As ScotRail had found no yaw damper cracks, no limit criteria were defined for the Class 385 units and the existing requirement to withdraw any vehicle with a crack in this area remained.

Subsequent activities

RSSB workshops

105. Hitachi asked RSSB to assess the risks associated with the cracks and to consider the actions required for the safe return to service of trains affected by cracks. RSSB organised two workshops. The first involved Hitachi and its technical advisers Ricardo and TWI, and sought to assess the potential failure modes and their likelihood of occurring. The second workshop was for the train operators of AT200 and AT300 rolling stock and their train maintainers. Its scope was to review the outcomes of the first workshop, identify hazards relating to the cracks in the jacking plate and to develop a model of the consequences using event trees.

106. RSSB was supportive of the approach being taken by Hitachi and did not identify any activities that had been overlooked.

Technical Review Forum

107. The Technical Review Forum was established as a regular meeting led by Hitachi where the various activities being undertaken to evaluate the problem and establish a solution could be communicated to a range of stakeholders including TOC, RoSCo, RSSB and technical consultancy representatives.

108. It included an ongoing issues log where points for resolution could be raised and tracked to completion.

Fleet Recovery Programme Board

109. In July 2021, the Fleet Recovery Programme Board was established to have oversight of the fleet recovery programme, with objectives focusing on the passenger needs and providing an independent advisory board role. It was chaired by The Nichols Group, a consultancy specialising in supporting change.

Potential improvements

110. Potential improvements will be considered in the final report of this 'Lessons Learnt Review', once the long-term rectification process has been established.

Analysis

The criteria for selecting the materials, the joining methods and any post-joining treatment when designing vehicles to operate for the life of the contract

Regulatory requirements – Authorisation for placing into service

111. The UK regulatory regime requires new passenger rolling stock to be authorised by ORR before an operator may use it for the carriage of passengers. At the current stage of the investigation, it is not known whether the root cause is a matter that could or should be addressed by the authorisation process. This will be addressed in the final report.

112. Authorisation is granted when the applicant has provided, among other things, certification from an accredited third party that the rolling stock complies with the applicable standards. At the time of authorisation of the AT200 and AT300 fleets this role was referred to as a 'Notified Body' or 'NoBo'.

113. The individual fleets of Hitachi AT200 and AT300 rolling stock were authorised on the basis that they complied with Commission Regulation (EU) No. 1302/2014 *Locomotives & Passenger Rolling Stock Technical Specification for Interoperability* (LOC&PAS TSI) in force at the time of application. The purpose of the TSI is to provide harmonised standards that support the interoperability of the railway system across the European Union. Interoperability sets out to remove barriers to trade by identifying common requirements, but it is not intended to impose detailed design requirements.

114. The requirements for fatigue strength were defined in the TSI by reference to EN126631:2010 *Railway Applications – Structural Requirements of Railway Vehicle Bodies*. In accordance with the defined processes for interoperability, Hitachi provided evidence of conformity of the design to Interfleet (subsequently SNCL), acting as the NoBo, who in turn certified the design. Interfleet also assessed Hitachi's management

systems and certified that they would ensure the individual vehicles were constructed in conformity with the design.

115. The train design and joining methodology were subject to computer modelling and analysis, and fatigue load testing of a sacrificial car body. Input loads were calculated using track data received by Hitachi as a part of contractual documentation.

116. The TSI does not define requirements for the evaluation of SCC risks.

The potential for the original design and manufacturing choices to lead to further SCC and fatigue issues elsewhere in the train

117. The investigation into the development of the cracks identified the design factors that made the affected areas susceptible to SCC, fatigue cracking or both. Hitachi reviewed the vehicle design for both AT200 and AT300 designs to consider whether there were other locations in the vehicles that could be susceptible. The factors that were considered for SCC included the metallurgical specification of the materials used, their thickness, the presence of a cut or machined surface, and stress-relief processes; for fatigue the focus was on the load conditions, the design factors of safety, the level of NDT carried out during welding processes, and the technical characteristics and difficulty of the welding activity.

118. Locations assessed as being at risk were subject to a 10% fleet check. This found SCC in the coupler support plates, in addition to the lifting plates and obstacle deflector brackets already exhibiting cracking.

The long-term management of the technical issues

119. Proposals for long-term management are still being developed by Hitachi, supported by Nichols. The objective is to ensure that there is no further need for additional containment activities to be undertaken as part of train maintenance. At the time of writing this interim report, it was expected that these proposals would be confirmed at the end of September 2021. They will be considered in our final report.

120. Analysis of the following five points is still taking place and will be considered in our final report:

- *How the design, manufacturing and testing processes addressed the potential for SCC and fatigue cracking in the design;*
- *Hitachi's processes to identify cracking in components during the life of the train;*
- *The background to the identification of the SCC and fatigue cracks in the bolster area, and how Hitachi managed the subsequent investigation and development of solutions;*
- *Whether the cracks in the lifting plates could have been found earlier; and*
- *The effectiveness of the forward recovery planning processes for returning the trains to service, for immediate rectification of defective vehicles.*

Interim conclusions of technical review

121. Hitachi's activities to investigate the causes of the cracking and to develop proposals for safe operation of trains with cracks, as well as long-term rectification, have a wide scope and no significant omissions have been identified.

122. Hitachi's work is being informed by independent technical specialists and being scrutinised both by third parties commissioned by Hitachi and by technically competent stakeholders.

123. The investigation is incomplete but is developing a clear understanding of the factors leading to SCC and fatigue cracking. Further work is needed to establish the root cause.

Safety Management System (SMS) capability review

How we collected evidence

124. Evidence was gathered from each train operating company affected. A series of questions exploring those areas considered by this review was initially put to each operator as a basis for discussion. Meetings were held with the relevant Fleet Engineers, Directors / Professional Heads of Engineering and Heads of Safety for all but one of the operators.

125. The meetings were focussed around the questions and answers exchanged previously, allowing for each operator to provide their views on how the cracking issue was managed. They explored any lessons learnt within each organisation and the actions of other stakeholders such as rolling stock leasing companies, DfT and ORR.

126. In order to secure open and candid discussion, we agreed with operators that we would anonymise their responses in this review.

127. ORR requested sight of risk assessments for returning trains to passenger service from the operators with affected trains. The risk assessments were reviewed as part of ORR's oversight of the initial return of trains to service, but also as part of this review.

128. A desktop review was conducted of each operator's safety management system (SMS) signposting documents, which ORR holds as part of an operator's application for a safety certificate to run on the British railway network. The review considered whether the operator's SMS was set up to manage whole fleet withdrawals due to a safety related defect.

Summary of evidence

Initial notification and actions

129. All operators reported that by 5am on 8 May 2021, their 24-hour/7-day control centres had received notification by Hitachi Maintenance Control of the lifting plate cracking. They were also informed of Hitachi's decision to stand the whole fleet down from

service to conduct further checks. Whilst detrimental to operations, this was seen as a sensible safety decision.

130. Operators confirmed that the method of notification was in line with what they expected, triggering internal processes to ensure the right people in their organisations were alerted, by telephone or notifications through internal 'on-call' arrangements.

131. Hitachi also provided the same early notification of the issue with the AT300 vehicles to operators of other Hitachi trains (Class 385 and 395).

132. Operators reported that the early notification by Hitachi enabled them to initiate their emergency plans early on 8 May 2021 and put in place arrangements for mitigating the significant impact of the decision to stand down the fleet. These arrangements included identifying alternative rolling stock, updating social media for customers, arranging bus replacement services and providing frontline staff information to manage passengers.

133. One operator deployed their engineering team to look at the cracks and noted that:

- the lifting plate cracks were different to the fatigue cracking in yaw dampers;
- trains had probably been running around for some time with lifting plate cracks; and
- nothing had actually fallen off.

134. They considered the safety risk was low and it would be safe to return the trains to service whilst further investigation and analysis took place to understand the issue, with continued monitoring of the cracks in the interim. They shared this view at the update meetings chaired by Hitachi over the weekend of 7/8 May 2021.

135. ORR consider that Hitachi provided prompt notification of the matters identified on 7 May 2021 raising this through the expected channels with operators, allowing those operators to initiate their emergency response plans, and put in place appropriate activities to mitigate the immediate withdrawal of the fleet.

Information flows

136. In the early stages of the crisis, information and updates passed from Hitachi to operators through control centres, and this was appropriate. Given the impact of the issue across operators, a bespoke interface was then established, through a pan-industry forum chaired by Hitachi. This was attended by all the affected operators, rolling stock owners and other stakeholders including, as the day and weekend of the crisis proceeded, ORR and DfT.

137. This helped Hitachi to manage the information flow, the impact of questions coming from multiple organisations and facilitated knowledge-sharing between operators and a common line to take with external communications. Having agreed timescales when Hitachi updated, and shared information was recognised by operators as being very important. It managed expectations and allowed Hitachi to get on with the problem-solving, in the interim. However, one operator commented that meetings full of engineers were not always constructive; there were lots of very good questions being asked but not enough decisions being made. Another commented that a strong independent chair would have maintained focus and ensured all voices were heard.

138. One operator commented on their perception of the culture in Hitachi. They felt that Hitachi's pride meant they were compelled to give an answer, regardless of whether they knew it; they explained that Hitachi should feel comfortable to say they don't know and will seek further advice. They also considered that, in the early stages, Hitachi were withholding information and highlighted a comment that "[Hitachi] shared all contractually-required information", which raised their concern. However, this was not a widely held view by other operators who felt that Hitachi were transparent, and that information was either not available or was being checked, rather than it was being withheld.

139. One operator raised issues around document control, reporting that they had not received information that had been widely sent to others. The same operator did note that the cracking issue had improved their relationship with Hitachi in terms of collaboration over process and procedures, and information-sharing, supporting the operator to make informed decisions. Their view was that Hitachi's focus on the cracking issue means that other 'business as usual' matters are taking longer to resolve.

140. Internal communication within all operator organisations has been effective, securing engagement from board members through to staff representatives. Operators explained that there is robust board oversight, challenge and support for plans for returning trains to service. They described how they were able to reassure staff that trains are safe to run in service with SCC present, effectively managing situations where staff may have otherwise refused to work on safety grounds.

141. Three of the operators are within the same owning group; this brings further oversight and challenge, and all have drawn on the synergy from the collective expertise and information sharing across the group. Similarly, the other two operators are part of larger owning groups and reported oversight and challenge from their parent groups. One owning group commented that the issues with the AT300 vehicles had brought all the operators into a closer collaborative arrangement on AT issues.

142. Overall, ORR considers that information flows within and across organisations worked well, with information from Hitachi generally timely, although not always consistent with all operators. The information flow enabled all operators to demonstrate that they were appropriately managing the risks of operating the vehicles with SCC present.

Assurance

143. Each of the six operators of AT200/300 vehicles have the duty to ensure the risks associated with operation of their trains are managed, so far as is reasonably practicable. Therefore, each operator needed to assure themselves that they had the correct information, and that information was accurate, in order to make an informed safety decision.

144. The operators' safety management systems set out processes for managing significant safety related defects and in this scenario, some operators opted to follow their major incident review process, others their change management process. This ensured the correct people within each organisation were involved.

145. These processes typically required ratification by board members. Where board sign-off was not part of an operator's process this additional governance was put in place, due to the significance of the issue being managed. Irrespective of the process followed, the approach followed by each operator demonstrated capability to manage the issue and secure a high level of governance and ratification that did not rely on individual decision making.

146. All operators were involved in the cross-industry working group and, early on, all endorsed the requirement of an independent review of Hitachi assessments, assumptions and proposals, because this information would inform the operators' internal change management or major incident review processes. Ricardo Rail undertook this third-party check supported by TWI and all operators had access to the reports.

147. Only one operator commissioned an independent consultant to review both the outputs from Hitachi and inform their own safety decisions around returning vehicles to service. Other operators noted that this operator had commissioned the independent review but felt that the collective engineering expertise across the owning group was capable of reviewing the outputs from Hitachi, Ricardo Rail and TWI. To facilitate this, they set up a cross-group engineering team to review the arguments and justifications made by Hitachi. All operators could evidence high visibility of safety leaders, engineering and operational professional heads, and the board through assurance activity.

148. All operators incorporated their own on-site checks of the stress corrosion crack inspections being undertaken by Hitachi. All reported that Hitachi recognised the importance of these checks and fully cooperated, enabling the operators to undertake all the assurance activities they wanted to. Only one operator reported an issue of concern and that related to Hitachi staff at an outlying location not being in possession of the most up to date inspection information.

Getting trains back into service

149. The six operators that took part in this review have all been affected differently by the withdrawal of AT200/300 fleets partly related to their type of services they operate and the availability of other trains as cover.

150. Generally, and in terms of safety, operators reported that the only internal pressure was to do the right thing and follow the correct processes, following an engineering-led judgement free from commercial influence. One operator reported pressure from Hitachi to get trains back into service. No operators reported any pressure from vehicle owners, one operator specifically commented that the vehicle owners were only comfortable themselves when the operator was comfortable.

151. All operators explained that they only accepted the process for returning trains to service once they had received all the relevant information from Hitachi, so they could review their risk assessments and complete internal checks and governance. One operator noted that, due to a well-planned process, this was as quickly as 2 hours from receiving the final sign-off by Hitachi. All operators confirmed that they received sufficient information from Hitachi to inform their internal process, promptly, once they had specified to Hitachi what they required.

152. Some attendees at early pan-industry meetings and one owning group, described pressure from DfT to put trains back into service based on the view that if Hitachi said their trains were safe, then they were safe. However, this position was quickly resolved with clarity from ORR that the duty to ensure safe operation was with the operator and not Hitachi.

153. All operators considered that the processes defined in their SMS, all worked well to manage both the initial impact of the withdrawal of the fleet and the return of vehicles to service. Generally, operators have not commenced their own reviews of how they responded to this situation, but at this stage were comfortable that they would not need to make changes to their SMS procedures for risk assessment, change management, emergency preparedness, assurance and governance.

154. One operator said that they had applied some additional governance to their change management, engaging their Board to validate the engineering argument to return

trains to service, but this would not be routinely done. Overall, operators reported that key leaders in their organisations were engaged, proactive and responsive at this critical stage. Any significant pressure that was applied within organisations or externally was “on the right side of governance”, as one operator described it, to justify why trains can be allowed back into service.

155. There was acknowledgement by all operators that there has been a high level of effective collaboration between all the stakeholders to deliver the common goal of understanding and managing the risk of SCC in the lifting pocket assembly.

Interface with Hitachi

156. The operators’ safety management systems should include arrangements to manage the interface with Hitachi, as the train maintainer, to ensure that sufficient information in sufficient detail is provided so the operators can assure themselves that the trains are safe for daily service. Most operators were satisfied that their interface arrangements were well-defined, and they had a good and open working relationship with Hitachi.

157. One operator explained how they were working to improve their SMS to manage this interface. They felt they were often ’in the dark’ about maintenance issues which may affect their trains, for example how many maintenance exams are overdue, and Hitachi were not always forthcoming with information. They described how Hitachi have very much adopted a ‘can do’ attitude in relation to the SCC, but this isn’t the case with more day-to-day issues.

158. In relation to what information is shared daily by Hitachi with operators, there appeared to be inconsistency: some operators had daily conference calls, others received information sheets; some operators had real-time access to SAP, the Hitachi maintenance system, others did not. Evidence from the operators indicates that what they have access to is related to what is in their Train Service Agreement (TSA) with Hitachi, with more recent contracts providing access to SAP. Most operators who do not have access to SAP would like it.

159. Two operators commented that Hitachi have been too slow in identifying and publishing data around crack progression rate. This information has relevance in determining if the repair / modification programme can keep ahead of issues requiring that further units are stopped from service. One operator considered that Hitachi were heavily reliant on the design authority (Kasado) and intelligence which is based in Japan. They believed that establishing intelligence and engineering support in the UK would expedite this and many other issues raised.

160. All operators agreed that the user group set up for this issue has worked well and allowed Hitachi to cope with the multiple operators' demands and requirements. One operator has recommended to Hitachi that this successful approach is replicated where there are other issues which affect all the operators, for example train management system upgrades.

161. Generally, the interface arrangements set out in the operators' SMS are delivering effective collaboration between the operator and Hitachi. Where the arrangements are not working so well, the operator has an action plan to improve this. As set out in paragraph 154, there are inconsistencies in the level and method of information provision to the different operators. ORR plans to undertake further assessment in this area.

The Department for Transport role

162. In early pan-industry meetings some operators felt that there was initial pressure from DfT on operators that they should accept Hitachi's authority that the trains were safe and should commence operations, but this pressure eased on operators with clarification that the duty in law was with operators to assure themselves that the risk is managed. Attention was then focussed on Hitachi to move more quickly to provide information to the operators.

163. One operator commented that in early meetings many opinions were offered without facts, which didn't progress matters. They appreciated the direction and focus that DfT brought, setting meetings on the right track. Those involved agreed that DfT's role expedited matters.

The Office of Rail and Road role

164. The team of ORR inspectors and engineers, with responsibility for the operators and maintainers of the AT300 trains, were party to the pan-industry meetings over the weekend of 8/9 May 2021. This team separately considered information coming through from operators and Hitachi over the extent of the issue in the four AT300 fleets, the checks being undertaken and the approaches by each operator to manage the risk of operating their fleets.

165. Two operators considered that the level of challenge made by ORR, at the pan-industry meetings, was excessive, unnecessary and beyond our remit, given that it is the operator which holds the duty to ensure their trains are safe. One operator believed that ORR's initial stance was to prohibit the fleet from operating. They appreciated the clarification by ORR that it was for the operators to assure themselves that they were armed with adequate information; principally around the level of checks and assumptions made by Hitachi, to inform their own risk

assessments about operating vehicles in passenger service. ORR's role as safety regulator is to challenge the industry on safety decisions made, but we will look at what improvements we need to make to ensure that our role is understood and that challenge is appropriate and timely.

166. Another operator welcomed ORR's approach and intervention at the pan-industry meeting, which they felt helped ensure all voices and approaches were heard.

167. All operators felt that the ongoing assurance activity and challenge, by local ORR inspectors and engineers, around the capability of the relevant safety management systems to manage the risk of reintroducing trains to service, worked well, was highly constructive and at an appropriate level; with ORR inspectors acting as a good sounding board. Reference was made to the important role that ORR's Railway Safety Director made to keep a check on process and behaviours, reminding all parties on where the duty for safe operation of the trains is vested.

Other observations

168. In March 2020, cracks were found on a Class 395 Javelin on the bracket holding the obstacle deflector, this was found to be SCC. The operator was not part of the early meetings around the AT300 cracks and felt that they could have helped the other operators; sharing their experience of how they worked with Hitachi and Kasado to return the two units to service. Within 2 days of identification of the cracks and the vehicles being stopped, the operator had detailed structural analysis from Kasado, reviewed the information and had reinstated the trains to service. The operator is now part of the working group dealing with the SCC on the AT200/300 fleets.

169. *Regulation 22, The Railways and other Guided Transport Systems (Safety) Regulations 2006 (ROGS)*[1] includes a duty of cooperation. One operator considered that if this duty extended to Hitachi, then that would help improve the flow of safety related information, supporting compliance by the operator with the wider provisions of the regulations.

170. One owning group commented on the IEP contract between Hitachi and the DfT. They considered that the contract did not have sufficient focus around safety responsibilities or draw on experience of running a Train Service Agreement; it doesn't envisage a scenario of this scale of the cracks on vehicles or handle it well. They observed that lessons had been learnt from this and therefore more recent contracts include additional requirements, for example access to SAP and other safety information.

[1] The Railways and Other Guided Transport Systems (Safety) Regulations 2006 (legislation.gov.uk)

Desktop review of operators' Safety Management Systems

171. Operators are required to apply to ORR for a safety certificate under ROGS, typically this has a validity of five years. The operator must apply for a renewed certificate if they wish to continue operation. This application sets out how the operator's safety management system has the capability of delivering the requirements of Schedule 1 of ROGs.

172. ORR holds copies of all current applications and we have undertaken a desktop review of the six operators interviewed as part of this lessons learnt review.

173. We found that all operators have in place measures within their SMS to deal with this issue, through processes and procedures. We did not check whether they followed the procedures expected, but the operators' responses above support this position. Most operators followed processes to manage major incidents, with one operator using their engineering change procedure.

174. All operators referenced interfaces with Hitachi where relevant.

175. Only one operator identified a need to make a minor change to their SMS and this related to the process for reporting such incidents; this is currently through a shared control centre with another operator.

Interim conclusions of SMS capability review

176. All operators were able to demonstrate that they had appropriate safety management systems in place to manage the fleet stand down, to liaise appropriately with Hitachi and to make suitable and sufficient risk assessments for returning trains with minor defects back into passenger service.

177. Operators were supported by high-level governance within their organisations, and from the two main owning groups, with board sign-off for key decisions being required. They resisted any early external pressures to get trains back into service before the correct internal procedures had been followed.

178. Each operator implemented their own assurance measures to ensure that the information provided by Hitachi was correct, and the proposals to return trains to service subject to enhanced checks were based on sound evidence. Hitachi has fully cooperated with operators carrying out assurance activities on train checks.

179. Interfaces between both AT200/300 users and Hitachi appear well-managed although some operators would prefer more detailed information to be shared from Hitachi to satisfy their safety and assurance processes for fleet management. The AT300 user group is seen as a positive arrangement to share information and good practice.

Glossary

Term	Definition
Class 385	Suburban and inter-urban electric passenger rolling stock of the Hitachi AT200 family, operated by ScotRail in the Central Belt of Scotland
Class 395	High speed electric passenger rolling stock of the Hitachi AT300 family, operated by L&SER on conventional and high-speed lines in the southeast of England
Class 800	Inter-city diesel & electric bi-mode passenger rolling stock of the Hitachi AT300 family, operated by GWR and LNER on routes in England, Scotland and Wales
Class 801	Inter-city electric passenger rolling stock of the Hitachi AT300 family, operated by LNER on routes in England and Scotland
Class 802	Inter-city diesel & electric bi-mode passenger rolling stock of the Hitachi AT300 family, operated by GWR, Hull Trains and TPE on routes in England, Scotland and Wales
AC	Alternating current, a characteristic of the electric power supply
Agility	Agility Trains is a consortium working with DfT to provide rolling stock for the Intercity Express Programme (IEP), replacing the previous generations of inter-city rolling stock on the Great Western and East Coast Main Lines
Angel Trains	Train owner, which leases Hitachi Class 802 trains to both TPE and Hull Trains
CRL	Caledonian Rail Leasing Ltd, a train owner, which leases Hitachi Class 385 trains to ScotRail
DC	Direct current, a characteristic of the electric power supply
DfT	Department for Transport
Eversholt Rail	Train owner, which leases Hitachi Class 395 Javelin trains to L&SER, and Class 802 trains to GWR.

Term	Definition
FEA	Finite Element Analysis, a process of computerised modelling of stresses within an assembly
GWR	Great Western Railway, a train operating company operating Class 800 and 802 rolling stock manufactured by Hitachi on the Great Western Main Line and associated routes to South Wales and the west of England
Hull Trains	Train operating company operating Class 802 rolling stock manufactured by Hitachi on the East Coast Main Line and in East Yorkshire
IEP	Intercity Express Programme, initiative of the DfT to procure new trains to replace the Intercity 125 and 225 fleets on the East Coast Main Line and Great Western Main Line (see Agility above)
Kasado	Hitachi site in Yamaguchi Prefecture, Japan, developing and manufacturing railway vehicles
LNER	London North Eastern Railway, a train operating company operating Class 800 and 801 rolling stock manufactured by Hitachi on the East Coast Main Line
L&SER	London & South Eastern Railway (trading as Southeastern). Train operating company operating Class 395 rolling stock manufactured by Hitachi on conventional and high-speed lines in London, Kent and Sussex
Nichols	The Nichols Group, a strategic change consultancy
NDT	Non-destructive testing
NIR	National Incident Report, a report of a safety-related technical incident made in accordance with Rail Industry Standard RIS-8250-RST *Reporting High Risk Defects* Issue 1
NoBo	Notified Body, an independent accredited commercial organisation employed as part of the processes for interoperability to check and certify compliance with Technical Specifications for Interoperability. Superseded in the UK by Approved Body in 2021
ORR	Office of Rail and Road
Ricardo	Ricardo Rail, a railway engineering consultancy

Term	Definition
RoSCo	Rolling Stock Company, an owner of rail vehicles
RSSB	Rail Safety and Standards Board, a body funded by the rail industry to develop standards, manage research, and collect, collate and analyse data
Safety Certificate	Under The Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS) no one is able to operate vehicles on the UK railway unless they have obtained the appropriate safety certificate from ORR
SCC	Stress corrosion cracking
ScotRail	Train operating company operating Class 385 rolling stock manufactured by Hitachi on electrified lines in the Central Belt of Scotland
SNC-L	SNC-Lavalin, a railway engineering consultancy
TPE	TransPennine Express, a train operating company operating Class 802 rolling stock manufactured by Hitachi between the northwest of England and Edinburgh via the East Coast Main Line
TSI	Technical Specification for Interoperability, a harmonised standard forming part of the processes for interoperability. Superseded in the UK by National Technical Specification Notice in 2021
TWI	The Welding Institute, a research and technology organisation with specialisation in welding

Annex 1 – terms of reference

Learning the lessons: ORR review into Hitachi AT200 & AT300 rolling stock cracking

ORR will work closely with all parties to ensure that lessons are learnt from the discovery of cracks in Hitachi AT200 (Class 385) & AT300 (Classes 800, 801 and 802) rolling stock. The review will focus mainly on safety lessons, but will also cover the impact on passengers from the withdrawal of trains from service.

ORR will work with Hitachi's design and manufacturing teams and all relevant parties to:

- find the root cause of the
  - cracking in the jacking plate
  - cracking at the yaw damper bracket/anti-roll bar end of the bolster
- examine the industry processes relating to
  - identification of the problem
  - assessment of the safety risk
  - withdrawal of the trains from service
  - return of the trains to service
- identify potential improvements

The review will cover:

- The criteria for selecting the materials, the joining methods and any post-joining treatment when designing vehicles to operate for the life of the contract.
- How the design, manufacturing and testing processes addressed the potential for stress corrosion cracking and fatigue cracking in the design.
- Hitachi's processes to identify cracking in components during the life of the train.
- The background to the identification of the cracks in the bolster area, and how Hitachi managed the subsequent investigation and development of solutions.
- Whether the cracks in the jacking plates could have been found earlier.
- The immediate response; considering the roles of Hitachi, the train operating companies (TOCs), Department for Transport (DfT) and ORR.
- The communication flows within Hitachi as maintainer / builder / designer and between Hitachi and the TOCs, including whether they could be improved to speed up identification and resolution of common issues.
- Cooperation between all parties, and whether information flow or decision-making were affected by commercial, organisational, geographic or cultural factors.
- Contractual responsibilities for inspection, maintenance, repair and remedial action, and how these could be improved.
- The effectiveness of the forward recovery planning processes for returning the trains to service, for immediate rectification of defective vehicles.
- The potential for the original design and manufacturing choices to lead to development of cracks elsewhere in the train.
- The long-term management of the technical issues.

ORR will work closely with TOCs and passenger groups to review the impact on passengers from the withdrawal of trains, with a specific focus on the operators of Hitachi class 800 trains – Great Western Railway, London North Eastern Railway, TransPennine

Express and Hull Trains (although the impact on the latter was more limited). The passenger review will not include ScotRail given there was minimal impact to passengersusing its services.

The review will cover:

- consistency and clarity of travel information, both over the weekend of 8 May 2021 as the safety issues became apparent but also in the following week(s) including information provided by National Rail Enquiries;
- ticket refunds - information provided by train companies, National Rail Enquiries, and independent rail retailers to passengers about their refund rightsand the application of administration fees;
- advice to passengers on alternative travel arrangements including ticketacceptance on other operators; and
- the steps taken to contact passengers who had booked assistance to travel andthe accessible alternative arrangements offered.

We will report on the passenger impact by 25 June 2021 and produce an initial report covering the history, withdrawal and reintroduction of the rolling stock by 9 September 2021. A final report will follow when the long-term rectification programme has been established.

Annex 2 – progress against the terms of reference

Aim/*Activity*	**Status**
Aim 1: Determine the root cause	
The criteria for selecting the materials, the joining methods and any post-joining treatment when designing vehicles to operate for the life of the contract: **Analysis underway but further requested information needed.**	**Ongoing**
How the design, manufacturing and testing processes addressed the potential for SCC and fatigue cracking in the design. **Analysis underway but further requested information needed.**	**Ongoing**
Hitachi's processes to identify cracking in components during the life of the train. **Analysis underway but further requested information needed.**	**Ongoing**
The background to the identification of the cracks in the bolster area and how Hitachi managed the subsequent investigation **Completed, in technical review,** *and development of solutions.* **Methodology reviewed, but further work analysis needed as solutions are finalised.**	**Complete** **Ongoing**
Whether the cracks in the jacking plates could have been found earlier. **Analysis underway but further requested information needed to complete.**	**Ongoing**
The potential for the original design and manufacturing choices to lead to development of cracks elsewhere in the train. **Analysis underway but further requested information needed.**	**Ongoing**
Aim 2: Examine how the industry went about identifying the problem, assessing the safety risk, withdrawing the trains from service and returning trains to service	
The immediate response; considering the roles of Hitachi, the train operating companies (TOCs), Department for Transport (DfT) and ORR. **Completed in technical and SMS Capability reviews.**	**Complete**
The communication flows within Hitachi as maintainer / builder / designer **Further work to review with Hitachi.**	**Ongoing**

and between Hitachi and the TOCs, including whether they could be improved to speed up identification and resolution of common issues. **Completed in technical and SMS Capability reviews.**	**Complete**
Cooperation between all parties, and whether information flow or decision- making were affected by commercial, organisational, geographic or cultural factors. **Completed in SMS capability review.**	**Complete**
Contractual responsibilities for inspection, maintenance, repair and remedial action, and how these could be improved. **Further work needed to review contractual responsibilities including those set out in Train Service Agreements.**	**Ongoing**
The effectiveness of the forward recovery planning processes for returning the trains to service, for immediate rectification of defective vehicles. **This will be reviewed when the rectification plan is made available to ORR.**	**Ongoing**
The long-term management of the technical issues. **Analysis underway but further requested information needed to complete through technical review.**	**Ongoing**
Aim 3: Identify potential improvements	
We will report on areas for improvement in our final report.	**Ongoing**

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