Australian Transport Safety Bureau

AUSTRALIAN TRANSPORT SAFETY BUREAU

RAIL INVESTIGATION REPORT

Derailment of passenger train 8622, Sydney – Melbourne daylight XPT service

Wodonga, Victoria

25 April 2001

COMMONWEALTH DEPARTMENT OF TRANSPORT AND REGIONAL SERVICES

ATSB

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This report was produced by the Australian Transport Safety Bureau (ATSB), PO Box 967, Civic Square ACT 2608.

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1. EXECUTIVE SUMMARY

At 0743 on 25 April 2001, the Countrylink XPT daylight service ST3 (train 8622) left Sydney bound for Melbourne. The train consisted of a lead power car followed by seven passenger cars designated from 'A' through to 'G' and a trailing power car. On board the train was a crew of five- the driver, a passenger service supervisor and three passenger attendants- and 127 passengers.

The run from Sydney south was routine. No problems were reported at the driver changeover in Junee at approximately 1354. At 1528 the train arrived in Albury where the passenger service supervisor and three passenger service attendants changed over. The train departed from Albury Station at 1532, approximately 30 minutes late, with 98 passengers on board.

After leaving Albury Station, the driver accelerated to 80 km/h and maintained that speed until approaching the Melbourne end of the Wodonga coal sidings, where he reduced the train speed to slightly below the 40 km/h posted speed. Shortly after this, the train passed the Hovell Street level crossing in Wodonga and continued to round the tight right-hand curve in the main line before the High Street level crossing. The train's speed was approximately 25 km/h. As the train entered this section of curve, the driver applied some power to maintain the train's speed through the curve.

At approximately 1538 at 301.1086 km[1], the inner wheel on the lead axle of the lead bogie (NHA 198B) of car 'E' (XF 2214) dropped from the low rail of the curve. At 301.105 km the inner wheel dropped completely from the low rail into the track four-foot[2]. The train travelled approximately 2.75 m further until the outer wheel on the same axle climbed over the high rail and onto the ballast shoulder on the outside of the curve. At 301.0911 km the trailing wheel-set of the bogie also derailed with the outer wheel climbing over the high rail and the inner wheel simultaneously dropping into the four-foot. The bogie, now completely derailed, travelled in this condition for approximately 950 m until the train was brought to a stop by the driver. The driver had stopped the train in response to a passenger emergency alarm which had been initiated by the passengers in car E.

The derailment occurred on the sharpest curve on the main line between Sydney and Melbourne. The alignment at this point in the main line was originally dictated by the presence of a crossing diamond where the broad gauge branch line to Bandiana had crossed the standard gauge main line. The alignment of the curve had not been changed since the closure of the branch line and the removal of the diamond in 1997.

Assessment of the track at the derailment site revealed a number of factors which contributed to the derailment, the most significant of which was the condition of the high rail fasteners which resulted in gauge widening[3] of up to 49 mm at the point of derailment.

The derailment was unusual in some ways as there had been other freight and passenger train traffic on the line earlier in the day without incident. In addition, the derailment involved only one bogie in the middle of the train with bogies in the same

1 Kilometre positions are the measured distances from Melbourne on the standard gauge main line.

2 Four-foot is a term used to describe the section of track between the rails.

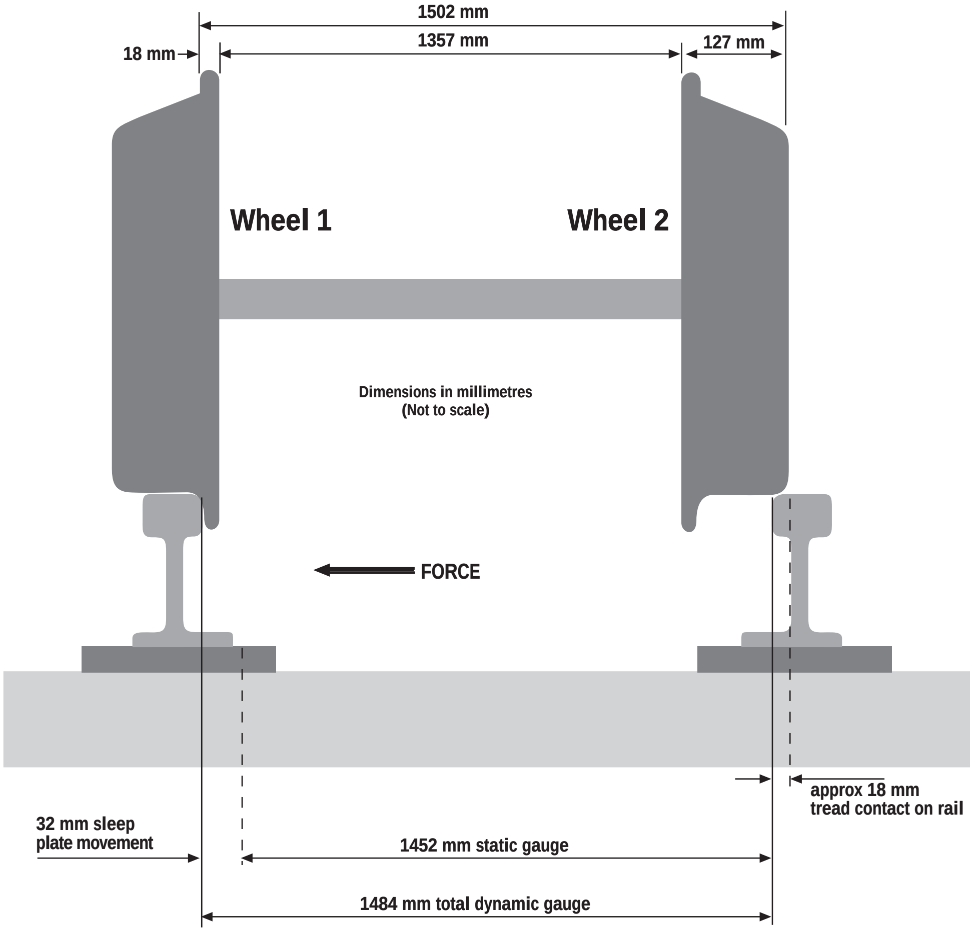
3 Gauge widening refers to an increase of gauge over the standard 1435 mm between rail gauge faces.

train passing safely over the site before and after bogie NHA 198B had derailed. This indicates, that while the track-based elements were the primary causal factors, it was the combination of the vehicle-based and track-based factors that caused the derailment.

Inspection of the bogie which derailed revealed some factors which contributed to the derailment including a thin flange on the number-1 wheel and the poor condition of the bogie's side bearer yaw friction pads.

Figure 1. is a schematic diagram representing the lead axle of bogie NHA 198B at the point of derailment. It shows the measured geometric contributions of the track gauge widening, wheel width, wheel back-to-back dimension and number-1 wheel flange thickness. At the point of derailment, allowing for the maximum measured dynamic gauge of the track and no rail roll, there was only 18 mm of the inner wheel overlapping the head of the low rail.

FIGURE 1:
Schematic diagram of leading axle of the derailed bogie on track at the point of derailment



The investigation engaged two consultants to provide independent analysis of the derailment, Weltrack Pty Ltd and Interfleet Technology Pty Ltd. Weltrack was commissioned to provide expert analysis of the geometry and condition of the track at the derailment site and interaction between the track and the rolling stock. Interfleet Technology was engaged to provide expert analysis of the derailment, computer modelling of the bogie tracking on the curve and data on the rotational resistance of the bogie.

Both consultants concluded that the derailment was the result of a combination of track and bogie factors and agreed that the most significant factor was the condition of the high rail fastenings. The consultants differed in their conclusions as to the degree to which the condition of the bogie's side bearer yaw friction pads contributed to the derailment. However, on the balance of all the evidence, the investigation considers that the condition of the bogie was such that it must be considered a causal factor in the derailment.

Factors identified during the investigation which contributed to the derailment include:

- The inadequately fastened high rail in the 175 m radius section of curve which resulted in gauge widening of up to 49 mm at the point of derailment. The fastenings also allowed the high rail to roll an additional 18 mm or more to allow the number-2 wheel of the bogie to drop off the low rail.
- NHA 198B was the only bogie on the train to derail due to a combination of factors. These include the thin flange on the number-1 wheel, an under-specification back-to-back wheel measurement on the leading axle, and the poor condition of the yaw friction pads that led to the number-1 wheel subjecting the high rail to higher than usual lateral loads.
- The poor alignment of the curve in the area of the derailment led to the high rail being subjected to relatively high lateral loads from passing trains including the train that derailed. This led to an increased rate of rail fastening deterioration and ultimately the derailment.
- The poor condition of the sleepers around the point of derailment had an adverse impact on the initial strength of the high rail fastenings.
- The shoulder ballast covering the fastenings on the field side of the high rail in the area of the derailment inhibited the effective inspection of the track. As a result, the failure of the high rail fastening and gauge widening around the point of derailment remained undetected prior to the incident.
- The lack of high rail lubrication may have led to some increase in the gauge spreading force on the track at the point of derailment.
- Decisions made during the 'resilient fastening project' some 16 months before the derailment relating to the number of fasteners fitted, sleepers renewed and the regauging of the curve.
- The decision in December 1999 to reduce the XPT wheel flange thickness condemning limit from 24.5 mm to 19 mm.

There were a number of organisational contributing factors also identified during the investigation which related to the management of the resilient fastening project, management of the track maintenance in the area of the derailment and the maintenance of the XPT rolling stock.

The investigation revealed that poor communication and coordination between the track maintenance staff and project management staff during the resilient fastening project contributed to project work in the area of the derailment being accepted as complete when it did not meet the contract specification or the required regulatory standard. It was also found that the track maintenance regime at the derailment site had not identified the curve as a 'significant risk' despite its small radius, poor alignment and thus predictable higher than usual rate of fastening deterioration.

Rolling stock maintenance was also implicated in the derailment by the poor condition of the derailed bogie's side bearer units and the thickness of the number-1 wheel flange which was below the current condemning limit at 18 mm.

The investigation also found that the difficulties associated with the evacuation of passengers from XPT carriages in an emergency needs to be addressed with appropriate procedures and training for train staff.

Several recommendations for safety actions have been made relating to findings of the investigation, these are that:

- ARTC ensure that the Victorian track under their control meets the requirements of the PTC Civil Engineering Circulars with respect to the number of spring spikes fitted to sleeper plates on curves.
- ARTC ensure that the Victorian track under their control is ballast regulated to allow all track fastenings to be effectively inspected.
- ARTC track project management practice in future includes effective consultation and communication with line maintenance staff to ensure that contracted track rectification and maintenance activities are properly coordinated and completed.
- Line maintenance practices in future include sufficient risk assessment to ensure that vulnerable sites are adequately monitored and maintained.
- XPT maintenance practices are reviewed to ensure that their rolling stock in service meets the required standards with regard to wheel flange thickness.
- XPT maintenance practices are modified to improve the serviceability of the NHA bogie side bearer friction surfaces and ensure that the design X factor of the bogies is maintained.
- Countrylink implement their Emergency and Evacuation Preparedness Plan as a priority and provide the necessary training for their train crews.

A number of these safety actions have been or are being implemented by the various organisations concerned (details are provided on pages 77 and 78 of the report).

2. INTRODUCTION

As a result of the derailment of the XPT at Wodonga on the 25 April 2001, the Victorian Minister for Transport, the Honourable Peter Bachelor MP, directed the Secretary of the Victorian Department of Infrastructure to establish an independent inquiry in accordance with the requirements of the *Victorian Transport Act (1983)*, as amended by the *Transport (Rail Safety) Act 1996* and by reference to the *Transport (Rail Safety) Regulations (1998)*.

Section 129U of the Act states:

> The Minister may require the Secretary or any other person or body to inquire into, and to report to the Minister, on any railway accident or incident that may affect the safe operation, construction, maintenance, repair or alteration of any rail infrastructure or rolling stock.

A team of investigators from the Australian Transport Safety Bureau were appointed, in consultation with the Victorian Department of Infrastructure's Safety and Technical Services Branch, to lead the independent investigation. The Office of the Director of Public Transport stipulated that the ATSB 'inquiry should be comprehensive and look for all pertinent issues that caused or may have caused the derailment.'

The independent investigation team was provided with assistance by the passengers and crew on the train and by the following organisations:

- Victorian Department of Infrastructure, Safety and Technical Service Branch;
- State Rail Authority, NSW;
- Australian Rail Track Corporation Ltd;
- Evans Deakin Industries Pty Ltd, Powerlines, Telecommunications, Rail Division;
- Freight Victoria Ltd;
- New South Wales Department of Transport;
- Railfleet Services Ltd;
- Williams Worley Pty Ltd;
- Bureau of Meteorology;
- Victorian Rail Track Corporation;
- Bombardier Transportation, Daimler Chrysler Rail Systems Pty Ltd;
- Sinclair Knight Merz Pty Ltd;
- Rail Infrastructure Corporation;
- EDI Rail, (Newport);
- Weltrak Pty Ltd; and
- Interfleet Technology Pty Ltd.

These organisations provided records, reports, logs and analysis of the events associated with the derailment, operating and maintenance procedures, analysis of recorded train information, records of maintenance and information relevant to the investigation. Their open participation and cooperation in the investigation process is gratefully acknowledged.

3. INVESTIGATION METHODOLOGY

The purpose of this investigation was to enhance rail safety. The investigation used a systemic methodology to not only identify and consider the immediate causal factors involved in the derailment, but to trace their origins back to their source within the design, operation, maintenance and management of the rail system. It is not the purpose of this investigation to apportion blame or liability to any person or organisation. The aim of this investigation is to identify the different factors which may have contributed to the incident and assess them with a view to preventing similar occurrences in the future.

The conduct of this systemic accident investigation and the analysis of the contributing causal factorsto the accident was based on the work of Professor James Reason of Manchester University, and the 'Reason model'.

During the investigation, information was obtained and analysed from a number of sources, including:

- Visits to the accident site;
- Inspection and technical analysis of the rolling stock involved in the derailment;
- Recorded train and train control information;
- Track and rolling stock maintenance records, procedures and standards;
- The history of organisational and infrastructure changes associated with the accident site;
- Interviews with personnel directly associated with the accident;
- Interviews with management of organisations relevant to the accident;
- A review of the rolling stock operators and track access provider's risk assessment methodology and application.

4. FACTUAL INFORMATION

4.1.1 XPT background

In 1982, the State Rail Authority of New South Wales (now State Rail) introduced express passenger trains (XPTs) for operation on their long distance country passenger services. The train was based on the British High Speed Train (HST) with the rolling stock adapted for Australian conditions.

Initially XPTs were used exclusively on intrastate services within New South Wales. However with the phasing out of traditional locomotive trains, XPT services were extended to Brisbane in 1990. In 1993, with the assistance of the Victorian Government, additional vehicles were purchased to provide XPT services for the Sydney-Melbourne route. Initially the trains operated a single daily overnight service until an additional daylight service was introduced at the end of 1994.

Countrylink is the division of State Rail which operates the company's non-metropolitan passenger services including the XPTs. The Countrylink XPTs are the only regularly scheduled passenger trains on the standard gauge (1435 mm) railway between Sydney and Melbourne.

Currently eight XPTs are required to operate Countrylink's scheduled services. One smaller train is used exclusively on the daily Sydney-Dubbo service. The remaining seven larger trains of a standard consist[4] operate the daily services to Brisbane, Murwillumbah, Grafton, Melbourne daylight and Melbourne overnight on a seven day cycle. Trains are maintained at the XPT maintenance depot at Sydenham in Sydney.

FIGURE 2:
XPT

4 Consist refers to the combination of locomotives and carriages of various types which are coupled to make up a train.

4.1.2 Wodonga

The derailment occurred 301.105 km from Melbourne on the standard gauge main line just outside the Wodonga Station yard between the High Street (300.951 km) and Hovell Street (301.193 km) level crossings. The train continued west through the station yard, towards Melbourne until brought to a stop with the lead power car at approximately 300.022 km.

The rail services in Wodonga are provided by two systems with main lines, the standard gauge (1435 mm) system, and the broad gauge (1600 mm) system. The broad gauge main line terminates at Albury Station and provides both passenger and freight services from the Albury/Wodonga area into Victoria. The standard gauge main line running through the Albury/Wodonga area provides interstate passenger and freight services between New South Wales and Victoria.

Both standard and broad gauge main lines run from Albury to Wodonga on a largely parallel alignment. After passing the coal sidings at Wodonga, both main lines curve to the west as they approach Wodonga Station and maintain a parallel alignment until they reach the Hovell Street crossing. At Hovell Street, the broad gauge main line continues in the constant radius curve, (800 m radius) until it crosses High Street.

The radius of the curve in the standard gauge main line between the Hovell Street and High Street crossings varies. Before the Hovell Street crossing the curve radius is 800 m which then decreases to 175 m over the crossing. This varation in curve radius causes the standard gauge main line to diverge from the broad gauge main line for a short distance after the Hovell Street crossing and then reconverge just before the High Street crossing.

After the High Street crossing, the two main lines divide again as they approach Wodonga Station. The broad gauge line enters the station to serve the single passenger platform located on its northern side. The standard gauge main line runs through the station yard in a curve to the south of the Wodonga Station buildings. As it passes through the station yard from the east, the standard gauge main line crosses the station entry road and then a pedestrian crossing before it curves north to bring both main lines back onto a parallel alignment on the western side of the station. Both main lines continue west on a parallel alignment without any curves until they pass out of the station yard at 300 km.

FIGURE 3:
Wodonga aerial photograph

4.2 Sequence of events

4.2.1 The incident

At approximately 0755 on 25 April 2001 (ANZAC day), the Countrylink daylight XPT service to Melbourne departed from Central Station in Sydney. The train consisted of a lead power car followed by seven passenger cars designated from 'A' through to 'G' and a trailing power car. On board the train was a crew of five- the driver, a passenger service supervisor and three passenger attendants- and 127 passengers. The service departed 12 minutes behind schedule, and as a result, could not use its tabled path through the Sydney metropolitan area. This resulted in further delays due to the suburban commuter train traffic.

Once the train had left the Sydney area, it proceeded south without incident until arriving at Junee Station at 1352. A driver change took place and during the changeover the outgoing driver indicated to the incoming driver that the train was 'going OK'. The train left Junee at 1354 now 2 minutes behind schedule.

After leaving Junee, the train made stops at Wagga Wagga, The Rock, Henty and Culcairn before arriving at Albury. During the stop at Albury, the passenger service supervisor, senior passenger attendant and the two passenger attendants were relieved. The train moved from the Albury Station platform at 1532 and after stopping briefly at the end of the platform to obtain authority to enter Australian Rail Track Corporation (ARTC) territory, the driver accelerated to the line speed of 80 km/h.

After the train departed from Albury, one of the passenger attendants was having a conversation with the passenger service supervisor in the rear of car 'G'. The passenger attendant then started walking through the train on his way to the buffet car. As he was passing through car ‘E’ he noted that the car was riding normally until he approached the front of the car when he heard a loud ‘bang’ and felt the car drop what he thought was approximately 150 mm. After this incident he felt the ride of the car return to normal and noted that the alignment of the diaphragm equipment connecting the cars was normal when he walked through into car ‘D’. At the time, the passenger attendant attributed the ‘bang’ and ‘drop’ to the car ‘bottoming out’ travelling over a dip in the track.

The driver maintained the train’s speed at 80 km/h until it was approaching the Melbourne end of the Wodonga coal sidings. He then allowed the train to coast without power and applied the brakes lightly at 1536. By the time the train was passing the 40 km/h speed board just before the Osburn Street level crossing (301.611 km), its speed was approximately 35 km/h. The driver allowed the train to coast past the Bandiana line turnout (301.630 km) and into the 800 m radius section of right hand curve prior to the Hovell Street level crossing (301.193 km).

Just after passing the Hovell Street level crossing, the driver moved the locomotive power control to notch two to maintain the train’s speed through the curve. The train continued into the 175 m radius section of the curve. As the lead bogie of car ‘E’ reached the 301.1086 km point in the curve, the inside wheel (number-2) on the leading axle dropped off the low rail. The wheel remained partly suspended with its rim rubbing against the gauge face of the rail. At 301.105 km the number-2 wheel dropped completely from the low rail. At 301.10225 km, 2.75 m further on, the outer wheel flange (number-1) on the same axle climbed over the high rail. At 301.0911 km, 11.15 m further on, the trailing wheel-set of the bogie also derailed with the outer wheel flange (number-3) climbing over the high rail and the inner wheel (number-4) dropping off the low rail into the track four-foot. The bogie was now completely derailed with its two inner wheels running in the four-foot and its two outer wheels running on the field side of the high rail.

As the lead power car passed through the High Street level crossing, (300.951 km) the crew all recalled feeling the train ‘jerk’. The driver felt that the jerk may have been the rear power car ‘shedding load’ (a reasonably common occurrence) and so he closed the throttle and then re-applied power.

At this time, a pedestrian waiting at the south side of the High Street crossing, who happened to be an ex-train driver, saw that lead bogie on car ‘E’ was derailed. He noticed that the bogie was ‘bouncing around at a high frequency, about 3–5 times per second’ and making a large amount of dust. He was concerned that the driver was unaware that the train had derailed and so ran to the Wodonga Station platform where he remembered that there was a railway telephone. He found that the telephone had been removed from its box and so ran further up the platform into the station booking office where he alerted the staff.

The passengers in car ‘E’ indicated that they heard a crunching sound around this time and that the carriage started to fill with dust. They also indicated that the car was riding very roughly and leaning over with luggage falling from the racks in the vestibule at the front of the car. They were alarmed and started to evacuate the car. The train was well inside the Wodonga Station yard by this time.

As the train approached the Wodonga ‘A’ signal box, the signalman in the box (who had arrived early for work) heard the train making an abnormal noise. He looked out of the signal box window and saw that the train was making dust around the middle of the train. He thought that the train may be derailed and proceeded to call the driver on the train radio.

As car ‘E’ passed over the pedestrian crossing on the western side of the station buildings, the wheels of the derailed bogie running in the four-foot struck and lifted the concrete block in the centre of the crossing. Soon afterwards, the air-conditioning units which were fitted under the middle of the car, also struck the raised concrete block pushing it along the track and off to one side. At this time the train crew recalled feeling a second ‘jerk’ probably as the bogie wheels made contact with the concrete block.

A passenger in car ‘E’ actuated the passenger emergency button at the Melbourne end of the car at this time.

The passenger service supervisor, in car ‘G’, and the driver both received the passenger emergency alarm. In response to the alarm, the passenger service supervisor made an announcement on the crew address system instructing the passenger attendants to make their way to their allocated cars to check which emergency button had been actuated.

At approximately 1540, the driver received the radio call from the Wodonga ‘A’ box signalman at the same time as the passenger service supervisor’s call to the passenger attendants. Initially the signalman’s message was not clear to the driver, who was in the process of bringing the train to a stop in response to the passenger alarm. After he had stopped, the driver called the signalman who indicated that he thought the train ‘might be in the dirt’. The driver then looked down the train to see that the front of car ‘E’ was out of alignment. He called the signalman back on the radio to indicate that it looked as if he was right and that the train had derailed. The driver then dismounted from the driver’s cab to make an inspection.

The train was brought to a stop at approximately 300.022 km, 70 m before the House Creek bridge (299.952 km).

At this time, one of the passenger attendants was making his way through car ‘D’ and saw passengers coming from car ‘E’ into the rear of car ‘D’. When he made his way into car ‘E’, he noted that door diaphragm was misaligned and saw that there were no passengers in the car. The car was filled with dust and some of the luggage racks in the vestibule had collapsed. The passenger service supervisor had also arrived at car ‘E’ by this time and reset the passenger alarm. The train crew then proceeded to check the passengers for injuries and reassure them.

After speaking with the driver on the radio, the signalman made contact with ARTC train control in Adelaide to indicate that the XPT had derailed and was stopped on the main line.

4.2.2 Subsequent events

At 1545, emergency service personnel from the police and fire brigade arrived at the scene.

By this time the driver had completed his inspection of the train and had ascertained that only the leading bogie of car ‘E’ was derailed. The driver made his way back to the driver’s cab. As he entered the cab, train control was already trying to contact him on his mobile telephone. He advised the train controller of the situation. The driver then rang Countrylink in Sydney to inform them of what had happened. The driver and the passenger service supervisor conferred at around this time with regard to arrangements for transhipping the passengers and arranging reliefs for the train crew. The driver indicated that Countrylink was organising road coaches for the passengers.

The fire service personnel during this time were inspecting the train for any risk of fire. The police interviewed the driver and later breath tested him for the presence of alcohol. The police also established a perimeter around the train. The Wodonga 'A' box signalman, in conjunction with the police and other railway personnel, organised for the High Street, station entry and Kelly Street level crossings to be manned. These crossings were causing road traffic delays with their boom gates down as a result of the train's occupation of the track circuitry and damage in the case of the High Street level crossing.

Around this time, the passenger service supervisor arranged for the passengers to be moved into the centre cars. He had conferred with the police and driver of the train and the decision was made that the centre of the train offered the best place for the passengers to disembark. The train crew also ensured that all of the passengers remained on the train as this was felt to be the safest and most comfortable place for them to wait for the road coaches. The buffet car was opened and complimentary refreshments were provided to the passengers while they waited.

At 1636, the State Rail first response contractor at Cootamundra (Freightcorp) were contacted by Junee train control and organised to attend the train and re-rail it. The EDI staff at the track maintenance depot at Seymour were also notified and a fettling gang was organised to attend the site to repair track damage so the line could be reopened. At 1650 a local signal fitter repaired some minor damage to the signal system at the High Street level crossing.

The road coaches arrived at 1715 and the passengers were transferred from the train to the coaches without incident. Three V/Line conductors based in Wodonga had arrived earlier to offer assistance and were used in conjunction with the XPT crew in the transhipment. By 1740, the passengers and their luggage had been loaded aboard, and the coaches dispatched for Wangaratta, Benalla and Melbourne.

At approximately 2030, the driver was relieved at the scene by another Countrylink driver and subsequently travelled to Melbourne by taxi, finally signing off duty at 2400. After the passengers had departed, the passenger attendants and passenger service supervisor stayed and cleaned the train until the three passenger attendants travelled by taxi back to Albury and finally signed off duty at 2308. The passenger service supervisor stayed on the train.

At 2106 the emergency response crew arrived and commenced re-railing car 'E'. The train was uncoupled between car 'D' and car 'E'. The front half of the train was moved forward to allow the re-railing crew access to the front of car 'E'. The leading bogie was then re-railed using hydraulic jacks and traversing equipment. By 2345, car 'E' had been re-railed and the train was then re-coupled and inspected by engineers from State Rail diesel services. The train was then cleared to proceed to Wodonga Loop where car 'E' was taken out of the consist and later shunted to a siding at approximately 0230 on 26 April.

The remainder of the train was then re-coupled and cleared to depart for Albury arriving at approximately 0320. The passenger service supervisor was relieved and signed off duty at Albury. After departing Albury, the train returned to the XPT maintenance depot in Sydney where it was inspected by NSW Department of Transport officers and the Hasler tapes[5] from the leading and trailing power cars were impounded.

5 Hasler tapes are the waxed paper event logs produced by the locomotive data recording equipment.

While the train was being re-railed, staff from ARTC and EDI had commenced work on examining the track and rectifying the damage. At 0120 the ARTC representative on site declared the track open with a 15 km/h speed limit between 300 and 301 km. At 0202, an ARTC representative reinspected the track and extended the area of the speed restriction to 302 km.

4.3 Injuries

None of the 98 passengers and five crew on board train 8622 reported any injuries as a result of the derailment. However, some passengers, particularly those in car 'E', which derailed, were distressed by the derailment.

4.4 Damage

The lead bogie (NHA 198B) of car 'E', XF 2214, derailed at 301.105 km and ran along the track until the train stopped at approximately 300.140 km. Both the train and rail infrastructure in this section of the standard gauge main line sustained damage as a result of the derailment.

4.4.1 Damage to the train

All wheels on the derailed bogie showed significant stone impact damage to flanges and treads as a result of running on the track ballast, over sleepers and other obstructions (see figure 4). Some components of the bogie showed signs of damage/impact as a result of lateral and vertical over-travel while the bogie was derailed:

- the outer end lateral control rod bushes were damaged,
- there were wheel rub marks on top of the brake hanger brackets on number-1 wheel,
- there were strike marks on the facing side of axle box guide bars on number-1 axle.

Other damage to car 'E' included:

- both refrigeration units slung under the carriage were damaged as a result of the impact with the concrete block in the pedestrian crossing (figure 5),
- damage to water chiller refrigerant lines, and small hole in the carriage floor caused by the top of the primary suspension damper on number-1 wheel of the derailed bogie over travelling vertically,
- damage to the toilet holdover tank water fill line caused by derailed bogie over travel,
- a broken rubber stop on the coupling at the leading end on the car.

During the inspection a locating pin and some bearing material from a side bearer plate were found lying on the bolster between wheels 1 and 3 of bogie NHA 198B. Inspection of the side bearer plates and bogie bolster when the bogies were changed indicated that the locating pin originated from the side bearer plate adjacent to wheels 1 and 3 of the bogie. Damage to the side bearer plate and its seat on the bolster indicated that at some time the pin had been dislodged from the plate and become trapped between the plate and the bolster (see figures 6, 7, 8).

FIGURE 4:
Number-1 wheel showing damage to flange and tread

FIGURE 5:
Damaged refrigeration units under carriage

FIGURE 6:
Side bearer mounting surface on bogie bolster showing deformation around locating hole

FIGURE 7:
Dislodged locating pin sitting on side bearer mounting surface in position of 'best fit' in the deformation around its locating hole

FIGURE 8:
Side bearer plate sitting on locating pin on mounting surface in the position of 'best fit' for deformations on mounting surface, locating pin and side bearer plate

4.4.2 Damage to the rail infrastructure

The track and some signalling infrastructure sustained damage between the point of derailment and where the train stopped, a distance of about 950 m. Many sleepers were damaged as a result of being struck by the wheels of the derailed bogie (figure 9). A number of sleepers were replaced to permit restoration of rail services. Some damaged sleepers were not replaced but the damage was sufficient to reduce their remaining service life.

Level crossings at High Street and the station entrance road sustained minor damage to sections of their concrete and bitumen roadway panels (figure 10). This damage was caused by the derailed wheel flanges riding over the roadway as car 'E' passed through the crossings. The concrete footway slab in the four-foot of the station pedestrian crossing was also damaged (figure 11).

Signalling cables and an insulated joint were damaged at the High Street level crossing, with some damage to relay equipment adjacent to one set of points. Interlocking equipment on three turnouts (300.758 km, 300.605 km and 300.417 km) was damaged as a result of hard contact with the derailed bogie wheels riding in the four-foot (figure 12). These points were subsequently locked out-of-use pending permanent repairs.

FIGURE 9:
Section of track showing damaged sleepers

FIGURE 10:
Station entry level crossing showing damage to roadway

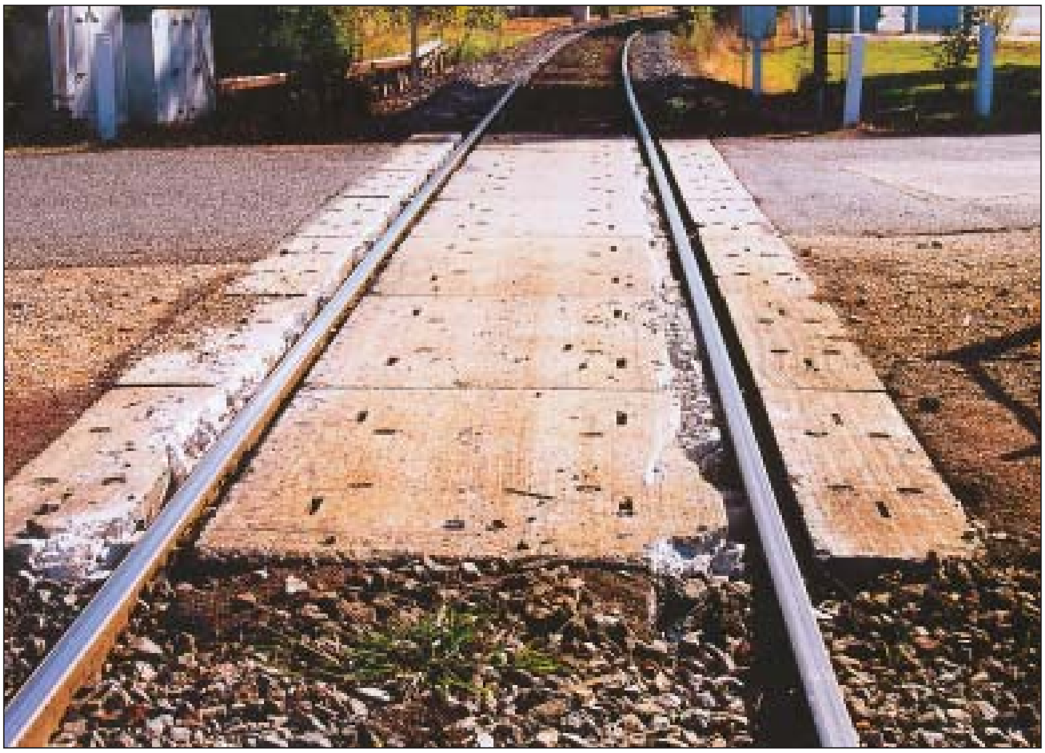


FIGURE 11:
Pedestrian crossing showing impact damage to concrete slab in track four foot

FIGURE 12:
Damage to interlocking equipment on a turnout

4.5 Train crew involved

The train crew of five consisted of:

- driver;
- passenger services supervisor;
- senior passenger attendant; and
- two passenger attendants.

Table 1.
Details of the XPT crew

Position	*Gender*	*Classification*	*Medical status*	*Qualifications*	*Time on duty prior to derailment*
Driver	Male	Locomotive driver	Fit for duty	Current	2½ hours
Passenger Services Supervisor	Male	PSS	Fit for duty	Current	1 hour
Senior Passenger Attendant	Male	SPA	Fit for duty	Current	1 hour
Passenger Attendant 1	Male	PA	Fit for duty	Current	1 hour
Passenger Attendant 2	Male	PA	Fit for duty	Current	1 hour

Countrylink passenger services supervisors (PSSs) have the overall responsibility for service delivery to passengers and supervision of the other three attendants. In addition, the passenger service supervisor undertakes certain safeworking duties under the direction of the driver. The senior passenger attendant (SPA), assisted by the passenger attendants (PAs), run the on-train refreshment services and perform other passenger related duties.

4.6 Train information

4.6.1 Train consist

The XPT train involved in the derailment was a standard seven car passenger consist with leading and trailing power cars. The train has seating capacity for 360 passengers, a tare mass of 460 tonnes and a length of 204 m including the two power cars.

Table 2.
Details of the train consist from the leading end

Car No	*Car ID*	*Car Type*	*Passenger seats*	*Length (m)*	*Tare (tonnes)*
Power car	XP 2016	Power unit	Nil	17.3	76
A	XAM 2182	Sleeping car	27 day/18 night	24.2	48
B	XL 2228	First sitting car	56	24.2	48
C	XBR 2156	Buffet car	21 + wheelchair position	24.2	44
D	XF 2220	Sitting car	68	24.2	42
E	XF 2214	Sitting car	68	24.2	42
F	XF 2212	Sitting car	68	24.2	42
G	XFH 2113	Luggage & sitting car	52	24.2	42
Power car	XP 2008	Power unit	Nil	17.3	76

4.6.2 Rolling stock date of build

The original XPT rolling stock was constructed by Commonwealth Engineering (Comeng) at its Granville factory between 1981 and 1982. Demand for the service and extension of the XPT routes necessitated the construction of more rolling stock in 1983 and 1986. Further rolling stock was constructed by ABB Transportation in Dandenong in 1993 when XPT services were extended to Melbourne.

4.6.3 Power cars

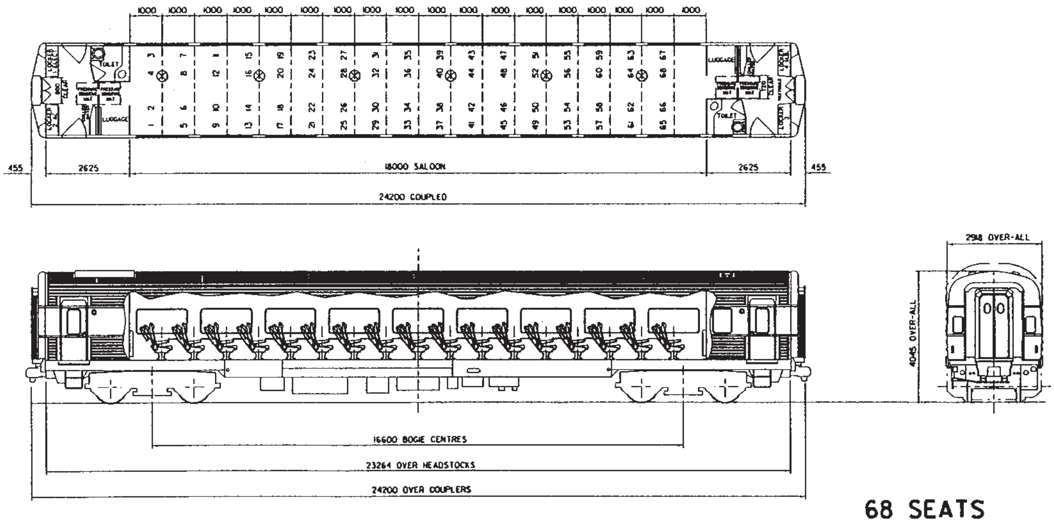
The train that derailed in Wodonga had diesel electric locomotives at each end of the consist. The driver was operating the train from XP 2016, the leading power car, with XP 2008 as the trailing power car. XP 2008 was built by Comeng in 1982, with XP 2016 built by ABB in 1992. The control systems of the power cars are designed so that the trailing power car acts as a 'slave' to the lead car. When the driver applies power or braking in the lead car, the trailing power car receives similar commands simultaneously. Train braking and auxiliary air may be supplied by either power car. Either power car may be used to supply train electrical power from its auxiliary alternator.

Since 2000, State Rail have had an engine replacement program running. The original Valenta engines rated at 1477 kW are being replaced with new Paxman 12VP185 diesel engines which are rated at 1860 kW. XP 2016 was the first locomotive to be fitted with the new engine. At the time of the derailment, XP 2008 was still fitted with an original Valenta engine.

4.6.4 Carriage XF 2214

FIGURE 13:
Carriage XF 2214

FIGURE 14:
Typical XF car schematic



Car ‘E’, XF 2214, was constructed by Comeng and delivered to the State Rail Authority on 20 August 1986. It was refurbished by A.Goninan & Co of Newcastle in 1992 which included the fitting of new seats. Like most of the trailer cars in the XPT fleet, XF 2214 was fitted at the time of the derailment with two NHA bogies.

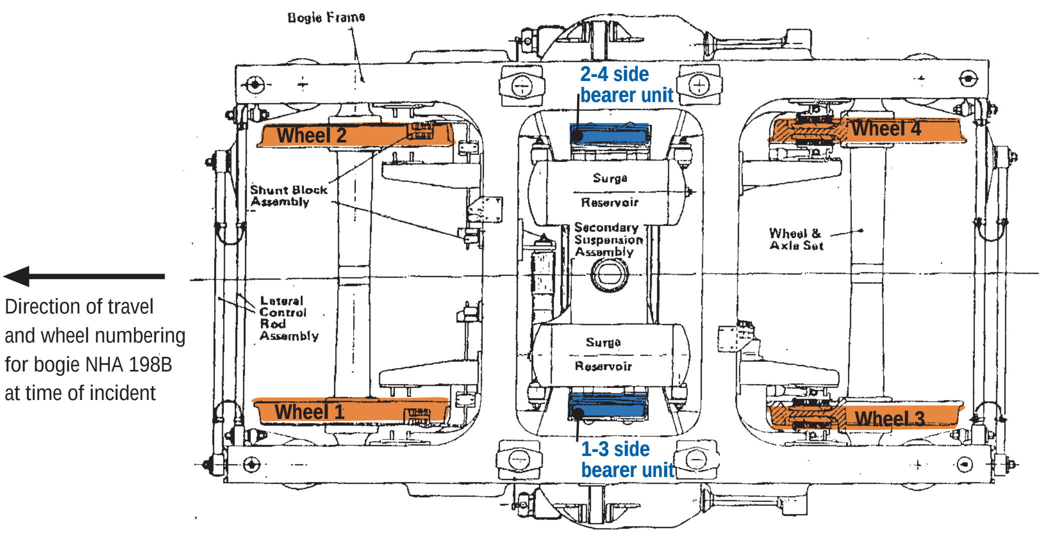
Inspection of train consist records shows the last time carriage XF 2214 ran from Sydney to Melbourne it was as car ‘C’ of service ST1 (overnight service) on 20 April 2001, five days prior to the derailment.

4.6.5 NHA Bogie

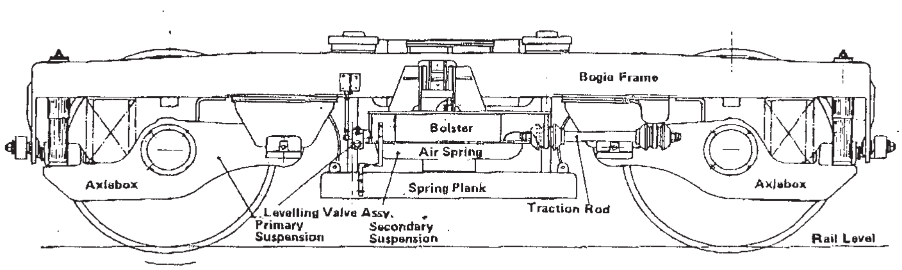
The NHA bogie is based on the British Rail BT 10 bogie used on the High Speed Train in Britain. When the XPT was initially proposed, BT 10 bogies were imported from Britain and trialed in NSW. After the trials, modifications were made to the bogie suspension to suit the track conditions in NSW. The modifications included, increased vertical and lateral primary suspension travel, and a softer air bag on the secondary suspension. The modified bogie was designated BT 23 by British Rail. A schematic of a typical NHA bogie is shown in figure 15.

NHA bogies carry the weight of the carriage on two constant contact side bearer units mounted on the bolster on either side of the centre pin assembly. The side bearers consist of a mild steel plate fitted with a low friction bearing insert. The plates are not secured to the bogie’s bolster but are located by two pins.

FIGURE 15:
NHA bogie schematic



BOGIE ASSEMBLY
(PLAN VIEW)



BOGIE ASSEMBLY
(SIDE VIEW)

4.6.6 Bogie NHA 198B detailed examination

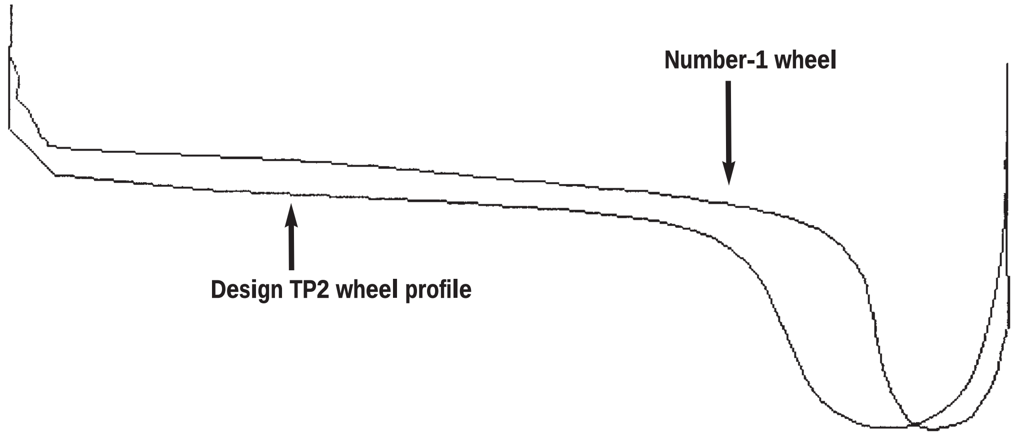
As it was the only bogie on the train to derail, NHA 198B was subjected to detailed inspection and measurement. Various wheel measurements where taken including diameter, flange thickness and static load. These measurements are tabulated below. The table also includes the static wheel loads measured at the time of the previous bogie overhaul.

Table 3.
Bogie NHA 198B wheel measurements

Wheel number	*Average wheel diameter (mm)*	*Wheel load on 19/2/00 (kg)*	*Wheel load on 6/6/01 (kg)*	*Flange thickness (mm)*
1	880.33	5155	4805	18.03
2	882.33	4951	4610	21.28
3	886.67	4920	4505	22.95
4	886.60	5085	5090	25.42

The wheel profiles show that the number-1 wheel flange was below the current State Rail condemning limit[6] of 19 mm. Figure 16 is the profile of number-1 wheel after the derailment overlaid on the standard TP2 profile. Wheel diameter measurements indicate that number-1 wheel was the smallest on the bogie and 2 mm smaller than number-2 wheel. Current in-service dimensional tolerance for the diameter of wheels on the same axle is 1 mm variation.

FIGURE 16:
Number-1 wheel and TP2 profiles



The geometry of the bogie frame and spring plank were also checked. Trammelling[7] revealed that the bogie frame was absolutely square. The spring plank and bogie frame were also placed on a level table and measured using a straight edge and dumpy level respectively. These tests revealed both parts were within acceptable limits, 3 mm variation for the spring plank, and 2.5 mm maximum variation for the bogie frame.

Static wheel loads are measured when bogies are overhauled using a purpose-built jig. The bogie is placed on the jig and is pulled down using a hydraulic jack acting on the centre pin housing in the bolster. Individual wheel loads are measured and adjusted as necessary during the overhaul by packing the primary suspension springs. The allowable load variation is 400 kg per wheel or axle total based on a total bogie load of 19.6–20.4 tonnes. From the tabulated results, bogie NHA 198B was within the tolerance at the time of the last overhaul and just outside on individual wheel variation when measured after the derailment. It was also determined that the number-1 wheel with the most tread wear and thinnest flange also had the highest static load when tested at the time of the last overhaul.

4.6.7 Rolling stock maintenance

The XPT rolling stock is maintained by State Rail using a planned maintenance and condition monitoring program. A trip inspection is carried out each time a train arrives at the Sydenham maintenance depot with more comprehensive inspections and maintenance carried out every 90 days. There are 10 different maintenance levels, which include running and trip inspections and eight different 90-day maintenance

6 Condemning limit is a designated flange thickness below which the wheel is considered to be unserviceable

7 Tramelling is the measurement of the distance between two fixed points with a calibrated gauge similar in principle to a beam compass

levels designated A–H. The maintenance regime is largely based on manufacturer's recommendations and is modified when condition monitoring dictates the need to focus more effort on specific items.

Maintenance scheduling and recording is facilitated by a computer based maintenance program. Regular inspections and maintenance tasks are performed using standardised and documented procedures. Each inspection or maintenance task is divided into a number of trade specific parts and an inspection sheet is issued for each different trade (mechanical, electrical, car and wagon examiners, plumbers, car builders and trimmers). The inspection sheets provide specific instructions on how to perform the maintenance and include a checklist, which must be completed and signed off by the tradesmen performing the maintenance. After a maintenance task is completed, the entries on the inspection sheets are entered into the computerised maintenance program.

Maintenance records show that the train involved in the derailment underwent a trip inspection on 24 April 2001 after arriving at the XPT maintenance depot on completion of the NT2 service from Brisbane. The trip inspection included a wheel examination (not including flange thickness measurement) and examination of various components of the trailer car bogies including the frame, axle box assemblies, air springs, lateral control rods and safety straps. There were no abnormalities noted during this inspection.

The maintenance records also show that carriage XF 2214 underwent a schedule 'F' 90 day inspection on 10 April 2001. This inspection also included a wheel inspection and a detailed inspection of the bogies including the condition of the radial wear plates (side bearer plates). Once again, there were no abnormalities noted at this time.

4.6.8 Wheel flange monitoring

In addition to other programmed maintenance, wheel flange thickness is regularly monitored on XPT rolling stock. Wheel-sets are machined on an underfloor lathe (at DELEC in Enfield) when flanges reach a pre-determined wear limit or the wheels display other faults which need rectification. In order to restore a full thickness flange, wheels may have up to 15 mm machined from their diameter. The geometry of the XPT wheels generally allows each wheel-set two full turns to restore a full flange before the wheel diameter condemning limit is reached. Wheel-sets are changed once the wheels have reached their condemning limit on diameter and flange wear. Once any wheel on either bogie on a carriage has reached this point, the carriage is lifted and both bogies are changed as a pair. The bogies are then fitted with new wheel-sets or overhauled completely depending on the 'frame' kilometres run.

Maintenance records for carriage XF 2214 show that both bogies (NHA 198B and 56B) were overhauled as a pair on 22 February 2000 and had their wheel-sets machined to provide full thickness flanges on 13 May 2000 and 7 November 2000 respectively.

Flange thickness records for bogie NHA 198B are tabulated below. The records show that the last time the wheel flanges were measured prior to the derailment was on 15 March 2001, approximately six weeks before. The records show that wheel number-1 was the most worn with 8 mm of wear making the flange 21.7 mm thick based on a full flange thickness of 29.7 mm.

Table 4.
Bogie NHA 198B wheel flange measurements

Date of measure	*Wheel number/flange wear (mm)*			
	1	***2***	***3***	***4***
Overhauled 22/02/00				
5/03/00	1	1	1	1
2/04/00	3	3	2	2
1/05/00	4.5	4	2.8	2.8
Re-machined 13/5/00				
26/05/00	0.8	0.8	1	0
12/07/00	4.2	4	3	1.8
13/08/00	5.5	5	4	2.8
10/09/00	6	5.5	4.2	2.8
6/10/00	7.8	7	5	3.5
2/11/00	10	8	6	4
Re-machined 7/11/00				
12/12/00	0	0	0	0
15/01/01	6	5.5	3.5	4
16/02/01	8	6	5	4
15/03/01	8	7	5.5	4

4.7 Track details

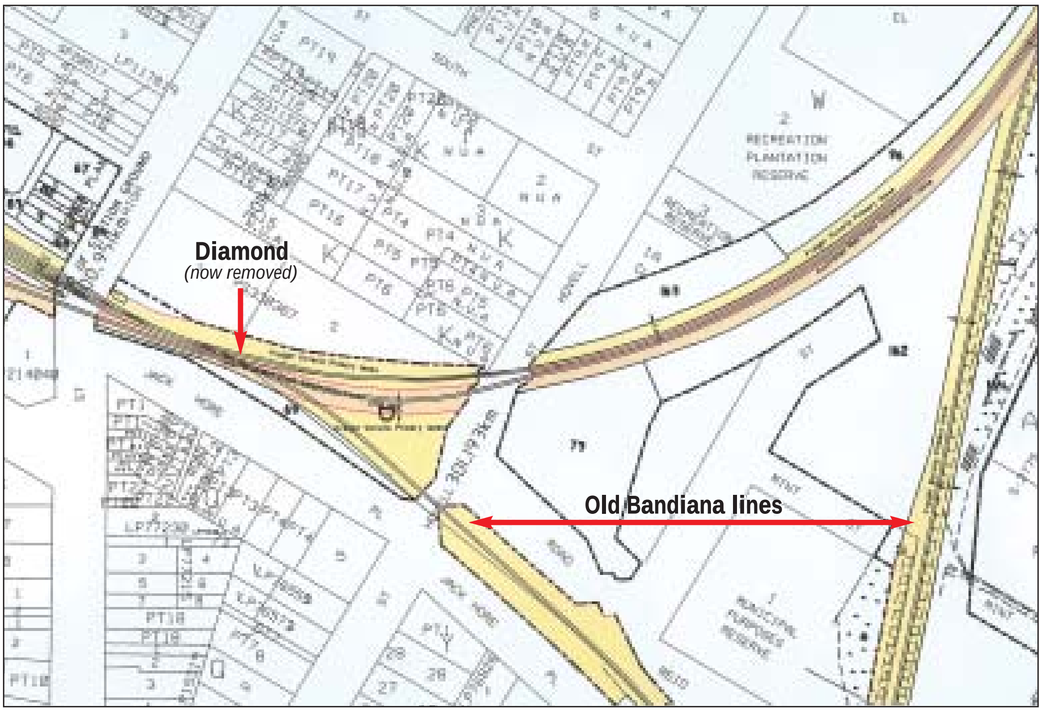
4.7.1 Background

The location of the derailment was established at 301.105 km (from Melbourne), east of Wodonga railway station yard between the Hovell Street and High Street level crossings on the standard gauge interstate corridor between Melbourne and Sydney. The track is sharply curved to the right in the direction of travel. The grade of the track is 1 in 75 climbing in the direction of travel. The posted train speed limit for all types of trains on the curve is 40 km/h.

The track in this area was laid as part of the 1959–1962 Wodonga-Melbourne standard gauge rail project. The new standard gauge main line was routed around the Wodonga Station to keep the main line clear of the existing broad gauge facilities. At the time, there was a broad gauge crossing of the standard gauge line just east of the High Street level crossing for the broad gauge line to Bandiana-Tallangatta-Shelly. As this line is now closed, the diamond crossing was removed in December 1997.

Figure 17 is an excerpt from Victorian Rail Track's plan of the Wodonga Coals Sidings showing the area of the derailment. The plan shows the original diamond and turnout to Bandiana, removed in 1997.

FIGURE 17:
Excerpt from Wodonga coal sidings railway plan showing area of derailment



4.7.2 Track specification

The track details for the standard gauge main line in the area of the derailment are as follows:

- Rail 47 kg/m, welded up to 82 m lengths.
- Timber sleepers 2590 mm x 254 mm x 127 mm, hardwood.
- Sleeper spacing 685 mm nominal.

4.7.3 Track geometry

The design geometry details of the Wodonga curve where the derailment occurred were obtained from the 1995 Victorian Public Transport Corporation curve register.

Table 5.
Curve register details

Location (km)	*Hand*	*Radius max/min (m)*	*Alignment Transition (m)*		*Curve cant Max (mm)*	*Cant Transition (m)*	
			up	down		up	down
301.060-301.190	L	175/175	0	50	40	25	50
301.190-301.280	L	800/800		50	40		50
301.280-301.630	L	300/350		35	40		25

4.7.4 Track gauge and cross-level

Selected measurements of the track gauge and cross-level (height difference between high and low rails) taken after the derailment by officers from ARTC are tabulated below.

Table 6.
Gauge and cross-level measurements around point of derailment

Station	*Approx km*	*Cross-level (mm)*	*Gauge (mm)*	*Station*	*Approx km*	*Cross-level (mm)*	*Gauge (mm)*
1	301.126	60	+1	11	301.106	37	+20
2	301.124	60	+10	12	301.104	34	+5
3	301.122	55	+12	13	301.10225	31	+2
4	301.120	54	+3	14	301.100	35	0
5	301.118	43	+20	15	301.098	20	+10
6	301.116	50	+5	16	301.096	15	+5
7	301.114	50	+10	17	301.094	0	+5
8	301.112	45	+15	18	301.092	0	+3
9	301.110	45	+18	19	301.090	0	+3
10	301.108	37	+15	20	301.088	0	0

Significant gauge widening was indicated in the area of the derailment by sleeper wear under the high rail sleeper plates. Figures 18 and 19 are photographs which show the wear pattern on the sleepers around the point of derailment as a result of high rail sleeper plate movement. Available gauge widening was calculated for this area by adding the static gauge variation to the measured plate movement. Total adjusted gauge (dynamic gauge) is the potential gauge under loaded conditions. The results are tabulated in table 7.

Table 7.
Gauge measurements and calculations around the point of derailment

Sleeper, Direction of travel	*Static gauge variation (mm)*	*Sleeper plate movement (mm)*	*Available gauge widening (mm)*	*Total adjusted gauge (mm)*
1	+10	8	+18	1453
2	+10	8	+18	1453
3	+10	2	+12	1447
4	+13	6	+19	1454
5	+13	12	+25	1460
Mark on low rail gauge face at 301.1086 km				
6	+15	16	+31	1466
7	+15	20	+35	1470
8	+15	25	+40	1475
9	+17	30	+47	1482
10	+17	32	+49	1484
Point of drop-in at 301.105 km				
11	+16	30	+46	1481
12	+15	30	+46	1481
13	+14	22	+36	1471

FIGURE 18:
TrakLok fastener on high rail showing sleeper wear as a result of plate movement

FIGURE 19:
Measuring plate movement on a Pandrol fastening fitted to the high rail the point of derailment

4.7.5 Alignment

The design radius of the curve in the area of the derailment is 175 m. It was the sharpest section of curve in the standard gauge main line between Sydney and Melbourne. The alignment of this section of the curve was governed at the time of construction by the presence of the broad gauge diamond which has subsequently been removed. There has been no work since the removal of the diamond to improve the alignment of the curve.

Measurements taken after the derailment showed a curve radius of 200 m then a significant sharpening of the curve in the direction the train travelled to 174 m approaching the point of drop-in. There was no alignment transition from straight track to the 174 m radius section of the curve at its Melbourne end. Figure 20 is a photograph of the curve where the derailment occurred looking towards the Hovell Street crossing, the standard gauge mainline is on the right.

FIGURE 20:
Curve where the derailment occurred

4.7.6 Rail

The rails at the derailment site were the original 47 kg/m rail stock laid in 1959/61. Rail wear on both high and low rails was modest with the gauge face of the high rail showing 8 mm wear.

4.7.7 Sleepers

Since this section of the line was laid, sleepers have been replaced principally during major sleeper renewal, at approximately five year intervals. The sleeper renewals conducted at these times were condition based. VicTrack provided the following Victorian PTC records for sleeper renewals in the Benalla to Wodonga maintenance area tabulated below.

Table 8.
PTC sleeper replacement records

Start week	*Finish week*	*Start km*	*Finish km*	*Distance km*	*Sleepers total*	*Density Sl/km*	*Average ratio*
23/8/80	4/4/81	194.388	304.166	109.778	26461	241	1:6
2/2/85	21/6/86	192.300	304.000	110.600	46190	418	1:3.5
21/4/90	9/6/90	195.000	304.000	109.000	27772	255	1:5.7
2/9/95	21/10/95	233.300	304.100	69.800	20838	299	1:4.9

As part of the resilient fastening project in 2000, 22 sleepers were renewed between 301–301.1 km and 1 sleeper was renewed between 301.1–301.2 km in January 2000. These are the only records of sleeper replacement since 1 July 1998 when ARTC took over the lease on the line. Figure 21 shows the condition of some sleepers in the curve where the derailment occurred and the ballast profile on the field side of the high rail.

FIGURE 21:
Sleepers and ballast in the area of the derailment

4.7.8 Fastenings

The rail fastenings in the area of the derailment were a mixture of configurations. On the low rail of the curve the rail was held at each sleeper by a pair of Rex-Lok-Ins. The Rex-Lok-In system consists of a stud that is hooked into the dog spike hole of the existing sleeper plate and a spring clip (B296) fitted to the stud which exerts constant pressure on the toe of the rail. Each sleeper plate was fastened to the sleeper by two spring (lock) spikes.

The high rail had a variety of fastenings consisting of cast iron Pandrol sleeper plates fitted with 'E' clips and TrakLok (Rex-Lok-Ins) mounted on double shoulder sleeper plates. The Pandrol sleeper plates were fastened to each sleeper using two screw spikes with the TrakLok plates fastened by two spring spikes. The table below shows the high rail fasteners and their disposition as recorded by ARTC officers after the derailment.

Table 9.
High rail fastener disposition after derailment

Sleeper	*Plate movement (mm)*	*Dynamic gauge (mm)*	*High rail fastener type*	*Spike type and disposition, (dimensions in mm)* Inside	Outside
1	5	+15	Pandrol	Screw, down, skewed	Screw, down, skewed
2	8	+18	TrakLok	Spring, down	Spring, down
3	8	+18	TrakLok	Spring, down	Spring, down
4	2	+12	Pandrol	Screw, up 20, skewed	Screw, up 20, skewed
5	6	+19	TrakLok	Missing	Spring, up 30
6	12	+25	TrakLok	Spring, up 20, skewed	Spring, up 40
Mark on low rail gauge face at 301.1086 km					
7	16	+31	Pandrol	Screw, up 20, skewed	Screw, up 20, skewed
8	20	+35	TrakLok	Spring, down	Spring, up 15
9	25	+40	TrakLok	Spring, up 70	Spring, up 40
10	30	+47	Pandrol	Screw, up 10, skewed	Screw, up 15, skewed
11	32	+49	TrakLok	Spring, up 60	Missing
Point of derailment 301.105 km					
12	30	+46	TrakLok	Spring, up 90	Spring, up 50
13	30	+46	Pandrol	Screw, up 20	Screw, up 20
14	22	+36	TrakLok	Spring, up 30	Spring, up 20

Both Pandrol and TrakLok fasteners are designed to exert constant pressure on the toe of the rail. In the case of the TrakLok system nominal toe load is of the order of 9 kN for each clip and for the Pandrol fasteners 8.6 kN per clip.

4.7.9 Ballast profile

In the area of the derailment the ballast profile is crushed stone typical of main line size. The top most ballast was clean and free draining but the lower material showed signs of fouling. Ballast had been discharged on the shoulder of the curve in February 2001 in preparation for track rectification works including tamping. At the time of the incident, the ballast had not been tamped or regulated in the area of the derailment and there was ballast covering the sleepers and fastenings on the field side of the high rail.

4.7.10 Lubrication

At the time of the derailment a lubricator was fitted to the high rail on the Melbourne end of the curve. The lubricator was fitted to provide grease to the gauge face of the high rail throughout the curve where the derailment occurred. It was apparent on inspection after the derailment, that the lubricator had been inoperative for some time as the gauge face of the high rail exhibited a bright rough surface (figure 22). The plucking and pitting of the gauge face indicated a high rate of local wear consistent with a lack of lubrication. In addition there were fresh metal flakes lying on the inside toe of the rail throughout the 175 m radius section of the curve.

FIGURE 22:
High rail gauge face showing wear from lack of lubrication

4.7.11 Infrastructure maintenance

The standard gauge main line in Victoria, formerly owned by the Victorian Public Transport Corporation (PTC) is now owned by VicTrack. On 1 July 1998, ARTC took a long-term lease on the standard gauge rail infrastructure on the interstate corridors from Wolseley to Melbourne and Albury. Up to this time all maintenance on the rail infrastructure had been performed by the Victorian PTC. After leasing the track, ARTC set up an alliance contract with Asea Brown Boveri (ABB) to maintain the Victorian standard gauge infrastructure under their control. ABB subsequently employed many ex-PTC staff who had had previous experience maintaining the track. In 2000, ABB's rail infrastructure maintenance division was purchased by Evans Deakin Industries Pty Ltd (EDI) and now forms part of their Powerlines, Telecommunications and Rail (PTR) division. The ARTC maintenance contract was continuous during the change of ownership from ABB to EDI, with the PTR division providing the same contracted service with the same employees and equipment.

EDI's responsibilities under the provisions of the alliance contract are the day-to-day maintenance, emergency maintenance, and condition monitoring of the track infrastructure. ARTC run larger infrastructure works as projects and let contracts via a tender process for these works. Such projects on the Victorian standard gauge system recently have included: rail resilient fastening and re-sleepering and track rectification works including rail straightening, grinding, tamping, ballast cleaning and regulation.

The agreement between ARTC and EDI stipulates that the track in Victoria is to be maintained to the standards contained in the Victorian Public Transport Corporation's civil engineering circulars (CECs).

EDI maintenance staff, responsible for the track maintenance in the Wodonga area, stated that they based their maintenance and condition monitoring on the geometry standards specified in CEC 8/86 with reference to CEC 7/86 for track recording car operations.

ARTC monitor the performance of their track maintainers by periodic spot checks of maintenance records and track condition. In addition, some of EDI's Victorian maintenance management staff are co-located with ARTC staff in Melbourne.

4.7.11.1 Track patrols

EDI maintenance staff patrol the standard gauge main line between Benalla and Albury five times a fortnight using Hi-Rail vehicles (conventional road vehicles fitted with rail wheels that may be lowered onto the track). The last patrol of the area of the derailment was the day before, or Tuesday 24 April 2001. The track inspectors did not note anything unusual during this inspection in the area of the derailment.

4.7.11.2 Front-of-train inspections

Once a month the EDI section maintenance supervisor travels in a locomotive over his section of track. The purpose of these inspections is to assess track condition based on the ride of the train with some input from the driver. The last front-of-train inspection, prior to the derailment, of the Wodonga area was on 1 April 2001. The area maintenance supervisor did not note anything unusual during this inspection in the area of the derailment.

4.7.11.3 Track recording car

Track recording cars are routinely used to record track geometry throughout the ARTC standard gauge network. Recording cars have the advantage of measuring track geometry under dynamic conditions of load and thus may detect defects which may not be apparent to maintenance staff performing Hi-Rail inspections. The track recording car is equipped with trolleys, fitted with measuring transducers, which ride the track and measure the following geometric parameters:

- track gauge,
- surface irregularities (top), each rail separately,
- alignment (line), each rail separately,
- superelevation (cant),
- short twist,
- long twist.

The car is also equipped with a computer and statistical analysis software, which may be used to calculate various track geometry indices including track quality and ride. The recording car is able to quantify the observed condition of the track and compare it to specified standards. Its primary functions are to:

- highlight track faults that require corrective action by local maintenance crews. These faults are categorised and may be of high, medium or low priority,
- provide information for planning major scheduled maintenance by comparing results over time,
- comparison with other sections of track for setting maintenance priorities.

Since 1995, the ARTC standard gauge main line geometry has been recorded under contract by an EM80 track recording vehicle based in Adelaide. This vehicle is owned and operated by the Rail Infrastructure Corporation formerly Rail Services Australia.

The track recording car is scheduled to record the Melbourne-Albury standard gauge main line every three months. The last recording car run in the Wodonga area prior to the derailment occurred on 28 February 2001. The previous two recording car runs in the area were on 30 November 2000 and 31 August 2000.

The track geometry in the area of the derailment was not recorded during the February 2001 or November 2000 runs as a result of automatic measuring trolley lifts. An automatic trolley lift occurs during a recording run when the trolley experiences an abnormal 'event'. The measuring trolley is automatically lifted from the track to protect the measuring equipment. As the trolley is no longer in contact with the rails, a section of track is not recorded, the length of the section being dependent on the time taken to bring the car to a stop to reset the trolley. Common causes of trolley lifts are an object on the track, a level crossing, or a turnout. Trolley lifts may also be caused by track faults that have the potential to cause a train derailment such as excessive gauge.

When a trolley lift occurs, the recording car is stopped and the equipment checked and reset. Standard operating procedures dictate that the preceding section track must be investigated at the time by track maintenance staff to ascertain the cause of the trolley lift. When a trolley lift occurs, a report is also issued to the area maintenance supervisor on the car, which details:

- date,
- location,
- which trolley lifted,
- direction of Travel,
- speed of EM80,
- track type,
- track features,
- track components,
- parameters identified as exceedences, their maximum value and safe speed,
- cause and track defects identified,
- comments,
- actions taken.

The 28 February 2001 trolley lift report indicated that the leading trolley lifted at 301.120 km while the recording car was travelling at 25 km/h. There were no parameter exceedences at the lift point entered in the report. The comments section states: 'Very tight curve – large line values. (Also refer Nov 00)'. The 30 November 2000 trolley lift report indicates that the leading trolley lifted at 301.100 km with no vehicle speed entered, no parameter exceedences entered and no comments.

4.8 Train control

The train control system on the standard gauge main line in the Wodonga area is Centralised Traffic Control. The operations of signal and points are controlled from the ARTC train control centre in Adelaide.

When required, local standard gauge operations can be controlled by switching in the Wodonga 'A' signal box. The signal box is operated by Freight Australia. This usually occurs when shunting operations are being performed, generally for freight. The

Wodonga signal box may also be switched in to provide local train control in an emergency as was the case with the XPT derailment, where some signalling equipment had been damaged.

No technical defects or operational issues concerning train safeworking or control were found that may have contributed to the derailment.

4.8.1 Other traffic

Records obtained from train control indicate on 25 April 2001 the three trains which traversed the derailment site prior to XPT service 8622 were: National Rail's freight service 9602, southbound arriving at Wodonga at 0456; Freight Australia's freight service 9681, northbound arriving at Wodonga at 0558; and Countrylink's passenger service 8611, northbound arriving at Wodonga at 1122. There were no records of anything abnormal being reported by these services in the area of the derailment.

4.9 Environmental factors

The derailment occurred during daylight hours. Weather observations from the Bureau of Meteorology indicate that the day was fine with the temperature in the area at the time of the derailment approximately 17°C, the maximum temperature for the day was recorded as 17.6 °C at 1500. Wind was from the north-north-west at 9 km/h. Weather is not considered to be a contributing factor.

4.10 Recorded information

4.10.1 Train control

Recorded information from ARTC Train Control Centre in Adelaide, indicated that Authorities had been issued correctly and in accordance with prescribed procedures.

The train control centre also provided the investigation with copies of the major incident log, the train control report detailing the incident, and the notifications of the incident to the Victorian Department of Transport-Rail Safety Section and Comcare Australia. The incident log and notifications were issued in accordance with ARTC's 'Interface Procedure, Incident Management Plan, Document TA44'.

4.10.2 Locomotive data recorders

XPT locomotives are equipped with Hasler event recording hardware. Parameters are recorded on a waxed paper roll by four stylii which continuously record time, speed, power circuit status, and brake cylinder pressure. Vigilance acknowledgment is also recorded on the power circuit trace. It is a requirement that the Hasler equipment is recording any time the locomotive is being operated, with the waxed paper charts being routinely changed each time the locomotive arrives back at the XPT maintenance depot.

The Hasler event recording tapes from the leading and trailing locomotives on the train were impounded by officers from the NSW Transport Safety Bureau when the train arrived back at the XPT maintenance depot in Sydenham at 1200 on 26 April. The tapes were held in safe keeping at the office of the NSW Transport Safety Bureau. On 4 May, the tapes were analysed by a representative from Countrylink in the presence of a Transport Safety Officer from the NSW Transport Safety Bureau. The

Countrylink officer produced a report of his analysis of the Hasler tapes. The following is an excerpt from that report:

> Event Recording tapes from both power cars on the consist, being XP2016 leading vehicle, and XP2008 the rear power car on the train consist were read and analysed.
>
> The method of reading the tapes were to overlay them on a master sheet, which is printed with major locations, kilometrage from Sydney, and maximum speed at documented locations, and conduct a comparison between what is the maximum permitted speed on the master sheet, and the actual recorded speed displayed on the tape. Time, power circuit and braking zones are not printed on the master sheet. They can be aligned to the speed by reading all at any given point on the tape in a vertical line.
>
> The readings show that:
>
> - There is a 1 minute differential between the clock settings on the two tapes.
> - The tape extracted from XP2016 gave a compressed reading, which displayed a shorter distance travelled, due to tight operating mechanism in the recording machine. However, careful analysis and comparison with speed line recordings on the tape extracted from XP2008, which practically matched the master sheet, definitive conclusions could be reached.
> - The power circuit status trace displayed on the tape extracted from XP2008 did not record correctly.
> - The service departed Junee at 1352 hours
> - It stopped at Wagga from 1414-21 hours
> - It stopped at the Rock from 1436-39 hours
> - It stopped at Henty from 1452-53 hours
> - It stopped at Culcairn from 1504-05 hours
> - It stopped at Albury from 1528-32 hours
> - The driver operated the service within the required speed and operational parameters over this part of the journey.
>
> Following departure from Albury:
>
> - The service travelled a distance of 200 metres and then stopped for a period of one minute.
> - After moving the service accelerates to achieve a speed of 80 kilometres per hour after travelling a distance of 2.8 kilometres.
> - It then coasts at a speed of 80 kilometres per hour for a distance of 1.2 kilometres before reducing speed.
> - At 1536 hours, a light application of the brakes is noted, and over a distance of one kilometre the speed of the train gradually reduces to 25 kilometres per hour.
> - Power circuits are then activated and after a distance of 200 metres the speed is 35 kilometre per hour.
> - At 1540 hours a heavy application of brake cylinder pressure is noted, together with the power circuits opening and speed rapidly falling to zero. All occurring over a distance of 100 metres.
> - The service then stands at this location from 1540 hours until 0118 hours. Movement consistent with shunting is then noted.

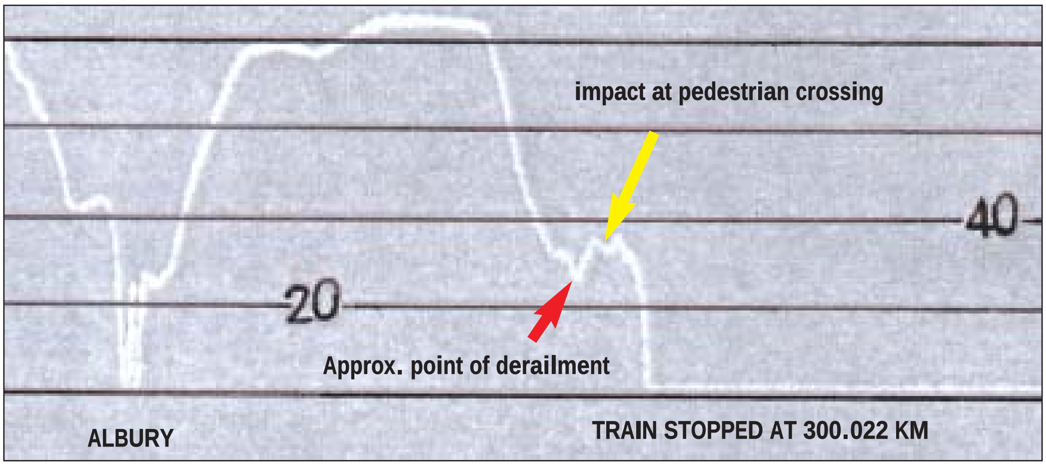
Conclusion

Evidence on the Hasler recording tapes used on this service display that the driver of the service operated the service within required speed parameters for the route.

Evidence also indicates that the operation of power and braking apparatus was consistent with correct driving practice.

A section of the Hasler speed trace is reproduced in figure 23. It shows, among other things, two points in the speed trace which corroborate the train crew's statements with regard to the 'jerks' they felt around the time of derailment.

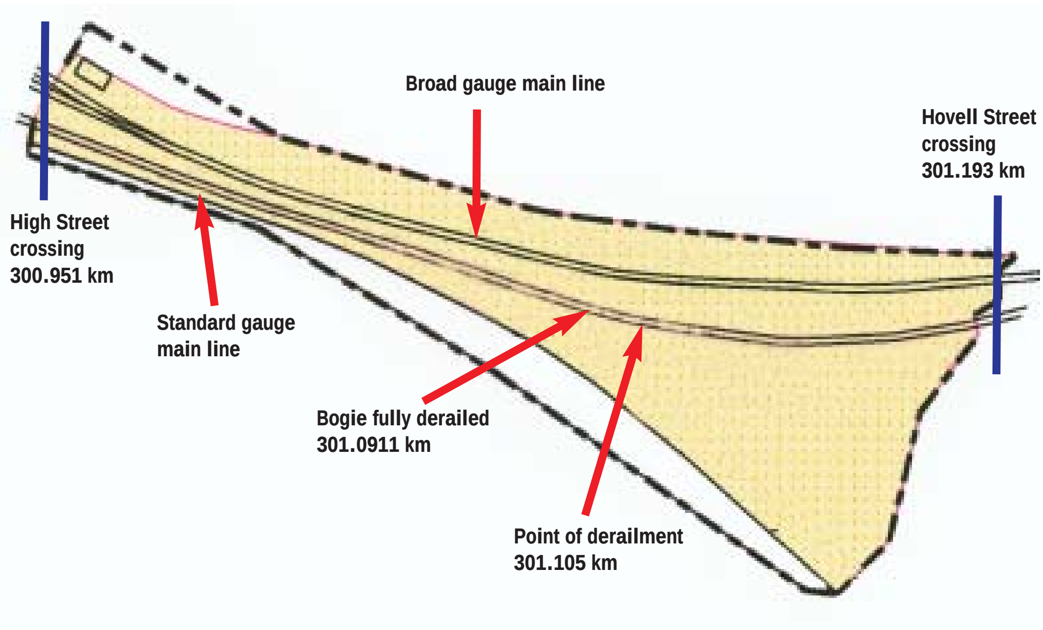
FIGURE 23:
Excerpt from Hasler speed trace



4.11 Site information

The schematic diagram shown in figure 24 provides general details of key locations at the derailment site.

FIGURE 24:
Derailment site



4.12 Medical issues and toxicology

The driver of 8622 underwent a breath test for the presence of alcohol by personnel from the Victorian Police who attended the scene shortly after the incident. The result was negative.

The Adelaide Train Controller was breath tested by authorised personnel at the ARTC Train Control Centre shortly after the incident. The result was negative.

4.13 Tests and research

Technical analysis of the derailment was provided for the investigation by the technical analysis unit of the ATSB and two companies with expertise in rail investigation, Weltrak Pty Ltd and Interfleet Technology Pty Ltd.

4.13.1 ATSB technical analysis

The ATSB technical analysis unit were provided with the side bearer plates from bogie NHA 198B and the mating plates from the carriage. The locating pin and bearing material found lying on the derailed bogie bolster, were also passed to the unit for analysis. The primary objective was to try to establish when the locating pin became lodged between the side bearer plate and the top of the bogie bolster.

The following is a summary of the substantive findings of the technical analysis:

- The locating stud of the left side bearer plate (1–3 side bearer plate) became trapped between the plate and bogie top member during abnormal bogie motions during the derailment.
- The threaded connection between the stud and plate had been affected by oxidation.
- Regions of thread damage on the stud did not display bright metal surfaces. It appears that the damaged thread had been oxidised.
- It was very evident that the friction material included in the bearer plate assembly had worn to a degree that contact between the elements of the assembly had occurred through metal to metal contact.
- It was evident that metal to metal contact had occurred in other bearer plate assemblies from the XPT carriage.
- Operation of bearer plate assemblies with metal to metal contact (excessively worn friction material) will result in heating. Frictional heating will result in the oxidation of steel components.

4.13.2 Weltrak analysis

Weltrak Pty Ltd was contracted to provide the ATSB with services including:

- Provide expert analysis of track at the site of the derailment including gauge, geometry, condition, lubrication, construction and comparison with existing standards.
- Provide expert analysis of rolling stock/track interaction with view to establishing the mechanism(s) of derailment.
- Provide expert assistance with assessing track maintenance and construction standards and procedures.
- Provide expert analysis of track maintenance history at derailment site.

- Report to ATSB investigation team findings with respect to both the track in the vicinity of the derailment and the derailed bogie.

The substantive points of Weltrak's analysis of the incident are set out in brief below. The complete Weltrak report is reproduced in appendix 1.

4.13.2.1 Track analysis

With respect to the track in the area of the derailment Weltrak found:

Track gauge

- The gauge widening, around the point of drop-in, of the magnitude indicated by the ARTC measurements after the derailment, is a serious defect warranting immediate repair once found.
- Wide gauge of this magnitude develops over many months with the growth likely to start slowly and ultimately become exponential.

Alignment

- The alignment of the curve where the derailment occurred was governed by the presence of the broad gauge crossing diamond removed in 1997.
- The design radius of 175 m is not suitable for the operation of the current types of interstate trains and is certain to result in high levels of deterioration compared to other parts of the line.
- The absence of any transition from straight track to the 175 m radius on the Melbourne end of the curve can be expected to result in alignment deterioration under heavy trains with hot weather exacerbating the problem further.
- Alignment problems in the curve were inevitable.
- The ARTC stringline data taken on 4 May 2001 shows curvature as little as 147 m following the track repair work after the derailment. It is of some concern that alignment this sharp was left in the main line even with the 15 km/h speed restriction.

Cross-level

- The change in cross level up to the point of drop-in is not excessive with no loss of vertical wheel load likely for the XPT rolling stock.

Rail

- The wear on both the high and low rails is modest. The wear on the high rail is consistent with regular deflection of the head of at least 3 mm. The low wear and the stiffness of the rail section means that the deflection is achieved by roll of the rail under load.

Sleepers

- The appearance of the sleepers in the area of the derailment would indicate that many were 18 to 20 years old. The condition of these older sleepers was not good with many showing, splitting, worn spike holes, rot and back cant wear.

Fastenings

- All sleepers in the vicinity of the derailment showed evidence of high rail plates being regularly pushed outward, adding up to 32 mm rail play to the static track gauge.

- The use of four spring spikes is appropriate for the Rex-Lok-In system in curves of radius 300 m or less.
- There were insufficient spikes to resist lateral forces and effectively hold the sleeper plate in place on the sleeper.
- There was play also present at the sleeper plates fastened with screw spikes. With the failure (movement) of the other plates, large loads are transferred to the stronger fastenings which fail as a result.

Ballast

- The shoulder ballast which was found to be covering the ends of the sleepers and fastenings on the outside of the high rail in the area of the derailment would have obstructed a proper inspection of the fastenings and plate movement.

Lubrication

- The condition of the gauge face was evidence of high flange forces and a high coefficient of friction (in excess of 0.5) on the high rail.
- The high coefficient of friction of the high rail gauge face could have affected the angle of attack of the bogie wheel-set.

Construction

- The track structure was not uniform as a result of the differing sleeper plates and fasteners. The mixed construction would have made deterioration less predictable and is less than best practice although could have provided an adequate track structure if properly maintained.

Track maintenance

- The diamond crossing was the sole cause for the non-transition shape of the curve at the derailment site but there was no subsequent work to improve the unsatisfactory curve geometry when the diamond was removed.
- The track recording car uses three different geometry limits applied along the same track between Albury and Melbourne depending upon the Line Speed. This seems overly complex given that the track loading and deterioration is governed much more by actual curve Speed Board speeds. A 40 km/h curve will experience the same order of loading and deterioration whether it is in an 80 or a 130 km/h Line Speed area. It is unlikely that field staff involved with this track would have a good understanding of recording car results in these circumstances.
- The trolley lifts which occurred on 30 November 2000 and 28 February 2001 have both occurred about 20 m south of the derailment site. The likely cause of the trolley lifts was the derailment of the gauge measuring trolley due to a combination of the very sharp alignment, the shape of the rail on the gauge corner and the trolley wheel profile.

Other track issues

- The site where the derailment occurred is vulnerable because it is at the end of a maintenance area and because it is slow speed and in a station yard. This means that it is likely that a lower than standard track condition may be tolerated for many months.
- The site has an owner, lessee, maintenance provider, and a geometry measurer. It is critical that the latter three are linked in an effective system which ensures that what

each do results in the track gaining or retaining its health. The system needs to have an internal quality control which picks up repeat errors or omissions in the interest of the track (as distinct from the party's legal or commercial obligations). This derailment has revealed a weakness, if not a hole in such a system.

4.13.2.2 Vehicle analysis

- Wheel profiles show number-1 wheel of bogie NHA 198B was 1 mm below the flange thickness condemning limit.
- Comparison of the worn wheel profiles with a the profile shows a progressive distortion of the back face shape, ie it appears that the wheel flanges bend as they wear with the bending commencing before they have worn down to 22 mm thickness. Number-1 wheel flange showed up to 3 mm difference in profile. It is understood that these wheel are relatively soft compared to heavier vehicles, which may account for the change, however it is also indicative of the amount of work the flanges must do in curves.
- With respect to the wheel diameters on bogie NHA 198B, the result of differing wheel diameters across a wheel-set can be increased flange wear on the lesser wheel. The diameter disparity of 2 mm between number-1 and number-2 wheels exceeds the 1 mm working limit.
- The side-bearer condition (of bogie NHA 198B) is a critical issue in this derailment as it affects the rotational stiffness of the bogie and hence its curving performance.

4.13.2.3 Vehicle/track interaction

- At the time of the derailment given the speed of the train and the superelevation of the curve the wheel loads would have been reasonably balanced.
- The XPT bogie is designed to run with its wheel-sets square in the bogie with as system of rods to maintain this configuration. In the case of bogie NHA 198B this arrangement has been assumed to be effective.
- There are two relevant boundary cases for bogie tracking. These are the 'chordal' position and the 'jamming' position. For sharp curves a bogie free to rotate will assume the 'chordal' position with both outer wheel flanges in contact with the high rail. A bogie with high rotational stiffness in a sharp curve will assume the jamming position with the leading wheel flange in contact with the high rail and the diagonally opposite wheel flange in contact with the low rail. A bogie that is restrained in its capacity to conform to sharp curvature will cause larger lateral load on the high rail than a bogie which is free to rotate as designed.
- In the 174 m radius curve where the derailment occurred, the lateral load on the high rail may have been of the order of six times higher if the bogie was tracking in the 'jamming' position compared to the 'chordal' position.
- Consideration of the high rail profile in the area of the derailment and the number-1 wheel profile on bogie NHA 198B leads to the conclusion it is unlikely that any reduction in curving forces on the rail, through design profile wheel-set steering, has been available from the profiles in this incident.

4.13.2.4 Mechanism of derailment

The derailment occurred as a result of the spreading of track gauge at 301.105 km which has allowed number-2 wheel of car XF 2214 to drop in to the four-foot, the number-1 wheel subsequently being forced over the outer high rail of the curve.

The factors contributing to the spreading of the track gauge include the following.

- Fastening condition allows a potential movement of up to 32 mm gauge. This is additional to the static gauge of 1455 mm, which is 17 mm wide, and makes a total of 49 mm potential wide gauge.
- Forces on the rails from the vehicle have spread the gauge 49 mm and a further 18 mm to allow drop-in.
- The excess wear on the flange of number-1 wheel of bogie NHA 198B has reduced the amount of spread needed for drop-in.

The factors contributing to the spreading forces on the rail include the following.

- The sharp and varying curvature of the track.
- Variations in the bogie performance of bogie NHA 198B in curving due to the detached pin (side bearer plate locating pin), and possible foreign body in the 1–3 side bearer causing higher lateral forces than a bogie in normal running condition.

4.13.3 Interfleet technology analysis

Interfleet Technology Pty Ltd was contracted to provide the investigation with expert analysis of the derailment including the computer modelling of the bogie behaviour in the curve using their Vampire computer software. Interfleet Technology also undertook to provide data on the bogie rotational resistance and comment on the effect of increasing rotational resistance on derailment performance.

The substantive points of Interfleet Technology's analysis of the incident are set out in brief below. The complete Interfleet Technology report is reproduced in appendix 2.

4.13.3.1 Vehicle based effects

Interfleet Technology found:

Bogie rotational resistance

- The considerable wear damage to the secondary yaw friction surfaces (side bearer plates and mating carriage plates) of the derailed bogie is not thought to be of great relevance as such damage is common on UK BT 10 bogies.
- It seems most likely that the locating pin from the 1–3 side bearer was dislodged/damaged during the derailment as the side bearer mounting surface does not show any signs of fretting which would be the case if the pin was damaged previously (wedged beneath the plate).

Other vehicle factors:-

- The rolling radius difference on the derailed wheel-set was such that Wheel 1, the leading outer wheel that derailed, would be expected to be subjected to a higher than usual lateral flange force.
- The thin flange on number-1 wheel is likely to be a consequence of the rolling radius difference causing the wheel-set to run off-centre, but is not likely to have contributed to the derailment itself. However the additional flangeway clearance would result in:-
- A higher angle of attack, hence slightly increased flange force.
- More significantly, the inner wheel would be closer to the edge of the inner rail when the outer wheel is in flange contact.

4.13.3.2 Track based effects

- There is a small amount of static gauge widening on the curve, but a considerable amount of dynamic gauge widening indicated by the signs of movement of the base plates on the sleepers.
- Weakness of the rail fasteners would allow rail roll that would further increase the gauge.
- Some track twist is noted from the cant measurements that may be contributory to the derailment.

4.13.3.3 Cause

- Analysing the derailment based on wheel-set dimensions:

Bogie

Flange back-to-back……………………………………………….. 1357 mm

Wheel thickness number-2 wheel (inner wheel)…………………..… 127 mm

Flange thickness number-1 wheel (outer wheel)…………………..… 18 mm

Total distance number-1 wheel flange to number-2 wheel rim….… 1502 mm

Track at 301.105 km

Static gauge……………………………………………………... 1452 mm

Measured sleeper plate movement on high rail…………………....… 32 mm

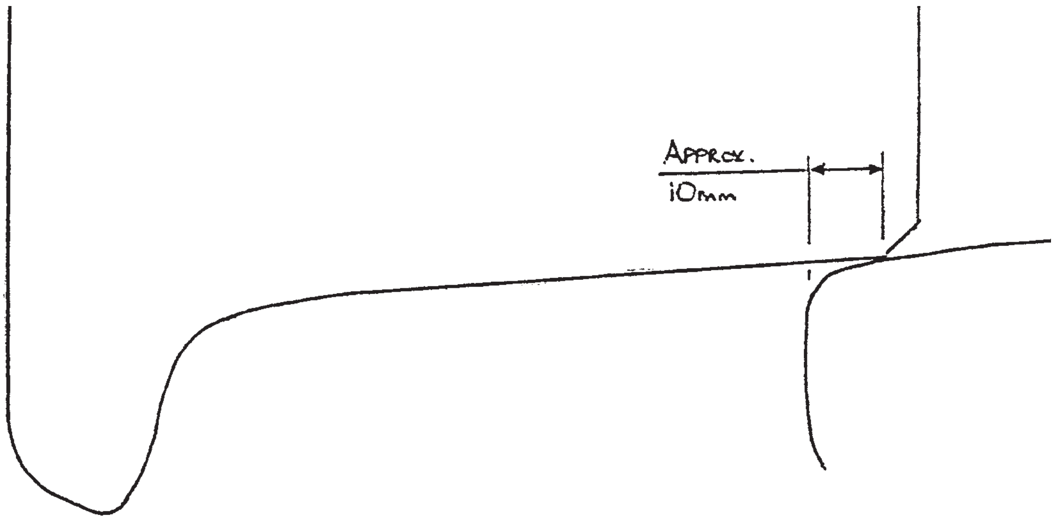
Total dynamic gauge……………………………………………….. 1484 mm

Therefore: overlap of the inner wheel on the low rail at 301.105 km was 1502 – 1484 = 18 mm

Allowing for the 6 mm chamfer on the wheel rim, the actual contact between the tread of the inner wheel and the rail head could have been as little as 12 mm. Hence there is high risk of derailment caused by the inner wheel tread dropping into the track four-foot. Figure 25 shows that the flange of the leading outer wheel (number-1) fits well into the worn side of the outer rail. By taking account of the 1357 mm back to back dimension and 49 mm dynamic gauge widening the position of the inner wheel on the inner rail may be predicted as shown in figure 26.

FIGURE 25:
Predicted number-1 wheel contact with high rail

FIGURE 26:
Predicted number-2 wheel contact with low rail



4.13.3.4 Investigation

- It is notable that following derailment of the one bogie, the remainder of the train passed over the derailment site safely. This would indicate that, whilst the track based elements must be relevant, it is only the combination of the vehicle-based and track-based elements together that caused the derailment.

Bogie rotational resistance

- The bogie rotational resistance is measured and the 'X-factor' is calculated according to the following formula:

$$X = \frac{\text{Body-bogie yaw torque}}{\text{Wheelbase x Axle load}}$$

- Based on tests conducted on comparable British rolling stock an X factor of about 0.05 would be expected for an XPT trailer car.

- The effect of increasing the X factor was modelled using rolling stock comparable to carriage XF 2214 on a simulated section of track of the same geometry as the curve where the derailment occurred. The testing produced the following results:

Case	*Leading outer wheel lateral force (kN) **	*Leading inner wheel lateral force (kN) **	*Total gauge spreading force (kN) **	*L/V ratio*
1. X=0.00	27.1	15.1	42.2	0.44
2. X=0.05	30.5	14.6	45.1	0.48
3. X=0.20	40.6	13.2	53.8	0.61

* Positive force indicate that lateral force is pushing the rail outwards

- For a design X factor of 0.05, the calculated side bearer friction pad coefficient should be μ = 0.12.
- For the derailed bogie where dry metal to metal contact was found between the side bearer plates and the mating carriage plates, the coefficient of friction would be an average of μ = 0.3, yielding an X factor of about 0.13. The maximum value of sliding friction would be μ = 0.5 which yields X = 0.20. Hence for the derailed bogie X factor would be in the range 0.13–0.20. For a maximum X factor of 0.20, the results of the modelling yield a total gauge spreading force of 53.8 kN for a vehicle travelling at 36 km/h on a 175 m radius curve with 40 mm installed cant.
- The rolling radius difference between the inner and outer wheels of the leading wheel-set of bogie NHA 198B was modelled. The modelling showed that the wheel-set tracked with a mean lateral offset on straight track sufficient for the number-1 wheel to be contacting the flange root area of the wheel profile, close to flange contact.
- The effect of the reduced back to back (1 mm less than the 1358 mm minimum dimension specified) and thin flange on number-1 wheel showed little effect on the curving forces when modelled.
- If the measured dynamic gauge and cross-level inputs are superimposed as an irregularity on the curve, model testing reveals that the resulting dynamic lateral forces are increased. The effect of the dynamic gauge widening in the area of the derailment is equivalent to a 17 mrad kink (a kink of angle equal to 17 milliradians) superimposed on to the 175 m radius curve. A peak gauge-spreading force of 70 kN is seen (at the point of derailment), with a force of 65 kN sustained for 2 m.
- All model testing was based on a wheel rail co-efficient of friction of μ = 0.23. A higher coefficient of friction may be appropriate for this derailment, with the effect of a higher friction coefficient being to increase the lateral force values.
- Modelling showed a 20 tonne axle load vehicle approximating the preceding freight trains over the derailment site produced leading outer wheel lateral forces in the order of 50 kN.
- For heavier axle load vehicles, the lateral force on the outer rail in the curve is increased, but not by the same proportion as the increase in restraining vertical wheel load on the rail. As a result, the heavier freight vehicle does not have an increased derailment risk, over a lighter passenger vehicle.

4.13.3.5 Conclusions

- The freight trains preceding XPT service 8622 did not derail due to their higher axle loads and proportionally higher vertical rail loads with respect to the lateral gauge spreading/rolling load.
- The reason why the lead bogie on carriage XF 2214 derailed and none of the subsequent bogies in the train, was due to the poor fixing of the rails. The rails were sufficiently flexible to spring back into place after the bogie derailed such that the remainder of the train passed safely over the site. If the track at the site had been as strong as expected prior to the derailment, and the derailment had been due to the passenger train exerting excessive forces on the track, then it would be expected that broken track fastenings would have been found due to the process of derailment. The rails would be expected to remain in a displaced position with further wheel-sets being derailed.
- The faults on the XPT trailer car such as the differing wheel diameters (2 mm difference in diameter on the leading wheel-set), the over-thin flange (1 mm below minimum flange thickness on wheel 1) and the reduced back to back dimension (1 mm too narrow on at 1357 mm on wheel-set 1) should not have been present. However, according to the 'Vampire' predictions these had little influence on the wheel forces generated at the derailment site. They had an influence on reducing the amount of tread remaining in contact on the inner rail of the curve but their contribution was small compared to the wide dynamic gauge of the track.
- Based on the evidence supplied, the primary cause of the derailment is seen to be the poor condition of the rail fastenings. The rails were not secured sufficiently to maintain the rails at a constant gauge and in an upright position under the passage of trains.
- The condition of the yaw friction pads (side bearers) of the train is not seen as a contributory cause to the occurrence of this derailment since the predicted level of increase in lateral wheel-rail force is small, and still less than that of a heavier axle load train. The condition of the yaw friction pads may well have been a contributory cause as to why this XPT trailer car derailed, and not a later train. However, it is clear from the dynamic gauge of the track that any train passing over this site was very close to the point of derailing.

4.14 Organisational and management issues

4.14.1 Organisational context

The operators and organisations that were considered relevant to this incident are described below.

4.14.1.1 Department of Infrastructure, Safety and Technical Services Branch (STSB)

The Safety and Technical Services Branch is a unit of the Victorian Department of Infrastructure.

The Branch manages the accreditation of railway organisations in Victoria accordance with the Transport (Rail Safety) Act 1996 Part 2 — Amendments to the Transport Act 1983.

In order to gain accreditation, rail organisations must demonstrate that that they have an appropriate safety management system, the competence and capacity to meet the relevant safety standards, and that they possess public risk insurance.

Once accredited, organisations are responsible for managing the safety of their operations. The Australian rail industry in general operates in this type of co-regulatory environment. Therefore, STSB does not prescribe specific standards and practices. Australian Standard AS4292 Part 1— Railway Safety Management and AS4360 — Risk Management, are not specifically referred to in legislation but are generally used by STSB as the guidance documents for the accreditation process.

4.14.1.2 NSW Department of Transport, Transport Safety Bureau (TSB)

The Transport Safety Bureau is a unit of the New South Wales Department of Transport.

The Bureau manages the accreditation of railway organisations in New South Wales in accordance with the *Rail Safety Act 1993*, in a similar manner to the Victorian STSB.

Under mutual recognition arrangements, accreditation of railway organisations in New South Wales are recognised by the STSB in Victoria with requirements for meeting local factors.

4.14.1.3 Australian Rail Track Corporation (ARTC)

The Australian Rail Track Corporation commenced operations on 1 July 1998 under transitional accreditation provisions and was formally accredited by the STSB on 1 May 1999.

ARTC owns the former Commonwealth standard gauge railway infrastructure from Adelaide to Kalgoorlie, Alice Springs, Broken Hill and Wolseley, and has a 15 year lease on the standard gauge interstate rail infrastructure in Victoria from Wolseley to Melbourne and the Victorian-New South Wales border. The two key functions of the company are; the provision of rail access, and train control over the network it manages.

ARTC has been accredited as a track owner in Victoria, New South Wales, Western Australia, and Northern Territory and a manger of infrastructure in South Australia. ARTC is owned by the Commonwealth Government.

4.14.1.4 Victorian Rail Track Corporation (VicTrack)

VicTrack owns the rail track previously owned by the Victorian Public Transport Corporation (PTC). VicTack is accredited by STSB as a manager of non allocated infrastructure.

VicTrack leases its standard gauge track on the interstate corridors to ARTC. VicTrack ‘head-leases’ its intrastate network to the Victorian Department of Infrastructure which, in turn, ‘on-leases’ that network to Freight Victoria. VicTrack is owned by the Victorian Government.

4.14.1.5 State Rail Authority of New South Wales (State Rail)

State Rail, under the names CityRail and Countrylink, operates standard gauge passenger trains in New South Wales and interstate to Melbourne and Brisbane. Countrylink was accredited by the STSB on 20 December 2000 as a provider and operator of passenger rolling stock on the Victorian north east standard gauge corridor to Spencer Street.

State Rail is an authority of the New South Wales Government.

4.14.1.6 Rail Infrastructure Corporation (RIC)

The Rail Infrastructure Corporation was established on 1 January 2001 after the amalgamation of the Rail Access Corporation (RAC) and Rail Services Australia (RSA). RIC is owned by the New South Wales Government.

4.14.1.7 Evans Deakin Industries Ltd (EDI)

Evans Deakin Industries Ltd, Powerlines, Telecommunications Rail Division (PTR) has been the ARTC infrastructure maintenance provider on the Albury-Melbourne standard gauge railway since purchasing ABB's rail maintenance business in August 1999. EDI's PTR division has been formally accredited by the STSB as a manager of rail infrastructure and a provider of rolling stock for infrastructure maintenance since 28 June 2000.

4.14.2 Safety management systems

The *Victorian Transport (Rail Safety) Act 1996* Part 2 — Amendments to the *Transport Act 1983*, provides for the accreditation of the managers of rail infrastructure, and providers and operators of rolling stock. The STSB manages the accreditation of railway operations in accordance with the Act.

Accredited organisations are responsible for rail safety. The STSB assesses organisation's safety management systems against the relevant safety management standard, generally Australian Standard AS4292 Parts 1-6 'Rail Safety Management'. Both ARTC and Countrylink demonstrated to the satisfaction of the STSB during the mutual recognition process that they had adequate safety management systems in place.

Both ARTC and Countrylink maintain a database of incidents and accidents in accordance with reporting requirements of the Transport Regulations (Rail Safety) 1999 and referred to in Appendix C of AS4292 Part 1. The database is monitored for developing adverse trends.

4.14.3 History of similar incidents

There have been no derailments recorded on the standard gauge curve between the High Street and Hovell Street level crossings in Wodonga in the past. Inspection of Countrylink records indicated several XPT derailments have occurred mainly as a result of collisions with passenger vehicles on level crossings. The records also indicate that service SP24 derailed at Newtown on 12 August 1998 due to a defective wheel. There is insufficient evidence to suggest that the derailment in Wodonga on 25 April 2001, was similar in any manner to the derailment at Newtown.

4.15 Emergency response

4.15.1 Emergency response plans

When ARTC Train Control received the initial notification of the derailment they implemented the ARTC incident management plan set out in ARTC document TA44. TA44 contains information relating to, and procedures for managing, an incident including the responsibilities of various parties, reporting, site management and investigation and emergency planning. The plan also contains a pro-forma for a major incident log. A copy of the completed log was provided to investigation and provided evidence that that incident was managed by train control in accordance with their procedures.

State Rail (and thus Countrylink) use incident management procedures based on the Rail Access Corporation document ‘Incident Management Manual’ AM 0007 MM. The Rail Access Corporation incident management manual contains information and procedures for the most part identical to the ARTC incident management manual.

Countrylink also have documented procedures for train crew which detail their responsibilities and response to various emergencies. The passenger service supervisor and the driver receive training in these areas. At the time of the derailment, there was no formal evacuation procedure for XPT trains however Countrylink were in the process of developing detailed procedures in the form of their ‘Emergency & Evacuation Preparedness Plan’. A draft of this document was provided to the investigation. All train crews will receive training in these evacuation and emergency response procedures at some time in the future.

4.15.2 Emergency response actions

After derailing, the driver brought the train to a stop in response to a passenger emergency alarm. At that time he did not realise that the train had derailed but was following the standard procedure in the event of an alarm. The passenger service supervisor also received the alarm at his work station and responded immediately by directing the passenger attendants to investigate via the crew address system.

When interviewed, the passengers in car ‘E’ reported that there was some delay in activating the emergency alarm. The delay was due in part to the initial shock of being in a swaying, derailed carriage rapidly filling with dust but also by a lack of knowledge of what to do in an emergency. With the train not slowing, and no train staff either in car ‘E’ or the adjacent carriages ‘D’ and ‘F’, some passengers realised that they needed to raise the alarm. It took a further time to locate an emergency alarm button and activate it. Given the train travelled about one kilometre at approximately 35 km/h after the car derailed, it took about 90 seconds for the emergency alarm to be activated by the passengers.

When the train was stopped, the driver conferred with the signalman, who subsequently called ARTC train control to notify them of the incident. As a result of this initial notification, train control started the process of notifying the various other parties detailed in their incident management plan and also attended to the issues concerning train traffic on the line. The safeworking procedures applicable on the standard gauge main line at Wodonga are contained in the ARTC document TA020 – Victorian Network Operations. These procedures include safeworking priorities in an emergency. The first priority is to determine if any adjacent line is affected and if so take urgent action to stop any approaching trains. In this derailment, the adjacent broad gauge main line was not obstructed.

Wodonga police received initial notification of the incident from the Victorian police communication centre at Wangaratta following a call from the public. As police were in the area at the time, they were able to attend the incident quickly. The police were on site before ARTC train control had the opportunity to report the incident to the emergency services. The police liased with the driver and established a perimeter around the train in accordance with standard incident management procedures. The police also assisted with the direction of traffic on High Street, the station entrance road, and Kelly Street as the boom gates were down on the crossings at these places due to the train’s occupation of track circuitry.

A Country Fire Authority of Victoria (CFA) crew were on site a few minutes after the police. The CFA crew examined the train for potential fire risks. After assessing that there was no identifiable hazards and reporting this to the police the CFA crew departed.

Following their inspection and assessment of the train and site the passenger service supervisor and driver had prudently decided to keep the passengers on the train until the road coaches arrived. They had correctly identified that the train was the safest place to hold the passengers in relative comfort for this period of time. They had also identified that the centre of the train offered the most convenient place for the passengers to dismount from the carriages and congregated the passengers in this area where they could be closely monitored.

Disembarking the passengers from the train presented the train crew with some problems. The train had stopped on a section of typical ballasted track. The passengers were forced to step down from the carriage onto the rough and steep surface of the ballast shoulder. The unloading of passengers was undertaken by the train crew with the assistance of the three Wodonga V/Line conductors. Many of the 98 passengers were frail or elderly with some problems with mobility and thus needed at least two able-bodied persons to assist them down from the carriage. Passengers interviewed reported that they received valuable assistance from the crew in alighting from the train. However some of the elderly reported that they had great difficultly with the steps, particularly the step above the ground.

The incident highlighted a need to consider the difficulties associated with disembarking passengers from XPTs in an emergency. Countrylink appear to have considered this problem and addressed the issues in their proposed 'Emergency and Evacuation Preparedness Plan'. Implementation of the Plan and training for all train staff in these procedures is indicated as a priority.

The investigation examined the actions of the XPT driver, train crew, train control, and other rail staff involved in the incident with respect to safeworking, incident management procedures and good railway practice. It was found that there was compliance with the relevant procedures. In particular, the 'A' box signalman and train staff demonstrated considerable initiative and performed creditably in the circumstances.

4.16 Other factors relevant to the incident

There were several organisational factors which pre-dated the incident and are relevant to the derailment of XPT service 8622 at Wodonga on 25 April. These factors include decisions relating to the XPT wheel profiles, the management of the resilient fastening project, and some other rail infrastructure works proposed in the Wodonga area.

4.16.1 XPT wheel profiles

When the XPT was introduced into New South Wales, much consideration was given to the wheel profiles on the new train. At the time, British Rail were leading the world in wheel profile development using computer based techniques and were asked to develop a profile based on samples of worn rail and worn passenger train wheel profiles. Their main objective was to develop a wheel profile which would optimise in-service wheel life and passenger comfort. The profile they developed for the XPT was designated TP2.

Currently, one of the major operating cost centres for State Rail's XPT fleet is maintenance. The largest single contributor to the cost of maintaining the fleet is wheel maintenance and accounts for around 20 per cent of the total workshop budget. Since the middle of 1998, diesel services maintenance at State Rail have noticed increasing rates of wheel flange wear on their XPT carriage bogies. The increased flange wear has had a detrimental impact on their overall maintenance costs with flange thickness rather than tread wear determining the need to machine/change wheel-sets at increasingly frequent intervals.

The original XPT wheel specification stipulated a minimum flange thickness of 25.4 mm and a standard flange thickness condemning gauge was developed specifically for the wheel profile. (ROA Manual of Engineering Standards and Practices 1992, diagram 17-4-2). In November 1999 State Rail Passenger Fleet Maintenance applied to the Rail Access Corporation in NSW for a dispensation to run the XPT flanges to 19 mm, the freight bogie standard, and thereby increase the time between wheel machining and consequently the life of the wheels. They proposed that bogies with flange thicknesses in the range 19–22 mm would be run at maximum speed of 130 km/h. RAC agreed to the 'engineering concession' after comparing the XPT wheel profile with a standard freight wheel. They determined that the minimum thickness of a section of wheel measured between the root radius of the profile and the inner web transition was 3 mm greater than a freight wheel for the XPT wheel with maximum tread wear and a 19 mm flange.

RAC recommended that wheels with flanges in the 19–22 mm range be regularly inspected to ensure that wheels with flanges less than 19 mm thick do not enter service. RAC also recommended that the ride quality of vehicles with flanges in the minimum range are checked to ensure acceptable passenger comfort.

State Rail did not apply to ARTC for a similar engineering concession to run trains with flanges less than 25.4 mm on the standard gauge main line from Wodonga to Melbourne. Since being granted the dispensation from RAC, Countrylink have been regularly operating rolling stock across the border on ARTC's Victorian track with wheel flanges in the 19–22 mm range.

In early 2000, a wheel management committee was set up by State Rail 'in an effort to better understand the current position with respect to wheel management' and 'review the situation using TQT (Total Quality Transformation) principles.' The committee included members from passenger fleet maintenance, Rail Services Australia and the Rail Access Corporation and 'worked in conjunction with the RAC chaired Wheel/Rail Interface Committee.'

In October 2000 the committee released a report which detailed their findings and proposed solutions to improve wheel wear rates. The report identified that: 'State Rail is almost unique in suffering very high flange wear and almost no tread wear.' The committee looked at various possible causes for the increasing rates of flange wear including wheel and rail profiles, wheel machining accuracy, track curvature, wheel material, track gauge variation, gauge face lubrication and rail grinding.

In 1996, RAC initiated a program of rail grinding in NSW. The grinding program was progressive with one aim being to provide gauge corner relief on selected lines to prevent rolling contact fatigue of the gauge corner under the high axle loads of freight trains. The State Rail wheel management committee considered the effect of the rail grinding program after identifying that: 'the general trend shows that flange wear increases after rail grinding.' They compared the profiles of their passenger fleet wheels and rail from selected locations, which had been ground, and identified that two point wheel contact was occurring. The report states:

> …the relief of the gauge corner destroys the rail's ability to provide steering to the higher speed passenger trains on tight curves. Where two point contact between the wheel and rail occurs, heavy flange wear results.

The wheel management committee's plan for continuous improvement included recommendations relating to wheel/rail profiles, gauge face lubrication, wheel material, bogie dynamics and wheel defects. The wheel/rail profiles recommendations included reference to new profiles being developed by BHP's Monash University research team as a result of a commission from the Wheel/Rail Interface Committee. The State Rail wheel management committee's recommendations with respect to bogie dynamics included improving bogie rotational stiffness and improving the constant contact side bearer material.

4.16.2 Rail resilient fastening

In July 1999 ARTC called for tenders on project number RT052. ARTC stated in the tender documentation under 'Project Background':

> ARTC intends to increase operating efficiency and reduce transit times on the Melbourne to Adelaide and Melbourne to Sydney Corridors. This project will help to achieve this aim by improving track stiffness and strength through the installation of resilient fastenings on all main line timber sleepers.

The scope of works for the project involved the resilient fastening of main line track in Victoria in sections between Dynon and Albury and Tottenham to Gherringhap. The tender also required spot replacement of timber sleepers in conjunction with the installation of the resilient fastening components.

The tender document stipulated that existing sleeper plates were to be utilised where possible and the fastening system should incorporate the use of two spring spikes per sleeper plate on straight track and curves of greater than 300 m radius. On curves of less than 300 m radius, four spring spikes were to be fitted in each sleeper plate. The proposed fastening arrangements met the requirements of the PTC civil engineering circular (CEC) 2/91 on the fitting of spring spikes.

B.T. & K.A.Coleman Pty Ltd tendered successfully for the project and in early 2000 they began fitting the Rex-Lok-In resilient fastening system to the scoped areas of the network. The Rex-Lok-In system has the advantage of being easy to retro-fit as it is designed to fit to most of the pre-existing double shoulder sleeper plates in use in the Victorian standard gauge system. Where the Rex-Lok-In system was fitted, the dog spikes were removed and the sleeper plate was fastened to the sleeper using spring spikes.

On 12 January 2000, an RT052 project general meeting was held with representatives from Coleman Pty Ltd, ARTC and ABB (the track maintenance provider at that time) present. The minutes from the meeting indicate that two curves in the main line in the Wodonga area were identified as being of less than 300 m in radius including the curve where the derailment occurred. It was agreed that the sleeper plates on the curve were to be fitted with the four spring spikes as required by the contract and that the spikes would be supplied by Coleman. One of the Coleman representatives also indicated that the 'timbers are in poor condition' in the curve. It was decided at the meeting that the curve would not be re-gauged and the existing Pandrol fastenings fitted on every fourth sleeper would be reinstalled.

The minutes of the subsequent RT052 project meeting on 27 January 2000, indicate that the sleeper plates on the curves of less than 300 m in radius would be fitted with two L51 and two PC3 spring spikes.

The original estimates for spring spikes required for the resilient fastening project were, 1.5 million L51 and 200 000 PC3 spikes. General and Railway Supplies Pty Ltd, the suppliers of the Rex-Lok-In fasteners, also undertook to supply the spring spikes for the project eventually sourcing some 367 900 L51 spikes from Pandrol Australia (data from Pandrol records) and the balance of the 1.5 million L51 spikes from a supplier in India. Railway and General Supplies stated that they supplied 20 000 PC3 spring spikes for use in the project.

On 18 July 2000, a representative from ARTC inspected the project works from 266–304 km including the works in Wodonga and issued a Certificate of Practical Completion in accordance with ARTC's project management procedures. The certificate indicated, among other things, that the resilient fasteners and spring spikes had been installed. The defects section listed as point '2' that 'this section of track has a quantity of broken spring spikes installed. Spring spikes to be replaced at end of 12 month warranty period. 30 June 2001'

On 17 August 2000, a 'Notice of Handover to Maintenance Provider' for the section of track between 266 and 304 km was signed by representatives of ARTC and ABB. The certificate included two declarations:

> ARTC hereby authorises the following sections of track detailed in the practical completion certificates, subject to the defects noted, are ready for hand back to ABB

and:

> ABB hereby accepts the following sections of track detailed in the practical completion certificates, subject to the defects noted are ready for hand back and take full responsibility for the maintenance as of 17/8/2000.

At the time of the derailment, the sleeper plates around the point of derailment where the Rex-Lok-In fasteners had been installed had only been fitted with two L51 spring spikes. The PC3 spikes which are specifically designed to fit in the sleeper plate holes adjacent to the toe of the rail, had not been fitted as per the project team minutes of 27/1/00.

4.16.3 Gauge standardisation, Wodonga by-pass and realignment projects

Since the late 1990's there has been considerable discussion relating to rail infrastructure changes in Victoria and in the Wodonga area specifically. Gauge standardisation and a rail by-pass for Wodonga are two projects which have been proposed and discussed for some time. Both of the projects mean major changes to rail infrastructure in the Wodonga area and consequently the track where the derailment occurred. In addition, ARTC's project team recently proposed to re-align the standard gauge mainline through the Wodonga Station yard including the curve where the derailment occurred.

4.16.3.1 Gauge standardisation

Prior to 1962, Albury and Wodonga were where the New South Wales standard gauge rail system met the Victorian broad gauge rail system. Interstate passengers changed trains at Albury with Albury and Wodonga sharing freight transhipment facilities. In 1962 the Wodonga to Melbourne standard gauge main line was opened, and Melbourne became the break of gauge point. The new standard gauge main line was designed to carry the interstate rail traffic while the existing broad gauge main line continued to carry the Victorian freight and passenger trains.

In 1995 the Adelaide-Melbourne broad gauge main line was converted to standard gauge along with western Victoria branch lines to Portland, Yaapeet, Hopetoun and Maryborough (Dunolly). Since then there has been discussions about the converting the remaining broad gauge grain lines to standard gauge. The Seymour-Wodonga corridor has been seen as a high priority because the route already has a standard gauge main line and there are significant operational and capital benefits to be gained from rationalising the rail infrastructure.

In the May 2001 budget, the Victorian Government included a five year $96 million program to convert most of the rural broad gauge grain lines to standard gauge. The first stage of the program in 2002 will be the Geelong/Mildura/Pinnaroo lines. This is to be followed in 2003 with the Seymour-Wodonga line and the Benalla-Oaklands branch. Prior to the Victorian Government announcement to fund of the gauge conversion in the Seymour-Wodonga corridor there were extensive discussions with the rail industry. ARTC as the lease holder on the standard gauge infrastructure was a party in the discussions.

Gauge standardisation in Wodonga offered the opportunity to realign the standard gauge main line to the superior existing broad gauge alignment through the station yard. Thus, up until a decision was made to by-pass the town centre in December 2000, the gauge standardisation proposal meant that the curve where the derailment occurred would eventually have been realigned.

4.16.3.2 Wodonga by-pass project

In 1989 the Wodonga Chamber of Commerce developed a proposal to move the existing railway infrastructure out of the centre of the town. Their focus was on improving road traffic flows through the town by eliminating the large number of level crossings and on developing the prime rail land in the centre of Wodonga for commercial purposes. The proposal was contentious and ignited debate within the local community and at State and Federal government levels.

Since the original Chamber of Commerce proposal there has been a number of studies considering a by-pass and other alternatives including a rail tunnel under the town. Eventually a plan to relocate the rail infrastructure to the floodplain to the west of the town was decided to be the most appropriate with significant benefits for the largest local manufacturer.

In December 2000, the Federal and Victorian governments agreed in principle to jointly fund a Wodonga rail by-pass project, with the Federal Government agreeing to provide $20 million towards the estimated $57 million project. After the agreement was reached, the Victorian Government assembled a project team to consider the engineering aspects of the bypass to provide accurate project costs and undertake an environmental effects study. Aside from re-aligning both broad and standard gauge railway lines, the project includes the construction of a new Wodonga railway station and extensive new freight handling facilities. The new track alignment by-passes the curve where the derailment occurred. ARTC, as the lease holder on the standard gauge Wodonga infrastructure, were actively involved in the development of the by-pass project.

4.16.3.3 Realignment project

Towards the end of 2000, ARTC's strategic planning group nominated project VC06 for inclusion in ARTC's 2001-2 financial year capital works plan. The project involved realigning the standard gauge main line through Wodonga between 300.470 and 301.700 km including the curve where the derailment occurred. The objective of the plan was to increase the minimum radius of curves in this section of track to 365 m to allow an increase in line speeds to 85 km/h. The benefits of the proposed project included a 4.4 minute reduction of transit times for trailerail and superfreighter trains. The project was costed at approximately $600 000. The alignment of the proposed by-pass meant that the section of standard gauge main line where project VC06 works were proposed would be by-passed in due course.

Project VC06 did not proceed, with evidence provided by ARTC strategic planning management stating the reason as:

> …the Victorian Government and others promoted a proposal to build a new track bypassing the Wodonga station area. This project is now to proceed.

5. ANALYSIS

The derailment of XPT Service 8622 at Wodonga on 25 April 2001 was due to a combination of factors relating to the track and rolling stock and associated maintenance, organisational and management issues.

5.1 Track factors

The most significant causal factor in the derailment was gauge widening as a result of the inadequately fastened high rail around the point of derailment. The poor state of the high rail fastenings also allowed the high rail to roll out the additional 18 mm required for the number-2 wheel of bogie NHA 198B to drop off the low rail at 301.1086 km. There were a number of other contributing track factors and these include the alignment of the curve, the ballast profile, the condition of the sleepers and the lubrication of the high rail.

There were also a number of organisational or management factors relating to the track which were precursors to the derailment. Organisational factors including the effectiveness of track inspections and the management of the resilient fastening project had a direct bearing on the quality of the track structure and are also implicated in the derailment.

5.1.1 Gauge widening

Standard gauge track is nominally 1435 mm measured between the gauge faces of each rail in a position 16 mm down from the rail head. According to the Victorian PTC CEC 3/87 a curve of 175 m radius should be layed 3 mm wide ie. 1438 mm. (Track is routinely layed wide on curves to provide additional flangeway clearance for vehicles negotiating the curve.)

ARTC static gauge measurements taken after the derailment indicate that the gauge was 15–17 mm wide immediately prior to the point of drop-in. The static gauge widening was partially the result of approximately 8 mm of wear on the gauge face of the high rail. This amount of wear is not considered to be excessive. According to the track geometry standards specified in CEC 8/86, static gauge widening on a curve of this magnitude would not have elicited any unusual or automatic maintenance response if detected during regular track inspections. The static gauge widening around the point of derailment can only be considered to be a causal factor in combination with the additional gauge widening due to movement of the high rail under load.

In the immediate area of the derailment, there was considerable gauge widening due to the movement of the sleeper plates on the sleepers under the high rail. The sleepers were marked/worn where the plates had been regularly moving. The wear was not new and indicated that there had been sleeper plate movement for some considerable time. The pattern of the wear marks also indicated that the high rail was being rolled out in addition to the lateral movement to cause 'back cant wear' on each sleeper.

Dynamic gauge is the track gauge measured under conditions of load. Dynamic gauge includes both the static gauge of the track and the measured distance the rails are allowed to move under load. The dynamic gauge around the point of derailment was measured by adding the distance of the sleeper plate movement, indicated by the wear on the sleepers, to the static gauge. Gauge widening of up to 49 mm was measured at the point of drop-in with the drop in occurring near the centre of a group of six sleepers with potential widening of 35 mm or more. Gauge widening of this magnitude is a priority exceedence requiring immediate inspection and repair.

The Weltrak report in appendix 1 includes some discussion on gauge growth and indicates that gauge widening of the magnitude found in the area of the derailment would have occurred over many months. The graph of Gauge versus Time for a site at Martin's Creek shows that initial rate of gauge 'growth' is low but increases exponentially over time. In the area of the derailment, the growth of the gauge would have started from some time after the rails had been fitted with resilient fasteners in early 2000. Given the known characteristics of gauge growth, there should have been a number of opportunities to detect the adverse trend during routine track inspections.

The Interfleet Technology modelling of the track in the area of the derailment showed that the movement of the high rail under load could have significantly increased the peak lateral force exerted by a vehicle on the rail by acting as a 17 milliradians 'kink' in the curve. Their modelling showed a peak gauge spreading force of 70 kN at the point of derailment. This result agrees with the Weltrak report in that it implies that the rate of gauge growth would have increased as the size of the 'kink', and consequent peak loads from passing trains, had increased. In the final stages before the derailment, large peak lateral loads from passing trains would have been concentrated in the curve where the track fastenings had already effectively failed.

Given the apparent lack of awareness of the poor and rapidly deteriorating condition of the high rail fastenings a derailment at this site was inevitable at some time.

5.1.2 Track fastening

The high rail in the immediate area of the derailment was inadequately fastened. At the time of the derailment, there were insufficient fasteners holding the sleeper plates to the sleepers. What fasteners there were, had effectively failed. The excessive dynamic gauge of the track at the point of derailment was a direct result of the failure of the high rail fastening.

The high rail fastening consisted of a mixture of TrakLok and Pandrol fastening systems with the Pandrol fasteners fitted to every third sleeper. The TrakLok double shoulder sleeper plates were fixed to the sleepers using a single L51 spring spike on each side of the rail. This fastening is not adequate and does not comply with the requirements of CEC 2/91, the applicable standard, which states: 'On curves of radius 300 metres and less, four spring spikes shall be used per plate, on both the high and low legs.' Two spikes per plate were insufficient to carry the relatively high lateral forces imposed on the rail by trains transiting the curve without relatively rapid deterioration of the track gauge.

The Pandrol plates fitted on every third sleeper on the high leg of the curve were fastened to the sleepers with two screw spikes per plate. After the derailment, the Pandrol fasteners were also found to have effectively failed with loose and skewed spikes and evidence of plate movement on the sleepers. When fitted initially, the Pandrol fastenings would have been more resistant to the repeated lateral loads from passing trains than the TrakLok fasteners in the curve as they have a larger base plate fixed to the sleeper with the stronger screw spikes. However, once the TrakLok fasteners had started to fail, the Pandrol fastenings would have been subjected to increasing loads and eventually failed also. There is no applicable standard for the number of screw spikes to be fitted to the Pandrol fasteners contained within the CECs however the NSW Rail Infrastructure Corporation stipulates four screw spikes per plate on curves less than 300 m radius. Pandrol also recommend that four spikes per plate (spring or screw) are installed on a face throughout sharp curves.

Most of the spring spikes and screw spikes around the point of derailment on the both the inside and outside of the high rail were found to be loose, raised and/or skewed after the derailment. It was concluded that the loose condition of the spikes was not a result of the derailment as many spikes and holes showing signs of repeated movement and working. However it was not clear whether the extent of the skewed/raised condition of some of the spikes was the result of the derailment or regular rolling of the rail under the load of passing trains or a combination of both.

The Weltrak analysis indicates that the worn profile of the high rail shows that it had been regularly rolling at least 3 mm under load. The marking on the sleepers under some plates showed back cant wear which must have taken place over a period of time. This indicates that the high rail had been rolling to some extent regularly before the derailment. However, given the frequency of track inspections, it would seem unlikely that the number and extent of the raised/skewed spikes found on the inside of the high rail after the derailment would have been missed for any length of time by the track maintenance staff. The raised/skewed spikes on the outside of the rail were covered by ballast and were not visible as a consequence. The likelihood is that the derailment contributed significantly to the extent of the lifting and skewing of the spikes found on the inside of the curve at least.

In conclusion, there were half the required number of fastenings holding the sleeper plates to the sleepers in the area of track where the derailment occurred. The evidence shows that the inadequately fastened high rail had been 'working' for a period of time around the point of derailment which has eventually resulted in the remaining fastenings failing.

5.1.3 Alignment

The alignment of the curve where the derailment occurred was poor and varied from its design ie. a constant radius of 175 m for this section of the curve. Stringline measurements taken after the derailment showed a sharpening of radius from 199 m to 174 m approaching the point of drop-in. The field data taken by ARTC officers, after work had been performed to re-open the line after the derailment, suggests that the radius of the curve could have been even tighter than 174 m at the time of the derailment. This curve is the tightest radius in the standard gauge main line between Sydney and Melbourne with the Weltrak report suggesting that a curve of this radius 'is not suitable for the operation of the current types of interstate freight trains and is certain to result in high levels of deterioration compared to other parts of this line.' Further: 'Under the loading of heavy trains and the absence of a transition curve the deterioration was predictable.'

The proposed realignment project VC06 is evidence that ARTC management had considered that there was a need to improve the track alignment in the Wodonga Station area, including the curve where the derailment occurred, if only to increase the line speed.

The tight radius and the lack of a transition curve meant the high rail particularly was subjected to increased loads from train traffic which contributed to the deterioration of the fastenings in the area where the derailment occurred.

5.1.4 Shoulder ballast

The shoulder ballast on the field side of the high rail throughout the curve between the High Street and Hovell Street level crossings was high enough to completely cover the rail fastenings. In the area where the gauge widening found after the derailment none of the sleepers or sleeper plates outside the high rail were visible. A thorough visual inspection of the fasteners in this area of the curve with the ballast profile as it was at the time of the derailment would have been very difficult.

PTC CEC 8/86 stipulates that track must be ballasted to standard plan F598 with additional ballast for track which has rail lengths of 55 m or more, curves under 800 m in radius and on the approaches to open top bridges. For curves under 800 m in radius, the Circular states that the shoulder ballast on the outside of the high leg is to be '450 mm wide plus 150 mm heaped above top of sleeper level'. The circular also states: 'Ballast must not be left so as to be above rail level in the 'five foot' (four-foot in this case) or covering any part of the rail or fastening.' CEC 2/91 'Springspikes' also states in section 3: 'Excess ballast must be removed from the tops of sleepers so that all track fastenings are clearly visible'.

The ballast covering the high rail fastenings was clean and looked as though it had been discharged recently. EDI maintenance records indicate that ballast was discharged in the area of the derailment on 22 February 2001. At the time of the ballast discharge, ARTC was running a track rectification program which included rail straightening, grinding, and tamping work between Wodonga and Benalla. Approximately 7000 cubic metres of ballast were discharged in this section of line around this time to provide sufficient ballast for the tamping operation. The ballast was discharged by the line maintenance staff from EDI in places where they felt there was a deficiency of ballast. In the case of the curve between the High and Hovell Street level crossings, the area maintenance supervisor indicated that he had discharged extra ballast on the outside of the curve to help prevent track buckles in hot weather. There had been a number of track buckles in this area during his time as section supervisor.

In the case of the curve where the derailment occurred, a fuller ballast profile was appropriate but there should have been no ballast covering the fastenings or the rail. Any ballast left covering the rail fastenings should have been removed as soon as possible after the ballast discharge to allow an effective inspection.

5.1.5 Sleeper condition

The condition of the sleepers in the area of the derailment was poor. Many sleepers appeared to be at the end of their effective life with some showing splitting, worn spike holes, and rot. One Coleman Pty Ltd representative stated at a resilient fastening project meeting in January 2000 that the sleepers in the curve 'were in poor condition'. The condition of the sleepers had a direct impact on the strength of some of the high rail fastenings around the point of derailment and was thus a factor in the incident.

The PTC sleeper renewal records were not specific to the area of the derailment and only indicate total numbers of sleepers renewed from Benalla to Wodonga. It is not possible to accurately quantify the age of sleepers in the curve however based on total numbers of sleepers renewed since 1980, at least 16.8 per cent of the sleepers in the line were older than 20 years, with 62 per cent older than 10 years at the time of the derailment.

The initial scoping of the resilient fastening project included a sleeper inspection throughout the areas of the system to be fitted with resilient fasteners to determine the numbers of sleepers which needed to be renewed. The final project scope of works stipulates the renewal of sleepers between 232.00 km and 305.150 km at the rate of 300 per kilometre. Despite the fact that it was identified that many of the sleepers in the curve where the derailment occurred were in poor condition, only 23 sleepers (out of approximately 350) were replaced between the Hovell Street and High Street level crossings. This represents a renewal rate of approximately 96 sleepers per kilometre, one third of the rate stipulated in the project scope of works.

One of the stated advantages of the TrakLok system is that it can be used on 'spike killed' sleepers and increases timber life by up to 10 years. This may have been one of the reasons why it appears that the only the worst sleepers were replaced during the resilient fastening project with the expectation that the useful life of other sleepers would be extended by the TrakLok fastening system.

The poor condition of some of the sleepers around the point of derailment had an adverse impact on the initial strength of the high rail fastenings and thus contributed to their eventual failure.

5.1.6 Track lubrication

The high rail lubricator on the Melbourne end of the curve where the derailment occurred had not been working for some time. As a result, the gauge face of the high rail was dry, bright and rough. The quantity of metal flakes found lying on the toe of the rail under the gauge face throughout the 175 m radius section of the curve indicate that the rail had been dry for some time.

The condition of the gauge face was evidence of the high flange forces within the curve and a high coefficient of friction between the wheel flange and the high rail. The Weltrak report states with regard to the high rail lubrication:

> The condition of the gauge face was evidence of high flange forces and high coefficient of friction eg in excess of 0.5 on the high rail. This compares to the normal smooth surface of the opposite low rail where the coefficient of friction would be much lower. This may affect the angle of attack of the wheel-set.

The lack of lubrication on the high rail was a factor in the derailment in that the dry, rough state of the gauge face may have increased the angle of wheel-set attack and thus increased the gauge spreading force exerted by the bogie on the rail.

5.1.7 Track maintenance

Gauge is the most basic parameter of track geometry and must be maintained to allow the safe passage of trains. The track in the area of the derailment exhibited gauge widening of an unacceptable magnitude and other faults including the lack of high rail lubrication which indicates that the monitoring and maintenance regime in this section of the main line had been inadequate.

The track where the derailment occurred is subject to a program of periodic track inspections and geometry measurement. These include track patrols five times per fortnight, front of train inspections every month, and a recording car run every three months. These track inspections form the primary defence against accidents resulting from poor or deteriorating track geometry/condition. In this instance, the inspections did not detect the poor condition of the track fastening around the point of derailment and thus failed as defences.

5.1.7.1 Inspections

The track patrols in the 110 km section of the main line between Benalla and Albury are performed using Hi-Rail vehicles. The track patrol inspections are conducted by EDI track maintenance staff who are experienced in assessing the condition of the track and identifying areas which need maintenance. In the days leading up to the derailment, (and indeed the day before) the track patrols in the Wodonga area did not identify the section of 'working' track around the point of derailment, nor did they identify that the high rail lubricator was not working. The ballast obscuring the fasteners on the outside of the high rail would have made a thorough inspection of the track difficult. The bright condition of the high rail gauge face, and the likely condition of some of the fasteners inside the high rail around the point of derailment, indicated that a closer inspection of the track was warranted. One possible explanation for the apparent lower level of vigilance in this area of track may be that the fact that it lies within the station yard, has a 40 km/h speed limit, and is at end of a maintenance area.

The last front of train inspection of the area of the derailment was conducted by the area maintenance supervisor on 1 April, 24 days before the derailment. During this inspection the maintenance supervisor was looking for areas of track exhibiting defects which adversely affected the ride of the train. Given the pre-existing alignment of the track in the area, and the low speed of the train, it is unlikely that the maintenance supervisor would have identified any additional 'abnormality' in the ride of the train to indicate the presence of any gauge widening around the point of derailment.

There is evidence to suggest that the curve between the High Street and Hovell Street level crossings was a relatively high maintenance section of track and warranted close scrutiny from the maintenance staff. At some time in the past (approximately eight years ago) area maintenance staff fitted the Pandrol fasteners to every fourth sleeper on the high rail, presumably in response to their experience of gauge widening in this section of the curve. This history of problems, its poor alignment and several track buckles in the recent past are reasons why this area of track should have been identified as a risk and subjected to a more rigorous track inspection/maintenance regime.

5.1.7.2 Response to EM 80 trolley lifts

On the past two occasions when the EM80 recording car has run on the track in the Wodonga area, 30 November 2000 and 28 February 2001, the leading measuring trolley lifted some 20 m south of the point of derailment which resulted in the track geometry not being recorded. Any gauge widening trend around the point of derailment may have been detected if the geometry of the track had been recorded on these occasions. The trolley lifts at these times and the adequacy of the subsequent response, are thus factors (failed defences) in the derailment of the XPT on 25 April 2001.

A trolley lift report was issued to the area maintenance supervisor in the recording car by the car operator in November 2000 and February 2001 in accordance with standard procedures. Neither report stipulated a cause for the trolley derailing with the February report commenting 'very tight curve, large line values'. The maintenance supervisors notes taken on 28 February state '301.140 gauge derail sharp curve' with a note is his diary stating 'Inspect trolley derailment 301 km (worn rail)'. When interviewed, the maintenance supervisor indicated that he had inspected the track after each trolley lift in November and February. He indicated that he had taken gauge measurements and had attributed the trolley lifts to the worn gauge face on the high rail.

The Weltrak report stated with respect to the trolley lifts:

> The rail is not sufficiently worn to cause a gauge excedent or to derail a measuring trolley. It is a common error to assume that gauge problems found by the Recording Car on sharp curves are due to rail wear.

And further:

> Derailment of the gauge measuring trolley is more likely to be due to a combination of the very sharp alignment, the shape of the rail on the gauge corner and the trolley wheel profile. Automatic trolley lift would then be triggered by trolley derailment.

CEC 7/86 stipulates that all derailments of trolleys must be followed by a detailed investigation. Despite these requirements, the inspections undertaken by the area maintenance supervisor after the trolley lifts were insufficient to identify any developing trend with regard to gauge widening around the point of derailment. In any case, like the track inspectors, the inspection of the high rail in February would have been hampered by the ballast covering the fasteners, discharged six days before.

5.1.8 Fastening project management

ARTC project RT052 involved the fitting of resilient fasteners on all main line timber sleepers on the Melbourne-Albury corridor. The track where the derailment occurred was fitted with resilient fasteners on both the high and low rails in January 2000. The management and execution of the project directly affected the quality of the track structure in the curve where the derailment occurred. The low number of sleepers renewed, the decision not to regauge and the fitting of an inadequate number of spring spikes during the project were all precursors to the derailment of service 8622 on 25 April 2001.

The project specification called for curves under 800 m radius to be regauged. Minutes from the project meeting on 12 January 2000 indicate the decision not to regauge the curve was made at this time despite the fact that it had a radius less than 800 m. It appears the decision was based on the poor condition of the sleepers and the fact that Pandrol fasteners were fitted on every third sleeper. This decision not to regauge the curve led to a static gauge 17 mm wide at the time and place of the derailment. Had the curve been regauged to 1435+5 mm as stipulated in the project specification, with the consequent replacement of substantially more sleepers, it is unlikely that the derailment would have occurred.

The decision not to fit four spring spikes per sleeper plate in the curve at the time the TrakLok fasteners were fitted, played perhaps a more significant role in the derailment than the decision not to regauge. Fitting the additional spikes would have provided the TrakLok fastenings with substantially more resistance to wear from the repeated lateral loads of passing trains and the rate of gauge growth would have been reduced. With four fasteners per plate it is less likely that there would have been dynamic gauge up to 49 mm at the point of derailment when service 8622 passed on 25 April 2001.

The minutes of the project meetings on 12 January and 27 January 2000 both state that it was resolved to fit four spring spikes per plate on the curves of less than 300 m radius. This is in accordance with the contract and CEC standard requirements. It was also stated in the minutes that a representative from Coleman Pty Ltd would source the additional PC3 spikes from Robert Rex (General and Railway Supplies Pty Ltd). The PC3 spikes have a special profile, necessary when fitting spring spikes in the sleeper plate holes adjacent to the toe of the rail.

At the time of the derailment the PC3 spring spikes were not fitted to any of the sleeper plates in the curve. The evidence supplied to the investigation from General and Railway Supplies indicates that there they had supplied 20 000 PC3 spikes to Coleman for use on the project, only one tenth of the PC3 spikes originally estimated as being required.

ARTC project management issued a certificate of completion for the project works on the north eastern line between 266 and 304 km on 18 July 2000. Prior to issuing the certificate, the track had been inspected by ARTC project management staff on 14/15 June 2000. The inspection notes do not refer specifically to the track in the area of the derailment, and with respect to spring spikes only observe that there were a number broken which would be replaced at the end of the warranty period. The project work was accepted as complete in the area of the derailment despite the absence of the additional spring spikes. On 17 August 2000, ABB as the maintenance provider, accepted the track was ready for hand back and took full responsibility for the maintenance. The project works in the curve where the derailment occurred were not complete according to the terms of the contract and ARTC should not have issued the certificate of practical completion nor should ABB have accepted full responsibility for the maintenance of track which did not meet the required standard.

At interview, the track maintenance staff in the area of the derailment indicated that they had expressed some concerns to management over some aspects of the fastening project including the timing of the sleeper renewals and the tamping of the track after the sleeper replacements. In the curve where the derailment occurred, sleeper replacements were made in summer but not tamped immediately which led to several track buckles on hot days over the period. The area maintenance staff also indicated that they had little direct input into the scheduling of the project works and were not informed on regular basis what project works were being carried out and where, within their maintenance area. They were aware that the track around the derailment site did not meet the standard, with respect to the spring spikes, specified in the CECs but indicated that they expected that the contractor would be back to fit the additional spikes at some time. The evident lack of communication, coordination and consultation with area maintenance staff, directly responsible for the 'health' of the track, is further indication of inadequate project management.

5.1.9 Other track factors

The track where the derailment occurred was in a relatively poor condition. The alignment was poor, the sleepers were in a poor condition and the rails were inadequately fastened. In addition, the decision not to regauge and the low number of sleepers replaced during the resilient fastening project suggest that there has been a decision to minimise capital expenditure in the area of the derailment in the recent past.

The Wodonga by-pass and gauge standardisation projects have been under consideration for a considerable period of time and have involved consultation with ARTC. Both of these projects involve major infrastructure works in the Wodonga area which would be expected to result in the re-alignment and/or by-pass of the track where the derailment occurred. Given the relative certainty that one or both projects would eventually proceed, they may have influenced ARTC's short term management strategy in relation to the track in the area. As a result of the Wodonga by-pass project, ARTC decided not to proceed with realignment project VC06, taking a longer term, strategic approach to capital expenditure.

5.2 Vehicle factors

There were some factors inherent in bogie NHA 198B which led to it alone derailing when other bogies in the train passed safely over the derailment site. The thin flange on number-1 wheel and a below tolerance wheel back to back dimension of the leading wheel-set effectively reduced the amount of the inner wheel tread which remained on the inner rail of the curve. The relatively high rotational stiffness of the bogie due to the poor condition of the yaw friction surfaces (side bearer plates) had the effect of increasing the gauge spreading/rail rolling forces the bogie exerted on the track. Analysis suggests that individually none of these factors would have resulted in bogie NHA 198B derailing, it is only the cumulative effect of all of the factors which led to the derailment.

Given the condition of the number-1 wheel flange and side bearer plates on bogie NHA 198B, the maintenance of XPT rolling stock must also be considered to be a factor in the derailment.

Other possible contributing factors were considered during the investigation including the likely dynamic forces through the train due to coupling effects and the possibility of a 'hit up' due to differential powering or poor synchronisation between the leading and trailing power cars. These factors were eventually discounted on the basis of timing based on the driver's statement and analysis of the Hasler tapes.

5.2.1 Flange thickness

Bogie NHA 198B, the flange on the number-1 wheel was measured at 18 mm, 1 mm below State Rail's current condemning limit of 19 mm. It was the thinnest flange on the bogie by more than 3 mm.

The XPT maintenance records of wheel flange wear measurements reveal when last measured on 15 March 2001, approximately six weeks before the derailment, the number-1 wheel flange was the thinnest on the bogie at 21.7 mm. Thus in six weeks this flange experienced wear of approximately 3.7 mm. This is more than twice the wear of the number-2 wheel flange which had worn only 1.42 mm in the same period. Both wheels should experience similar amounts of flange wear as they are both on the bogie's leading wheel-set and act to steer the bogie. Indeed past measurements show that the number-2 had maintained a similar, albeit slightly lower, rate of wear to the number-1 wheel up to the time of the measurement on 15 March.

There are several possible reasons why the number-1 wheel flange had experienced a higher rate of than other wheels on the bogie. These include the steering function of the wheel and less than optimal bogie tracking.

The maintenance records show that the flanges of the leading wheel-sets on XPT bogies at either end of a carriage wear at a higher rate than the trailing wheels as the leading wheels act to steer the bogies through curves. In tighter curves (generally <600 m radius), there is saturated wheel flange contact with the outer rail head, and thus higher flange wear rates. On XPT bogies the rate of flange wear is not linear with respect to time with very high initial flange wear taking place after wheel-sets are renewed or machined. Once the 'new' wheel profiles have worn sufficiently to increase the flangeway clearance and achieve a worn tread profile, the wheels track with less flange contact and the rate of flange wear decreases. Each wheel flange wears at a slightly different rate and thus it is difficult to predict exactly when a wheel flange will reach the thickness condemning limit.

Bogie tracking has direct impact on the rate of flange wear. A bogie may track poorly with flange contact on straight track for a number of reasons, these may include less than ideal wheel/rail profile matching, poor bogie geometry or mismatched wheel diameters. When negotiating curves, all of these factors may effect the bogie tracking in addition to the bogie's ability to self-steer based on its suspension design and the condition of its suspension components. All of these factors were considered in respect of bogie NHA 198B. Checks of the bogie revealed that its geometry was satisfactory, but the rolling radius difference between the wheels on the leading wheel-set and the condition of the side bearers may have had an adverse effect on the bogie's tracking. The condition of bogie's suspension members, particularly the side bearer plates, was also considered in detail.

Wheel number-1 was 2 mm smaller in diameter than wheel number-2. Different diameter wheels on the same axle have the effect of making the wheel-set track to allow the wheel conicity to equalise the rail contact diameters of the wheels. The Interfleet Technology modelling showed that the difference in rolling radius was sufficient to cause the bogie to track with the number-1 wheel flange very close to the rail head on straight track. This means there would have been hard flange contact even in relatively large radius right hand curves and consequently a high rate of wear on the number-1 wheel flange. Machining records for the last wheel turn on 7 November 2000 indicate that the number-1 wheel diameter after turning was 0.9 mm smaller than the number-2 wheel. This exceeds the allowable machining tolerance of 0.5 mm and may be why the number-1 wheel tread, with a slightly smaller initial rolling circumference, appears to have worn faster than the number-2 wheel in the 5 months before the derailment. The static wheel loads of bogie NHA 198B measured during the previous overhaul showed that the number-1 wheel was 200 kg 'heavier' than the number-2 wheel. This is within tolerance and it is difficult to predict any dynamic consequence as a result of the different static wheel loads. Previous wheel turn records indicate that both wheel treads had been wearing at a similar rate between machining in the past and this infers that the wheel loads and wheel material is not likely to be a factor in the differing rates of tread/flange wear.

5.2.2 Wheel back to back dimension

Like the thin flange on number-1 wheel, the slightly reduced back to back dimension of the leading wheel-set had the effect of reducing the amount of the number-2 wheel's tread remaining on the inner rail. Although only 1 mm under the specified minimum tolerance of 1358 mm, the wheel-set back to back dimension was a contributing factor as to why bogie NHA 198B derailed and others did not. If the back to back dimension for the leading wheel-set had been the maximum allowable at 1360 mm, there would have been 3 mm more of the number-2 wheel tread on the inner rail at the point of derailment before taking any rail roll into consideration.

5.2.3 Bogie side bearers

The rotational resistance of the bogie NHA 198B was a factor in the derailment. The condition of the bogie's side bearer plates and their mating carriage plates was found to be poor. The low friction bearing insert material in each side bearer plate was worn, broken and degraded to such an extent that there was dry metal to metal contact occurring between the side bearer plates and the mating plates on the carriage. The condition of the constant contact side bearers as found would have had an adverse effect on the bogie's ability to track efficiently in tight curves.

The dislodged locating pin found on the bogie bolster after the derailment and the damage to the 1-3 side bearer plate and bogie bolster that indicated the pin had been lodged under the plate at some time also required analysis to decide whether it was factor in the derailment or was a result of it.

5.2.3.1 Side bearer locating pin

The damage to the 1-3 side bearer plate on bogie NHA 198B, its mounting surface on the bogie bolster and the locating pin found on the bolster after the incident was unusual. The shape and location of the indentations on the bottom of the side bearer plate, and the deformation around the locating hole in the side bearer mounting surface on the bolster, indicated that the locating pin had been trapped under the plate in two different positions at some time. The side bearer plate was also deformed where it had been seated 'cocked' on the locating pin and had been subjected to the weight of the carriage.

The amount of corrosion and wastage on the locating pin threads suggests that the locating pin must have been very loose in the side bearer plate prior to becoming dislodged.

The amount of wear on the end of the side bearer plate that had been sitting raised by the locating pin was compared with the rest of the plate. It was found that the 'cocked' end was approximately 0.1 mm thinner than other areas of the plate. This suggests, in addition to the lack fretting evident on the locating pin and plate, and the absence of any 'road dust' on the bolster mounting surface under the plate, that the pin had been lodged under the plate for a relatively short period of time. It is also considered unlikely that repeated train examinations, including the trip inspection the previous afternoon, would have failed to detect a 'cocked' side bearer plate on bogie NHA 198B.

The NHA bogies have had some problems with the locating pins falling out of the side bearer plates in the past. In these instances, the locating pins have been vibrated out of the threaded holes in the plates and fallen through the locating hole in the side bearer mounting surface onto the bolster below. In the past, when a locating pin has fallen out, the side bearer plate has usually become rotated on its seat with the train examiners detecting the problem at the maintenance depot. Given the history of these problems, the side bearer plates have become an area of focus for the XPT maintenance staff who have made several modifications to the side bearer plates and specifically scrutinise these areas of the bogies during a train inspection.

The various marks and damage to the side bearer plate, its mounting surface and the locating pin suggest that a possible sequence of events was:

- the bogie dropped quickly enough away from the carriage, which would have been partly suspended by its leading coupling, for the carriage weight to be momentarily suspended clear of the side bearer plate, immediately followed by,
- the side bearer plate lifted (or was forced) upwards from its mounting surface on the bolster until the locating pin cleared its locating hole, (the car centre pin assembly allows the car to lift approximately 40 mm clear of the bolster before the bogie starts to be lifted by the car off the track),

- the carriage weight came back onto the side bearer plate, the head of the locating pin made contact with the mounting surface, stood momentarily, and with increasing weight, collapsed side-ways with any remaining thread pulled out of the side bearer plate, which caused the,
- the side bearer plate to be rotated slightly off its seat to leave the locating pin lying horizontally across the mounting surface with its head in the locating hole and its threaded end adjacent to its hole in the side bearer plate.

The second indentation on the bottom of the side bearer plate and the top of the mounting surface was probably caused when the locating pin moved due to the rotation of the bogie or possibly during the re-railing process.

A possibility considered was that the locating pin may have been dislodged at the time that the passenger attendant reported hearing the ‘bang’ and feeling carriage ‘E’ drop shortly after the train had left Albury and just before the train derailed. The passengers in the carriage who were interviewed could not confirm the event, however it is possible that the carriage may have ‘bottomed out’ while travelling over the transition onto the open top Murray River bridge. Detailed consideration of the event as described by the passenger attendant led to the conclusion that it is unlikely that this particular ‘bottoming out’ would have provided sufficient opportunity for the pin to become lodged under the side bearer plate.

The Technical Analysis unit of the ATSB examined all side bearer and mating carriage plates from carriage XF 2214 and the locating pin from the 1–3 side bearer of bogie NHA 198B. They concluded that the locating pin became trapped between the side bearer plate and its mounting surface on the bogie bolster during the abnormal bogie motions during the derailment. The most probable time was when or shortly after the bogie derailed when the ex-train driver at the High Street crossing indicated that he saw the bogie was ‘bouncing’ at a high frequency. The wheel flange marks on the sleepers in the four-foot also indicate that the bogie was tracking highly skewed with respect to the carriage shortly after derailing before the bogie crossed High Street. At this time the bogie over-rotated to the extent where damage was caused to both side bearer plates as they made contact with the heads of the bolts securing the mating carriage plates to their mountings on the carriage. The over-rotation combined with the bogie riding low and bouncing on the shoulder ballast could have provided the right mechanism for the locating pin to become wedged under the side bearer plate.

5.2.3.2 Bogie X factor

The X factor is a calculated dimensionless number proportional to the rotational resistance of a bogie (or the carriage/bogie yaw torque) when the wheelbase distance and axle load are constant. In the case of the XPT NHA bogies, where the weight of the carriage is transmitted through the side bearers, their X factor is determined by the friction between the side bearer plates and their mating plates fitted to the carriage.

The state of the side bearer plates found on bogie NHA 198B indicated that there had been dry metal to metal contact occurring between these plates and their mating carriage plates for a lengthy period of time. The technical analysis unit of the ATSB found that the type of oxidation found on the side bearer plate assemblies indicated some localised heating, probably generated by friction between the plates. The mating plates on the carriage consisted of a mild steel backing plate faced with a 3 mm stainless steel sacrificial wear plate welded to it. The stainless steel wear plate exhibited grooving and wear in places up to a depth of 2 mm. The effect of such metal to metal contact between the sliding faces on the side bearers is to increase the rotational resistance of the bogie, which in turn affects the bogie's ability to track effectively in curves. In the worst case scenario, the bogie assumes a 'jamming' position in the curve which may increase the gauge spreading force by up to six times the 'chordal' tracking force for a curve of 174 m radius (Weltrak report). In the case of this derailment, the 'less than optimal' bogie tracking effectively increased the gauge spreading forces on the track at the point of derailment and may also have contributed to the high rate of flange wear on the number-1 wheel.

The design X factor of a bogie is almost invariably a compromise. For a bogie to steer optimally in tighter curves, (generally less than 600 m radius), a low X factor is required. However if the X factor is too low the bogie will tend to hunt at speed on straight track. As a result, the design X factor is carefully considered and a material is selected for use on a bogie's secondary yaw friction surfaces which provides the appropriate balance between the desired curving behaviour and ride stability at normal operating speeds on straight track.

The Interfleet Technology report states that the appropriate value for the bogie design X factor is 0.05 with the corresponding value of side bearer friction coefficient $\mu = 0.12$. When modelled on a 175 m radius curve at 36 km/h with 40 mm installed cant this led to a total gauge spreading force of 45.1 kN. For bogie NHA 198B at the time of the derailment, the actual side bearer friction coefficient would have been considerably higher due to the dry metal to metal contact at the side bearers and would have been in the range of $\mu = 0.3$–0.5 to yield X = 0.13–0.20. In this case modelling revealed that the total gauge spreading force would have been higher at 53.8 kN for X = 0.20. Thus the effect of increasing friction at the side bearers is to increase the potential gauge spreading forces exerted on the track by the bogie.

The increased gauge spreading force due to the effect of the increased friction at the bogie's side bearers is only one contributing factor. It must be considered in combination with the dynamic gauge widening ('kink') at the point of derailment and the lack of gauge face lubrication on the high rail and possible higher angle of leading wheel-set attack. Considering all of these factors, the peak gauge spreading force exerted by the bogie could have been even higher than the 70 kN predicted in the Interfleet Technology modelling.

5.2.4 Vehicle maintenance

The condition of the number-1 wheel on the leading axle, and the side bearer plates on bogie NHA 198B were factors in the incident. The condition of these components raise some questions about some of the operating and maintenance decisions and practices relating to the bogie and XPT rolling stock generally, which pre-dated the incident.

5.2.4.1 Flange thickness

The State Rail decision in December 1999 to reduce the wheel flange thickness condemning limit from 25.4 mm to 19 mm, the freight wheel standard, had a direct impact on the derailment. If the number-1 wheel flange had been 6.4 mm thicker, there would have been commensurately more of the number-2 wheel tread on the low rail and thus a reduced probability that the bogie would have derailed. A thicker flange on number-1 wheel would also have presented a lower angle of incidence to the high rail and the lateral force on the rail would have been reduced as a consequence.

When State Rail applied to RAC for the 'engineering concession' to run the thinner flanges, RAC made comparisons between the differing material, strength and fatigue resistance of the XPT wheels with respect to standard freight wheels. They concluded that 'the operation of XPT wheels with a minimum flange thickness between 19 mm–22 mm, and a maximum speed of 130 km/h is considered to be acceptable'. XPT wheels are nominally 127 mm in overall width, including the 6 mm chamfer on the wheel rim. Freight bogie wheels have a minimum width of 130 mm and are up to 140 mm wide for higher axle load rolling stock, 3–13 mm wider than the XPT wheels. It is not clear whether State Rail or RAC considered the fact that XPT wheels are thinner when the decision was made to reduce the minimum flange thickness to 19 mm. An XPT bogie with a 19 mm outer wheel flange will have 3–13 mm less inner wheel tread on the inner rail than a freight bogie when negotiating a tight curve.

As a part of the 'engineering concession' State Rail agreed to regularly inspect the flange thickness of wheels in the 19–22 mm range to ensure that a wheel did not enter service with a flange below 19 mm. The number-1 wheel on Bogie NHA 198B had a flange thickness of 18 mm and thus should not have been in service. The flange monitoring program at the XPT maintenance depot did not detect that this wheel flange was below the minimum acceptable thickness.

5.2.4.2 Side bearers

The side bearer plates on bogie NHA 198B exhibited a complete breakdown of the low friction bearing insert material (Fluon VX2). This allowed the metal to metal contact with the carriage plate. XPT maintenance practice in the past has been to renew the side bearer plates only when the bogies are changed on a carriage.

XPT maintenance staff from State Rail indicated that the poor condition of the side bearer plates on bogie NHA 198B was typical of a bogie with its time service. The side bearer plates from the other bogie on carriage XF 2214, and the plates from carriage XF 2220, with the same time in service, exhibited similar wear. Evidence from British Rail indicates that they regularly find the side bearer plates from BT 10 bogies fitted to their High Speed Trains in a similar condition. Thus the pattern of wear on the side bearer plates taken from bogie NHA 198B, although less than optimal, is considered to be 'normal'. The maintenance staff indicated that have had difficulty sourcing a dry bearing material with the appropriate friction characteristics capable of lasting the time between bogie exchanges when subjected to the aggressive service conditions experienced at the constant contact side bearer.

The carriage plates also exhibited severe wear to their stainless steel facing plates, the result of prolonged contact with the mild steel of the side bearer plates. The staff from the XPT maintenance centre indicated that the carriage plates were probably original and fitted when the carriage was built in 1986. Prior to the derailment, the carriage plates were not subject to any planned maintenance and were not routinely changed when bogies were exchanged.

To maintain the design X factor of the bogie and consequently optimal bogie tracking, both the carriage plates and the side bearer plate bearing surfaces must be maintained in a serviceable condition. Neither the carriage plates nor the side bearers on carriage XF 2214 could be considered to be serviceable and this suggests that the maintenance has been deficient in this area for some time.

It is of note that the State Rail wheel management committee's plan for continuous improvement included:

> Study Bogie Dynamics to determine if improvements can be made to wheel wear characteristics by improving:
>
> - bogie rotational stiffness
> - constant contact side bearer material...

It is clear from these recommendations in the wheel management committee's report that State Rail had considered the problem of the side bearer material and possibly less than optimal bogie tracking prior to the derailment if only in the context of managing wheel wear. At the time of the derailment, State Rail had taken no action to implement these recommendations.

6. CONCLUSIONS

The following conclusions identify the different factors contributing to the derailment and should not be read as apportioning blame or liability to any particular organisation or individual.

6.1 Findings

The derailment of XPT service 8622 at approximately 1540 on 25 April 2001 between the High Street and Hovell Street level crossings in Wodonga was the result of a combination of factors including:

- The inadequately fastened high rail in the 175 m radius section of curve which resulted in gauge widening of up to 49 mm at the point of derailment. The fastenings also allowed the high rail to roll an additional 18 mm or more to allow the number-2 wheel of bogie NHA 198B to drop off the low rail.
- Factors which led to bogie NHA 198B alone derailing include:
  - the thin flange on the number-1 wheel,
  - the under specification back-to-back wheel measurement on the leading axle,
  - the poor condition of the yaw friction members on the bogie which led to the number-1 wheel subjecting the high rail to higher than usual lateral loads.

It is considered that:

- The locating pin and friction material found on the bolster of bogie NHA 198B after the derailment was a result of the derailment.
- The train was being driven in accordance with accepted practice and in compliance with the speed restrictions in force at the time.
- The response to the derailment by the train crew, local signal staff, train control and the other parties involved was in accordance with the relevant incident management procedures.

6.2 Contributing factors

- The poor alignment of the curve in the area of the derailment led to the high rail being subjected to relatively high lateral loads from passing trains including the train that derailed. This led to an increased rate of rail fastening deterioration and ultimately the derailment.
- The poor condition of the sleepers around the point of derailment had an adverse impact on the initial strength of the high rail fastenings.
- The shoulder ballast covering the fastenings on the field side of the high rail in the area of the derailment inhibited the effective inspection of the track. As a result, the failure of the high rail fastening and gauge widening around the point of derailment remained undetected prior to the incident.
- The lack of high rail lubrication may have led to a higher angle of attack for the leading wheel-set of the bogie and thus an increase in the gauge spreading force on the track at the point of derailment.

- The track maintenance regime prior to the derailment did not identify the curve where the derailment occurred as a 'significant risk' and focus sufficient effort on its monitoring/maintenance.
- The investigation of the track geometry after two successive recording car trolley lifts in the area of the derailment was insufficient to detect any developing trend in respect of gauge growth.
- The number of spring spikes fitted to the TrakLok fasteners in the curve during the resilient fastening project was insufficient and did not comply with accepted standards or the terms of the project contract.
- The decision not to regauge the curve during the resilient fastening project led to static gauge up to 17 mm and a relatively low rate of sleeper renewal around the point of derailment.
- The poor communication and coordination between line maintenance staff and project management staff during the resilient fastening project led to the works at the site of the derailment being accepted as complete despite not meeting the required standard.
- Minimising capital expenditure on the track in the area of the derailment, pending an agreed longer term solution, evidenced by various aspects of the resilient fastening project, had a significant impact on the quality of the track at the time of the derailment.
- The decision to reduce the XPT wheel flange thickness condemning limit from 25.4 mm to 19 mm indirectly led to number-1 wheel of bogie NHA 198B being in service with a flange thickness of 18 mm at the time of the derailment.
- The XPT flange thickness monitoring program did not detect that the number-1 wheel on bogie NHA 198B was below the minimum acceptable thickness at 18 mm and a more rigorous monitoring regime may have mitigated the increased risk from the change to the flange thickness condemning limit.
- The XPT maintenance program has not addressed the long term issue of NHA bogie side bearer serviceability.

7. SAFETY ACTIONS

7.1 Recommendations

The following recommendations are not designed to be prescriptive or exhaustive and are made in the recognition that some of the issues raised have already been addressed or are being addressed by the organisations involved.

- It is recommended that ARTC ensure that the Victorian track under their control meets the requirements of the PTC Civil Engineering Circulars with respect to the number of spring spikes fitted to sleeper plates on curves.
- It is recommended that ARTC ensure that the Victorian track under their control has ballast regulated to allow all track fastenings to be effectively inspected.
- It is recommended that ARTC track project management practice in future includes effective consultation and communication with line maintenance staff to ensure that contracted track rectification and maintenance activities are properly coordinated and completed.
- It is recommended that line maintenance practices in future include sufficient risk assessment to ensure that vulnerable sites are adequately monitored and maintained.
- It is recommended that XPT maintenance practices are reviewed to ensure that their rolling stock in service meets the required standards with regard to wheel flange thickness.
- It is recommended that XPT maintenance practices are modified to improve the serviceability of the NHA bogie side bearer friction surfaces and ensure that the design X factor of the bogies is maintained.
- It is recommended that Countrylink implement their Emergency and Evacuation Preparedness Plan as a priority and provide the necessary training for their train crews.

7.2 Safety actions taken

The following safety actions have already been taken by various organisations in response to the derailment of XPT service 8622 at Wodonga on 25 April 2001.

7.2.1 Track

EDI have performed a considerable amount work on the track in the area of the derailment including:

- a substantial number of sleepers have been renewed in the curve where the derailment occurred,
- sleeper plates in the curve have been fitted with four fasteners,
- a new high rail gauge face lubricator has been fitted to the curve,
- the ballast has been removed from the high rail fasteners in the curve.

Australian Rail Track Corporation Ltd have addressed issues raised by the derailment by:

- checking all curves with a radius less than 300 m on Victorian track under their control for compliance with PTC Civil Engineering Circular fastening requirements and fitting additional spring spikes where necessary,
- the regulation of ballast on Victorian track under their control to remove ballast covering rail fastenings where necessary,
- the introduction of refined project management practices to improve the consultation and communication between line maintenance staff and third party contractors which include new procedures for the inspection, and hand over at the completion of project works,
- the establishment of systems for risk identification, review, monitoring, amelioration and the revision of infrastructure inspection and maintenance procedures and standards.

7.2.2 Rolling stock

State Rail have also responded to some issues raised by the derailment by:

- modifying their monitoring procedures to ensure that no XPT rolling stock enters service with a wheel flange thickness less than 19 mm,
- modifying the NHA bogie side bearer plates with the fitment of a new bearing insert material,
- initiating a program to renew all carriage side bearer mating plates when bogies are exchanged,
- the implementation of their Emergency and Evacuation Preparedness Plan for Countrylink operations.

APPENDIX 1

Report prepared by Weltrak Pty Ltd

SUMMARY

Following the derailment of the XPT at Wodonga on the 25th April 2001, site and vehicle inspections were made. Information from these inspections, together with data from ARTC, and SRA were considered in the light of experience with other derailments.

The track contained a serious level of available gauge widening. It had remained undetected due to being covered with ballast, and being missed by the track geometry car when trolley lift occurred on the last two runs.

The XPT car which derailed had a loose pin which lodged in its 1-3 side-bearer. If this had occurred prior to derailment, forces derived from this condition and the sharp curvature would have contributed significantly to spread of gauge.

This report reviews contributing factors among the physical aspects of the derailment and also factors associated with the maintenance systems involved.

CONTENTS

THE TRACK AT THE SITE

1.1 Background

The derailment location established by ARTC officers was at kilometrage 301.105 km from Melbourne, on the Standard Gauge interstate line. The site is just east of Wodonga Railway Station, between Hovell Street and High Street level crossings. The track is sharply curved to the right in the direction of travel. The grade of the track is understood to be 1 in 75 (climbing in the direction of travel) but close to where it becomes level.

Standard gauge track has existed south of the Murray River since a permanent wrought iron bridge was built over the river in 1884, and the track was incorporated into the Standard Gauge (S.G.) interstate line in 1962 although with modified alignment. The track at the derailment site formed the mainline leg of the triangle connection to the Bandiana branch. This branch has served the Army facilities established during the 1940's and the Wodonga Coal Sidings before then. The southern (Up) end Broad Gauge (B.G.) connection was removed recently.

The track structure appears to be based on former Victorian Railways requirements namely 47 kg/m rails and timber sleepers, nominally 2590 x 254 x 127 mm (8'6"x10"x5"), although it is not clear what the design spacing is. The rails have been supported on 'double shoulder' sleeper plates fastened with square dog-spikes. Subsequent work has included the fitting of resilient clips using the Rex-Lok-In system on existing plates and also the later introduction of some Pandrol E clips on cast s.g. iron sleeper plates, prior to the derailment.

1.2 Track Geometry

1.2.1 Design Geometry

The design geometry for this curve was shown in the PTC Curve Register dated 6 September 1995. The curve is the first on the Up end of a compound curve which runs from 301.060km to 301.630km. The details for the derailment site curve are as follows.

- From 301.060km to 301.190km
- Radius 175m
- Superelevation (Track Cant) 40mm
- Alignment Transition Up (Melbourne) End ------- **Nil**
- Alignment Transition Down (Albury) End -------- 50m
- Cant Transition Up (Melbourne) End ------- 25m
- Cant Transition Up (Albury) End ------------- 25m

1.2.2 Track Gauge

The gauge for a curve can depend on the radius being applied. Normally gauge should be 1435 mm. However the design radius approaching the derailment site was 175m for which radius some deliberate widening (3mm) is applicable, according to PTCV Circular 3/87. For the purposes of this assessment and to assist in the wheel/rail analysis, 1435 mm is used.

ARTC information shows static gauge of 15 to 17 mm wide immediately prior to drop-in. It includes evidence of significant regular plate movement giving potential widening there of 40 to 47 mm, and of 49 mm at the point of Drop-in. Drop-in has occurred near to the centre of a group of 6 sleepers with potential widening of 35 mm or more.

Widening of this magnitude is a serious defect warranting immediate repair once found.

Wide gauge of this order does not appear suddenly but develops over many months. However the growth is likely to become exponential, as the example of a similar case shows.

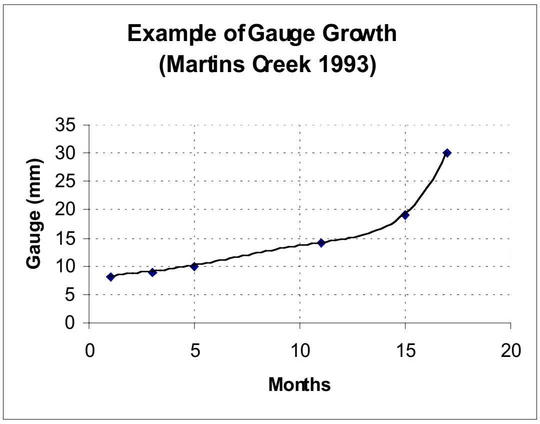


Figure 1

1.2.3 Alignment

The design of the curve at this site was clearly governed by the presence of the B.G. diamond and the S.G. turnout which used to exist, in this track between the road crossings at 300.950km and 301.220km. The design radius of 175m is the sharpest curve between Sydney and Melbourne. It is not suitable for the operation the current types of interstate freight trains and is certain to result in high levels of deterioration compared to other parts of this line.

It is noted that ARTC have a proposed realignment for this site, based on a 365m radius.

The derailment measurements show a radius of 200m then a significant sharpening of curvature down to 174m radius approaching the Point of Drop-in. The derailment appears to have occurred in the transition area close to the south end of the curve and where the design radius normally would have started to increase, not reduce.

The field data for string-lining dated 4 May 2001 shows curvature as little as 147m radius following some repair work. ***It is of some concern that alignment this sharp was left in the main line, even with a speed restriction of 15km/hr.***

The derailment measurements are not comprehensive and do not give curve data beyond the 174m segment noted above. Given the nature of the repairs done prior to survey and the adjoining 200m segment in this 175m design radius curve, it is very likely that a severe sharpening existed, where the 147m is shown, at the time of the derailment.

The absence of any transition from straight track to 175m radius can be expected to result in alignment deterioration under heavy trains. Hot weather can exacerbate the condition further. ***Alignment problems in this curve were inevitable.***

1.2.4 Cross-level

The cross-level manually measured by EDI after the derailment and that recorded by the EM80 on 28 February 2001 were compared. There appears to be a 30m difference in kilometrage, which appears to result from a variation in EM80 distance synchronisation. (There is a difference of 10m between the recordings done on 28.2.2001 and 30.11.2000 at the derailment site.) The kilometrage posts are over on the Down side of the Broad Gauge. Allowing for that difference and the EM80 measurements reflecting the track under load, the data on cross-level corresponds well. The data is shown in Appendix 1.

The derailment has occurred in the transition where the cross-level has started to reduce from the actual superelevation, of about 60mm, around the curve.

The change of cross-level up to the Point of Drop-in is not excessive. The changes shown in both sets of data are well within the normal capacity of the car XF2214 and that of its bogies. No loss of vertical wheel load is likely to be caused by the change in cross-level.

1.2.5 Track Recording Car Data

Over time there appears to have been two different Track Geometry Recording Cars used to measure the track and three different ways of interpreting the results.

For many years the NSW EM120 car ran the S.G. line and the Curve Register of 1995 specifically refers to RVX4, as it was then coded. The Victorian limits were programmed into RVX4 for each run. More recently, including November 2000 and February 2001, the former Australian National EM80 has been used. The operative instructions were found in STA Circular CEC 7/86, which is written around the Victorian EM100 used for the B.G. tracks. All three cars show parameter outputs differently on their chart.

There are different geometry limits applied along the same track between Melbourne and Albury. This arises because there are different sets of limits according to the "Line Speed". On the S.G. the Line Speed between Chiltern and Wodonga Loop is 130km/hr, between Wodonga Loop and Wodonga it is 115km/hr and from Wodonga to the Murray River it is 80km/hr. This seems overly complex given that the track loading and track deterioration is governed much more by the actual curve Speed Board speeds. A 40km/hr curve will experience the same order of loading and deterioration whether it is in an 80 or a 130km/hr Line Speed area.

It is unlikely that field staff involved with this track would have a good understanding of the Recording Car results in these circumstances.

Trolley lift is a feature of many mechanical contact measuring systems. It has the effect of stopping measurement of most parameters. A manual check is normally required in the area of track involved. Track cant or superelevation can be measured with the use of a gyroscope and is not affected by the lift. Twist can be calculated from the superelevation by the system programme on the car.

The charts from the two most recent recordings were reviewed. In the section with trolley lifted, immediately after the Point of Drop-in the charts show a twist, which has grown from 34mm in November to 43mm in February. It is not clear how the track maintenance system has dealt with it. While this twist would not effect the derailing wheels, action on it could have brought the gauge problem to notice in the absence of any other response.

1.3 Track Material

1.3.1 Rail

The rails at the derailment site are 47 kg/m. Their age was not established but the rails are assumed to date from around 1962.

Rail wear is modest. The profiles show 1mm worn from the top of the low (inner) rail and 3mm from the top and 8mm from the gauge face of the high (outer) rail. The wear on the high rail is consistent with regular deflection of the head of at least 3mm. The low wear and the stiffness of the rail section means that the deflection is achieved by roll of the rail under load.

No information was available about the rail adjustment of the curve, and therefore the likely stress state of the rails is not known. However, the alignment discussed above suggests that any excess steel may have been relieved prior to the derailment.

1.3.2 Sleepers

The appearance of the sleepers suggests that many were 18 to 20 years old at the time of the derailment. Some younger sleepers had been installed more recently. The former PTC kept very good records of sleeper renewals and these may give a more accurate age profile.

The condition of the older sleepers was not good, most showing one or more of the following:

- Splitting
- Worn spike holes
- Rot
- Back Cant wear

The Back Cant was usually about 4 mm deep and its effect is already included in the Gauge measurements.

It was noted that there was deflection of the sleepers under a passing freight train, which indicated flexing of some sleepers.

1.3.3 Fastenings

The fastenings were a mixture of configurations. On the low or inner rail of the curve the rail was held at each sleeper by a pair of Rex-Lok-Ins (a B296 clip held in a hook-in adaptor) fitted to a double shouldered sleeper plate held by two spring spikes (also referred to as lockspikes).

The high rail had a variety of arrangements as shown in Appendix 2.

The spring characteristics of the clips used (Pandrol E and TrakLok B296) are different, however both are able to deflect if the rail is rolled outward by a large enough force. A key difference between the fastenings is that in deflection the Pandrol clip is opened while the B296 is being closed. All clips appeared to perform in accord with design.

As the B296 is the predominant fastening component at this site, some consideration of its function is appropriate. While the nominal toe load of this clip is 10kN, past test data suggests that an average of 9kN should be used for this discussion.

The clip has a two stage deflection. The first stage lasts until contact between the upper and lower legs of the clip occurs. The available deflection is about 5mm. In the second stage the deflecting length of the lower leg is shorter and ultimately acts with the upper leg. The resulting spring is very stiff and, for our purposes, its deflection can be ignored. The spring rate for the first stage is understood to be about 0.9kN/mm.

The lateral load required to overcome the toe load and roll the rail to the full extent of deflection depends on the wheel load and wheel and rail profiles. For this case the necessary lateral load is estimated to be in the order of 50kN.

All sleepers in the vicinity of the derailment showed evidence of high rail plates being regularly pushed outward, adding up to 32mm rail play to the static track gauge.

The PTCV has specific instructions for the use of spring spikes set out in Circular CEC 2/91. Though not clearly stated the circular refers to use with resilient clip fastenings. For curves of radius 300m and less, it calls for four spring spikes per plate to be used. It recognises the higher lateral forces acting on the rail in these sharper curves and the capacity of the timber to cope with the direct bearing pressure of spikes under lateral load.

The use of four spring spikes is still appropriate with the Rex-Lok-In system in these curves for the same reason. This has not been put into practice at the derailment site. ***There were insufficient spikes to resist lateral forces and effectively hold the sleeper plate in place on the sleeper.***

Play was also present at plates fastened using screw spikes. With the failure (movement) of the other plates, large loads are transferred to the stronger fastenings, which then fail in turn.

1.3.4 Ballast

The ballast is crushed stone of typical main-line size. The top-most ballast was clean and free draining but the lower material showed some fouling. The shoulder ballast had recently been replaced with crushed rock of slightly larger grading. From its appearance this had been done within the last two years.

The ballast profile was full and, in addition, the new shoulder ballast was heaped on the sleeper ends. It covered the top of the sleepers and the rail foot on the outer side of the curve. ***The ballast obstructed a proper inspection of the fastenings and plate movement and had done this for some time.***

The quality of the ballast is not a factor in this derailment, but its profile appears to be one.

1.3.5 Lubrication

The gauge face of the high rail of the curve exhibited a bright rough surface when inspected on 27.4.2001. The plucking and pitting of the surface indicated a high rate of local wear consistent with a lack of lubrication. It understood that the lubricator had been empty for at least two weeks before the derailment.

The condition of the gauge face was evidence of high flange forces and a high coefficient of friction eg in excess of 0.5 on the high rail. This compares to the normal smooth surface of the opposite low rail where the coefficient of friction would be much lower. This may affect the angle of attack of the wheel-set.

1.3.6 Construction

The track structure was not uniform as result of the differing sleeper plates and fastening arrangements. This affects the way the track handles the loads imposed on it and makes deterioration less predictable. It is less than best practice but can provide an adequate track structure, ***if properly maintained***.

1.4 Track Maintenance

1.4.1 History

It is not clear as to the sequence of maintenance actions at this site prior to the derailment but several had a direct influence on the derailment.

- **Diamond Removal** – When the Broad Gauge diamond was removed from the Standard Gauge line no improvement to the alignment was made. The diamond was the sole cause for the non-transition shape of the curve at the derailment site, yet nothing was done to change the unsatisfactory geometry when it was removed.

- **Shoulder Cleaning** – There are two issues here. How long before the derailment was it done? For how long was the ballast obscuring the track plates and fastenings? Another concern is the effect of hot temperatures on the track alignment at the time it was done or immediately after.

- **Track Patrol** – Track patrol is often the last line of defence against a deteriorating condition. The system has failed in this case. When was the last patrol on this site? Is there a process to be followed when ballast prevents an inspection being made?

1.4.2 Response to EM80

A review of Circular CEC 7/86 shows two requirements related to the operation of the Track Recording Car which are relevant to this incident.

- Manual inspection of any track not recorded by the Car immediately after the run (Cl. 3.4). There is no indication that this was carried out effectively.

- All derailments of trollies must be followed by a detailed investigation (Cl. 5.6).

It is noted in the Track Supervisors diary on the 28 February 2001 to *"Inspect trolley derailment 301km (worn rail)"* and in his notebook of the run *"301.140 Gauge Derail Sharp Curve".* Any inspection made was neither sufficiently detailed nor effective.

The rail is not sufficiently worn to cause a gauge excedent or to derail a measuring trolley. It is a common error to assume that gauge problems found by the Recording Car on sharp curves, are due to rail wear.

The trolley lifts on 30 November 2000 and 28 February 2001 have both occurred about 20m south of the derailment site. Derailment of the gauge measuring trolley is more likely to be due to a combination of the very sharp alignment, the shape of the rail on the gauge corner and the trolley wheel profile. Automatic trolley lift would then be triggered by trolley derailment.

There has been a break down in the maintenance arrangements following the Track Recording Car. ***The break down has happened twice and indicates a system failure associated with response to information provided from the Car at the time of the run.***

1.4.3 Issues

There are some issues requiring comment. The first relates to the site.

This site is **a vulnerable site** because it is at the end of a maintenance area and because it is slow speed and in a station yard. Being at the end of the area means that a strong management regime is necessary to overcome the tendency for inspection frequency and rigour to slacken. Frequency is yet to be tested here but rigour does appear to be inadequate. Being in a slow speed zone and in a station yard means that a lower than standard track condition is likely to be tolerated for many months, and this has clearly occurred here.

Another issue is the number of parties involved and **the system which integrates** their information and the actions.

This site has an owner, a lessee, a maintenance provider, and a geometry measurer. It is critical that the latter three are linked in an effective system which ensures that what each do results in the track gaining or retaining its health. That system needs to have an internal quality control which picks up repeat errors or omissions in the interest of the track (as distinct from the party's legal or commercial obligations). This derailment has revealed a weakness, if not a hole, in such a system.

2 THE VEHICLE

2.1 General Description

The derailed vehicle (XF2214) was inspected at Wodonga Loop on 27 April 2001 and the derailing bogie (NHA198B from the No.1 end) was further inspected at Newport Workshops on 8 May 2001. Additional data on the wheels was supplied by SRA Rail Fleet Services. The salient issues arising from these are considered below.

The vehicle is an E**x**press **P**assenger **T**rain trailer car of around 42 tonnes mass, 24 200mm over the pulling faces and having 16 600mm bogie centres. It is designed to run at up to 160km/hr. The derailing bogie was leading in the direction of travel with the No.1 wheel travelling the high or outer rail of the curve.

The both the leading and trailing bogies are of original type, as supplied with the train in 1982 or 3. The design is based on the British Rail BT10, a well-proven bogie which regularly operated up to 200km/hr. The modifications for Australia were in lateral performance and suspension tuning to suit local standards of track geometry.

2.2 Inspection Results

2.2.1 Wodonga Inspection

The vehicle was inspected following its re-railing and placing in the loop. It was sitting on its bogies with No.1 end facing Melbourne.

An examination was made of the wheel condition, the relative damage and the disposition of loose ballast in the undercarriage area. The evidence supported reports that the leading wheel-set was first off. A very thin flange on No.1 wheel was noted.

In the course of the examination two loose components were found sitting on the top of the bolster, between Nos. 1 and 3 wheels and adjacent to the side-bearer mounting for that side. These loose parts were subsequently identified as the side-bearer face-plate and a pin which, with another, located the side-bearer shoe. It was later advised that they were from the 1-3 side-bearer and fell out when the car was lifted off the bogie during re-railing operations.

The pin showed evidence of having been dislodged for some length of time in that the thread was oxidised with a dark rust colour and had dirty material embedded in it. The pin was also worn in the shank in an unusual local and angled manner and not bent, indented or gouged, damage which might be more typical from derailment.

2.2.2 Newport Inspection

The general condition of the No.1 bogie (NHA198B) was noted. This bogie was about 18 yrs old, and in reasonable condition except for wheel wear, rubber bushes and side-bearers. The rubber bushes had clearly been damaged in the derailment whereas the other items were from in-service condition and were ready for overhaul.

The wheel-sets were checked for wheel width (127mm), back to back distance and diameter. A check of wheel flanges confirmed that of the No.1 wheel was worn beyond the minimum thickness limit.

It was noted that the 1-3 side-bearer had unusual damage. There is a hole near each end in it, at the top of a sleeve which encloses the bearer locating pin. The leading end pin was missing and the edge of this hole was dished on the field side. This appeared to be due to heavy local wear and was consistent with the lodgement of the loose pin on its side across the edge of the hole, pointing across the long centre-line of the bearer.

There was another light indentation on the bearer parallel to that centre-line and slightly nearer to the middle of the bearer. Its length corresponded to that of the loose pin.

The surface contact material on the side-bearers was broken into fragments.

2.3 Issues

There are several issues about the wheels and side-bearers which arise from these inspections and the SRA data.

2.3.1 Wheels

Profiles show that ***No.1 wheel was 1mm below the flange thickness condemning limit***. With a wheel sitting normally on a rail, the horizontal plane for flange thickness measurement is approximately 8mm above that for track gauge measurement. For The amount of wheel wear on this wheel (32-18 =14mm) has the same effect as widening gauge by 15mm at track gauge level. On the diagonally opposite wheel (No.4), the effect is 8mm on gauge.

A peculiarity noted on the XPT Trailer Car flange profiles is the progressive distortion of the back face shape, compared to the shape when new. ***It appears that these flanges bend as they wear***, with bending commencing before they have worn down to 22mm thickness. No.1 wheel flange showed up to 3mm difference in profile. It is understood that these wheels are relatively soft compared to those used on heavier vehicles. This may account for the change, however it is also indicative of the amount of work the flanges must do in curves.

A consequence of this flange profile change is the increased likelihood of lateral impacts when negotiating points and crossings, and then reduced bogie component life.

The diameter measurements done at Newport and those provided by SRA gave different results. Whether equipment calibration was done is not known, but there was only one reading per wheel at Newport while the SRA report results from three readings on each wheel, and is preferred.

The result of differing wheel diameters across a wheel-set can be increased flange wear on the lesser wheel. The difference tends to affect the steering of the wheel-set and introduce a small angle of attack between the flange of the lesser wheel and the rail. The difference in circumference (6.3mm) appears to be taken up by slippage of the lesser wheel, which shows the greater wear at the tread line. ***The diameter disparity of 2mm exceeds the 1mm working limit.***

2.3.2 Side-bearers

The side-bearer condition is a critical issue in this derailment. It affects the rotational stiffness of the bogie and hence its curving performance. From the evidence of the inspections, the 1-3 side-bearer of Bogie NHA198B has had a loose locating pin, lodged crossways between the contact faces for a time. It has also had it lodged in a different position for a very short time. As the two positions may correspond to travel before and after the derailment, this needs to be clarified.

The effect of such a foreign body in running service is to markedly increase the turning resistance of the bogie and to interfere with the load distribution from the car body.

If the pin was lodged in the contact faces by the derailment, it was clearly unscrewed and detached prior to the derailment and not securing the position of the shoe bearing the contact face.

3 VEHICLE / TRACK INTERACTION

3.1 Vehicle Balance

The approach of the vehicle (XF2214) is of particular interest in this incident. Data on superelevation, speed, curvature, has been considered to shed light on it.

The **design** geometry provides for 40mm superelevation on 175m radius. With the appropriate deficiency allowed, the speed-board speed is set at 40km/hr maximum. The balance speed, ie with no deficiency or excess superelevation, is 25km/hr. As this is similar to the actual speed, the vertical wheel loads would be close to equal on such a curve. It is to be noted that design maximum deficiency for the XPT at maximum curve speed is normally 110mm.

In the **actual** curve, the radius is about 199m with approximately 60mm of superelevation at 30m before derailment, and then changes so that the 174m radius has about 40mm of superelevation just before derailment. At 30km/hr the wheel loads should be back close to balance at the time of derailment.

3.2 Bogie Tracking

The way that the bogie moves through the curve has a big bearing on the forces on the rails. In this, the disposition of the wheel-sets is critical.

The XPT bogie is designed to run with its wheel-sets square in the bogie and has a system of rods to maintain this configuration. In this case, the arrangement has been assumed to be effective.

3.2.1 The Bogie

In curves there are two relevant boundary cases for bogie tracking. They are the **chordal** position and the **jamming** position. In the chordal position the wheels on the *same side* of the bogie are both in flange contact with the high rail. In the jamming position one wheel of the leading wheel-set is in flange contact with the high rail and the *diagonally opposite* wheel of the trailing wheel-set is in flange contact with the low rail.

In very sharp curves these two positions (chordal and jamming) reflect that of freely rotating bogies and that for those with high rotational stiffness, respectively. Under normal circumstances, a position somewhere between these two can be expected.

Some calculations were done for this site, comparing the angles of attack which can occur from these positions, in order to see the relative effects of radius change and tracking position. See Appendix 3.

The calculations show that the change of radius has only a small effect on chordal tracking but a significant effect on jamming. However in the 174m radius the difference between chordal and jamming is dramatic. The effect of the jamming position is <u>six times</u> that of the chordal position. Of the two parameters, bogie tracking position is more important than radius change, in their effect on lateral forces on the rail at this site.

A bogie, which is restrained in its capacity to conform to sharp curvature, will cause larger lateral load on the high rail than a bogie which is free to rotate as designed.

3.2.2 The Wheel-set

From the diameter measurements there is a 1mm difference in rolling radius at the tread line. There is insufficient information in the profile information to see to what extent the adverse steering on the tread line is overcome as the wheel-set traverses sharp curves.

It is clear that this difference significantly changes when the high rail rotates, moving the tread contact on the rail head towards the field side. The high rail profile indicates regular rolling (see 1.3.1 above). The No.1 wheel profile is nearest to conforming with the rail profile when the rail has rolled approximately 3.3 mm. When this occurs, the tread contact appears to shift from above the gauge corner across to the rail centre line.

In sharp curves (eg 300m radius or less), the leading flange and the rail are usually in saturated contact. Well designed and maintained wheel and rail profiles are used to steer the wheel-set, to minimise flange contact in flat curves and significantly reduce the force on rail during saturated curving on sharp curves. In this case wheel and rail profiles do not fit the requirements for this to occur.

It is unlikely that any reduction in forces on rail has been available from the profiles in this incident.

3.3 Vehicle to Vehicle Effects

In some cases the car ahead of the derailing car can increase the tendency to derail. There is insufficient data available to calculate the effect in this incident. The adjoining car XF2220 may have influenced the lateral force on the rail at the leading bogie of XF2214, but this would depend on the angle between cars and the longitudinal state of the train.

The angle between the cars is not large (in the order of 3 to 5 degrees) and is unlikely to contribute to the derailment unless there has been a bunching up of the cars due to differential powering up in the train.

3.4 Derailment Mechanism

This derailment has occurred as the result of the spreading of track gauge at 301.105km which has allowed No.2 wheel of Car XF2214 to drop in to the four-foot, the No.1 wheel subsequently being forced over the outer high rail of the curve.

The factors contributing to the spreading of the track gauge include the following.

- Fastening condition allows a potential movement of up to 32mm gauge. This is additional to the static gauge of 1455mm, which is 17mm wide, and makes a total of 49mm potential wide gauge.
- Forces on the rails from the vehicle have spread the gauge 49mm and a further 20mm to allow drop-in.

- The excess wear on the flange of No.1 wheel of bogie NHA198B has reduced the amount of spread needed for drop-in.

The factors contributing to the spreading forces on the rail include the following.

- The sharp and varying curvature of the track.
- Variations in the bogie performance of bogie NHA198B in curving due to the detached pin, and possible foreign body in the 1-3 side-bearer causing higher lateral forces than a bogie in normal running condition.

4 CONCLUSIONS

4.1 Track Geometry

The alignment of the curve varies from its design, with radius changing from 199m to 174m and sharper through the derailment site. Under the loading of heavy trains and the absence of a transition curve, the deterioration was predictable.

4.2 Track Materials

The track fastenings had an insufficient pattern of spikes to prevent plate movement and potential widening of gauge.

4.3 Vehicle Condition

The wear of the No1 wheel was a contributing factor to derailment, but more important would be any foreign body in the 1-3 side-bearer interfering with the rotation of the leading bogie.

4.4 Derailment

The derailment was the culmination of the opportunity for wide gauge and the forces from the vehicle, which were sufficient to take up the potential and go further, to achieve the gauge necessary for drop-in.

4.5 System Issues

A number of concerns emerged behind the physical attributes of this derailment.

- A failure to improve the alignment when the diamond was removed.
- The difficulty of understanding data provided by the track geometry car/s.
- The failure to investigate the track reasons for the trolley lift on two occasions.
- A failure to clear ballast from the fastenings when originally placed.
- The procedure to be followed during patrol inspections when ballast covers fastenings and prevents inspection.
- The need for more systematic track measurement after derailments.
- The adequacy of XPT side-bearer checks.
- The working limits on XPT wheel wear and flange distortion.
- Effective integration of information and action across the parties involved in this track.

WODONGA - DERAILMENT OF XPT ON 25.4.01

Track Geometry Measurements

EDI Station No.	Km	Distance from Point of Drop-in (m)	Static Gauge Variation (mm)	EDI Nett Gauge (mm)	Addl. Plate Movemt (mm)	Available Gauge Widening (mm)	Total Adjusted Gauge (mm)	EDI Cross Level (mm)	EM80 Cross Level on 28.2.01plus 30m	ARTC Radius for 30m chord (m)	ARTC Radius for 10m chord (m)	Inst. Radius (m)	Note
1	301.158	0.053	3	1438				66	60				
2	301.156	0.051	0	1435				56	62				
	301.155	0.050										250	
3	301.154	0.049	3	1438				67	61				
4	301.152	0.047	2	1437				67	64				
5	301.150	0.045	6	1441				60	65		192	184	
6	301.148	0.043	5	1440				73	63				
7	301.146	0.041	10	1445				71	62				
	301.145	0.040								201		179/250	ave IR 215
8	301.144	0.039	3	1438				62	61				
9	301.142	0.037	3	1438				60	59				
10	301.140	0.035	3	1438				63	59			216/151	ave IR 184
11	301.138	0.033	2	1437				63	58				
12	301.136	0.031	6	1441				57	59				
	301.135	0.030								199		227	
13	301.134	0.029	0	1435				58	61				
14	301.132	0.027	5	1440				60	62				
15	301.130	0.025	2	1437				61	62		188	198/192	ave IR 195
16	301.128	0.023	3	1438				59	62				
17	301.126	0.021	1	1436				60	63				
	301.125	0.020										160/147	ave IR 154
18	301.124	0.019	10	1445				60	65				
19	301.122	0.017	12	1447				55	65				
20	301.120	0.015	3	1438				54	60	174	174	198	
21	301.118	0.013	20	1455				43	57				
22	301.116	0.011	5	1440				50	55				

Wodonga-TrackGeometry .xls

EDI Station No.	Km	Distance from Point of Drop-in (m)	Static Gauge Variation (mm)	EDI Nett Gauge (mm)	Addl. Plate Movemt (mm)	Available Gauge Widening (mm)	Total Adjusted Gauge (mm)	EDI Cross Level (mm)	EM80 Cross Level on 28.2.01	ARTC Radius for 30m chord (m)	ARTC Radius for 10m chord (m)	Inst. Radius (m)	Note
	301.115	0.010										151	
23	301.114	0.009	10	1445				50	50				
													Sleeper L
24	301.112	0.007	15	1450				45	42				
			10		8	18	1453						Sleeper J
			10		8	18	1453						Sleeper I
			10		2	12	1447						Sleeper H
25	301.110	0.005	18	1453				45	52			167	
			13		6	19	1454						Sleeper G
	301.109	0.004	13		12	25	1460						Sleeper F
	301.109	0.004											Mark on GF 301.1086
			15		16	31	1466						Sleeper E
26	301.108	0.003	15	1450				37	52				
			15		20	35	1470						Sleeper D
			15		25	40	1475						Sleeper C
27	301.106	0.001	17		30	47	1482	37	46				Sleeper B
			17	1455	32	49	1484						Sleeper A
	301.105	0.000											**Drop-in**
28	301.104	-0.001	5	1440				34	41				
29	301.102	-0.003	2	1437				31	33				

High Rail Fastenings

Location	Diagram	Description
301.1050km	<=	Point of Drop-in (Low Rail)
	A	DS Plate,1outer dogspike(new), 2 RLI
	B	Cast Plate, 2 Screwspikes (rebored),2 Pandrol E clips
	C	As on A, with loose raised lockspike on inside
	D	DS Plate, 2 loose lockspikes, 2 RLI
	E	As on B
301.1086km	<=	Mark on Gauge Face (Low Rail)
	F /\	As on D, lockspikes raised
	G I	As on A, with inner lockspike loose with broken leg
	H Direction	As on B
	I of Travel	DS Plate,2 RLI and 2 firm lockspikes
	J	As on I, lockspikes leaning outward,outer clip unsquare
	K	As on B loose screwspikes and holes leaning outward
	L	DS Plate,1 very loose inner lockspike only,2 RLI

Note: Leading wheel-set over high rail at 301.10225km
Trailing wheel-set at 301.0911km

DS Plate = Double shouldered rolled steel plate
RLI = Rex-Lok-In = B296 Clip with Hook-in Adaptor

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Angle of Attack of Derailing Wheelset

Location	Radius (m)					Total Rail Clearance (mm)						Angle of Attack	
	ARTC 30m	ARTC 10m	Instant 10m	String-line	Adopted	At Full Flange	Total Flange Wear[1]	Gauge Widening No1 Wheel	Gauge Widening No4 Wheel	Nett Gauge Widening	Total Clearance	Sine Angle of Attack-Chordal[2]	Sine Angle of Attack-Jamming
105					174	20	22	49	35	84	126	0.009394	0.055933
106					174	20	22	47	28	75	117	0.009394	0.052471
107					174	20	22	40	22	62	104	0.009394	0.047471
108					174	20	22	31	18	49	91	0.009394	0.042471
109				147	174	20	22	25	16	41	83	0.009394	0.039394
110			167		174	20	22	19	15	34	76	0.009394	0.036702
111					174	20	22	18	12	30	72	0.009394	0.035164
112					174	20	22	15	8	23	65	0.009394	0.032471
113					174	20	22	15	5	20	62	0.009394	0.031317
114					174	20	22	10	8	18	60	0.009394	0.030548
115			151		174	20	22	7	16	23	65	0.009394	0.032471
116					174	20	22	5	15	20	62	0.009394	0.031317
117					174	20	22	10	7	17	59	0.009394	0.030164
118					174	20	22	20	5	25	67	0.009394	0.033240
119				174	174	20	22	12	10	22	64	0.009394	0.032087
120	174	174			174	20	22	3	11	14	56	0.009394	0.029010
121					180	20	22	7	10	17	59	0.009145	0.029915
122					181	20	22	12	8	20	62	0.009105	0.031028
123					182	20	22	11	3	14	56	0.009066	0.028681
124					185	20	22	10	2	12	54	0.00895	0.027796
125					187	20	22	6	3	9	51	0.008875	0.026567
126					188	20	22	1	2	3	45	0.008838	0.024223
127					189	20	22	2	2	4	46	0.008801	0.024571
128					192	20	22	3	4	7	49	0.008694	0.025617
129				194	194	20	22	2	4	6	48	0.008624	0.025163
130	199				199	20	22	2	3	5	47	0.008456	0.024610

WODONGA XPT DERAILMENT 25.4.01

Angle of Attack of Derailing Wheelset

Wodonga-Angle of Attack.xls

Angle of Attack of Derailing Wheelset

Bogie Tracking		Chordal		Jamming	
Radius		R 174 m	R 199 m	R 174 m	R 199 m
Angle of Attack	Sine **<**	0.009394	0.008456	0.055933	0.024610
	<	$0^{0}32.29'$	$0^{0}29.07'$	$3^{0}12.38'$	$1^{0}24.61'$

Effect on Lateral Force

The lateral force at the leading wheel is directly proportional to the Sine **<**

1. Increase due to sharpening of Radius
   - Chordal 11.0% (Small increase)
   - Jamming 127% (Over $2^1/_4$ times)

2. Increase due to rail clearances and bogie tracking (jamming)
   - R 174 m 495% (This is close to 6 times chordal)
   - R 199 m 191% (This is close to 3 times chordal)

APPENDIX 2

Report prepared by Interfleet Technology Pty Ltd

1. Executive Summary

This study considers the derailment of an XPT trailer car on a tight radius curve at Wodonga on 25 April 2001.

The purpose of this report is to review the incident report documentation and photographs as supplied by the ATSB, to carry out simple dynamics calculations to look at the normal curving forces of an XPT trailer car, and to consider the effects of any key issues arising from the document on the curving forces and the propensity of derailment of the vehicle.

The report finds that although there were some faults on the vehicle, the primary cause of the derailment was the poor conditions of the fixings of the rails that allowed lateral and roll motion of the rails under the passage of the train.

CONTENTS

2. Introduction

On Wednesday 25 April 2001, a Countrylink Sydney-Melbourne XPT passenger train derailed at Wodonga on 175m radius, right hand curve. The consist was power car + 7 passenger cars + power car. The leading bogie of the fifth passenger car derailed. Since the train travelled for about 1000m following derailment, the last two passenger cars and the rear power car must have passed over the derailment site without derailing. The process of derailment, as indicated by site evidence, was that the inner wheel of the leading axle dropped into the four-foot. Following this, the outer wheel climbed the outer rail. Installed cant at the derailment site was nominally 40mm. At the time of derailment, the train speed was aproximately 30 km/h, within the 40km/h line speed.

3. Objectives

The objectives of the report are as follows:

1. To review the derailment incident report documentation [Ref. 7.1] supplied by the Australian Transport Safety Bureau (ATSB).

2. To find measured bogie-rotational resistance data for the UK Mk3 coach with BT10 bogies (very similar to XPT trailer car) and comment on the effect of increased bogie rotational resistance on derailment performance.

3. To carry out simple railway vehicle dynamics calculations to consider:

   i) The normal curving forces generated by an XPT trailer vehicle on a 175m radius curve with 40mm installed cant at 36km/h.

   ii) The effects on the curving forces and propensity to derailment of any key issues arising from the ATSB documentation.

4. Analysis

4.1. Review of ATSB Documentation

The documentation supplied that was reviewed is listed in Ref. 7.1.

4.1.1. Vehicle Based Effects :-

- Bogie rotational resistance

  The photographs show considerable wear damage to the secondary yaw friction surfaces on the derailed XPT trailer car bogie. However, wear damage such as this is not uncommon on UK BT10 bogies so is not thought to be of great relevance. It seems most likely that the pin on the sidebearer became bent as a result of the derailment, and was not a cause. The photo of the sidebearer mounting surface does not indicate (as far as can be seen from the photo) any signs of fretting that would be expected if the pin was damaged previously.

  Also, in order to bend the pin as shown in the photographs, it would be necessary to lift the pin partially out of its holder, and then apply a lateral force. Normally, the weight of the vehicle body on the bolster would locate the pin in its holder. The weight of the vehicle on the bolster would be reduced, or possibly removed, during derailment. It therefore seems most likely that the damage to the pin occurred during derailment.

  Two test reports have been found for bogie rotational resistance for UK Mk3 coaches. One is for a Mk3 RF restaurant car and the other is for a Mk3 sleeper car. Both show X-factor of about 0.05, well within the limit of 0.10. These vehicles are both heavy Mk 3 coach examples but of similar axleload to that given for the XPT trailer car (10.5t). However, these results show that the measured rotational resistance can nearly double on a Mk3 coach and still be within acceptable limits. This is discussed further in Section 6.2.

- Rolling Radius Difference

  The rolling radius difference on the derailed wheelset was such that Wheel 1, the leading outer wheel that derailed, would be expected to be subjected to a higher than usual lateral flange force.

- Thin flange:

  The thin flange is likely to be a consequence of the rolling radius difference causing the wheelset to run off-centre, but is not likely to have contributed to the derailment itself. However, the additional flangeway clearance would result in :-

  - A higher angle of attack, hence slightly increased flange force.
  - More significantly, the inner wheel would be closer to the edge of the inner rail when the outer wheel is in flange contact.

- Flange-back spacing

  The UK requirement for flange-back spacing is 1360 - 1362mm. The Australian requirement applies the tolerance the other way, i.e., it is 1360 - 1358mm. The XPT wheelset that derailed had a flange-back spacing of 1357mm. This is equivalent to an additional 1-3mm flangeway clearance, as discussed above.

4.1.2. Track Based Effects :-

- Gauge Widening

  There is a small amount of static gauge widening on the curve, but a considerable amount of dynamic gauge widening indicated by the signs of movement of the base plates on the sleepers.

- Rail Roll

  Weakness of the rail fasteners would allow rail roll that would further increase the gauge.

- Track Twist

  Some track twist is noted from the cant measurements that may be contributory to the derailment.

- Check Rail

  It is noted that no check rail is present on this curve. Previously, UK practice was to have check rails on all passenger running lines of 200m radius or less, although currently it is simply a recommendation.

- Cant Excess/Deficiency

  For 1435mm gauge track the expression for calculating cant deficiency is:-

$$CD = \frac{11.82 \times V^2}{R} - Ea$$

Where CD = cant deficiency (mm)
Ea = installed cant (mm)
V = speed (km/h)
R = curve radius (m)

Therefore, at the derailment site:

$$CD = \frac{11.82 \times 36^2}{175} - 40$$

$$= 48\text{mm}$$

This shows that the vehicle is at a speed above balancing speed, and is experiencing a small amount of cant deficiency.

Generally, vehicles are most at risk of derailment when travelling at slow speed on curved track with high installed cant. Under these conditions, the vehicle weight is shifted towards the inner rail enabling a higher lateral force to be generated that is reacted at the leading outer wheel. Hence, gauge-spreading force is high. In addition, since the vehicle weight is shifted away from the outer wheel, the L/V ratio is high so the risk of flange climbing is increased.

Under cant deficiency conditions, the leading outer wheel has a greater vertical load, reducing the risk of flange-climbing. The cant deficiency force tends to be reacted by the trailing wheelset of the bogie moving towards the outer rail. This helps align the leading wheelset reducing its angle of attack.

At very high levels of cant deficiency, there is a risk of overturning, but under still wind conditions, this is well beyond the usual operating regime.

Hence, at 48mm cant deficiency, the risk of derailment would normally be low.

4.1.3. Cause

It is noted that the process of the derailment was that the inner wheel dropping into the four-foot, followed by the outer wheel climbing over the outer rail.

Analysing this simply, based on wheelset dimensions:-

For new wheels on new rails:

Flange-back	1360mm
Wheel thickness	127mm
Flange thickness	30mm
Track gauge	1435mm

If the outer wheel is in flange contact with the outer rail, the distance from the outer wheel flange face to inner wheel rim is: 30+1360+127=1517mm.

Hence, overlap of inner wheel over inner rail is 1517-1435 = 82mm.

For UK track, we might expect about 6mm gauge-widening for a 175m radius curve, maximum 18mm side-wear (for secondary route only) and 24mm minimum flange thickness.

Hence, minimum expected UK overlap of inner wheel over inner rail is:-

(24+1360+127) – (1435+6+18) = 52mm

In practice, such a case would not normally occur since presence of a check rail would maintain a greater overlap of the inner wheel.

For the case of the XPT derailment, we have:-

Flange-back	1357mm
Wheel thickness	127mm
Flange thickness	18mm
Track gauge	1435+49 dynamic gauge = 1484mm (page 19 of Report [Ref. 7.1], sleeper 12)

Hence, XPT overlap of inner wheel over inner rail is:

(18+1357+127) – (1484) = 18mm

This is clearly a small value of overlap. If we take into account the outer chamfer of the wheel that effectively reduces the wheel rim width by a further 6mm, we have just 12mm of overlap remaining. Hence, there is a high risk of derailment caused by the inner wheel tread dropping into the four foot.

Further analysis is made on this, based on the measured wheel and rail profiles.

Figure 1 shows that the flange of the leading outer wheel (Wheel 1) fits well into the worn side of the outer rail. By taking account of the 1357mm back-back dimension and 49mm dynamic gauge widening the position of the inner wheel on the inner rail may be predicted as shown in Figure 2. This demonstrates the narrow band of contact on the inner rail with the wheel chamfer close to the gauge corner of the rail. No allowance has been made in this illustration for outer rail roll which would reduce the inner rail contact further.

4.1.4. Investigation

It is notable that following derailment of the one bogie, the remainder of the train passed over the derailment site safely. This would indicate that, whilst the track-based elements must be relevant, it is only the combination of the vehicle-based and track-based elements together that caused derailment.

Our dynamics calculations to investigate this are therefore based around the following plan:-

1. For 175mm constant radius curve, 40mm installed cant, 36km/h train speed, what are lateral wheel-rail forces caused by:-
   - Bogie rotational resistance?
   - Rolling radius difference?
   - Gauge widening?
   - Flange-thickness and flange-back spacing?

   These are applied individually, then all together.
2. To repeat the above, but for track of 175mm constant radius curve, measured track cross level and measured track dynamic gauge.

These calculations are described in Section 4.3.

4.2. Bogie Rotational Resistance

A search was made for British Railways (BR) test reports for bogie rotational resistance tests carried out on BR Mk3 coaches fitted with BT10 bogies. The BR Mk3 coach with BT10 bogies was the basis for the XPT trailer car. Although there are differences, the frictional interface that controls bogie rotational resistance is similar on Mk3 and XPT, so the results for Mk3 should be representative of XPT.

Although many rotational resistance tests must have been carried out for the various Mk 3 coach types during their development and build, only two test reports could be found. These were for:-

- Mk3 RFM Restaurant car [Ref. 7.2].
- Mk3 Sleeper car [Ref. 7.3] - Note that this Sleeper car had various suspension modifications for improved ride development, but no alterations were made that would change bogie rotational resistance.

The bogie rotational resistance is measured and the "X-factor" is calculated according to the following formula:

$$X = \frac{\text{Body-bogie yaw torque}}{\text{Wheelbase x Axle Load}}$$

The current UK requirement is that $X \leq 0.1$ for passenger vehicles, parcel vehicles and locomotives (higher values of X are permitted for low (<8t) axleload freight vehicles). The value of X should not be exceeded for the bogie yaw angle required for the minimum curve radius and for rotational speeds representative of curve entry and exit in service conditions.

The Mk3 RFM vehicle gave X-factor results in the range 0.050 and 0.053 (for an axleload of 9.8 Tons).

The Mk3 Sleeper gave X-factor results in the range 0.049 and 0.053 (for an axleload of 103 kN).

It is noted from the ATSB report that the XPT passenger car axleload is about 10.5 tonnes, similar to the Mk3 coaches tested. Hence an X-factor value of about 0.05 would be expected for the XPT trailer car.

This value of X-factor is well inside the UK limit of 0.10 for passenger vehicles. The effect of X-factor on derailment is discussed further in Section 4.3.

4.3. Railway Vehicle Dynamics Calculations

Railway vehicle dynamics calculations were made using the program "Vampire". A computer model of a UK Mk3 coach was used since, as discussed in Section 4.2, this is very similar to the XPT trailer car. The only change made was to increase the body mass of the UK vehicle to give a 10.5t axle load as per XPT. A check was made that the model demonstrated an X-factor of 0.05, as measured by test on actual Mk3 coaches (see Section 4.2).

A piece of track was set up in Vampire of 175m radius, 40mm installed cant, and the vehicle model was run around this curve at 36km/h. The wheel and rail profiles used for the purposes of the calculations was a UK P8 wheel profile and 113A rail inclined at 1:20 at 1435mm gauge. Wheel-rail friction coefficient was set at an average value of 0.23.

4.3.1. Effect of X-Factor

The "base case" run was for an X-factor of 0.05. Further runs were then made for X-factor values of 0 (i.e., freely-pivoting) and 0.20 (i.e., 4 x the measured X-factor value).

The resulting leading wheelset forces for these cases are:-

Case	Ldg.Outer Wheel Lateral Force *	Ldg.Inner Wheel Lateral Force *	Gauge Spreading Force	L/V Ratio
1. X=0.00	27.1 kN	15.1 kN	42.2 kN	0.44
2. X=0.05	30.5 kN	14.6 kN	45.1 kN	0.48
3. X=0.20	40.6 kN	13.2 kN	53.8 kN	0.61

* Positive force indicates lateral force is pushing rail outwards

The L/V ratio is a measure of the likelihood of a flange-climbing derailment and is the ratio of the vertical load on the leading outer wheel divided by the lateral force. For safety, the L/V ratio should be less than 1.20.

These results show that the differences in wheel-rail lateral force between a freely-pivoting bogie case and a bogie with an X-factor of 0.05 are small (leading outer wheel-rail force increases from 27.1 to 30.5 kN). Increasing X-factor further to a value of 0.20 increases the leading outer wheel-rail force to 40.6 kN. Hence, the increase in this force is a linear increase over this X-factor range of about 3.4 kN per 0.05 increase in X-factor. In all cases, L/V is well inside the 1.20 limit.

Let us consider the body-bogie yaw friction coefficient, μ, for this vehicle at 10.5 tonne axle load :-

Re-arranging the X-factor equation gives us :

Body-bogie yaw torque = X x Wheelbase x Axle Load

For X=0.05 :
Body-bogie yaw torque = 0.05 x 2.60 x 10.5 x 9.81
= 13.4 kNm/bogie

Bogie mass (approx.) = 5.5 tonnes

$$\text{Pivot load} = \frac{[(4 \times 10.5) - (2 \times 5.5)] \times 9.81}{2} = 152 \text{ kN}$$

Body-bogie yaw torque is due to pivot load on friction pads.

Yaw torque = Pivot load x μ x friction pad semi-spacing

Friction pad semi-spacing = 0.725m

Hence, for X=0.05 :

Yaw torque = 13.4 = 152 x μ x 0.725

$$\text{Friction pad friction coefficient, } \mu = \frac{13.4}{152 \times 0.725} = 0.12$$

For the derailed vehicle where metal-metal contact was found, the friction coefficient would be higher. Ref. 7.4 gives values of friction coefficient for dry metal-on-metal of 0.15-0.60 static and 0.1-0.5 sliding. Hence, an average value of sliding friction of 0.3 would represent an X-factor of about 0.13, and the maximum value of sliding friction of 0.5 would represent an X-factor of about 0.20.

Hence, an X-factor applicable to the derailed bogie would appear to be in the range 0.13 – 0.20.

4.3.2. Effect of Other Vehicles & Track Factors

Further calculations were made to look at the effects of the following factors noted in the ATSB report:-

- Rolling radius difference (2mm)
- Thin flange (18mm)
- Reduced wheelset back-back distance (1357mm)
- Wide track gauge (max. +17mm static, +49mm dynamic)

These effects were applied first individually, then all together to the base model. However, none of these showed any great effect :-

- The rolling radius difference of 2mm on the leading wheelset of the bogie in the Vampire model causes that wheelset to roll with a mean lateral offset on straight track sufficient for the leading outer wheel to be contacting the rail in the flange root area of the wheel profile, close to flange contact. However, once in flange contact on a 175m radius curve, the change in lateral wheel-rail force, compared to that of wheels of equal radius, is minimal.

- The effect of the reduced wheelset back-back distance and the thin flange had little effect on forces. Once combined with the gauge widening, the lateral forces actually reduced. The reason for this is thought to be that at such excessive gauge widening the contact point on the inner wheel tread is on the outermost 1:10 coned portion of the tread. This increases the rolling radius difference between the inner and outer wheels such that the lateral forces are reduced.

Combining all these effects together as constant input values throughout the curve has little effect on the results, such that the wheel-rail force at the leading outer wheel remains at about 30kN, the inner wheel-rail force is about 15kN and the gauge-spreading force is about 45kN (as per X-factor results in Section 4.3.1).

If the measured dynamic gauge and cross-level inputs are superimposed as an irregularity on the curve, the resulting dynamic lateral forces are increased. A peak gauge-spreading force of 70kN is seen, with a force of about 65kN sustained for 2m. This is made up from an outer rail force of about 41kN and an inner rail force of 24kN, both sustained for 2m.

This increase is greater than if a random irregularity is superimposed on to the smooth curve, indicating that the shape of the measured input is an important factor to the higher force levels predicted. Figures 3 & 4 illustrate the gauge variation input and leading outer wheel lateral force output, showing the similarity of the shape of the input and output data.

The measured dynamic gauge [Ref. 7.1] shows a rapid increase in gauge approaching the derailment site, followed by a rapid decrease in static gauge. The dynamic gauge increases from +12mm at sleeper 5 to +47mm at sleeper 11. Assuming an average sleeper spacing of 700mm, this equates to a dynamic gauge change of just over 8mm/m. This is followed by a rapid decrease in gauge of around 9mm/m from sleepers 14 to 18. This is equivalent to a 17mrad kink superimposed on to the 175m radius curve, giving rise to the dynamic increase in lateral wheel-rail force close to the point of derailment.

In order to consider the likely force levels that would have been exerted on the track by the preceding freight trains over this derailment site, a further run was made for the Mk3 coach, but with axle load increased to 200 kN. This approximates to a 20t axle load bogie freight vehicle. The leading outer wheel force increases from the 30 kN of the 10.5t axle load passenger vehicle to about 50kN for the 20t axle load freight vehicle.

These lateral forces were all predicted for a wheel-rail friction coefficient of 0.23, which is considered to be an avaerage value for rolling wheel-rail friction in the UK. A higher friction coefficient may be appropriate for this derailment. The effect of a higher friction coefficient would be to increase the lateral force values.

The effect of a large lateral force at the outer rail would be to try and push the rail outwards. The lateral force is applied at the rail head. The rail is restrained from lateral and roll movements by the fasteners at the foot of the rail. If the fasteners are loose in the sleepers, the rail will slide sideways until the slack in the fasteners is taken up, and will then try to roll the rail outwards about a point at the outside of the rail foot.

The effect of the vertical wheel load is to apply a moment to the rail that opposes the moment of the lateral force attemting to rail the rail outwards.

Therefore, the rail will not begin to roll outwards until the torque from the lateral force equals that of the vertical force. After this point the rail is restrained by the torsional stiffness of the rail itself, probably over a length of 2.6m to the trailing wheelset, where there is a restraining vertical force and a lesser lateral force. (Structural calculations could be made to estimate the rail displacements under such forces).

Figure 5 shows the vertical and lateral wheel forces acting on the outer rail. This diagram shows that for an axle load of 10.5 t (51.5 kN wheel load), if there is no restraint from the rail fasteners to react the rail roll, then the rail will have a tendency to roll out for any lateral wheel-rail force that exceeds about 27 kN. The calculations show that the lateral wheel-rail force is predicted to be 30 kN for X=0.05 on a smooth curve. Figure 2 (with no rail roll) shows that there is little overlap of the inner wheel over the inner rail. Hence, very little rail roll is required for the inner wheel to drop off the inner rail and into the four foot.

For a heavier axle load vehicle the lateral force at the outer rail is increased, but not by the same proportion as the increase in restraining vertical wheel load. Figure 5 shows that a lateral force is in excess of 53 kN is required to roll the rail outwards with a 20 t axle load. The calculations for a 20 t axle load vehicle predicts a force of 50 kN at the outer rail for a smooth curve, but the track irregularities would produce dynamic forces in excess of this. Therefore, although a heavier freight vehicle produces higher lateral forces, the restraining axle load is also higher. As a result, the heavier freight vehicle does not have an increased derailment risk, over a lighter passenger vehicle, as may have been perceived.

5. CONCLUSIONS

In order to conclude this study, there are three questions that arise from this derailment :-

1. Why did this passenger train derail and not the preceding heavier freight train?
2. Why did just one bogie derail and then subsequent bogies pass safely over the derailment site?
3. What was the primary cause of the derailment?

It has not been possible to fully answer all these questions within the scope and available information for the report, but they are discussed below:-

5.1. WHY DID THE PASSENGER TRAIN DERAIL AND NOT THE PRECEEDING HEAVIER FREIGHT TRAIN?

At first sight, it may be expected that the preceding freight train may have been at greater risk of derailing on this curve than the passenger train, since it imposes greater forces on the track. However, this overlooks the fact that the greater axle load of the freight train actually helps to restrain the track.

With loose track fastenings, the only restraint from initiating rail movement comes from the weight of the train acting vertically on the rails. Initially, the rail and its baseplates will slide sideways on the sleeper. The only resistance to this will be the resisting frictional resistance between the rail baseplate and the sleeper. Once the lateral freedom is taken up, there will be a tendency for the rail to roll outwards. Resisting this will be the restoring moment from the vertical load of the train on the rails. Once the moment from the vertical load is overcome, the torsional stiffness of the rail will resist rail roll.

Due to the tight curve radius of 175m, the static lateral wheel-rail curving forces will be high. Increasing the axle load of the vehicle will give a proportional increase in the resistance to rail lateral and roll movement. However, the increase in lateral force is smaller than the proportional increase in vertical load, so there is less tendency for rail to begin roll out with a heavier axle load.

The calculations made show the margins to be relatively small, such that the derailment risk of the freight train was only slightly better than that of the passenger train. However, this is a contributory factor to the passenger train derailing when the preceding freight train did not.

5.2. Why did just one bogie derail and then subsequent bogies pass safely over the derailment site?

It is this fact that leads to the conclusion that the condition of the track was the primary cause of derailment.

Usually, in a derailment that begins by the inner wheel dropping off the inner rail into the four foot, the wheelset would be expected to become "jammed" with the outer rim face of the inner wheel against the gauge face of the inner rail and the outer wheel remaining on the outer rail, forced hard into flange contact. Further forward motion of the train will cause many track fixings to be broken as the derailed wheelset forces the rails apart.

In this case, the rails were sufficiently flexible that once the inner wheel had derailed, the outer rail rolled out until the outer wheel climbed over the rail (with the leading wheelset of the bogie derailed, the trailing wheelset has no guidance and would be expected to derail in the same manner). What is surprising is that once derailed, the rails appear to have sprung back into a position close to their original position, such that the rest of the train passed safely over the site.

If the track at this site had been as strong as should be expected prior to the derailment, and the derailment had been due to the passenger train exerting excessive forces on the track, it would have been expected that broken track fastenings would have been found due to the process of derailment. The rails would be expected to remain in a displaced position, leading to the likelihood of further wheelsets being derailed.

The fact that the rails were able to move outwards until derailment occurred and then spring back into position is illustration of just how poorly the rails were fixed.

5.3. What was the primary cause of the derailment?

The faults on the XPT trailer car such as the differing wheel diameters (2mm difference in diameter on the leading wheelset), the over-thin flange (1mm below minimum flange thickness on wheel 1) and the reduced flange back-back dimension (1mm too narrow at 1357mm on wheelset 1) should not have been present. However, according to the "Vampire" predictions these had little influence on the wheel forces generated at the derailment site. They had an influence on reducing the amount of tread remaining in contact on the inner rail of this curve, but their contribution was small compared to the wide dynamic gauge of the track.

The secondary yaw friction pads had worn into poor condition and this is likely to have led to an increase in bogie rotational resistance of the bogie. However, the order of increase in the leading outer wheel-rail force would be expected to be just 3–10 kN due to the increase in rotational resistance, and the lateral force level would be less than that of a 20t axle load freight train.

For a tight curve radius of 175m radius, high static lateral curving forces should be expected. Therefore, it is essential that the rails are securely located in position. This is even more important on such a tight curve with no check rail. The presence of a check rail, correctly installed, would share the lateral forces between the outer rail and the check rail. In addition, the check rail would restrain the inner wheel flange back to keep the inner wheel tread on top of the inner rail. It is clear from the description and photographs of the track that the rails were not secure. The fixings were loose, or even missing, and there was clear evidence of the baseplates sliding sideways on the sleepers. These faults should have been noted on inspection. A preventative measure that could have been put in place before major repair would have been to fix tie-bars across the rails in order to retain the static gauge. These prevent lateral movement of the rails, but offer no additional restraint to rail roll since they are located at the foot of the rail. However, there is no note of even this simple preventative measure.

Based on the evidence supplied, the primary cause of the derailment is seen to be the poor condition of the rail fastenings. The rails were not secured sufficiently to maintain the rails at a constant gauge and in an upright position under the passage of trains.

The condition of the yaw friction pads of the train is not seen as a contributory cause to the occurrence of this derailment since the predicted level of increase in lateral wheel-rail force is small, and still less than that of a heavier axle load train. The condition of the yaw friction pads may well have been a contributory cause as to why this XPT trailer car derailed, and not a later train. However, it is clear from the dynamic gauge of the track that any train passing over this site was very close to the point of derailing.

6. Recommendations

The recommendations arise from this derailment are a series of actions to ensure that maintenance practices in place are sufficient to prevent a recurrence of such an event :-

6.1. Track Maintenance Considerations

Consideration needs to be given to track maintenance :-

A. Inspections for :-
   - defective/cracked/broken baseplates/pandrol housings/chairs;
   - missing, defective or not secure chair screws/spikes/bushes;
   - missing, defective or not secure clips/keys;
   - poor sleeper condition, cracked, broken, rotten, providing inadequate vertical or lateral restraints to baseplate or rail.

B. Rectification action trigger if number of defects exceed intervention level over fixed length of track or if number of consecutive defects along track exceed another intervention level.

C. Could have layered rectification action responses, with urgent actions needed to mitigate serious safety risk and less stringent actions for track conditions with less rail fastening defects.

D. Audit to check process is working.

6.2. Vehicle Maintenance Conditions

Consideration also needs to be given to vehicle maintenance :-

1. A review of the compatibility of the wheel-rail interface geometry including maximum track gauge, allowable rail side wear, minimum flange thickness and flange back-back spacing.
2. A review of the wheelset inspection and maintenance procedures in place for XPT trailer cars.
3. A review of the bogie overhaul procedures and intervals for XPT trailer cars with particular reference to the condition of the yaw friction pads on vehicles that arrive for overhaul.

Interfleet could give guidance on such systems.

7. REFERENCES

7.1 Documentation provided by ATSB to Interfleet Technology Pty on 13.6.01 that included:-

- CountryLink "Analysis of Hasler Speed Recording Tape Report" dated 4 May 2001, 4 pages.
- "Wheel Profiles taken at Railfleet Services, Chullora on 24.5.2001, 4 pages.
- Incident report "Derailment XPT Car XF2214, Wodonga, 25 April 2001, 11 pages.

Also the following photographs sent by email:-

- Bogie.jpg
- Bogie2.jpg
- Carriage plate1.jpg
- Carriage underside.jpg
- Track and pin.jpg
- Track fastenings.jpg
- Track overhead.jpg

In addition, some clear measured wheel and rail profiles were supplied by fax.

7.2 B.R. Testing & Workshops Section Report no. 888, "R.F.M. Acceptance Tests, Bogie Rotational Resistance Test", 11 April 1985.

7.3 B.R. Testing section Report no. 1276, "Mk3 Sleeper Coach Improved BT10 Bogie, Static Tests", 31 October 1991.

7.4 Kempe's Engineers Year Book.

FIGURE 1

WHEEL-RAIL CONTACT AT LEADING OUTER WHEEL
FROM MEASURED WHEEL & RAIL PROFILES

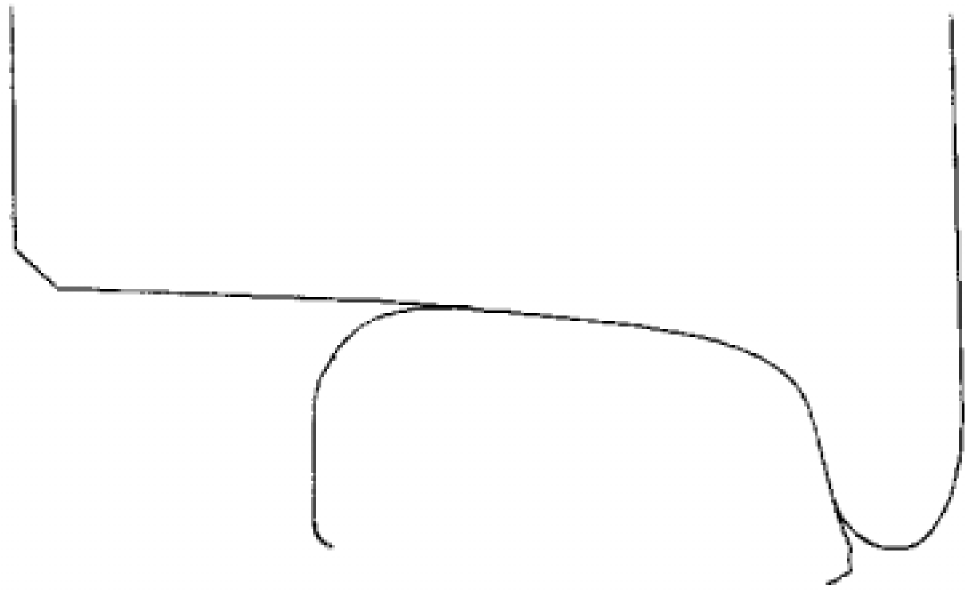


Figure 2

Wheel-Rail Contact at Leading Inner Wheel from Measured Wheel & Rail Profiles & Measured Dynamic Track Gauge

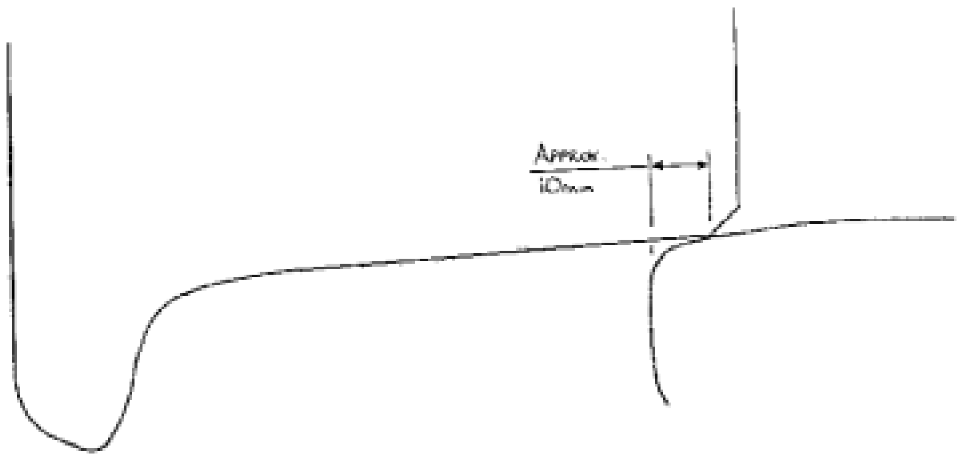
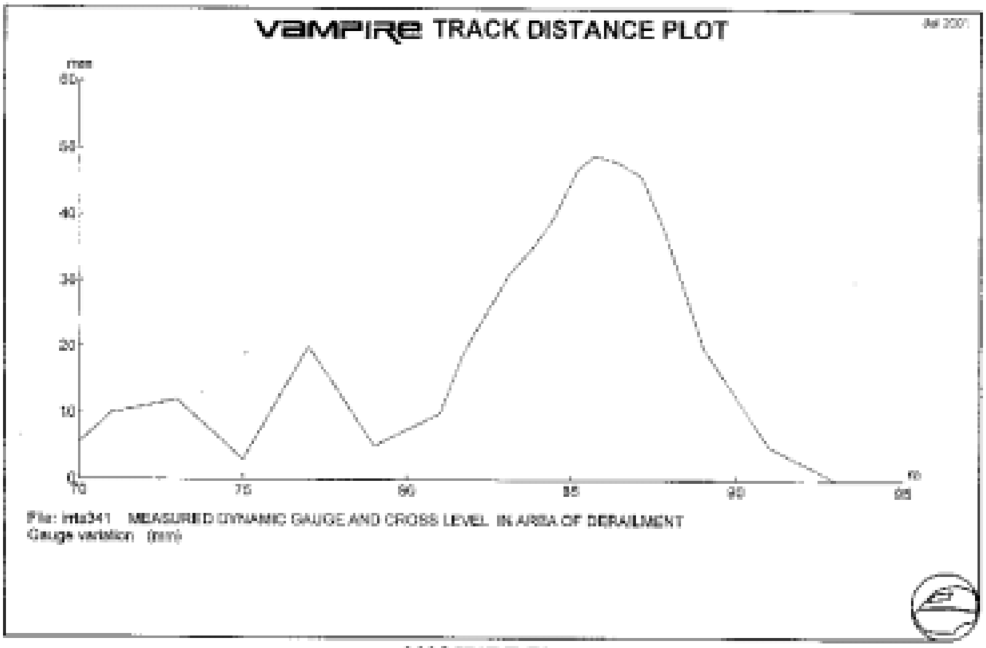


FIGURE 3

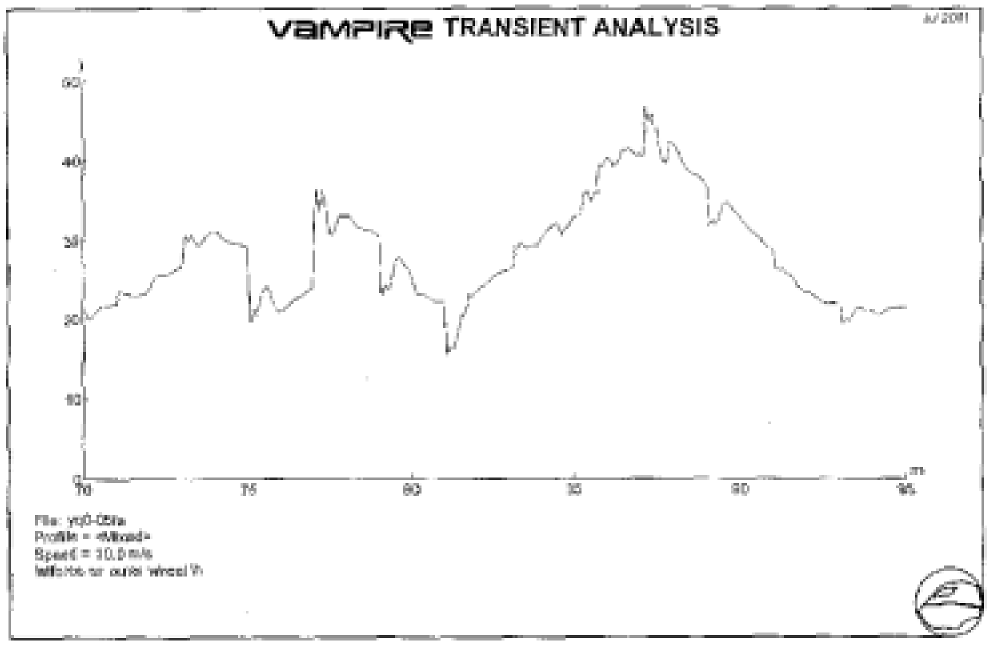
MEASURED DYNAMIC GAUGE IRREGULARITY INPUT TO VEHICLE



VAMPIRE Plot

Figure 4

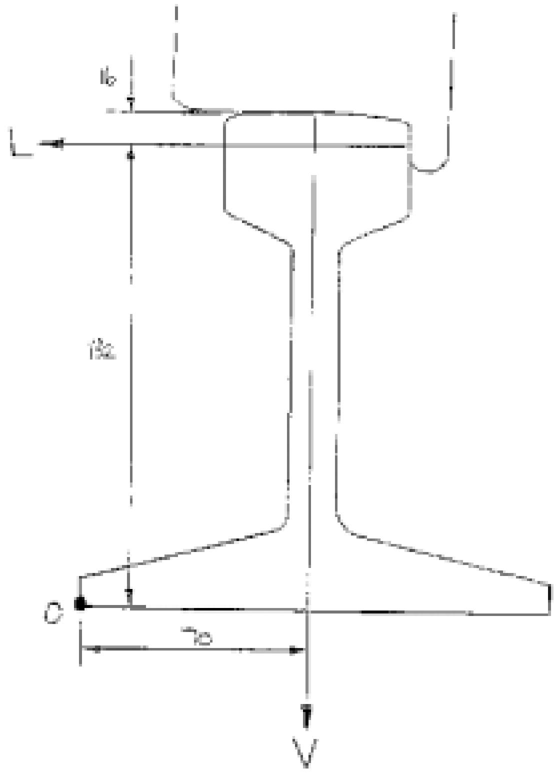
Predicted Lateral Force Output at Leading Outer Wheel for Calculation Including Measured Dynamic Gauge Irregularity Input to Vehicle



VAMPIRE Plot

Figure 5

Moments Acting on Outer Rail



Assume lateral force acts at the height at which gauge measurements are taken, i.e. 16mm from top of rail.

Rail will start to overturn if :

$$132 \times L \geq 70 \times V, \quad \text{i.e.} : \; L \geq \frac{70}{132} \times V$$

Hence, if V = 51.5 kN : $L \geq \frac{70}{132} \times 51.5 = 27.3$ kN for start of overturning.

Or, if V = 100 kN : $L \geq \frac{70}{132} \times 100 = 53.0$ kN for start of overturning.

ATSB

Derailment of passenger train 8622, Sydney – Melbourne daylight XPT service

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