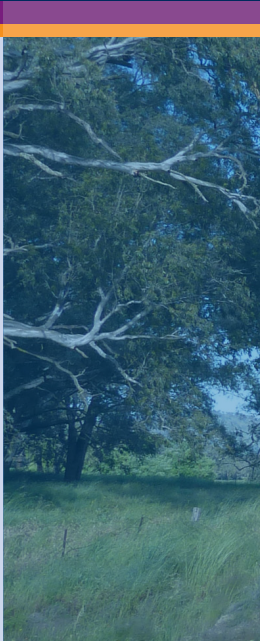




Australian Government
Australian Transport Safety Bureau



ATSB TRANSPORT SAFETY REPORT
Rail Occurrence Investigation
RO-2010-011
Final

Derailment of train 3PW4 Wodonga, Victoria

23 October 2010



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Wodonga, Victoria
23 October 2010**

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Abstract

At approximately 0710 on 23 October 2010, 15 wagons on freight train 3PW4 derailed near Wodonga, Victoria. There were no injuries but serious damage to rolling-stock and rail track (including a bridge structure) was sustained during the derailment.

The investigation concluded that an axle bearing on wagon RKWY-4125C failed and completely seized, causing the inner rings to spin on the axle journal, generating and transmitting sufficient heat to the journal to make it 'plastic' and causing it to separate from the axle (commonly referred to as a screwed journal). The most likely cause of bearing seizure was a loss of interference fit between the inner rings and journal which allowed the inner rings to turn or spin on the axle journal leading to increased wear and ultimately generating significant heat and damage until the bearing completely seized. It was possible that fretting and rotational creep contributed to the loss of interference fit.

Examination of data recorded by the ARTC Bearing Acoustic Monitoring system (RailBAM) found that, over the previous 12 months, the system detected potential looseness or fretting defects on wagon RKWY-4125C, but did not record any apparent fault trend. Nor did the system record any bearing defect on wagon RKWY-4125C when train 3PW4 passed through the system on 21 October 2010.

While there was no documented evidence of such, Pacific National advised that they actively in-service monitor the risk of looseness and fretting damage to bearing components, but since mid-2007 have not relied solely on fault indications identified by RailBAM. It is recognised that, with current maintenance processes in place, bearing failure due to looseness and fretting is relatively rare. However, without documented records, bearing failure due to looseness and fretting damage cannot be effectively monitored.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes appropriate, or to raise general awareness of important safety information in the industry. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which ‘saved the day’ or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: The ATSB’s assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

1 FACTUAL INFORMATION

1.1 Overview

At approximately 0710¹ on 23 October 2010, 15 wagons on freight train 3PW4 derailed near Wodonga, Victoria. There were no injuries but serious damage to rolling-stock and rail track (including a bridge structure) was sustained during the derailment.

Location

Wodonga is a regional city in Victoria, located on the southern bank of the Murray River. The Murray River defines the state border between Victoria and New South Wales. The regional city of Albury is located immediately across the river in New South Wales. Albury and Wodonga are also located on the Hume Highway and the Defined Interstate Rail Network (DIRN), the major inland road and rail transport corridors between Sydney and Melbourne (Figure 1).

Figure 1: Location of Wodonga, Victoria



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The derailment occurred on track leased from the Victorian Government by the Australian Rail Track Corporation (ARTC) and maintained under contract by Downer EDI Works. The section of track formed part of the newly opened Wodonga bypass which was part of the North East Rail Revitalisation project enabling trains to operate more efficiently between Melbourne and Sydney. The bypass consisted of about 5 km of dual track constructed of continuously welded rail secured to concrete sleepers supported on ballast. The track was routed to the

¹ The 24-hour clock is used in this report to describe the local time of day, Eastern Daylight Time (EDT), as particular events occurred.

north of Wodonga and included the construction of a new railway station and six rail bridges, which enabled the removal of 11 level crossings from within Wodonga. The bypass was opened for rail traffic on 23 July 2010.

Train information

Freight train 3PW4 was owned and operated by Pacific National (PN). At the time of the derailment, train 3PW4 consisted of three locomotives (NR46 leading, AN4 and NR87) hauling 60 wagons. The train was about 1121 m long with a total weight of about 3365 t. The maximum allowable speed for train 3PW4 was 80 km/h. The drivers at the time of the derailment were appropriately qualified and medically fit for duty.

The wagon first derailed was RKWY-4125C, the 20th wagon behind the locomotives. The RKWY class wagons (Figure 2) were originally built in 1968² and are used to carry structural steel products. The wagons ride on three-piece bogies, have constant contact style side bearers and 6"x11" cartridge tapered roller bearings, often referred to as packaged bearings. When loaded up to 84 t (gross), the wagons are rated to operate at a maximum speed of 115 km/h, but are limited to a speed of 80 km/h if loaded between 84 t and 92 t (gross). At the time of the derailment, wagon RKWY-4125C was carrying structural steel beams giving the wagon a gross mass of 85.37 t³.

Figure 2: RKWY class wagon⁴



Table 1: RKWY class wagon

Tare weight	26 t
Length	23.724 m
Max gross weight	92 t
Max allowable speed	115 km/h @ 84 t 80 km/h @ 92 t

1.2 The occurrence

Freight train 3PW4 originated at the Perth Freight Terminal and was travelling to Port Kembla. However, the train was scheduled to pick-up and drop-off wagons at a

² While first built in 1968 as GOX class wagons, they continued to be built until 1977 and have undergone modifications over the years resulting in various class identifiers such as RKWY.

³ Gross wagon mass as reported in the Pacific National train consist report

⁴ Image and data as per Pacific National 'Wagon Details Manual' (WDM-RKWY_04)

number of locations throughout its journey. Wagon RKWY-4125C originated at Whyalla, South Australia and joined train 3PW4 at Spencer Junction, near Port Augusta. On its journey to the Victoria / New South Wales border, train 3PW4 passed through three trackside condition monitoring sites, Nectar Brook (RailBAM®)⁵ and Port Germein (WILD)⁶ in South Australia and Lara (WILD) in Victoria.

Train 3PW4 passed through Nectar Brook and Port Germein at about 1821 and 1850 (respectively) on 21 October 2010⁷. The train continued its journey via Adelaide and passed through Lara at about 1906 on 22 October 2010. After passing through Melbourne, train 3PW4 headed towards New South Wales.

Train 3PW4 and another train (5BM7) crossed at Longwood (about 162 km south of Wodonga) at about 0215 on 23 October 2010. The drivers of train 5BM7 noticed what appeared to be an out-of-gauge load on train 3PW4. The crew of train 3PW4 inspected their load and found that wagon RKMx-20540W (the 35th wagon behind the locomotives) had a piece of metal sticking up above the container by about 300 mm. The crew member from 3PW4 would have walked past wagon RKWY-4125C to inspect the out-of-gauge load, but at no point did he notice anything abnormal about the bearings on the wagon.

After a stop of about 45 minutes and with authorisation from the network controller, train 3PW4 travelled at reduced speed to Violet Town (about 128 km south of Wodonga) where wagon RKMx-20540W was detached and stabled in the siding. Train 3PW4 spent about 1 hour at Violet Town during this process and again, nothing abnormal was noticed about the bearings on wagon RKWY-4125C.

Train 3PW4 departed Violet Town at about 0445 and continued its journey towards Wodonga. The train stopped for about 30 minutes at Glenrowan (about 80 km south of Wodonga) to allow a south bound XPT passenger service to cross. It then continued to Allumatta (about 66 km south of Wodonga) where it stopped a further 10 minutes for the cross of southbound train 5BA6. Neither crew (XPT or 5BA6) reported anything abnormal about train 3PW4.

At Barnawartha (about 16 km south of Wodonga) the train encountered a track gang standing clear on the left hand side of the track (same side as the bearing failure). Again, there was no report of any abnormal condition for train 3PW4.

At about 0710, while passing over the recently opened Wodonga rail bypass at a speed of about 65 km/h, the drivers noted a loss of brake pipe pressure, indicating that brake pipe air was exhausting to the atmosphere and the train brakes would be in the process of applying. As train 3PW4 was slowing, the driver noticed a large amount of dust in the rear vision mirror and stated to the second driver that it appeared as though their train had derailed.

The driver contacted the ARTC train controller to advise that train 3PW4 had stopped due to a loss of brake pipe pressure and reported that they suspected their train had derailed. The second driver walked back to investigate the cause of the brake application and discovered that the rear bogie on wagon RKWY-4125C (the 20th wagon behind the locomotives) had derailed. It was evident that a bearing on

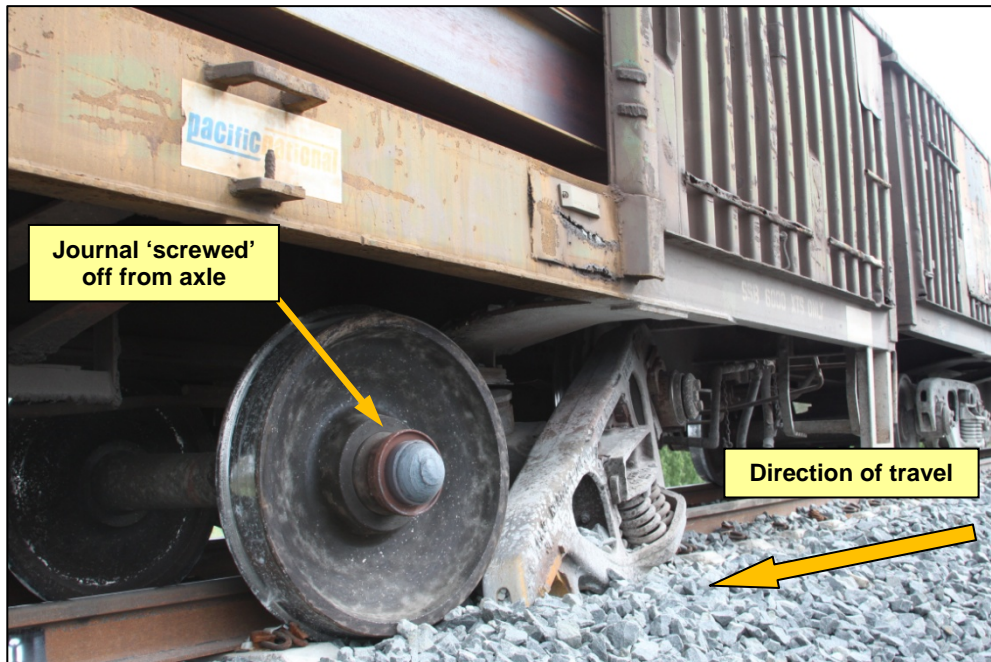
⁵ Bearing Acoustic Monitoring system

⁶ Wheel Impact and Load Detection

⁷ Note that the times for Nectar Brook and Port Germein are Central Daylight Time (CDT)

the lead axle of the bogie had failed, resulting in the bearing journal separating from the axle (commonly referred to as a screwed journal - Figure 3).

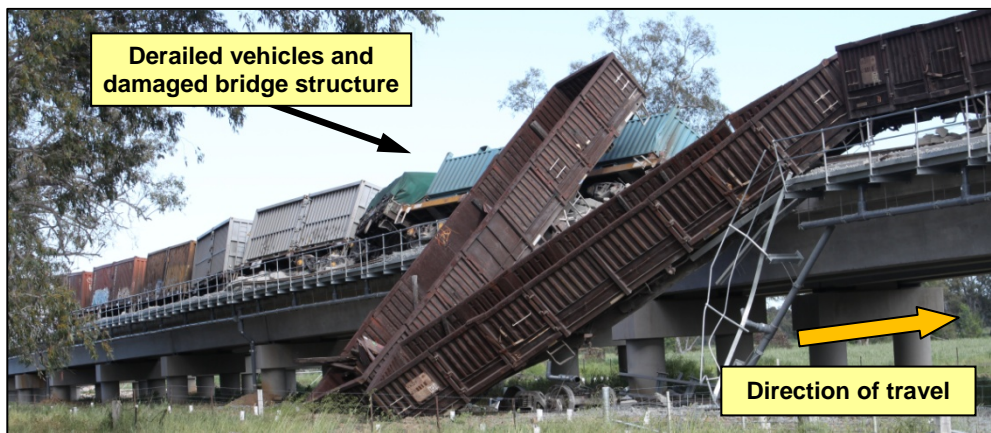
Figure 3: Rear bogie of wagon RKWY-4125C



Bogies under three of the following four wagons had also derailed, beyond which a gap of about 140 m existed before the remainder of the train. Most of the derailed wagons had come to rest on one of the Wodonga bypass bridges (spanning the Wodonga Creek). In total, 15 wagons had derailed and were lying at various angles to the track, including two which had fallen, each with one end resting on the ground and one end on the bridge (Figure 4).

The drivers contacted the ARTC train controller and advised that train 3PW4 had derailed, a significant portion of track had been destroyed and the adjacent track was obstructed.

Figure 4: Derailment site



Post occurrence

The position of derailed wagons and the environmental sensitivity of the site served to make the recovery operations a challenging task. Limited freight services were restored on 25 October 2010, with trains operating on the adjacent track at a restricted speed of 10 km/h. Heavy lift cranes and recovery equipment arrived later in the week and began removing rolling-stock and freight from the derailment site. Passenger services recommenced on 3 November 2010 and operated along with freight services on the adjacent track, but recovery of wagons continued for many days. The two wagons that fell from the bridge were finally cut up and removed from the site, before major track restoration works could commence.

While trains continued to operate on the adjacent track, rail, sleepers and ballast were removed from the damaged track to permit an engineering assessment. Significant bridge repair works were required, especially to the concrete panels retaining the ballast bed. While the precast concrete beams (between columns) retained their structural integrity, two spans required repair of localised damage, plus lifting and realignment to return them to their original position on their columns. The track was reinstated for train operations on 24 February 2011.

A total of 15 wagons sustained damage and the track restoration site extended over a distance of about 550 m.

2

ANALYSIS

An investigation team from the Australian Transport Safety Bureau (ATSB) travelled to the derailment site at Wodonga on 23 October 2010. Investigators examined, surveyed and photographed the derailment site, and sourced evidence from various individuals and rail companies, including the ARTC and Pacific National.

2.1 Sequence of events

It was evident from site observations that the bearing journal had separated from the axle of wagon RKWY-4125C as it began to traverse the 3rd (in direction of travel) and longest (about 400 m) bridge of the new Wodonga bypass. The first sleeper impact point, caused by the journal stub, was about 55 m onto the bridge. The stub was found on the adjacent track, about 25 m further along the bridge. The first evidence of derailed wheels (wagon RKWY-4125C) was adjacent the journal stub, about 80 m onto the bridge. By the time train 3PW4 stopped, wagon RKWY-4125C had travelled in its derailed state for a further 370 m, stopping about 50 m past the end of the bridge. In effect, the derailment occurred over a total distance of about 400 m, almost all of which was on the bridge spanning the Wodonga Creek.

The evidence suggested the following as the most likely derailment sequence.

As the train approached Wodonga, it is likely that the condition of the wheel bearing on wagon RKWY-4125C had deteriorated to the point where the bearing had seized, causing it to ‘screw off’ (Figure 5). Once the bearing journal had separated from the axle, the bogie side-frame and axle could not be contained within their normal configuration. The side-frame fell down and dragged along the sleepers and ballast while the wheel-set was permitted to turn sideways and derail. As the train continued, the side-frame and wheels impacted with the concrete sleepers which ultimately failed to maintain track gauge and allowed further wagons to derail.

Figure 5: Axle journal



Bogies under three of the following four wagons derailed before the train parted behind the 24th wagon and following wagons began to plough into the ballast. The rear portion of the train continued to push into the rapidly slowing derailed wagons, thereby causing more wagons to derail until the wagons came to a complete stop. Of the 15 wagons that derailed, 13 remained on the bridge but at various angles

along the track. However, two wagons (27th and 28th) fell off the bridge structure, each with one end resting on the ground and one end on the bridge.

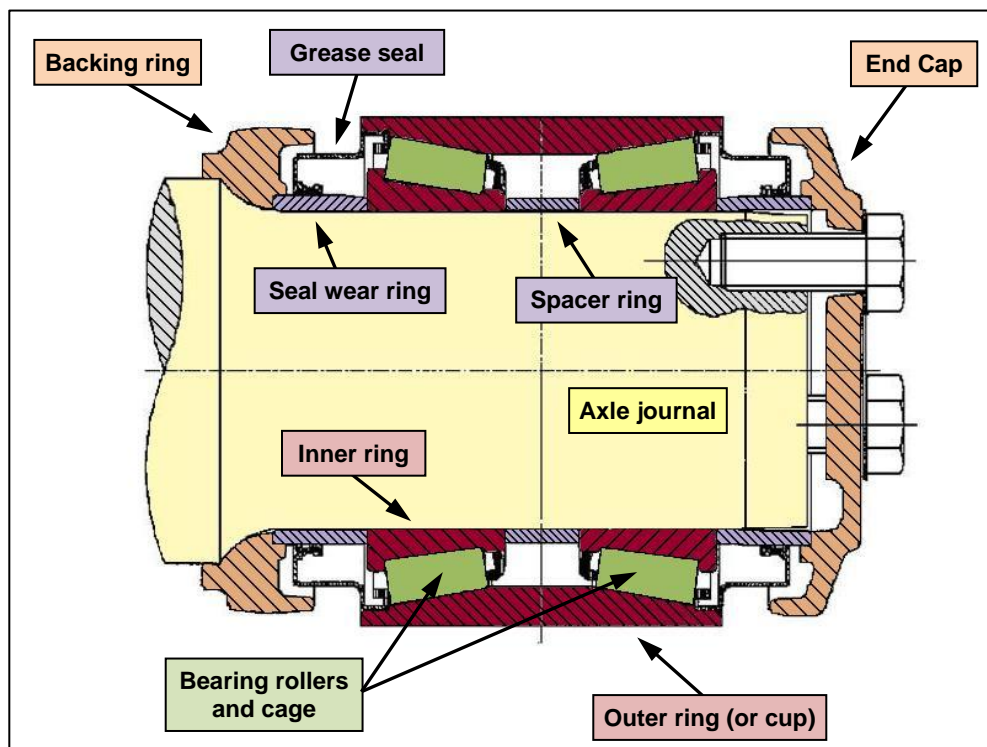
Derailment site observations suggested that the failure of a bearing on wagon RKWY-4125C resulted in the derailment of train 3PW4. Consequently, the following analysis examines the possible cause of the failure and processes in place to mitigate the risk of bearing failure.

While not a contributing factor, the analysis also examines the issue of containment of derailed rollingstock with respect to wagons falling from the bridge structure.

2.2 Bearing examination

The bearing that failed on wagon RKWY-4125C was a 'Class E' (6" x 11") cartridge tapered roller bearing, often referred to as a packaged bearing. Packaged bearings consist of two tapered roller bearing assemblies (sometimes referred to as cones and includes the inner ring, rollers and cage) mounted inside a common outer ring (sometimes referred to as the cup). Between the two bearing assemblies is a spacer ring of specific width so as to correctly position the two cones when the bearing is assembled. Outside each bearing assembly is a seal wear ring, over which the grease seal is positioned. When installed on the wheel-set, a backing ring is mounted on the in-board side of the axle journal and an end-cap is bolted onto the outer end of the bearing journal (Figure 6).

Figure 6: Packaged bearing



Packaged bearings are installed as fully greased sealed units and are press fitted onto the axle journal. The bearings do not require in-service regreasing, which reduces the risk of inadequate, excessive or contaminated lubricant during operation.

In this case, the bearing that failed was completely destroyed and many of its components were not found. Consequently, much of the evidence that may have indicated the cause of its failure was either lost or damaged beyond useful examination. Only the partner bearing (other end of the axle) could be examined to determine if any detrimental condition existed that may have been common between both bearings.

Bearing history

The date engraved on the end-cap locking plates indicated that the bearings were mounted on the axle (number 7E3S09561) on 1 February 2007. According to the EDI wheel-set fitment records, the two bearings mounted on the axle had been requalified at SKF (Williamstown, Victoria) and had the reconditioning numbers of BV30554 and BV30570. Normally, the reconditioning number would be engraved on the bearing cup, but in this case, neither number could be found on the partner bearing. An attempt was made to trace the bearings through the reconditioning records, but the SKF workshop was unable to locate the records, citing a recent change in workshop management as the reason for the lack of records. While it is likely that both bearings had been overhauled before they were mounted on the axle, it was impossible to determine exactly which of the reconditioned bearings failed and which was the partner bearing.

The partner bearing was manufactured in 1995 by Brenco. Engraving on the inner face of the bearing cup indicated that the partner bearing had been overhauled in 1999, 2001, 2003 and 2006. As mentioned above, it is likely it was also overhauled in 2007, though it had not been engraved as such.

Over its life, the partner bearing is likely to have been installed on six different axles under six different wagons (once when new and once for each of the five times it had been overhauled). However, Pacific National records do not provide sufficient information to trace a bearing's complete history as it is used under Pacific National rolling stock. The best that can be achieved is their history under wagon RKWY-4125C. Records indicate that axle number 7E3S09561 was installed under wagon RKWY-4125C on 19 February 2007 and the wagon had travelled about 472,000 km by the time the bearing failed on 23 October 2010.

Examination of the partner bearing

The partner bearing was examined by ATSB failure analysis specialists and BES Technology⁸.

The BES report noted mechanical damage to the out-board edge of the bearing cup, along with damage to the out-board seal and a bent cage on the out-board cone. There was also some indentations and damage to the rollers, though the report stated that these may have been a consequence of the derailment. The in-board cone and seal wear ring showed evidence of minor fretting while the backing ring and in-board seal were in an acceptable condition. The report also noted evidence of minor electric burns on the rollers from the out-board cone and corresponding electric burns to the outer raceway of the bearing cup.

The electric burns identified were not typical of defects normally found on Pacific National bearings, and presented as a line of very small pits (like small pin pricks)

⁸ BES is a division of the Schaeffler Group and is a re-conditioner of bearings in Australia.

around the circumference of the cup's outer raceway and corresponding pits on the outer cone rollers. Pacific National advised that they had noticed similar electric burns on other bearings over recent years, but had been unable to identify the cause of the burns. While the rolling surface damage did not exceed the documented defect limits, Pacific National had set a voluntary requirement that bearings exhibiting this damage would be scrapped, pending further investigation into its cause.

The BES report concluded that most of the bearing faults were likely to be the result of the derailment. However, the report noted that the electric burns (not derailment caused) would have resulted in the bearing being condemned⁹ as per Pacific National's instructions, had it been inspected as part of the normal overhaul process.

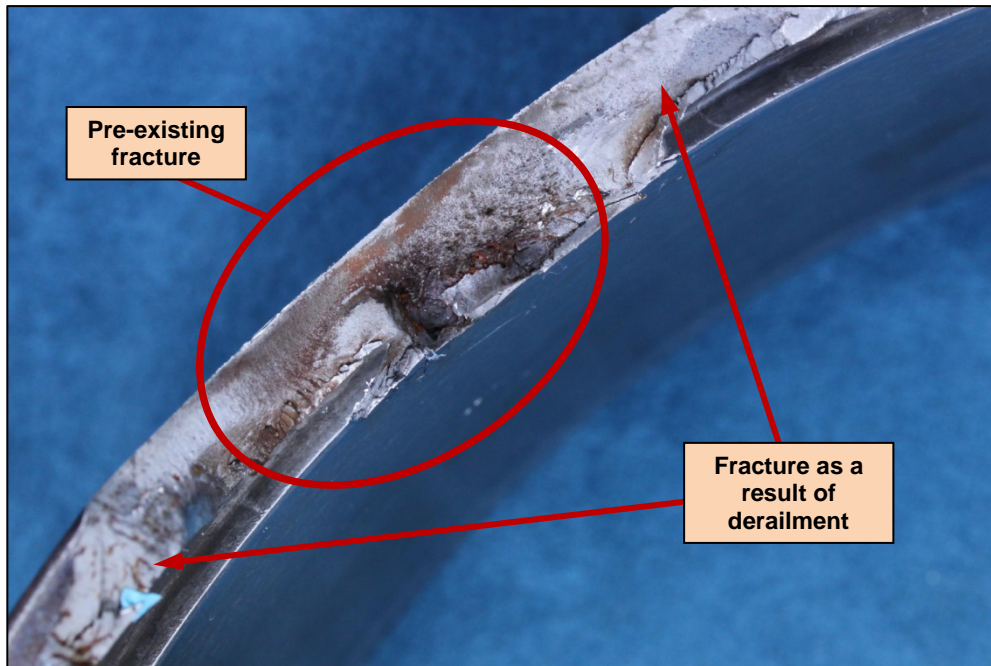
The ATSB failure analysis specialists conducted further examination of the partner bearing, with the aim of identifying any issues that may have indicated why the other bearing had failed.

Examination found evidence of impact damage to the bearing cup where six scalloped pieces were missing from its outer edge. There was accompanying damage (bruising and abrasive wear) to the adjacent steel areas of the grease seal and it was evident that grease had seeped out in the area of the largest missing piece. Closer examination (after the bearing had been disassembled and cleaned) showed that the area corresponded to some damage to the outer raceway of the cup and a 14 mm wide, flattened indentation of the grease seal.

Five of the fracture surfaces were matt grey/silver in appearance with very low levels of oxidisation, indicating that they probably occurred as a result of the derailment. However, the largest of the six showed higher levels of oxidisation, indicating that it may have occurred before the derailment. Closer examination revealed evidence that each fracture mode was ductile overload as a result of an external overload force acting on the edge of the outer diameter of the cup. The higher levels of oxidation on the larger fracture did not extend over the entire fracture surface (Figure 7), indicating that an earlier overload force may have caused an initial fracture with impacts during the derailment resulting in complete fracture. Additional evidence, in the form of grooving and wear at the edges of the initial fracture, suggested that rollers had rotated in both directions, providing further support to the possibility of pre-existing damage.

⁹ The criterion to condemn a bearing due to electric burns (as observed in this case) was a voluntary requirement by Pacific National. The condition did not exceed the documented defect limits that would be considered as presenting an unacceptable risk to rail operations.

Figure 7: Fracture surface (largest scallop)



Both inboard and outboard seal wear rings exhibited polishing, discolouration, pitting and adhesive wear consistent with a bearing that had been in service for some time. The grease seals contained thick, red and black-coloured grease between their two lips and the outer seal was slightly damaged as a result of the impact damage explained above.

Examination found that the raceways and the rollers were discoloured, mostly a light brown/straw colour on the rolling surfaces, but with blueing on the thrust ends of the outboard rollers. Some of the outboard rollers exhibited circumferential scratching while others were brinelled or bruised. The inboard rollers also had circumferential scratching, but not to the same extent as the outboard rollers. The inboard cage appeared to be in reasonable condition, but the outboard cage was scored; this corresponded with the scoring noted on the damaged outboard grease seal housing.

Foreign material was found suspended within the bearing grease. Analysis showed the particles to be consistent with the alloy steel of the bearing cup and the plain carbon steel of the bearing cage. It is likely that the alloy steel was introduced as a result of damage to the bearing cup and the plain carbon steel introduced as the damaged outer seal rubbed against the cage. It is also likely that the circulating foreign material contributed to the circumferential scratching and brinelling observed on the rolling surfaces. However, the relatively low level of rolling surface damage suggested that the foreign material had not been circulating for a long period of time. Consequently, it is likely that the pre-existing fracture of the bearing cup was relatively recent.

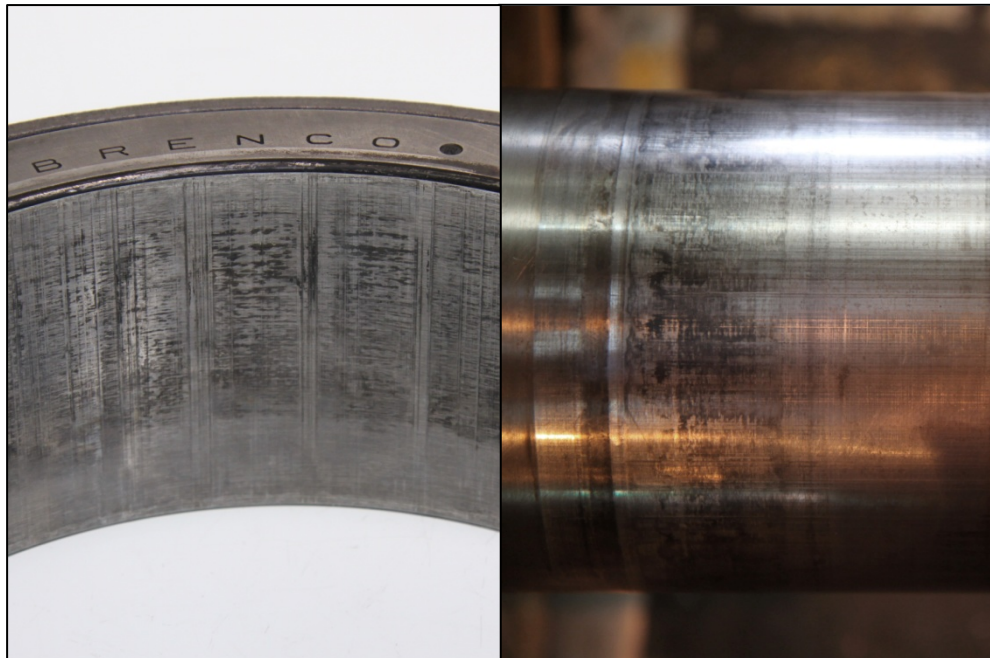
The spacer ring showed light fretting between its mating surface with the outer cone and moderate fretting where it mated with the inner cone. Heavier contact fretting was observed on the mating surfaces between the inner cone and the inboard seal wear ring. Similarly, fretting wear was evident between the backing ring, the inboard seal wear ring and the axle shoulder. (Figure 8)

Figure 8: Fretting wear (inboard cone)



Further examination of the cones showed score marks, both axial and radial, within the bore each cone (more prominent on the inboard cone). Corresponding marks were also observed on the axle journal. While the axial scoring was a result of mounting and demounting of the bearing, the radial scoring was likely to be the result of rotational creep¹⁰. (Figure 9)

Figure 9: Axial and radial scoring on bore of inboard cone and axle journal



¹⁰ Rotational creep refers to an effect in which relative motion takes place between a press-fitted bearing ring and its shaft.

2.2.1 Summary of bearing examination

The bearing that failed was completely destroyed, so it could not be examined to determine the cause of its failure. Consequently, the partner bearing (other end of the axle) was examined to determine if any detrimental condition existed that may have been common between both bearings.

The partner bearing was manufactured in 1995 and had been overhauled five times, so was likely to have been installed on six different axles under six different wagons. Under wagon RKWY-4125C, both bearings on axle number 7E3S09561 had travelled about 472,000 km before the bearing failed on 23 October 2010 and caused the derailment of train 3PW4.

Examination of the partner bearing found mechanical damage to the outboard edge of the bearing cup, the grease seal and the outboard bearing cage. The damage caused metal particles (cup and cage) to be ingested and suspended in the bearing grease which then circulated throughout the bearing resulting in circumferential scratching and brinelling of the rolling surfaces. However, the mechanical damage and consequential rolling surface damage were probably a result of the derailment itself.

Most of the contact surfaces (that is between spacer ring, cones, wear rings and backing ring) showed evidence of fretting wear, with heavier wear evident between the inboard mating surfaces. The cone bores also showed score marks and corresponding marks were observed on the axle journal. The axial score marks were a result of mounting and demounting of the bearing, while the radial scoring was likely to have been the result of rotational creep.

2.3 Bearing failure

Loss of interference fit between the bearing and axle journal often occurs later in the failure sequence. That is, other faults combine to cause the loss of interference fit. Slippage due to loss of interference fit can be progressive whereby the initial slippage is small, but as the journal material wears, the amount of slippage increases. Alternatively, slippage of the inner ring on the journal can occur suddenly due to bearing seizure.

In this case, the bearing that failed was completely destroyed so could not be examined to clearly identify the cause of the failure. Consequently, the investigation looked at the common failure modes for railway bearings to provide stronger support to any possible conclusions.

All bearings have a finite life. In a laboratory test environment, most bearings will reach their predicted fatigue life. However, in a field environment, a variety of factors may contribute to the premature failure of a bearing. Premature failure can be defined as a bearing failing to reach its predicted fatigue life. This could be due to in-service failure or removal during normal maintenance due to failure to meet the required servicing standards.

Fatigue life

Bearing fatigue life is commonly referred to as the L_{10} life. This is a calculated prediction of bearing life in terms of stress cycles (related to revolutions) based on 10% of bearings showing the first evidence of fatigue. The first evidence of fatigue

is defined as when one of the rolling contact surfaces develops a spall measuring approximately 6 square mm (refer to *Rolling surface damage*). The main parameter that influences bearing fatigue life is the applied load. For roller bearings, fatigue life is inversely proportional to the $^{10/3}$ power of the load applied. For example, if the load is halved, the fatigue life will increase by a factor of about 10. Conversely, doubling the load will result in a decrease in fatigue life by a factor of about 10.

The bearings used on the RKWY class wagon were 'Class E' tapered roller bearings and are commonly used on railway rolling stock throughout Australia. A typical fatigue life specification¹¹ for a Class E bearing indicates that its L_{10} life is equivalent to about 2,600,000 km (wheel diameter of about 840 mm) when operating at maximum bearing load for 50% of its time. Tapered roller bearings are designed to support both radial loads (weight of wagon and other vertical forces) and thrust loads (cornering and other lateral forces). When considering bearing load, manufacturers sometimes provide both radial and thrust load ratings for their bearings. The rating is usually specified at a specific rotational speed of 500 revolutions per minute, which equates to about 80 km/h for wagons with a wheel diameter of 840 mm (such as the RKWY class wagon).

An examination of manufacturers' specifications found that the Class E bearing radial load rating was about 19 t, which equates to an axle load of about 38 t. This is well above the axle load limit for wagons operating on the DIRN, (23 t for RKWY class wagons). Consequently, even at maximum wagon loads, the bearings are operating well below their maximum rating. This means that the fatigue life for Class E bearings operating on the DIRN is likely to be much higher than the L_{10} life specified in the manufacturer's documentation.

Records showed that wagon RKWY-4125C travelled an average of about 120,000 km per year, was usually only loaded when travelling away from Whyalla and often empty or lightly loaded when travelling towards Whyalla. At this rate, a bearing would need to be in service for more than 20 years to reach 2,600,000 km of service. However, when considering the actual loading of a bearing, its theoretical fatigue life is likely to be considerably more than 20 years.

In this case, the bearing that failed was completely destroyed and its age could not be determined, but the partner bearing was found to have been manufactured in 1995. The partner bearing was examined following the derailment of train 3PW4 and showed no evidence of spalling or fatigue related defects on the rolling surfaces after 15 years of service. However, there were other elements of bearing condition that indicated the bearing was reaching the end of its serviceable life. This was considered typical of railway bearings in service, in that their serviceable life is usually limited by factors other than simple bearing fatigue.

Considering the factors associated with bearing fatigue life, it is very unlikely that the bearing on wagon RKWY-4125C failed due to simple bearing fatigue.

Cage failure

The bearing cage is designed to retain the rollers within the bearing in a consistently spaced and correctly aligned position. The cage has no role in the transmission of forces. The cages in packaged tapered roller bearings are usually pressed out of metal plate.

¹¹ Timken, APTM Bearings, Size and Dimensional Data

The main philosophy with roller bearings is to avoid sliding friction. However, sliding at the cage surfaces cannot be avoided. Consequently, the softer material of the cage (when compared to other components) is likely to be the first area to wear when lubrication becomes inadequate or foreign material causes abrasion. As the cage windows increase in size due to wear, the cage loses its ability to correctly align and guide the rollers. The resultant forces can lead to rapid deterioration and fracture of the cage. Under these conditions, broken cage material may become jammed in the rolling surfaces with bearing seizure the likely result. The main causes of cage failure are vibration, excessive speed, wear and foreign material.

If cage failure was caused by vibration or excessive speed, it would be expected that similar indicators would exist on bearings at both ends of the axle. In this case, the partner bearing showed no signs of cage damage. Consequently, vibration and excessive speed are unlikely to have been contributing factors.

Excessive wear can contribute to cage failure as the metallic wear debris circulates in the bearing. If appropriately lubricated, excessive wear would only be expected in bearings that had been in service for long periods, for example, multiple wheel lives before bearing overhaul. Pacific National remove and overhaul bearings on RKWY class wagons every time a wheel is removed or re-profiled. Consequently, bearings are not in-service for excessive periods without the cage being examined for excessive wear. In this case, the failed and partner bearings were installed on the axle in 2007. Though not engraved on the bearings, both were almost certainly overhauled before fitting. The cage of the failed bearing could not be examined, but examination of the partner bearing cage showed no evidence of excessive wear.

Considering the evidence available, cage failure due to normal in-service wear was considered an unlikely contributing factor. However, excessive wear due to foreign material was still a possibility and is discussed in the following section.

Rolling surface damage

Spalling is the flaking of material from the rolling contact surfaces due to repeated stress cycles. Spalls generally begin as small cracks below the material surface, which gradually join and grow until they break through the surface. Metal fragments that separate from the spalled area are carried in the lubricant and gradually increase the size of the spalled area.

Spalling can be caused by metal fatigue (refer to *Fatigue life*) or other factors such as lack of lubrication, contaminants carried in the lubricant, or indentations created in the rolling contact surfaces due to impact loading (Brinelling).

The failed bearing was completely destroyed, so could not be examined for rolling surface damage. Examination of the partner bearing found no evidence of spalling, but did show evidence of minor brinelling. As mentioned previously (refer to section 2.2 *Bearing examination*), it is likely that the foreign material circulating in the lubricant contributed to the minor brinelling, which in turn was introduced as a result of a pre-existing fracture in the bearing cup.

In this case, the fracture mode (ductile overload) suggested an overload force acting on the outer edge of the bearing cup. While this mode of failure is common after a derailment, it is relatively rare in-service. The cause of such a defect in-service is likely to be a misaligned bearing adapter or a severe impact load acting on the bearing. Since there was no evidence of a misaligned bearing adapter, the most likely cause is a severe impact.

There was no evidence to suggest that a wagon or track defect contributed to an impact that would result in a fractured bearing cup. However, discussions with Pacific National suggested the possibility of a 'dropped load'¹². However, in PN's experience, such an occurrence is relatively rare with damage even rarer. While the possibility exists that the failed bearing may have sustained similar damage if a high impact was sustained to its axle, the minimal damage to the partner bearing would suggest it was not a contributing factor in this case. Similarly, had the failed bearing sustained greater damage than the partner bearing, the resultant rolling surface damage would probably be detectable by the trackside condition monitoring equipment. In this case, the ARTC Bearing Acoustic Monitoring system (RailBAM®) recorded no such defect (Refer to section 2.4.2 *Condition monitoring*).

In-service contamination of the lubricant could also have occurred through ingress of foreign material past the grease seals. Assuming the grease seals are in reasonable condition, ingress of foreign material through the seals is only likely to occur by force such as high pressure water used for cleaning. However, Pacific National has banned the use of high pressure hoses near rolling stock. Consequently, the likelihood of lubricant contamination by ingress of foreign material through the bearing seals is significantly reduced.

Assuming sufficient lubrication exists within a bearing, rolling surface damage and bearing deterioration is likely to be progressive and detectable by track side condition monitoring equipment. In this case, the ARTC WILD system showed no wheel impact alarms relating to wagon RKWY-4125C. Similarly, the ARTC Bearing Acoustic Monitoring system (RailBAM®) recorded no information that would indicate a developing rolling surface defect (Refer to section 2.4.2 *Condition monitoring*).

While it can't be completely ruled out, there was insufficient evidence to suggest that rolling surface damage was a contributing factor in this case.

Lubrication failure

The function of a lubricant is to separate the rolling contact surfaces at the points of high pressure contact. The lubricant film between the surfaces acts to reduce wear, friction and corrosion such that the bearing should be able to achieve its predicted fatigue life; assuming no other factors exist that may cause premature failure. Lubrication failure can occur due to an inappropriate grade of lubricant, insufficient lubricant or contamination of the lubricant.

Under operational conditions, lubrication failure will usually result in a rapid increase in temperature within the bearing. The ASM Handbook¹³ (Volume 11, *Failure Analysis and Prevention*) indicates that discolouration is often a result of surface heating and can be indicative of running with inadequate lubrication. The colour of steel after heating (and cooling) often provides an indication as to the temperature range the steel was heated to. The ASM Handbook (Volume 4, *Heat Treating*) provides information showing the relationship between temperature and

¹² Dropped load - a load accidentally dropped onto the deck of a wagon.

¹³ ASM International is an engineering and scientific society serving the materials science and engineering profession. The ASM handbook consists of a series of volumes providing comprehensive and practical information on the properties and performance of materials.

colour for carbon steel, but also indicates that tempering of carbon steel is not only temperature related, but time related as well.

In this case, the partner bearing exhibited discolouration of the raceways (light brown or straw colour) and the rollers (light brown or straw colour on the rolling surfaces and blue on the thrust ends) indicating that the surfaces had probably been exposed to elevated temperatures. However, considering the age of the bearing and the fact that it appeared to be well greased when disassembled, it is more likely that the discolouration of components within the partner bearing was the result of elevated temperatures over a long period of time rather than excessive heating over a short period of time. Consequently, the evidence of heat affected surfaces within the bearing were more likely an indication of a 'hard life', not an indication of a potential lubrication failure.

Packaged bearings are assembled as fully greased sealed units, are mounted on the axle as a complete unit and do not require in-service regreasing. Assembly processes are structured to minimise the risk of lubricant contamination and inappropriate lubricant grade or quantity. If lubrication contamination, grade or quantity issues occur during assembly, premature bearing failure is more likely to occur in the earlier stages of service life. Also, bearing faults due to inappropriate assembly practices would likely appear in other bearings that were assembled at the same time and location. In this case, the bearings on both sides of the axle had been in service for almost four years, had travelled about 472,000 km and the partner bearing showed no evidence of lubrication related problems. Consequently, it is unlikely that lubrication failure due to inappropriate assembly practices contributed to the bearing failure on 23 October 2010.

In-service contamination of the lubricant can occur if contaminants enter past the grease seals. As previously mentioned, Pacific National has banned the use of high pressure hoses near rolling stock thereby minimising the risk of contaminants being forced past the seals. While it is possible for contaminants to gradually seep past the seal as a bearing sequentially warms and cools, this is unlikely to be excessive unless the grease seals were damaged or ineffective (for example, due to a damaged cup).

Both the failed bearing and the partner bearing had been requalified and mounted on the axle in February 2007. The seal and wear ring on the partner bearing did not exhibit excessive wear and there was no evidence to suggest that the failed bearing was any different. While it can't be completely ruled out, there was insufficient evidence to suggest that lubrication failure was a contributing factor in this case.

Loose components

Packaged bearings are pressed onto the axle journal with an interference fit between the bearing cones and the journal. Once pressed on the journal, an end cap is bolted to the axle end which applies a clamping force through the inner rings of the bearing (cones, seal and spacer) and the backing ring. When tightly fitting surfaces are subjected to vibration or some other force, slight movement can occur between the surfaces, resulting in a wear process called fretting.

A major contributor to fretting between the tightly fitting surfaces of a packaged bearing is axle deflection under high loading. As an axle bends under load, the journal surface becomes slightly longer at the top and slightly shorter at the bottom. Under some conditions, this can cause very small amounts of sliding at the interface

between the journal and the bearing cone, and between the bearing components (cones, seals and rings). Over time, fretting can cause wear at these interfaces, resulting in a loss of clamping force and eventually leading to loose components.

Another form of movement between tightly fitting bearing surfaces is rotational creep. Rotational creep refers to an effect where the radial load on a bearing causes minor rotational motion between the bearing ring and the axle journal. The motion produces radial score marks on both the bore of the inner bearing ring and the shaft. The combination of rotational creep and fretting can result in accelerated wear, plus, any heat generated within the bearing may cause a slight increase in bore diameter due to metal expansion, further compromising the interference fit on the axle journal. The reduced clamping force and interference fit may eventually allow the inner bearing rings to turn more freely (or spin) on the journal, thereby generating significant heat and possible journal failure.

An examination of published material indicated that loose components are a major contributor to bearing failure on freight rolling stock. For example, in 1987/89, the Association of American Railroads (AAR) conducted a study of about 630 bearings that had been identified as hot by trackside hot box detectors¹⁴. The study found that 447 bearings had condemnable defects. Of these, 206 (46%) were found to be caused by loose components, 120 (27%) could not be determined because of excessive damage, 61 (14%) contained spalling and the remaining 60 (13%) a combination of broken cup/cone, brinelling, water etching and peeling.

In this case, minor fretting and rotational creep were observed on the partner bearing (Figure 8 and Figure 9). Since rotational creep and fretting can be related to factors such as axle load and rotation, they are conditions that can develop simultaneously in both bearings on a common axle. Consequently, it is likely that the bearing that failed on 23 October 2010 also suffered from these conditions. Also, examination of data from the ARTC Bearing Acoustic Monitoring system (RailBAM®) found that the faults, associated with wagon RKWY-4125C over the 12 months before the derailment, were dominated by looseness or fretting (Refer to section 2.4.2 *Condition monitoring*).

2.3.1 Summary of bearing failure

Examination of what little relevant evidence existed following the failure of the bearing on wagon RKWY-4125C, and consideration of the common failure modes for railway bearings, suggested the following:

- Considering the factors associated with bearing fatigue life, it is very unlikely that the bearing on wagon RKWY-4125C failed due to simple bearing fatigue.
- Considering the evidence available, cage failure due to normal in-service wear was considered an unlikely contributing factor.
- It is unlikely that lubrication failure due to inappropriate assembly practices or contamination contributed to the bearing failure on 23 October 2010.
- It is possible that a pre-existing fracture in the bearing cup of the partner bearing may have been the result of a dropped load. However, there was no evidence to suggest that a similar fracture existed in the failed bearing.

¹⁴ Summarised in a conference paper presented at the 7th International Heavy Haul Conference, 2001; *Journal Roller Bearing Defect Populations*, M.C. Fec, K.L. Hawthorne, D.H. Stone.

- While it can't be completely ruled out, there was insufficient evidence to suggest that rolling surface damage or contamination of the lubricant was a contributing factor in this case.
- Considering that the partner bearing showed evidence of rotational creep and fretting wear, it is likely that the bearing that failed on 23 October 2010 also suffered from these conditions.
- In the absence of any evidence to the contrary, a possible initiator of bearing failure was a loss of interference fit between the bearing and journal due to fretting and rotational creep.

2.4 Bearing failure management

As the rail industry continues to strive for greater operational efficiency, the demand to carry higher loads has increased. To counter the effect of reduced fatigue life due to increased load, bearings have had to undergo evolutionary change. This evolution included a major change when plain bearings (sliding metal surfaces using low friction coefficient alloys such as bronze) were replaced by two spherical bearings housed within an axle-box. The next step in rail bearing evolution was the introduction of the packaged tapered roller bearing which presented a number of advantages with respect to maintenance and load carrying capacity (depending on bearing size).

While the axle-box design has continued to be used, the adoption of packaged tapered roller bearings is recognised as the preferred option. However, bearing condition will progressively deteriorate regardless of the bearing type. Consequently, a regime of inspection and maintenance is required to minimise the risk of in-service bearing failures.

2.4.1 Bearing maintenance and Inspection

Pacific National's inspection and maintenance procedures are documented in their 'Wagon Maintenance Manual' (WMM). The maintenance process generally takes two forms, in-service inspections and scheduled maintenance¹⁵.

In-service inspections

In-service inspections consist of train examinations and roll-by inspections. In both cases, inspections are conducted by qualified workers and involve examination for defects or issues that may affect the train's ability to safely operate over the rail corridor.

A train examination involves an inspection of the train, while stationary, by qualified workers before commencement of its journey. In general, the inspection looks for issues related to the train brake system, couplers, bogies, wheels, bearings, load security and any other associated equipment essential for the safe operation of the train.

¹⁵ Note that in-service inspections and scheduled maintenance are an industry wide practice.

Roll-by inspections occur as a train departs its originating location and as trains cross or pass each other while travelling the rail network. The intent is to help verify that a train and its load are acceptable for travel over the intended route.

In this case, the last train examination before the derailment was conducted at the Melbourne Freight Terminal. No indication of imminent bearing failure was detected at that time. After leaving Melbourne, a number of roll-by inspections occurred before train 3PW4 derailed. Only one inspection detected any condition that may have increased the safety risk related to the train. This was a roll-by at Longwood where the crew of train 5BM7 noticed and reported an out-of-gauge load on train 3PW4. The crew of train 3PW4 examined their train and found a piece of metal sticking up above a container on the 35th wagon behind the locomotives. The relevant wagon was detached and stabled on a siding at Violet Town. At no point did the crew of train 3PW4, nor any other crew that conducted a roll-by inspection¹⁶, notice anything abnormal about the bearings on wagon RKWY-4125C.

Scheduled maintenance

Pacific National's RKWY class wagons are subject to three levels of scheduled inspection and maintenance, with kilometres travelled determining the period between inspections. Preventative maintenance (PM) is carried out at 150,000 km intervals with more comprehensive 'A' and 'B' inspections carried out at 300,000 km and 900,000 km intervals respectively.

With respect to bearings, scheduled maintenance generally takes the form of a visual inspection, looking for issues such as grease leakage or physical damage to the bearing. Pacific National's WMM states that bearings need only be removed for overhaul¹⁷ when any wheels on that axle require removal or re-profiling¹⁸.

In this case, the failed bearing occurred on axle number 7E3S09561. The bearing was installed on the axle on 1 February 2007 (date marked on end-cap locking plate) and the axle installed under wagon RKWY 4125C during scheduled preventative maintenance on 19 February 2007.

Wagon RKWY 4125C underwent an 'A inspection' on 27 May 2008. The wagon had travelled about 176,100 km since the installation of axle 7E3S09561. At this inspection, the wheel profiles were within the required limits, so there was no requirement to remove the axle (and bearings) for overhaul. There was no record of any visual bearing defect on axle 7E3S09561.

On 24 November 2009, wagon RKWY 4125C underwent a preventative maintenance inspection. By this date, the wagon had travelled about 356,400 km since the installation of axle 7E3S09561. Again, the wheel profiles were within the required limits and no visual defects were noted in relation to the bearings on the axle.

¹⁶ Note that the roll-by inspections may have been conducted from the opposite side from the failed bearing.

¹⁷ Overhaul or requalification of railway bearings involves disassembly, cleaning, inspection, repair (if necessary) and reassembly of the roller bearing components.

¹⁸ WMM 10-01_08 – *Bearings – Maintenance Policy & General Description* (dated 29/07/08)

The bearing failed on 23 October 2010, having travelled about 472,400 km since the axle was installed under wagon RKWY 4125C, or about 116,000 km since the previous scheduled service. The wheel profiles were measured after the derailment and were found to be within the required limits. Consequently, had the wagon undergone servicing at this time, it is possible that the bearings would not have been removed for overhaul because the wheels may not have required removal or re-profiling.

Equipment traceability

Tracing components (critical to safe railway operations) throughout their life cycle is desirable for gauging and trending component condition over time. Based on data gathered, maintenance regimes may be tailored to suit specific operational requirements and identify criteria that may help prevent in-service failures.

Pacific National's WMM states that an electronic database shall be used for traceability of bearing fitment to wheel-sets¹⁹. The database is to record information such as the bearing serial number, year of manufacture, the overhauler's number and date of overhaul (if applicable), and the corresponding wheel-set (axle) number that the bearing is installed on.

In this case, the bearings were mounted on the axle on 1 February 2007. This was prior to the traceability requirements documented in Pacific National's WMM (dated 6 September 2007). While manual recording was still normal practice, there were limitations with respect to what data was recorded. Consequently, the life history for these bearings could not be determined.

Pacific National had raised the issue of traceability with their maintainers in the years leading up to 2007, resulting in the modification of procedures and updating of documentation later in 2007. A database tracing the fitment of bearings to wheel-sets is now in place and maintained.

2.4.2 Condition monitoring

As described above, inspection and maintenance of rail bearings takes the form of a visual inspection. If the exterior of the bearing appears OK (that is, no grease leakage or physical damage), then the condition of the internal surfaces are also assumed to be OK. Only when the wheels require removal or re-profiling, are the bearings removed, disassembled and the internal surfaces inspected for defects. To manage the possibility that bearings may develop an internal defect before they require removal (that is, before a wheel requires removal), Pacific National access data from the trackside condition monitoring systems.

The condition monitoring systems can be split into two generic types, reactive and predictive, and are akin to reactive and preventative maintenance. A reactive approach requires an immediate action after a serious condition develops or equipment failure occurs, whereas a predictive/preventative approach identifies the requirement for future action before a serious condition develops. In the case of rolling-stock condition, the predictive/preventative approach is likely to be a more cost-effective approach, considering the consequences of a rolling-stock failure may be very costly in damage to infrastructure and operations.

¹⁹ WMM 10-04_06 – *Mounting & Demounting Packaged Unit Bearing on Axle* (dated 06/09/07)

Reactive condition monitoring

Reactive condition monitoring, such as hot-box detectors, are usually used as a ‘last line of defence’ to protect railway infrastructure assets critical to production processes such as coal and ore carrying railways. However, the reactive method of condition monitoring has not been widely adopted for freight/passenger rail operations on the DIRN. Consequently, more effort has been directed towards predictive condition monitoring of railway rolling-stock travelling on the DIRN.

In this case, there were no reactive condition monitoring systems in place that could have detected the imminent failure of the bearing on wagon RKWY-4125C.

Predictive condition monitoring

The ARTC has adopted two main systems of predictive condition monitoring for rolling-stock operating over the DIRN, Bearing Acoustic Monitoring (RailBAM®) and Wheel Impact and Load Detection (WILD)²⁰.

Bearing Acoustic Monitoring (RailBAM®)

RailBAM® is a predictive condition monitoring system that ‘listens’ to the acoustic signature of bearings and can detect faults as they develop. It is the primary method for detecting potential bearing faults on rolling-stock travelling on the DIRN. Recorded data from each train is stored in a database allowing evaluation, trending and maintenance²¹ of rolling-stock based on predicted bearing condition.

RailBAM® uses sensitive acoustic arrays to record the sounds emanating from wheels and bearings passing through the monitoring site. The recordings are processed for the sound characteristics that are unique to specific types of bearing faults. RailBAM® is best at detecting faults on rolling surfaces such as the inner and outer raceways, and rollers in rolling-stock bearings. RailBAM® can also detect looseness or fretting faults and ‘noisy’ wheels (flanging and wheel flats).

The processed data is stored in a database and available to rail operators through a web interface. The RailBAM® database categorises bearing faults in the form of levels of severity (1, 2, and 3 with level 1 being the most critical). The database allows operators to analyse bearing fault history and trends in order to plan their preventative maintenance strategies.

As for any monitoring system, there are some limitations. For example, RailBAM® is a system that ‘listens’ for bearing noises, and under some conditions, other noises (rubbing equipment, tread defects or flanging wheels) may affect the results. However, being a predictive condition monitoring system, multiple passes of potentially defective bearings allows true fault trends to be clearly identified and actioned before a defect reaches a critical level.

It is evident that predictive condition monitoring and a pro-active approach by train operators has become an integral tool for managing the risk of bearing defects on freight rolling stock, especially in relation to rolling surface defects. For example,

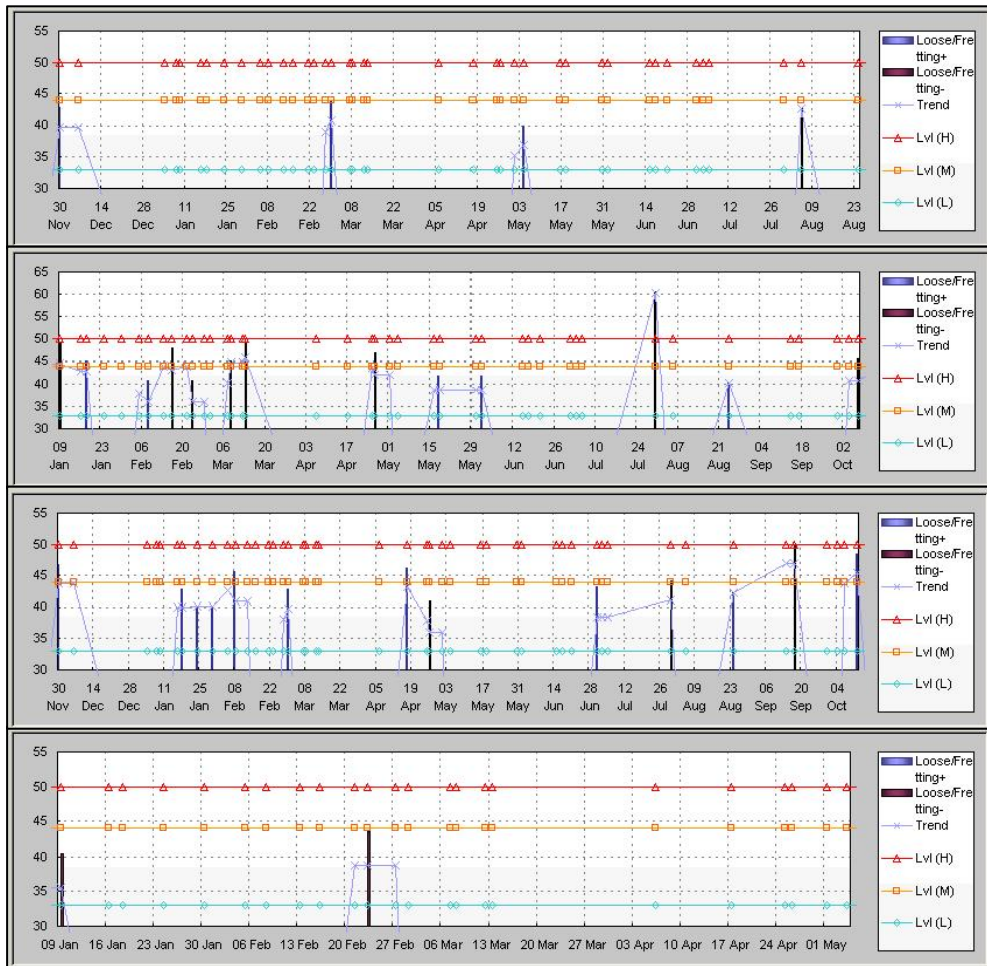
²⁰ Note, PN also operate over non-ARTC rail networks that also have predictive condition monitoring equipment.

²¹ This refers to maintenance action, in addition to scheduled maintenance, which removes a potential bearing fault from service before the complete failure of the bearing.

the ARTC RailBAM® site at Nectar Brook showed a reduction in the number of level 1 rolling surface faults from about 0.5% in 2002 to about 0.05% in 2010. However, Level 1 looseness or fretting (LF1) faults have not experienced the same improvement. In 2002, LF1 faults were about 1.2%, reducing down to about 0.6% in 2005 before rising back to 1.0% in 2009 and 2010.

In the 12 months before the derailment, wagon RKWY-4125C travelled through the ARTC RailBAM® site at Nectar Brook 49 times. About 50% of these passes recorded fault levels, almost all of which were level 3 (least severe) looseness or fretting faults. Most of the recorded faults were associated with axles two and three, noting that the bearing that failed was on axle number three. No faults were detected when train3PW4 passed through the RailBAM site at Nectar Brook (South Australia) on 21 October 2010. Figure 10 illustrates RailBAM’s graphical representation of looseness or fretting faults, between November 2009 and October 2010, for each axle on wagon RKWY-4125C.

**Figure 10: RailBAM Graph – Looseness or fretting faults
Axle one (top) to axle four (bottom)**



Note different axis scales for each graph (ARTC Copyright ©).

It was evident from RailBAM data that axles two and three had recorded significantly more potential looseness and fretting faults than axles one and four. However, the data was largely low level indications (level 3) and did not show any significant trend that would indicate a defect was present or becoming progressively worse.

Information provided to the ATSB suggested that the progressive development of looseness and fretting defects may not be reliably detected by RailBAM. This understanding appeared to be reflected in Pacific National's WMM²² which makes no reference to monitoring of looseness or fretting faults, but indicates that only rolling surface faults are considered when examining RailBAM data in relation bearing condition monitoring. A research report published in 2003 by the Federal Railroad Administration (USA), titled 'Acoustic Detection of Roller Bearing Defects', also identified potential limitations with respect to detecting loose bearing components. The report stated '...every test bearing with a spun cone defect did not generate observable high-frequency signatures during every pass...' The report went on to say, the acoustic '...pattern may vary and not always manifest itself in the same manner'. In this case, while RailBAM may not have indicated a fault trend (looseness or fretting) associated with wagon RKWY-4125C, it is still possible that components were wearing due to fretting and rotational creep²³ but did not consistently generate the relevant sound signature recognised by RailBAM at every pass.

While there was no documented evidence of such, Pacific National advised that they actively manage the risk of looseness and fretting damage to bearing components. Up until mid-2007, PN routinely removed and examined bearings that showed consistent LF1 (most severe fault level) indications on RailBAM. However, the process was abandoned because actual evidence of looseness or fretting faults was found to be inconsistent. In most cases, the RailBAM looseness and fretting indications were found to be a result of other noises not directly related to a bearing fault (for example, rubbing brake shoes or other components rubbing on the axle).

Pacific National advised that since 2007, RailBAM readings are considered in conjunction with wheel impact detection and other bogie faults such as steering issues. The approach is to only remove bearings exhibiting LF1 faults if there is no other explanation for the readings. Since abandoning the process of routinely removing bearings showing LF1 indications, Pacific National have not observed any increase in the number of faulty bearings exhibiting looseness and fretting issues.

Pacific National advised that they had implemented various risk mitigation strategies in relation to loss of interference fit and fretting of rolling stock bearings. Most of these strategies were associated with bearing installation and out-of-service inspection and maintenance practices. However, there was no documented evidence of in-service monitoring of potential looseness and fretting faults. While it is recognised that RailBAM may not reliably trend potential looseness and fretting defects, it is still evident that the system is capable of detecting potential defects. Also, considering the maintenance processes currently in place, it is recognised that bearing failures are relatively rare and of those that do occur, only some may be attributable to loose components. However, the consequences of a screwed journal derailment, if it occurs, can be significant (in this case, significant damage to rolling stock, track and bridge infrastructure) and this may warrant a review and documentation of the processes used to manage the risk of bearing failure due to looseness or fretting.

²² WMM 01-12_02 – *Management of Wayside Condition Monitoring Systems* (dated 04/11/09)

²³ Note that RailBAM is not designed to detect potential instances of rotational creep

Wheel impact and load detection (WILD)

The wheel impact and load detection (WILD) system is a predictive condition monitoring system that measures impacts and the mass of passing wheel-sets. It is the primary method for detecting wheel flats on rolling-stock travelling on the DIRN. While wheel flats are undesirable due to the potential damage they can cause to the track, they also place undesirable forces on rolling-stock components, including axle bearings. The data is stored in a database and available to rail operators through a web interface. There were no records of excessive wheel impact for wagon RKWY-4125C in the 12 months leading up to the bearing failure on 23 October 2010.

Data from the ARTC WILD system at Port Germein, South Australia was also used to examine the loading of wagon RKWY-4125C. The data indicated that wagon RKWY-4125C was usually loaded between 75 t and 85 t (gross weight) when travelling away from Port Augusta and often empty or lightly loaded when travelling towards Port Augusta. At no time did the wagon appear to be overloaded.

On-board condition monitoring

In the past, condition monitoring of freight rolling-stock has been the realm of trackside equipment (Hot box, RailBAM, WILD etc.), usually fixed at a specific geographical location. While predictive systems may provide a broader level of protection, reactive systems are limited to protection of equipment and infrastructure in the immediate vicinity.

The next evolution of condition monitoring would be one that continuously monitored each wagon for developing faults (predictive) and immediately communicated any critical conditions to the train drivers (reactive). This type of system is referred to as an on-board condition monitoring system. While various limitations (functional and economic) have prevented these systems being widely used on railway freight operations in the past, recent technological developments have now made the concept more attractive. However, at the time of this incident, only limited developmental work had been started within Australia and Pacific National did not have an on-board condition monitoring system installed on any of their freight vehicles.

2.4.3 Summary of bearing failure management

Pacific National's inspection and maintenance process generally takes two forms, in-service inspections and scheduled maintenance. Train 3PW4 underwent a train examination before it departed the Melbourne Freight Terminal and underwent a number of roll-by inspections occurred before it derailed at Wodonga. At no point did the crew of train 3PW4, nor any other crew that conducted a roll-by inspection, notice anything abnormal about the bearings on wagon RKWY-4125C.

Examination of the partner bearing suggested that it was in reasonable operating condition prior to the derailment. Consequently, there was no evidence to suggest that Pacific National's scheduled maintenance procedures were inadequate with respect to the partner bearing. However, an inability to examine the failed bearing prevented any similar conclusion with respect to the failed bearing.

Trackside condition monitoring systems are used to manage the possibility that bearings may develop an internal defect before they require removal (that is, before

a wheel requires removal). The primary method for detecting potential bearing faults on rolling-stock travelling on the DIRN is RailBAM, a predictive condition monitoring system that listens to the acoustic signature of various bearing faults as they develop.

In the 12 months before the derailment, wagon RKWY-4125C recorded looseness or fretting faults for about 50% of passes through the RailBAM site at Nectar Brook, South Australia. However, the data did not record any apparent fault trend and no bearing fault was detected on wagon RKWY-4125C when train 3PW4 passed through Nectar Brook on 21 October 2010.

While it is recognised that RailBAM may not reliably trend potential looseness and fretting defects, it is still evident that the system is capable of detecting potential defects even though bearing failures attributable to loose components are relatively rare. However, there was no documented evidence that Pacific National actively in-service monitors the risk of looseness and fretting damage to bearing components. Considering the potential consequence of a screwed journal derailment, a review and documentation of processes for managing bearing failure due to looseness or fretting may be warranted.

2.5 Containment of derailed rollingstock

It was evident that the derailed wagons from train 3PW4 were not all contained within the boundaries of the bridge structure. While 13 derailed wagons remained on the bridge but at various angles along the track, two wagons fell off the bridge structure, each with one end resting on the ground and one end on the bridge. In this case, the bridge was spanning a waterway where the possibility of a load spill could have represented an environmental risk. However, had the derailment occurred at the next bridge (about 750 m further towards Sydney) the possibility of injury to public would have been significantly greater since that bridge was spanning the Lincoln Causeway, a main road between Wodonga and Albury.

It was evident that, in this case, no facility was installed to manage the risk of derailed wagons falling from the bridge. Considering the perceived risk that a similar derailment could result in injury to public, the issue of derailed wagon containment was examined.

The most common strategy used to manage the risk of rollingstock falling from a bridge structure is the installation of guard rails. Guard rails are rails mounted between the running rails that keep derailed wheels tracked parallel to and in close proximity to the running rails thereby preventing a derailed train from striking adjoining infrastructure or falling off a bridge.

The ARTC Code of Practice (CoP), Section 9 *Structures* (dated June 2010) states that guard rails are not required on rail bridges in Victoria. However, for ballast top bridges in New South Wales, the ARTC CoP does require guard rails if any individual span exceeds twenty metres in length. At the very least, any ballast top bridge on the interstate mainline in New South Wales would be subject to a risk assessment to determine whether guard rails were required. It appeared that the ARTC CoP was inconsistent with its requirements for guard rails on ballast top bridges even though the risks would be similar in either State, noting that in this case, the border between Victoria and New South Wales was less than 2 km from the derailment site.

The ARTC advised that the inconsistent requirement for guard rails in New South Wales and Victoria was a legacy of previous design practices. The introduction of the current Code of Practice had been preceded by a series of robust risk assessments conducted in relation to guard rails, with input provided from Railway Engineering and Risk Specialists. The outcome of the assessment was that guard rails were not required. This outcome had been reflected in Code of Practice for Victoria but had not yet been adopted in New South Wales.

The derailment at Wodonga on 23 October 2010 also illustrated how guard rails may not guarantee the containment of derailed wagons. In this case, derailed wagons damaged the concrete sleepers such that any guard rail would have been unsupported. In addition, the rapidly slowing wagons digging into the ballast, accompanied by wagons pushing from behind, probably caused the wagons (27th and 28th in consist) to lift in an inverted 'V' formation before falling to the side and off the bridge. Consequently, in this case a guard rail was unlikely to contain the derailed wagons within the boundaries of the bridge structure.

3 FINDINGS

3.1 Context

At approximately 0710 on 23 October 2010, 15 wagons on freight train 3PW4 derailed near Wodonga, Victoria. There were no injuries.

From the evidence available, the following findings are made with respect to the derailment of train 3PW4 and should not be read as apportioning blame or liability to any particular organisation or individual.

3.2 Contributing safety factors

- An axle bearing on wagon RKWY-4125C failed and completely seized, causing the inner rings to spin on the axle journal, generating and transmitting sufficient heat to the journal to make it 'plastic' and causing it to separate from the axle (commonly referred to as a screwed journal).
- The most likely cause of bearing seizure was a loss of interference fit between the inner rings and journal which allowed the inner rings to turn or spin on the axle journal leading to increased wear and ultimately generating significant heat and damage until the bearing completely seized.
- It is possible that fretting and rotational creep contributed to the loss of interference fit.

3.3 Other safety factors

- There was no documented evidence that Pacific National actively in-service monitors the risk of looseness and fretting damage to bearing components.
[Minor Safety Issue]

3.4 Other key findings

- There was no evidence to suggest that bearing fatigue, cage failure or inappropriate assembly practices contributed to the bearing failure on 23 October 2010.
- It is possible that a pre-existing fracture in the bearing cup of the partner bearing may have been the result of a dropped load. However, there was no evidence to suggest that a similar fracture existed in the failed bearing.
- While it can't be completely ruled out, there was insufficient evidence to suggest that rolling surface damage or contamination of the lubricant was a contributing factor in this case.
- It is recognised that RailBAM may not reliably trend potential looseness and fretting defects. However, it is still evident that the system is capable of detecting potential defects.

- In the 12 months before the derailment, wagon RKWY-4125C recorded low level looseness or fretting faults for about 50% of passes through the RailBAM site at Nectar Brook, South Australia.
- No bearing fault was detected on wagon RKWY-4125C when train 3PW4 passed through Nectar Brook on 21 October 2010.
- Loose components are recognised as a significant contributing factor to premature in-service bearing failure.
- Pacific National has been successful at reducing their risk of bearing failure due to rolling surface defects.
- Records associated with the fitment of the bearings to the axle could not be found and, at the time (2007), Pacific National did not have systems in place to record bearing fitment details. Pacific National has since addressed the issue with their maintainers and implemented processes for recording details.

4 SAFETY ACTION

The safety issue identified during this investigation is listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

Depending on the level of risk of the safety issue, the extent of corrective action taken by the relevant organisation, or the desirability of directing a broad safety message to the rail industry, the ATSB may issue safety recommendations or safety advisory notices as part of the final report.

4.1 Pacific National

4.1.1 Risk management of bearing failure due to looseness or fretting

Minor safety issue

There was no documented evidence that Pacific National actively in-service monitors the risk of looseness and fretting damage to bearing components.

Response from Pacific National

While there was no documented evidence of such, Pacific National advised that they actively manage the risk of looseness and fretting damage to bearing components, but since mid-2007 have not relied solely on fault indications identified by RailBAM. Their approach is to consider RailBAM readings in conjunction with wheel impact detection and other bogie faults such as steering issues and only remove bearings if there is no other explanation for the readings.

In addition, Pacific National advised that they are committed to developing a composite alarm application where trends may be better analysed individually and compared to bearing faults, wheel impacts and bogie faults such as steering issues.

ATSB assessment of response

Considering the maintenance processes currently in place, it is recognised that bearing failure due to looseness and fretting is relatively rare. Since abandoning the process of routinely removing bearings that have shown looseness or fretting indications (RailBAM), Pacific National advised they had not observed any increase in the number of faulty bearings exhibiting looseness and fretting issues. However, without documented records, this observation cannot be effectively monitored.

Considering the potential consequence of a screwed journal derailment, a review and documentation of processes for managing bearing failure due to looseness or fretting may be warranted.

APPENDIX A : SOURCES AND SUBMISSIONS

Sources of Information

The sources of information during the investigation included the:

- Australian Rail Track Corporation
- Pacific National

References

- 7th International Heavy Haul Conference, 2001; *Journal Roller Bearing Defect Populations*, M.C. Fec, K.L. Hawthorne, D.H. Stone.
- ARTC Code of Practice, Section 9 *Structures* (dated June 2010)
- Federal Railroad Administration (USA) research report, *Acoustic Detection of Roller Bearing Defects* (2003)
- Pacific National's Wagon Maintenance Manual
 - WMM 01-12_02 – Management of Wayside Condition Monitoring Systems (dated 04/11/09)
 - WMM 10-01_08 – Bearings – Maintenance Policy & General Description (dated 29/07/08)
 - WMM 10-04_06 – Mounting & Demounting Packaged Unit Bearing on Axle (dated 06/09/07)

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to:

- Australian Rail Track Corporation
- Independent Transport Safety Regulator
- Pacific National
- Transport Safety Victoria

Submissions were received from the Australian Rail Track Corporation, the Independent Transport Safety Regulator and Pacific National. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

Derailement of train 3PW4, Wodonga, Victoria, 23 October 2010