Havarikommissionen
Accident Investigation Board Denmark

Report 2022-34

Wheel failure on freight wagon at Ejby on 13-1-2022

PUBLISHED APRIL 2024

FOREWORD

This is a translation of the Danish report: “Redegørelse 2022-34, Hjulbrud på godsvogn ved Ejby d. 13-01-2022”. In the event of inconsistencies between the two versions, the Danish version applies

Accident Investigation Board Denmark (AIB) is an independent safety investigation authority, whose fundamental purpose is to investigate accidents and incidents involving civilian aircraft and railway operations.

AIB investigates accidents and incidents involving railway operations with the aim of improving railway safety and preventing accidents.

In accordance with the Danish Railways Act, this report reflects AIB’s investigations and safety assessments of the circumstances linked to the accident or incident, as well as its causes and consequences.

The sole purpose of the investigations is to improve railway safety and not to apportion blame or liability. Any use of this report for purposes other than to improve railway safety or prevent railway accidents may therefore lead to erroneous or misleading interpretations.

CONTENTS

GENERAL

Case number:	2022-34
Date:	13-1-2022
Time:	11:40
Location:	Right-hand track between Kauslunde and Ejby, km 195.8
Accident type:	Incident
Accident category:	Other
Operation category:	Train operation
Infrastructure manager:	Banedanmark
Railway undertaking:	Hector Rail

Personal injuries	Fatal	Serious injuries	Minor injuries
Passengers:			
Personnel:			
Persons on crossing:			
Unauthorised:			
Others:			

Notification

AIB received notification from Hector Rail at 12:43 on 13-1-2022 of a wheel failure in train 42702 at Ejby.

AIB decided to instigate an investigation, as, in slightly different circumstances, the wheel failure could have developed into a serious accident.

1 RESUMÉ

Shortly before freight train 42702 was about to pass Ejby Station, part of a wheel on one of the wagons fractured. The train was brought to a stand in Ejby and subsequent investigation revealed that around 40% of the circumference of the wheel in question was missing. The incident did not lead to any derailment and the damage was limited to the vehicle's wheel, brakes, bogie and wagon floor.

AIB concluded that, under slightly different circumstances, the incident could have led to a serious accident and therefore decided to instigate an investigation into the incident.

The investigation, which was conducted in collaboration with the parties involved, has revealed safety deficiencies in the maintenance system underlying the wagon concerned.

Special stricter safety requirements concerning the minimum dimensions of the wheel type involved had not been complied with, and the monitoring and checks carried out by the entities in charge of maintenance were not sufficient to identify this. Vehicle inspections during day-to-day operations and repairs carried out by the mobile repair service were also unable to identify one or more cracks which had developed in the wheel before the failure occurred while the train was travelling at a speed of 99 km/h near Ejby.

AIB has issued three recommendations:

AIB considers that the decision by the entity in charge of maintenance not to conduct its own supplier audits of maintenance providers which were subject to audits by VPI led to a weaker focus among the maintenance providers on the stricter requirements imposed by the entity in charge of maintenance regarding the minimum diameter for type BA004 wheels.

DK-2024 R 2

AIB recommends that Trafikstyrelsen notifies the relevant accredited or recognised body or national safety authority about AIB's safety investigation and the identified safety improvement that can be achieved by ensuring that VTG identifies areas where VTG-MI contains stricter requirements compared with VPI-EMG, and that VTG carries out activities which ensure that VPI-certified maintenance providers fulfil the requirements set out in VTG-MI for these areas.

AIB considers that monitoring of completed maintenance work via the Hermes system could lead to it being possible to register and close maintenance work with erroneously used safety-critical spare parts without the safety barriers built into the system being triggered, with the consequence that the maintenance work is then erroneously considered to be error-free.

DK-2024 R 3

AIB recommends that Trafikstyrelsen notifies the relevant accredited or recognised body or national safety authority about AIB's safety investigation and the identified safety improvement that can be achieved by ensuring that VTG monitors maintenance deliveries

from VPI-certified maintenance providers in cases where VTG-MI contains stricter requirements for execution or tolerances relative to what is described in VPI-EMG.

Remark

The investigation revealed that a wheel of type BA004 was deformed and developed cracks as a result of one or more thermal overload events. Despite this, the visible sign of thermal overload (burnt paint in the transition zone between wheel plate and wheel rim) was significantly below the limit where a closer examination of the wheel should be carried out.

AIB has transferred this knowledge to the working group "JNS Broken Wheels", where, by agreement, it will be included in the group's further work with safety-promoting measures.

The investigation was complicated by the fact that the incident concerned a number of stakeholders in Denmark, Germany and Sweden. Communication with these stakeholders has in some cases been slow.

On 10-1-2023, AIB published a preliminary report[1] (in danish), which gave an account of the findings and status of the investigation.

[1] https://havarikommissionen.dk/undersoegelsesresultater/soeg-i-jernbane/2023/2022-34

2 FACTS

2.1 Description of the incident

As freight train 42702 was passing through Ejby, the platform departure signals changed to stop in front of the train. The locomotive driver initiated emergency braking and brought the train to a stand. The driver notified the Signalling Centre about the changing signals and was then given permission to proceed again. Track workers near Ejby Station had noticed that the first wagon behind the locomotive was jumping violently as it passed them. They contacted the locomotive driver before the train was ready to continue, and explained what they had seen. Together, they inspected the first few wagons behind the locomotive, whereupon they noticed that part of the wheel tread of one wheel was missing.

2.2 Circumstances

During a wagon inspection conducted on 12-1-2022, the train preparation staff in Krefeld, Germany noticed that wagon no. 33 68 4955 387-8 had defective brake blocks (Bremssohlen gebrochen). On the same day, the mobile workshop replaced 16 of the wagon's 48 brake blocks and released the wagon to traffic.
The wagon was loaded with two trailers and, on 13-1-2022, train 42702 departed from Krefeld with 21 wagons (714 metres and 1,852 tonnes) destined for Katrineholm in Sweden hauled by locomotive BR 241.005.
The train was delayed en route to Padborg, where a change of driver was scheduled to take place. As the train was arriving at Padborg, the locomotive driver who was to take over the train from Padborg walked alongside the train in the direction of the rear of the train in order to prepare to carry out a brake adjustment and inspection.
The driver then walked from the rear of the train towards the front and adjusted the brakes on all wagons from brake type "G" to "P". At the same time, the driver checked the saddles on the pocket wagons to ensure that the trailers had been correctly loaded and secured. The driver also inspected the tarpaulins on all cargo units. The driver did not notice any irregularities during this task/inspection.

Train 42702 departed from Padborg at 10:14, 1 hour and 31 minutes late. The driver has stated that there was nothing unusual about the handling of the train and that the train rolled easily. The train's indirect pneumatic (IP) brake was used for the first time since Padborg as the train approached Lunderskov, where 42702 had caught up another freight train. Through to Kolding, 42702 braked on numerous occasions using the IP brake due to the freight train on the line ahead of it. 42702 overtook the preceding freight train in Kolding, after which the IP brake was not used until the driver initiated emergency braking due to the stop in Ejby. The train's maximum permitted speed was 100 km/h. Shortly before the entry signal to Ejby, the train was travelling at 99 km/h, when the left-hand wheel on the third axle (axle 3) of the first wagon fractured and lost almost half of its tread. The train then continued for a further 1,250 metres, whereupon the platform departure signals on track 1 through Ejby changed to stop in front of the train. The locomotive driver initiated emergency braking and the train stopped after a further approx. 600 metres. All wheelsets remained on the track.

2.2.1 Undertakings involved

A number of undertakings was involved in the systems relating to train operation and maintenance:

- Hector Rail, railway undertaking (operator) with its head office in Sweden and operations in Sweden, Denmark and Germany.
- VTG Rail Europe GmbH (VTG), Germany, wagon owner and entity in charge of maintenance, ECM-F1, F2 and F3.
- SweMaint AB, Sweden, maintenance provider, ECM-F4.
- NIAG (Niederrheinische Verkehrsbetriebe AG), Germany, maintenance provider, ECM-F4.
- VPI (Verband der Privatgüterwagen-Interessenten), Germany, certification body relating to the maintenance of goods wagons.
- Banedanmark, infrastructure manager.

Bundesamt für Unfallsuntersuchung in Germany and the Statens Haverikommission in Sweden have been notified of the investigation. The AIB has also been in dialogue with the "Joint Sector Group - Broken Wheels" of the European Rail Agency (ERA) to exchange experience.

2.3 Deceased, injured persons and other damage

No one was injured during the incident, and the damage was limited to wheel, bogie, brakes and wagon floor.

Photo 1. Axles 3 and 4 on the damaged wagon after stopping in Ejby.

2.4 External circumstances

The weather was dry, overcast and 7°C. Mean wind speed 7.1 m/s from the west.

3 INVESTIGATIONS

3.1 Interviews of those involved

3.1.1 Interview of locomotive driver

The locomotive driver explained that he had begun duty in Padborg in order to take over train 42702. He had ascertained the train's punctuality at home and therefore knew that the train would arrive later than planned in Padborg. The driver therefore waited before leaving home in his car so that his arrival time would coincide with the arrival of the train in Padborg.

The driver arrived at Padborg Station shortly before the train was due to arrive, and therefore set off on foot to where the rear of the train would stop. On his way, the train entered Padborg Station, and he greeted the arriving driver as the locomotive passed him.

Upon reaching the rear of the train, the locomotive driver began to systematically inspect the train wagon-by-wagon as he walked towards the locomotive, while he adjusted the brakes on all the wagons from brake type "G" to brake type "P". During this inspection, all trailers were checked for correct loading on saddles, and tarpaulins were inspected for holes, cracks and loose parts. As he walked along one side of the train, the driver did not notice anything unusual as he inspected the train.

The driver then prepared the locomotive for use in Denmark, and reported to the Signaller in Padborg that he was ready to depart. The driver departed with train 42702 approximately 1 hour and 40 minutes late.

The train rolled easily, taking into account its weight, and the driver did not detect any signs that the brakes were dragging. At Lunderskov, train 42702 caught up a preceding freight train. This freight train was to be processed on track 3 in Kolding, and the driver had to slow the train on numerous occasions using the IP brake between Lunderskov and Kolding, so as not to catch up with the preceding freight train.
Train 42702 was given the "pass-through" signal on the entry signal in Kolding, and the line ahead was then clear. The driver was told by the Signalling Centre that he should keep his speed up so that his train would maintain a good distance ahead of the following express train, and possibly recover some of the late running.

The train was now travelling at a speed of approx. 100 km/h, and while passing through Ejby, the driver noticed that both platform departure signals changed from flashing green to red (stop) shortly before the locomotive passed the first platform exit signal. The driver initiated emergency braking and when the locomotive passed the second platform departure signal, automatic train control (ATC) emergency braking was activated. After stopping, the driver informed the Signalling Centre about the changing signals and was then given permission to proceed again.
Just as the train's brakes had been released following the emergency braking, he heard someone knocking on the locomotive's cab door. Outside were two Banedanmark employees, who told the driver that there was something wrong with the first wagon behind the locomotive. They then all inspected the wagon and found that one wheel was damaged. The driver noticed a smell of hot wheels and brakes, but the wheels and brakes were not so hot as to cause any noticeable radiant heat.

3.1.2 Interview of track worker

The track worker was sitting with his colleague and eating lunch in their company vehicle in the old railway yard next to track 1 in Ejby. Before the track worker was able to see the train, he noticed that the approaching train was very loud and thought that something must be wrong with it. As the train passed them, he immediately noticed that the wagon behind the locomotive was jumping up and down and rocking from side to side. He said to his colleague that there was something very wrong with the train and, at the same time, he noticed that the train was braking. They decided to drive over to the driver, as the track worker was not certain that the train had stopped because of the wagon.

They knocked on the cab door of the locomotive and told the driver that the whole wagon had been jumping up and down and that there was something wrong. The driver went with them to check the wagon and could not see anything wrong at first, because they were standing on the trench side (the right-hand side of the train) – they agreed that the driver would try to move the train forward a little, whereupon they were immediately able to see that the wagon was jumping up and down and rocking, and that there was something wrong with one wheel.

The track worker and his colleague then immediately started inspecting the track for marks and damage, and looking for the missing wheel flange. They both looked under and behind the train as far back as km 195.8, where they saw marks on the track indicating that a wheel flange may have fallen off there. A rail fastener had been damaged, and there were marks in the ballast which indicated that the wheel flange had been thrown across the neighbouring track and ended up in the ditch on the opposite side of the track. There were impact marks on the left-hand rail all the way to where the wagon was situated on tack 1.

The train was in the process of emergency braking when the track worker saw the train – the track worker did not see the signals or what they were displaying. The track worker did not call the Signalling Centre.

3.1.3 Interview of train preparer

The train preparer (Wagenmeister), which inspected the wagons for train 42702, both when they arrived at Krefeld on 12-01-2021 and prior to departure on 13-01-2021, noticed after arrival that wagon no. 33 68 4955 387-8 had damaged brake blocks (Bremssohlen gebrochen).
He attached a “Muster K” notice[2] to the wagon and suspended the brakes according to GCU Appendix 9, Annex 1[3]). He then asked the mobile workshop from the undertaking NIAG (Niederrheinische Verkehrsbetriebe AG) to come and repair the damage. When the train preparer inspected the wagons for 42702 prior to departure on 13-01-2021, he noticed that the brake blocks on wagon 33 68 4955 387-8 had been replaced, the label removed, the brakes reactivated and the wagon reloaded with two trailers. The train preparer said that it

[2] Muster K is a label that is attached to wagons. The label means that, after unloading/emptying, the wagon must not be reloaded and must only be taken to a workshop (with suspended brakes).

[3] GCU Appendix 9 Annex 1 provides guidance on faults and defects on freight wagons, which includes damage codes and associated operational orders.

was normal for the workshop to repair minor faults and defects immediately, so that the wagons would not be out of use for any longer than absolutely necessary.

3.2 Safety management system

Train 42702 was operated by Hector Rail, and the wagons for the train were hired by the client Samskib/Van Dieren. According to Hector Rail's safety management system (SMS), it was a requirement that, before wagons were put into service in a train belonging to Hector Rail for the first time, checks must be performed to ensure that, inter alia, the wagons:

- were approved and registered in a National Vehicle Register (NVR)
- were approved for use on the intended sections
- were subject to a certified Entity in Charge of Maintenance (ECM). This was to be checked via the ERADIS database[4]
- had an approved revision status.

Similarly, it is apparent from Hector Rail's SMS that, when in daily use, the wagons were to be inspected before each loading, before each departure and after each arrival. Technical faults, including faults and damage to wheels and brakes, were logged (see GCU Appendix 9, Annex 1) and reported to the relevant maintenance providers (ECM-F4), who then reported the completion of maintenance tasks to ECM-F3 (see section 3.3).

3.3 Maintenance system

VTG was ECM-F1, -F2 and -F3, i.e.:

- F1: Had principal responsibility for the safe state of the wagon.
- F2: Responsible for safety-related documentation, including user manuals and maintenance instructions.
- F3: Responsible for taking the wagon in and out of service in connection with visits to and release from workshops.

In the case of this particular wagon, the ECM-F4 role (the actual workshop function) was performed by various subcontractors to VTG. Of relevance to this investigation are SweMaint AB in Sweden and NIAG in Germany.

Both of the subcontractors referred to above were VPI-certified. VPI is an organisation which maintains a regime with rules and procedures for the maintenance of freight wagons called the European Maintenance Guide (EMG), and audits its members in relation to compliance with the aforementioned rules and procedures.

In addition to EMG, VTG's subcontractors are also expected to follow VTG's own undertaking-specific maintenance rules and procedures: VTG-MI (Maintenance Instruction). These typically concerned circumstances where VTG had imposed stricter requirements compared with EMG, or were specific components such as middle bogies on 6-axles articulated waggons not was covered by EMG. VTG-MI was published and

[4] European Railway Agency Database of Interoperability and Safety, which inter alia contains a register of certified ECM and interoperability declarations for vehicles.

distributed to the subcontractors by VTG via the ConSence system. ConSence contained a system for subcontractors to acknowledge receipt.

Of relevance to this investigation are the following VTG-MI:

- 4.1.001, which inter alia stated that:
  - The general minimum limit for the diameter of type BA004 wheels was 860mm, although a special minimum limit of 880mm applied to centre (articulated) bogies.
  - All solid wheels were to be visually checked for signs of thermal overloading (burnt paint, corrosion and cracks) during each workshop visit, including in connection with the replacement of brake blocks by mobile workshops.
  - Type BA004 wheels were to be ultrasonically tested in the event of any signs of thermal overloading being detected.
- 4.2.001, which stated under section 4.2.4 that the minimum limit for the wheel diameter of type BA004 wheels was 860mm.
- 7.1.004, which set out procedures and rules for switching from cast iron (GG) to composite (LL) brake blocks. This included criteria for flange thickness, which was to be taken into account during the modifications and, particularly with regard to wagons with a maximum permissible speed of 120 km/h, reference was made to VTG-MI 4.2.001, section 4.2.4.

Of relevance to this investigation were the following VPI-EMG:

- 01-4.11, section 15. During workshop visits, wheels were to be checked for cracks, if there were any signs of thermal overloading, e.g. burnt paint.
- 10-4.0, Annex 4. In the case of servicing by a mobile workshop, burnt paint of less than 50 mm was not deemed to be a sign of thermal overloading.

According to VTG's maintenance system (document "Anlage 1 zur Business Unit SOP – Lieferantenmanagement"), VTG conducted supplier audits on its maintenance providers at intervals of not more than three years. Excluded from this were maintenance providers which were VPI-certified. These undertakings were audited by VPI at intervals of not more than three years.

When VPI audited the VPI-certified workshops, checks were carried out to ensure that the undertakings were complying with the requirements of VPI-EMG, amongst this if the workshops had access to ECM-specific maintenance instructions and if procedures for using them were in place.

The two VPI-certified maintenance providers to be investigated were last audited and approved by VPI on 17-10-2018 (SweMaint AB) and 11-11-2021 (NIAG) respectively.

When VTG audited maintenance providers, checks were carried out to ensure that the undertakings fulfilled the requirements set out in VPI-EMG, as well as the vehicle owner's maintenance documentation. As regards VTG, this concerns VTG-MI.

VTG also carried out regular quality checks at the maintenance suppliers. Here various themes were checked and discussed.

For example, attention was drawn to VTG-MI 4.1.001, section 4.2 "Einbausperren" [Prohibition on mounting certain wheel types in certain bogie types] during a quality check at NIAG on 05-02-2018 and 06-02-2018.

In the past five years prior to the incident on 13-01-2022, the following quality checks were carried out:

	2017	2018	2019	2020	2021	2022
SweMaint	-	-	13. June 8. July	20. February	-	-
NIAG	Januar 8. May 6. July 27. October	5. February 6. February	-	-	-	-

Table 1. Overview of completed quality checks carried out by VTG at the respective SweMaint and NIAG workshops. Source: VTG.

The maintenance providers used the VTG system Hermes to register repairs and maintenance carried out on VTG's wagons, including work carried out on safety-critical components such as wheelsets. The system kept track of many parameters, including:

- status of wheelsets (new, used, defective)
- deadlines for inspections and audits
- stock levels
- all vital geometric dimensions, including wheel diameter.

The system also included numerous control functions to ensure the correct use of safety-critical components. The system thus ensured that it was not possible to register the fitting of a wheelset to a wagon if it had not first been registered as being serviceable and in stock. Checks were also made on the mutual compatibility of the wheelset, bogie and wagon type and numerous other factors.

The system was structured so that it was not possible to close an order until registration had been carried out without any error messages. This ensured that repairs could not be registered as complete if incorrect spare parts had been used.

The system had no control function for the special increased minimum diameter (880 mm) that applied to type BA004 wheelsets fitted to centre bogies on six-axle wagons (Requirement according to VTG-MI 4.1.001).

3.4 Technical investigations of rolling stock

During the investigation of the damaged wagon, damage was visible on the centre bogie and the wagon floor above the bogie, which had been caused by severe vibrations and the part(s) of the wheel components which had broken off the wheel.

The bogie's hand brake was not in the end position (see photo 2), but due to damage to the brake equipment, it was not possible to determine whether the position of the hand brake meant that the brakes had dragged against the wheels prior to the accident.

Photo 2. Hand brake actuator with threaded rod 8-9 revolutions from the end position.

The brake blocks around the broken wheel were damaged. Eight of the 16 brake blocks on the centre bogie were new (two on each wheel) (see photo 3).

Photo 3. New brake blocks. The wagon's 3rd axle on the right-hand side.

The wheelset which was fitted to axle 3 had the number 85 19 147 193 and was of the BA004 type. It showed signs of thermal overload, with both burnt paint and deformation of the wheel tread. The burnt paint was approx. 20 mm up the wheel plate and is considered to predate the most recent use of the wagon due to the presence of corrosion around the burnt paint (see photo 4). The wheel diameter had not been written on the inner side of the wheel and was measured at 840 to 848 mm (ovality) after the incident.

Photo 4. Burnt paint and corrosion in the transition between wheel plate and wheel rim.

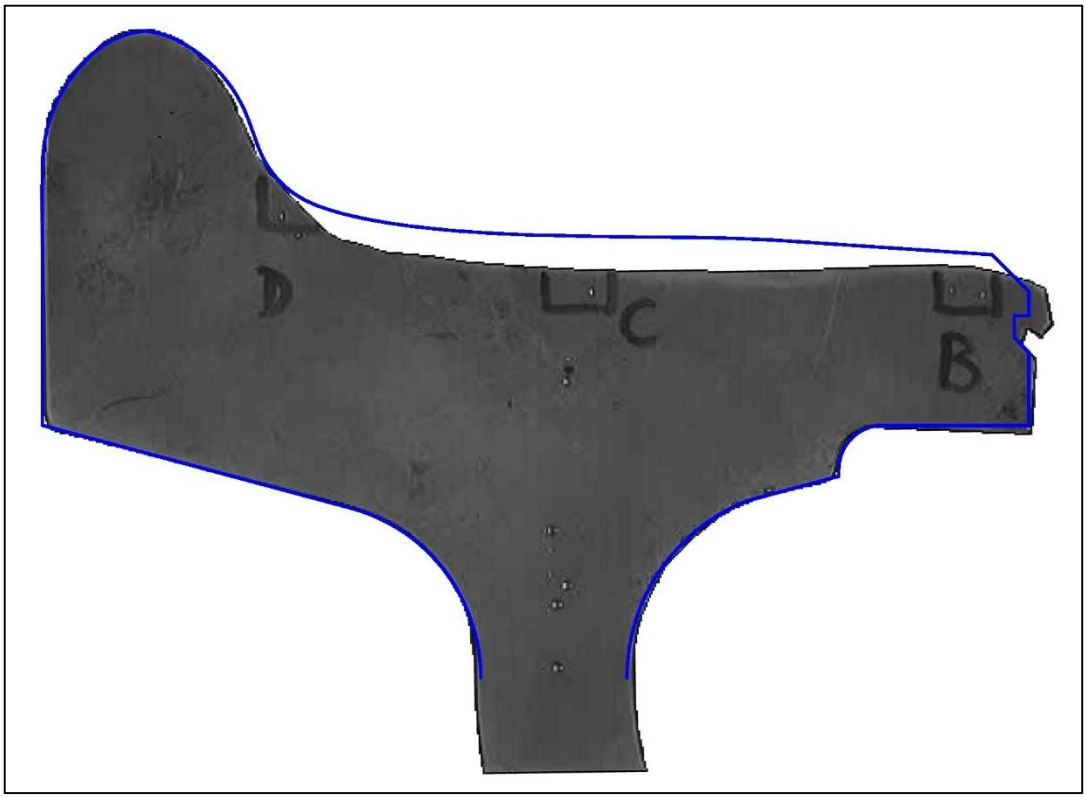

Figure 1. Wheel profile for the damaged wheel (Grey) compared with wheel profile according to EN 13715, at 862 mm (Blue line).

At the request of AIB, Force Technology has investigated the failed wheelset. Signs of crack formation and material loss were visible on the treads of both wheels (see photo 5).

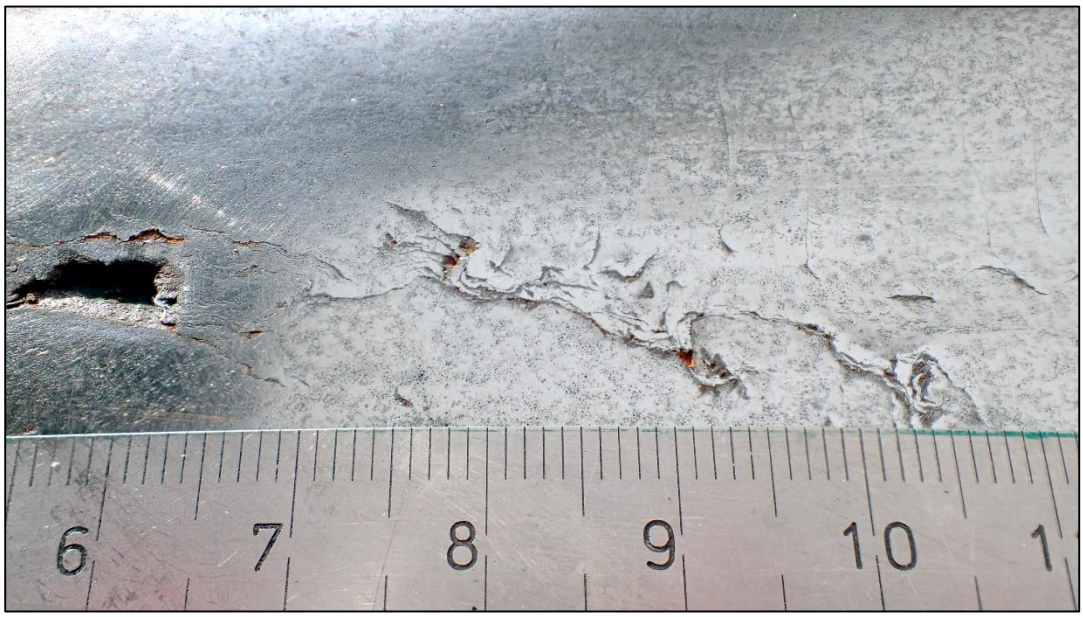

Photo 5. Close-up photograph of the intact wheel on wheelset 8519147193 showing cracks and material loss. The scale on the ruler shows cm. Source: Force Technology.

The investigation revealed that a fatigue crack had developed in the transition zone between the wheel plate and wheel rim on the outside of the wheel. See Figures 1 and 2.

The direction of propagation was clearly indicated by the curved failure lines. See Figures 1 and 2, and photo 6.

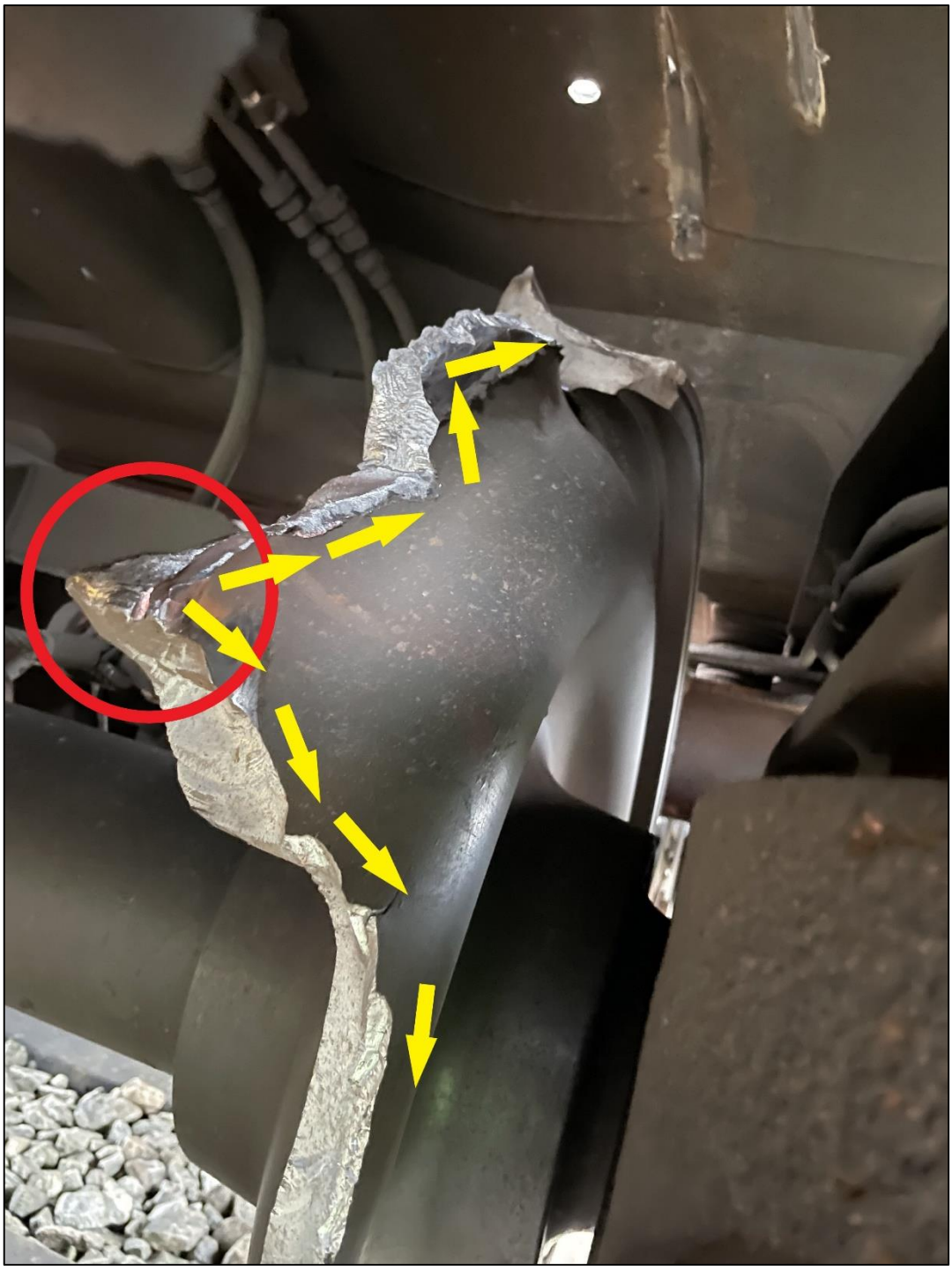

Figure 2. Initiation point (starting point) and direction of propagation. Source: Force Technology.

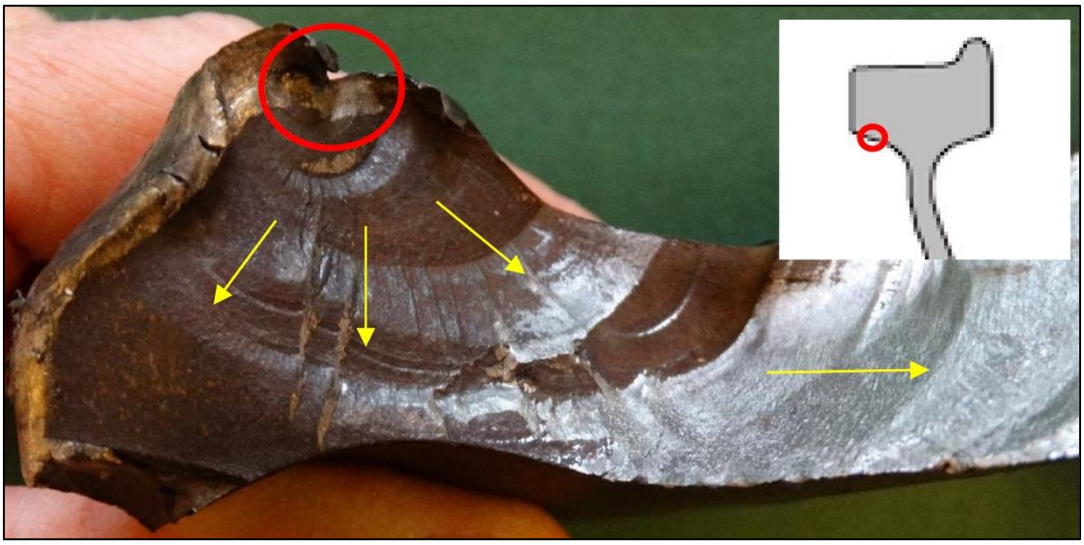

Figure 3. Initiation point and direction of propagation, before cleaning. Source: Force Technology.

Photo 6. Initiation point after cleaning with Alconox®. Source: Force Technology.

Scanning electron microscopy (SEM) revealed no visible imperfections in the fracture origin (see Figure 3).

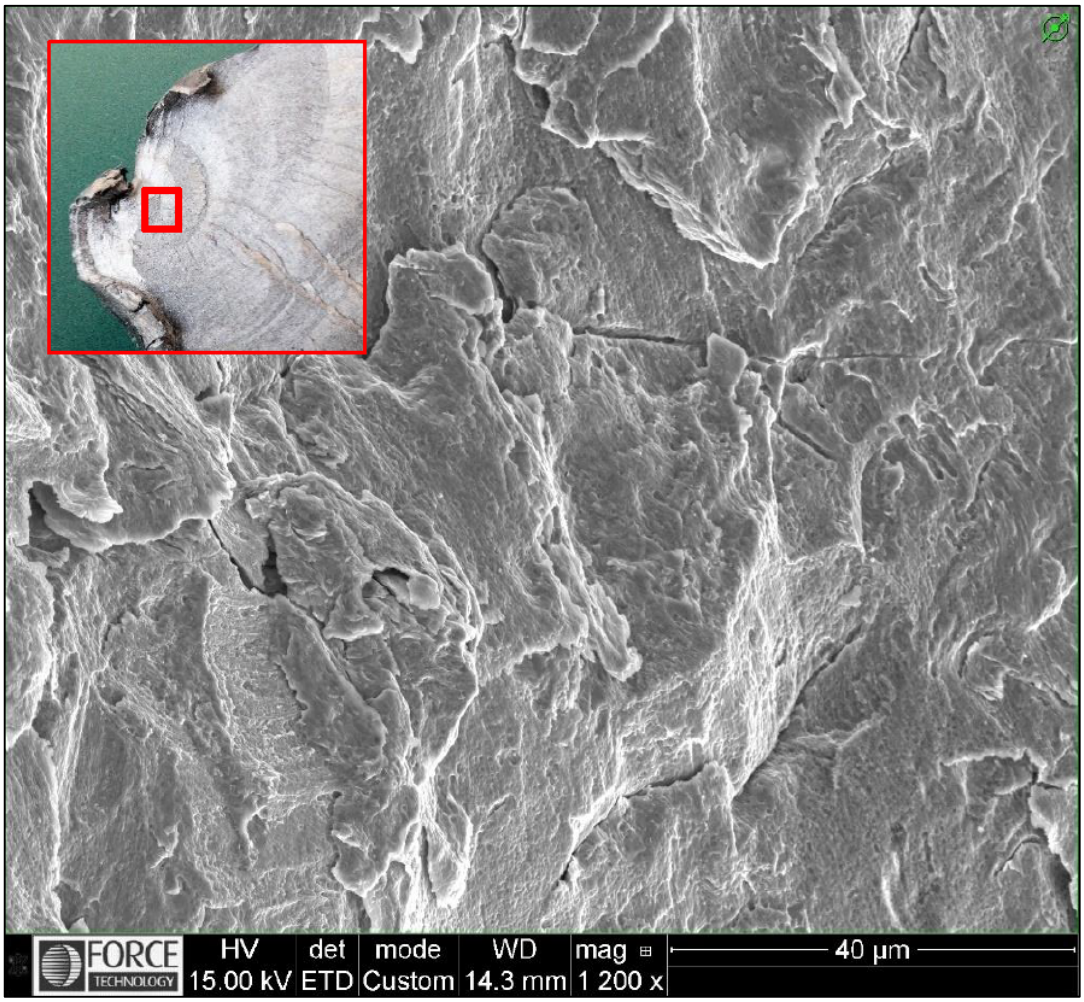

Figure 4. No visible imperfections in the fracture origin. Source: Force Technology.

A hardness test was carried out on a section of the failed wheel.
As the wheel had reached its wear limit, the test could not be carried out precisely in accordance with EN 13262, which specifies that measurement points b, c and d must be situated at the wear limit of the wheel.
These measurement points were therefore moved 3 mm down below the wear limit (see photo 7). At these points, the hardness was considerably above the requirement specified in EN 13262. Further down below the wear limit, the hardness was measured to be considerably below the requirement specified in EN 13262.

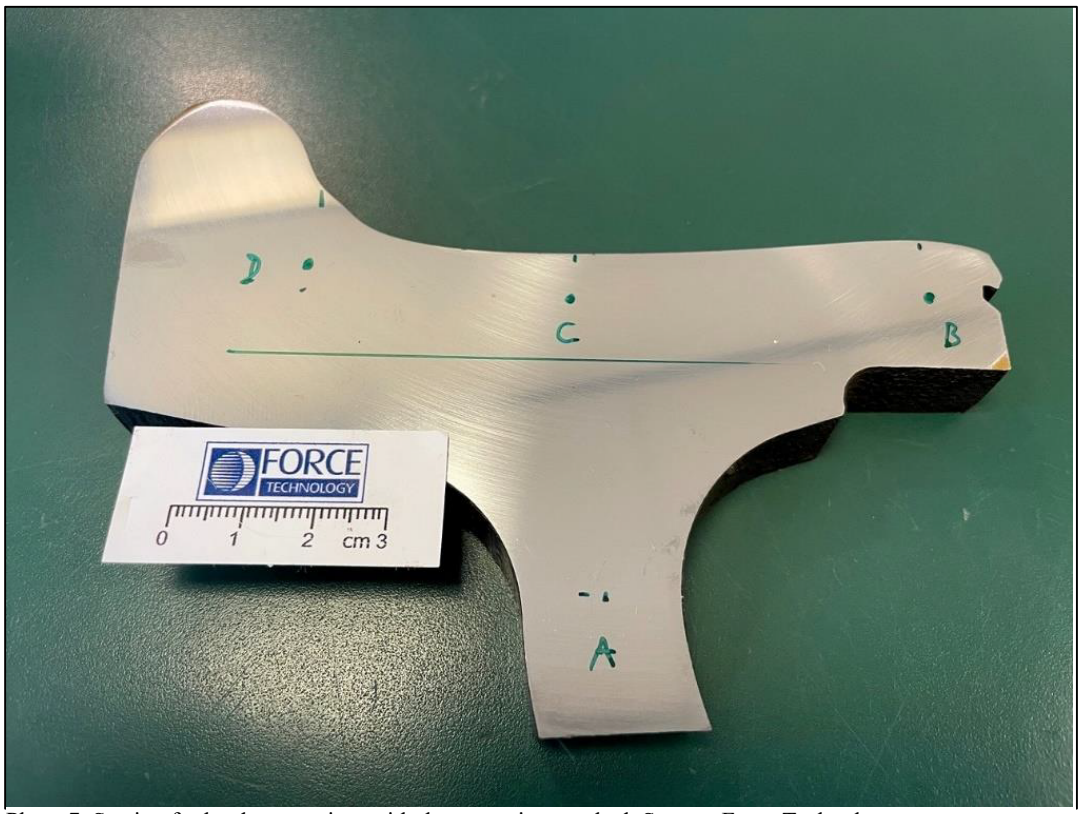

Photo 7. Section for hardness testing, with the test points marked. Source: Force Technology.

Force Technology concluded: The fracture was caused by fatigue and the fracture origin was located in the inner side of the wheel rim. Force Technology suggests that the fracture was caused by one or a combination of the following factors:

- Excessive heat from the friction between the wheel, brake and rim.
- Reduced wheel diameter could change the heat and stress distribution at the wheel rim.
- Reduced wheel material strength indicated by hardness testing results from the wheel rim cross-section.

3.4.1 Maintenance documentation

Wagon 33 68 4955 387-8 had VTG Rail Europe GmbH (Germany) as its owner, holder and entity in charge of maintenance (ECM). The undertaking has supplied maintenance documentation for use in this investigation. This documentation indicates that, by virtue of

the ECM-F2 function, VTG supplied maintenance instructions to both SweMaint and NIAG.
It is apparent from the changing maintenance instructions that the minimum wheel diameter was dependent on the position of the wheelsets (1/2/5/6 or 3/4) and whether the wagon was fitted with GG or LL brake blocks.
The requirements regarding minimum wheel diameter have been revised on several occasions over time, and the changes were distributed as VTG-MI via ConSence.

The following was deduced from the maintenance documentation provided by VTG AG. Only circumstances of relevance to the investigation are considered here.

SweMaint reprofiled the wheelset with number 75 19 147 193 to a diameter of 862 mm, and then fitted this wheelset as axle 3 on wagon 33 68 4599 387-8 on 14-06-2019.
At this time, the general requirements for minimum wheel diameter (see VTG-MI and VPI-EMG) were 856 mm and 860 mm respectively for wagons fitted with GG brake blocks, which this wagon had at this point in time. However, the VTG-MI specifically stated that a minimum wheel diameter of 880 mm was required for axles 3 and 4 on this type of wagon.

On 06-02-2020, NIAG inspected the wheelsets on the wagon and stated that they were all still in a serviceable condition.

On 23-06-2020, NIAG was ordered by VTG to modify wagon by fitting LL brake blocks to it. In addition to general references to VTG-MI, the order also included a direct reference to the fact that type BA004 wheels mounted on a middle bogie were to be at least 880 mm in diameter, and that they were to be replaced if their diameter was less than 880 mm. On 20-07-2020, NIAG fitted LL brake blocks to the wagon and again stated that all the wheelsets on the wagon were serviceable. The personnel who carried out the modifications did not see the written order from VTG and performed the task as described in VPI-EMG. The general requirement regarding minimum wheel diameter according to VTG-MI at this time was 865 mm for wagons fitted with LL brake blocks, although the minimum wheel diameter for wheelsets fitted to middle bogies on this type of wagon was 880 mm. The requirement stipulated in VPI-EMG was still 856 mm.

On 15-02-2021, after replacing the wheelsets on axles 1, 2 and 4, NIAG stated that all the wheelsets on the wagon were serviceable. The wheelset which was fitted as axle 4 had a wheel diameter of 870 mm. Here, the wheelsets on axles 3 and 4 were therefore both below the requirement for minimum wheel diameter according toVTG-MI, but above the minimum dimension according toVPI-EMG.

On 12-01-2022, the mobile workshop from NIAG replaced 16 LL brake blocks on the wagon, which had been reported as damaged on the same day under damage code 3.2.2 (Bremssohlen gebrochen). The wagon's brakes were then tested and the wagon declared serviceable again.

3.4.2 On Train Data Recorder (OTDR)

Compared with Banedanmark's time logs in signal video and radio calls, the OTDR from BR 241.005 (Appendix 7.1) can be seen to be approx. 2 minutes ahead of the correct time. In the following, times in parentheses have been corrected in relation to Banedanmark's system time.

The OTDR shows stopping [in Padborg] at 09.50 (09.48) and restarting at 10.16 (10.14).

The OTDR data supplied to AIB does not include data concerning electrical dynamic braking. AIB believes that the speed profile indicates that direct electrical dynamic braking was used to reduce the speed and that, where this was insufficient, braking was supplemented with Indirect Pneumatic (IP) braking.

From departure from Padborg and through to the time of the incident at Ejby, the locomotive driver appears to have made three IP brake applications:

- 11.05 (11.03) – 11.06 (11.04) 44 seconds, pressure reduction 0.83 bar, followed by overcharging of 0.1 bar. Speed 90.0 – 37.6 km/h
- 11.11 (11.09) – 11.12 (11.10) 48 seconds, pressure reduction 0.70 bar, not followed by overcharging. 92.7 km/h, speed steadily dropping through to the next brake application.
- 11.14 (11.12) – 11.14 (11:12) 12 seconds, pressure reduction 0.75 bar, not followed by overcharging 28.1 – 13.1 km/h.

Around the time of the incident, the following is seen:

- 11.42 (11.40) [1,279 metres before stopping] Speed: 98.82 km/h
- 11.43 (11.41) Emergency braking at 94,8 km/h
- 11.44 (11.42) ATC emergency braking at 26.5 km/h
- 11.44 (11.42) Stopping.

3.5 Infrastructure conditions

The investigation has not revealed any circumstances associated with the infrastructure that has had any effect on the incident.

In Rødekro, Bred and Glostrup, Banedanmark have installed Wheel and Axle Load Detectors (WALD).

These systems had two purposes. Their primary purpose was to warn about excessive forces impacting Banedanmark's infrastructure, while a secondary purpose was to provide vehicle owners with data on the condition of the wheels on their vehicles both as part of their maintenance planning and before situations became critical.
These measuring stations recorded increasing ovality/flat spots on each occasion that the vehicle passed the measuring stations, both during the days leading up to the incident and on the day of the incident itself. However, the values for these measurements (Peak Dynamic Wheel Force, PDWF) were below the limits for Banedanmark's alarm limits (400 kN, to protect the infrastructure).

Date	Train	Location	Axle load (tonnes)	PDWF (kN)
10.01.2022	42702	Rødekro	15.92	97.48
		Bred	15.71	116.80
		Glostrup	No recordings	
11.01.2022	42701	Glostrup	18.93	118.13
		Bred	19.21	147.97
		Rødekro	No recordings	
13.01.2022	42702	Rødekro	17.64	131.72

Table 2. Forces from the investigated wheel recorded during the days leading up to the incident. Source: Banedanmark.

For comparison, it is noted that the mean PDWF for train 42702 on 13.01.2022 at Rødekro was 20.40 kN.

AIB is only aware of one vehicle owner which receives wheel quality data from these systems for use in maintenance planning. VTG was unaware of the possibility of receiving data from the systems.

3.6 Human factors

VTG had based its monitoring of the maintenance providers' use of compatible safety-critical components on the Hermes system, which among other things did not allow maintenance orders to be finalized if incompatible parts had been used.
This often meant that a maintenance provider had to seek guidance from VTG when one or more error messages prevented finalizing of a task. VTG would then provide guidance on what the fault consisted of, so that the maintenance provider could rectify the fault and finalize the order. Users of the system were unable to see what checks had been performed by the system. Only failed checks were displayed to the user with error messages.

The comprehensive checks that the system carried out may have led maintenance providers to believe that the successful finalizing of a maintenance order constituted confirmation that it was error-free.

3.7 Previous incidents of a similar nature

Following a number of incidents in 2016 and 2017 involving wheel fractures and cracks in wheel types BA 314 / ZDB29 and BA004, the European Rail Agency (ERA) in 2017 set up a working group called "JNS Procedure Broken Wheels", which from May to July was of the type "Urgent" and worked on immediate measures (mitigations) aimed at eliminating the problem.

After the urgent tasks had been concluded, the working group switched to the type "Normal" from August 2017 to December 2019. The aim of this working group was to analyse all incidents involving the abovementioned wheel types in order to submit recommendations for more long-term mitigations aimed at the problems of cracks and failures.

The working group kept the industry informed of its findings on an ongoing basis, so by the time it published its report (Final output[5]) in December 2019, the entities in charge of maintenance had already had an opportunity to implement the mitigations proposed by the working group in their maintenance systems.

It is apparent from the working group's results that wheel type BA004 can no longer be considered to be thermostable. (Thermostable wheels have greater resistance to thermally initiated cracks.)

In addition, the working group has identified factors which individually have an impact on the risk of thermal overloading (See also Final Output[5]):

- Type of traffic (combined traffic or not) [Intermodal].
- Braking input (high or not)
- Brake blocks (composite or not).
- Wheel diameter (less than 860 mm or not).
- Traffic crossing the Alps or not.
- Traffic in northern countries or not.
- Articulated wagons (Middle bogie or not).

The working group also noted that the presence of several of these factors would result in an increased probability of overheating and thereby an increasing risk of crack formation.

The working group recommended that entities in charge of maintenance carry out their own risk analyses in relation to wheel type and use as per the abovementioned.

Since its final output, the working group has remained active regarding the implementation and updating of its results. The group also analyses new incidents as and when they occur. AIB has collaborated with the working group in connection with this investigation.

The working group "JNS Procedure Broken Wheels" was based on an accident in St. The Gotthard tunnel on 10-08-2023, reactivated with a scope of further investigations and possibly expansion of the group's recommendations to apply to other wheel types as well.

[5] https://www.era.europa.eu/system/files/2022-11/jns_np_tf_broken_wheels_final_output_en.pdf

4 ANALYSIS

Hector Rail's SMS describes that, before using a wagon for the first time, the undertaking was required to ensure that the wagon was subject to an ECM.
The undertaking was then required to ensure that the wagon was taken out of service if it had suffered damage (As per GCU Appendix 9, Annex 1) and not released back into traffic until a notification had been issued to the effect that the damage had been repaired.
Prior to each departure, a check was to be performed to ensure that the date of the next inspection had not been passed. Thus, Hector Rail had ensured that the wagon had an approved ECM and was subject to an approved maintenance regime.
In respect of Hector Rail's use of wagon 33 68 4955 387-8, AIB has not identified any non-conformities in relation to the description in the undertaking's SMS.

In relation to the maintenance of wagon 33 68 4955 387-8, the investigation has revealed a sequence of events which began back in June 2019, when the wagon was fitted with wheelset 85 19 147 193, of the type BA 004, by a maintenance provider.

At the time of fitting, the diameter of the wheelset was 862 mm. This was above the general minimum requirement for wheel diameter, but less than the special requirement imposed by the EMC for this particular wheel type in this position in a wagon with a middle bogie. In this case, the requirement was for a minimum of 880 mm.
The maintenance provider was inattentive to the ECM's stricter safety requirements in this particular case.

The ECM had defined the stricter safety requirement following a general recommendation issued by ERA[6] to ECMs to carry out their own risk analyses in relation to wheel type and use. The stricter safety requirements were implemented in the maintenance system, with inclusion in VTG-MI, and then distributed to the maintenance providers.

For this wagon in 2019, the combination of factors which increased the risk of thermal overloading, and thereby crack formation according to ERA[6], was combined [intermodal] traffic, traffic in northern countries and articulated wagon (middle bogie).

In 2020, the wagon was modified through the replacement of its cast iron brake blocks with composite brake blocks by another maintenance provider.
In this situation, the maintenance provider should have been aware of the VTG-MI, as well as the direct instruction in the order for this modification, which as a consequence of the wheel type and position in a middle bogie, specified a minimum wheel diameter of 880 mm.

Both maintenance providers were VPI-certified. And the requirements in VPI-EMG were fulfilled in connection with both maintenance jobs.
The entity in charge of maintenance did not carry out its own supplier audits of the two maintenance providers because they were both regularly audited under the auspices of VPI. As regards the maintenance work, audits were carried out under the auspices of VPI with respect to the requirements of VPI-EMG. It was also checked whether the maintenance suppliers had access to ECM-specific maintenance instructions, including VTG-MI.

As regards both maintenance providers, the monitoring carried out by the ECM was based on the Hermes system's control of safety-critical components. However, verification in

[6] The "JSG – Broken Wheels" working group set up under the auspices of the European Rail Agency. See section 3.7.

relation to the special requirements for wheel type BA004 fitted to a middle bogie was not programmed. As a result, the maintenance providers in both cases was able to finalize the maintenance work without any indication of errors.

From a human factors perspective, it is likely that the maintenance providers interpreted the system-related error-free finalizing of the maintenance work to constitute confirmation that the work had been performed correctly. This can be viewed in light of the fact that it was not normally possible to finalize maintenance work in the system if errors were present as a result of either the use of incompatible spare parts or errors in the Hermes system. This often required assistance from VTG's support function, which could then confirm the nature of the error and, in some cases, correct the system if necessary.

Following its conversion to composite brake blocks, the wagon had yet another of the factors which the ERA[6] believed increased the probability of thermal overloading.
During the use of the wagon from June 2019 the wheels had become worn, and by the time of the incident on 13-01-2022, the wheel diameter had decreased to as less as 840 mm.
After the incident, the wheelset showed signs of one or more occasions when the wheelset had been thermally overloaded. This was apparent through burnt paint and corrosion in the transition between wheel plate and wheel rim. The burnt paint extended approx. 20 mm up the wheel plate. Due to the presence of corrosion, the signs were considered to predate the day of the incident.

On the day before the incident, a damage report was issued for the wagon due to defective brake blocks. The same maintenance provider that had modified the wagon by fitting it with composite brake blocks therefore replaced 16 brake blocks on wagon 33 68 4955 387-8, of which four were fitted to axle 3 of the wagon and therefore on the wheelset which showed signed of thermal overloading. The work was carried out by the mobile workshop.

In accordance with VPI-EMG, wagons should be inspected for signs of damage to wheelsets on each workshop visit, including burnt paint in the transition between the wheel plate and wheel rim.
The rules for maintenance carried out by mobile workshops differed from those for workshop visits through the use of a "de minimis limit", which permitted burnt paint of up to 50 mm before the wheel had to be investigated further for crack formation. The investigation has indicated burnt paint of approx. 20 mm. This is less than the de minimis limit; hence, the mobile workshop was not required to remove the wheel for more detailed examination for crack formation. Although the amount of burnt paint was significantly below the de minimis limit, the wheel tread was worn and the outside of the tread was deformed, probably due to thermal overload.

During the AIB's examination of wagon 33 68 4955 387-8 following the incident on 13-01-2022, it was noted that the hand brake on the bogie in question was not in the end position.
It has not been possible to determine whether the position of the hand brake meant that the brakes had dragged against the wheels prior to the accident due to damage to the brake equipment. However, based on the newly fitted brake blocks not being worn down, it is considered that the brakes on this bogie probably did not drag on the journey from Krefeld. There was no record of dragging brakes on train 42702 on 13-01-2022.

During the days leading up to the incident, the wheelset produced results with increasing values for ovality / flat spots when it passed Banedanmark's WALD at Rødekro, Bred and

Glostrup. Even though it was not the purpose of the WALD to detect crack propagation in wheels, it is very likely that these results were due to the development of one or more cracks in the wheel at this time, and would probably have been discovered had the wheel been inspected and ultrasonically tested in connection with the replacement of brake blocks prior to departure in train 42702 on 13-01-2022. The measured values were below Banedanmark's limits (for protection of the infrastructure) and therefore did not give any rise to any need to stop the trains for inspection.

The ECM of wagon 33 68 4955 387-8 did not receive any data concerning wheel quality from Banedanmark's WALD. The ECM did not have any agreement with Banedanmark concerning this service, nor were they aware that the service even existed. In this regard, it should be noted that only a small proportion of the ECM's fleet regularly passed Banedanmark's WALD systems.

The metallurgical investigations carried out on the failed wheel revealed that a crack had developed as a result of one or more of the following three causes:

- Adverse heat development caused by friction between brake block and wheel rim.
- Reduced wheel diameter may have altered the distribution of heat and stresses in the wheel rim.
- Reduced wheel material strength, which was indicated by hardness tests.

5 CONCLUSIONS

On the basis of the completed investigations, it is AIB's view that wagon 33 68 4955 387-8 was used in service with a crack in one wheel, which developed at an accelerating rate through until the wheel failure occurred.
Since it had been fitted in 2019, the wheel had had a diameter which was below the ECM's stricter requirements for minimum wheel diameter. When the wagon was modified in 2020 through the fitting of composite brake blocks, there were a number of factors present, each of which individually increased the risk of thermal overloading of the wheel.

One or more events involving thermal overloading initiated a crack on the inside of the wheel rim. The crack propagated circumferentially in both directions through the wheel plate before finally fully penetrating the wheel rim, whereupon approx. 40% of the wheel's circumference separated. The failure took place at a speed of 99 km/h, and the train was then stopped due to a signal error after travelling a further 1,879 metres. The wagon did not derail.

Since 2019, the wagon had had several workshop visits, as well as visits from a mobile workshop. On several of these occasions, including in connection with the fitting of the wheelset, the replacement of other wheelsets on the wagon and modification to composite brake blocks, the maintenance providers have considered the wheelset to be serviceable. The two maintenance providers who were investigated were inattentive to the stricter requirements imposed by the ECM regarding minimum wheel diameter for this particular wheel type, nor did the monitoring of the maintenance work carried out by the ECM include checks on compliance with the stricter requirements. The maintenance providers were not audited in relation to compliance with the stricter requirements imposed by the ECM for type BA004 wheels.

On the day before the incident, a maintenance provider with a mobile workshop replaced some of the wagon's brake blocks, including four on the wheelset that subsequently failed. The wheelset probably was showing signs of thermal overloading by this point in time, but the burnt paint was less than 50 mm and thus under the de minimis limit for the mobile workshop. This is probably the reason why the wheelset was not investigated further. The investigation has shown that the wheel was oval and the outside of the running surface was deformed. The deformity was probably caused by one or more events with thermal overload, but the heat generation at this/these events did not result in burnt paint of more than approx. 20 mm in the transition zone between wheel plate and wheel rim.

Wagon 33 68 4955 387-8 had been in service since 14-06-2019 with a wheelset that had a smaller diameter than the minimum requirement stipulated by the EMC, and the wagon remained in service while the wheelset was at an elevated risk of thermal overloading. Before the incident on 13-01-2022, the wheelset probably showed signs of thermal overloading. A crack began to develop, but was not discovered by the mobile workshop, probably because the sign of thermal overload was burnt paint less than 50 mm.

5.1 Supplementary information

On 04-05-2023, AIB notified the Danish Civil Aviation and Railway Authority (Trafikstyrelsen) of what AIB considered to constitute a deficiency in the maintenance system of the German ECM. At this time, the investigation had revealed that the ECM had

not been able to detect the circumstances which had been in existence for an extended period of time and which ultimately led to the wheel failing under circumstances which could have led to a serious accident. At the request of AIB, the ECM had stated that no changes had been made to the maintenance system since the incident, despite the fact that, through its collaboration with AIB, the ECM had become aware of this safety deficiency. At the same time, the ECM has just had its ECM certificate renewed via a certification body in Luxemburg.

6 RECOMMEDATIONS

As a result of Article 26(2) of Directive (EU) 2016/798 of the European Parliament of 11 May 2016 on railway safety, the recommendations listed below are submitted to the Danish safety authority, Trafikstyrelsen.

AIB considers that the decision by the entity in charge of maintenance not to conduct its own supplier audits of maintenance providers which were subject to audits by VPI led to a weaker focus among the maintenance providers on the stricter requirements imposed by the entity in charge of maintenance regarding the minimum diameter for type BA004 wheels.

DK-2024 R 2

AIB recommends that Trafikstyrelsen notifies the relevant accredited or recognised body or national safety authority about AIB's safety investigation and the identified safety improvement that can be achieved by ensuring that VTG identifies areas where VTG-MI contains stricter requirements compared with VPI-EMG, and that VTG carries out activities which ensure that VPI-certified maintenance providers fulfil the requirements set out in VTG-MI for these areas.

AIB considers that monitoring of completed maintenance work via the Hermes system could lead to it being possible to register and close maintenance work with erroneously used safety-critical spare parts without the safety barriers built into the system being triggered, with the consequence that the maintenance work is then erroneously considered to be error-free.

DK-2024 R 3

AIB recommends that Trafikstyrelsen notifies the relevant accredited or recognised body or national safety authority about AIB's safety investigation and the identified safety improvement that can be achieved by ensuring that VTG monitors maintenance deliveries from VPI-certified maintenance providers in cases where VTG-MI contains stricter requirements for execution or tolerances relative to what is described in VPI-EMG.

Remark

The investigation revealed that a wheel of type BA004 was deformed and developed cracks as a result of one or more thermal overload events. Despite this, the visible sign of thermal overload (burnt paint in the transition zone between wheel plate and wheel rim) was significantly below the limit where a closer examination of the wheel should be carried out.

AIB has transferred this knowledge to the working group "JNS Broken Wheels", where, by agreement, it will be included in the group's further work with safety-promoting measures.

7 ANNEX

7.1 Extract from OTDR for BR 241.005